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Operations

EXPEDIENT METHODS

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This volume provides Air Force civil engineer craftsmen in the field with ideas and guidance for accomplishing expedient repairs for minimum-essential restoration of damaged facilities, utility systems (including electrical and plumbing), roads, and buildings. Additionally, methods for expedient construction of field latrines, berms, and dikes are also provided. The material presented in this publication does not include data on expedient beddown or airfield damage repair procedures. Detailed information about these applications is contained in other volumes within this publication series. This pamphlet applies to all Air Force active, reserve, and guard Civil Engineer units. It supports Air Force Instruction (AFI) 10-209, *RED HORSE Program* and AFI 10-210, *Prime Base Engineer Emergency Force (BEEF) Program*. Refer recommended changes and questions about this publication to the Office of Primary Responsibility (OPR) using AF IMT 847, *Recommendation for Change of Publication*; route AF IMTs 847 from the field through major command (MAJCOM) publications/forms managers. Ensure that all records created as a result of processes prescribed in this publication are maintained in accordance with Air Force Manual (AFMAN) 33-363, *Management of Records,* and disposed of in accordance with Air Force Records Information Management System (AFRIMS) Records Disposition Schedule (RDS) located at **https://afrims.amc.af.mil/rds_series.cfm.** The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Air Force. See **Attachment 1** for a glossary of references and supporting information.

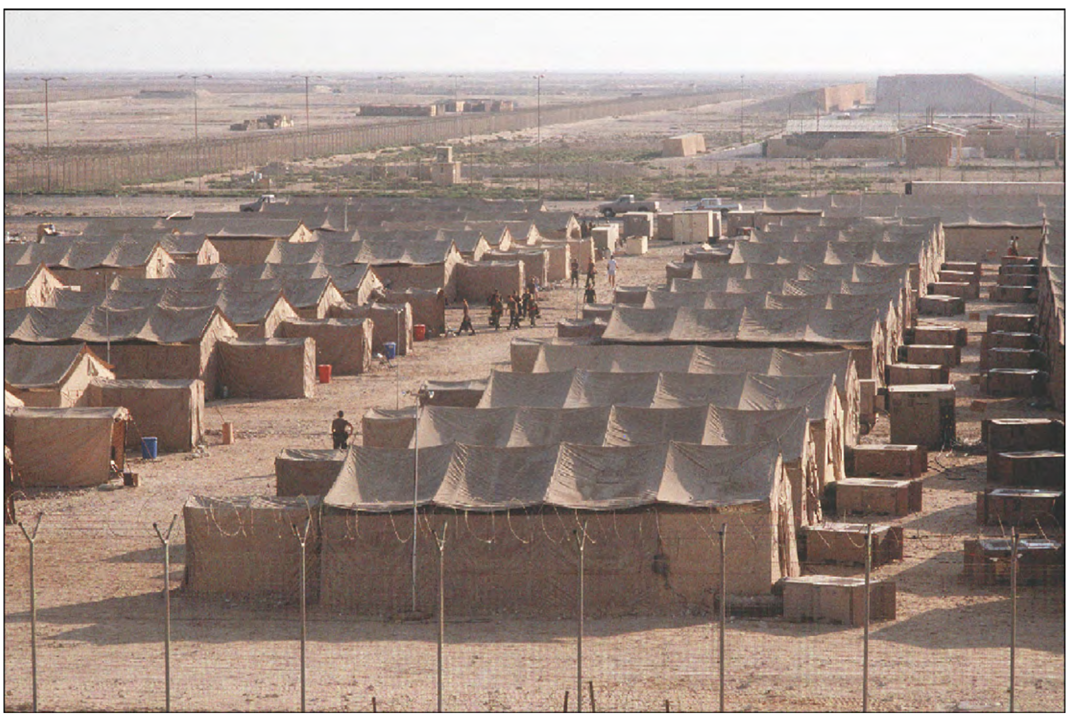
Chapter 1

INTRODUCTION

1.1. Purpose. This volume was developed to provide deployed Airmen with alternative methods of accomplishing certain engineering tasks when there is insufficient time or materials or it is impractical to employ conventional methods. Information regarding installation of standard expedient construction systems such as Basic Expeditionary Airfield Resources (BEAR), is beyond the scope of this publication, but is available in other pamphlets in this series.

1.2. Overview. This pamphlet contains illustrations of basic material applications and construction methods that have proven their worth during field applications. Any data and definitions presented are general in nature and should be used solely as guides. Detailed drawings are provided throughout this publication to help supervisors illustrate and explain requirements to their craftsmen. The data presented herein applies primarily to a field construction force operation in a remote or bare base area (**Figure 1.1.**) hampered by shortages of standard construction materials. However, it will be evident that some procedures may be relevant and helpful during peacetime disaster response. In addition, many of the techniques described may apply during post-attack recovery efforts. For the purpose of this document, the word "expedient" is defined as: "a means devised or employed in a time and place where prompt action is essential." Expedient engineering definitely does not preclude using normal engineer practices where time and materials are available.

Figure 1.1. Typical Desert Bare Base Beddown.



1.3. Environmental Considerations. The United States Air Force is committed to achieving and maintaining environmental quality to protect US interests. Upholding a high level of environmental quality during training exercises or actual contingencies is a difficult challenge that must be achieved. To this end, all Air Force personnel involved in these operations are charged with environmental stewardship. In no way is the intent of this responsibility either removed or diminished simply because expedient measures are to be employed. Further information on how to integrate environmentally responsible practices during contingency operations can be found in Air Force Handbook 10-222, Volume 4, *Environmental Guide for Contingency Operations*.

1.4. Task Identification. As a general rule, this volume attempts to address only expedient field construction and repair tasks that are accomplished during wartime or contingencies. However, some construction and repair tasks addressed in this pamphlet may also be employed during disaster recovery operations when immediate action is necessary and resources are limited.

1.5. General Safety Practices. One of the first rules for response to any situation requiring expedient applications is to be flexible and remain safe. Supervisors must always keep safety in mind when using nonstandard construction methods and materials. Losing or injuring personnel or disabling equipment during field operations can severely impact mission accomplishment. Never compromise personnel and equipment safety when implementing the expedient procedures described in this pamphlet.

1.5.1. Whether working alongside other military units; federal, state, and local disaster recovery forces; government civilian employees and contractors; or trained and untrained volunteers, it is essential that everyone involved is aware of the procedures used to identify hazards.

1.5.2. To ensure safety, crew leaders should know the capabilities and limitations of assigned personnel and monitor all work efforts. In addition, make certain that activities are coordinated with all involved. For example, debris removal in and around facilities is a dangerous, critical task. Vibrations from heavy equipment can cause a building to collapse on recovery workers.

1.5.3. When working in a contaminated environment, be sure to wear the appropriate individual protective equipment (IPE) for the hazard present. Wash contaminated clothing and take a shower as soon as possible after working in a contaminated environment. Even when working in an environment that is not contaminated, wear protective equipment for dust, noise, sharp objects, and construction materials. Plywood and lumber, brick and block, and sheet metal can all cause cuts and injuries. Even a small cut can develop into a serious injury if the wound becomes infected.

Chapter 2

ROAD AND DRAINAGE SYSTEM CONSTRUCTION AND REPAIR

2.1. Introduction. Expedient construction and repair of roads and drainage systems during disasters or after an attack could be crucial to recovery operations and mission sustainment. These efforts may include tree clearing, grubbing and stripping; grading and assessing the drainage system; repairing existing or constructing new roads and drainage systems; and implementing drainage system erosion control practices and maintenance. In remote locations, or during post-attack operations, engineer personnel may have few supplies and resources to accomplish needed construction and repair. In this type of environment, engineers will need to use ingenuity, available resources, and a lot of backbreaking labor to accomplish the mission.

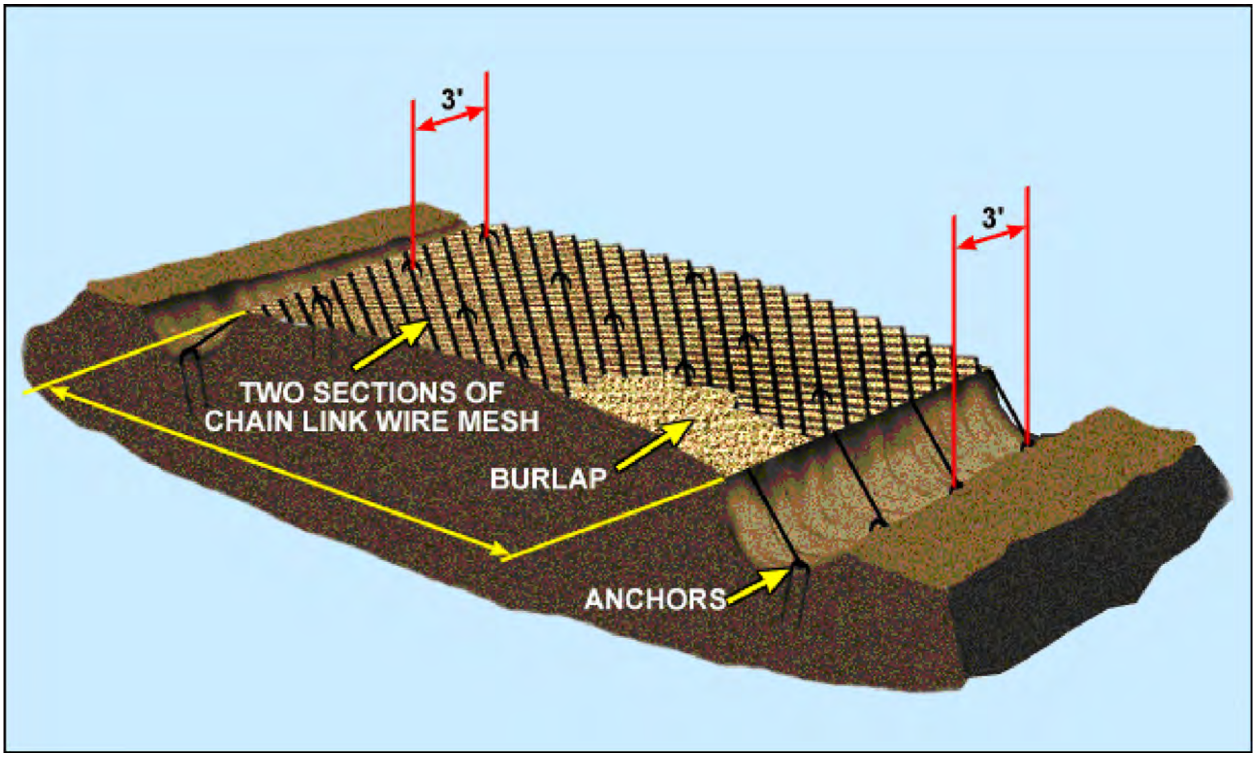
2.2. Overview. The concepts and examples in this chapter may be applied singularly or in combination or may be modified to suit field conditions for expedient construction. By using these procedures, an engineer contingent faced with resource shortfalls may be able to meet the minimum requirements for mission accomplishment until additional resources become available. The topics presented in this chapter consist of expedient road construction and repair, expedient drainage construction and repair, and drainage system erosion control and maintenance. **Note:** Information regarding airfield pavement repair procedures is contained in Unified Facilities Criteria (UFC) 3-270-07, *O&M*: *Airfield Damage Repair.*

2.3. Expedient Road Construction and Repair. Establishment of useable roadways during disaster recovery operations or after an attack is crucial. Tasks may be as simple as clearing existing pavements or as arduous as actually constructing new surfaces. At austere sites where equipment and materials are limited, expedient construction and repair measures may be needed to provide workable surfaces in a timely fashion. The expedient road construction methods discussed in this chapter are: wire mesh; sand grid; plank tread; landing mat; and snow and ice. In addition, soil cement, geo-fiber, lime, and fly ash stabilization procedures are also discussed. Field Manual (FM) 5-34, *Engineer Field Data* and FM 5-430-00-1, *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations—Road Design,* provide further options for dealing with problems related to expedient road construction.

2.3.1. **Expedient Road Construction Methods.**

2.3.1.1. **Wire Mesh.** Chicken wire or chain-link (cyclone) fencing material may be used for expedient surfaces over sand. Adding a layer of burlap or similar material underneath the wire mesh helps confine the sand. Longer life can be obtained by proper subgrade preparation, multilayer or sandwich construction, and staking the edges of the wire mesh at 3-foot intervals. As indicated in **Figure 2.1.**, diagonal wires that cross the centerline at 45-degree angles and are securely attached to buried pickets fortify the lighter meshes. The more layers used the more durable the surface will become. Other roads should never cross wire-mesh roads unless planking or some such material is placed over the mesh to protect it. In addition, mesh surfaces should not be used on muddy roads because they prevent grading and reshaping of the surface when ruts appear. Commercial wire/fabric barriers, laid flat, provide similar confinement and separation as the wire mesh/burlap and may be more available in the area of responsibility (AOR).

Figure 2.1. Wire-Mesh Road Construction Details.



2.3.1.2. **Sand-Grid Roads.** This technique involves the confinement of sand or sandy materials in interconnected cellular elements called grids (Geocells) to produce a load-distributing pavement base layer. It has application in areas where sandy materials are abundant and quality construction aggregates are not available. A sand-grid road over a sand subgrade is capable of supporting over 10,000 passes of heavy truck traffic, including tandem axle loads of up to 53,000 pounds. The plastic honeycomb grid is manufactured and shipped in unexpanded sections that are easily expanded for field use (see **Figure 2.2.**). Each 4-inch-thick section expands to form a honeycomb arrangement of 561 cells that cover an area 8 by 20 feet and weigh 110 pounds. Other applications of sand-grid technology include field fortifications, slope protection, channel protection, and retaining walls.

2.3.1.2.1. When installing this material, use pickets or place sand on the corners and sides to maintain placement. After positioning the entire first layer, use a bucket loader to begin filling the grid, working from one edge of the repair toward the center. A full grid section will hold the weight of a bucket loader. A four-person crew can quickly construct a sand-grid road using bucket loaders, light bulldozers and vibratory compaction rollers. The use of rough-terrain forklifts; water distributors; asphalt distributors; long-handled, round-point shovels; and 8-foot by 4-foot by 3/8-inch sheets of plywood can increase the effectiveness and speed of construction.

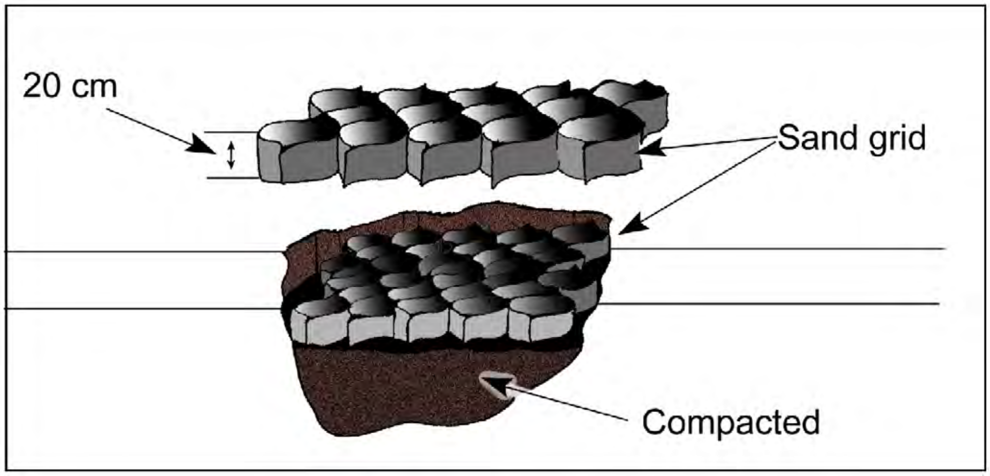
Figure 2.2. Typical Sand-Grid Material in Shipping Configuration.

2.3.1.2.2. As the grids are filled, the loader can drive forward onto the grids to expand their range. Use shovels and rakes to spread the material to overfill the cells by a uniform layer of 1 to 2 inches. Provide sufficient compaction by using a rubber-tire or steel-wheel roller. However, be aware that over compaction can damage the sand grid and result in premature failure. After compacting the first layer, repeat the process, starting by placing a porous layer of membrane (typically permeable geotextiles or geofabrics that are lightweight, waterproof, and breathable). Put the top layer of sand grid with its long dimension stretched 90 degrees to the first. This makes it perpendicular to the road centerline and increases strength. Once again, overfill the grid cells by 1 to 2 inches. The surface can be further stabilized by applying a sand-asphalt surface of about one-gallon of RC-250 asphalt cutback per square yard. **Figure 2.3.** is an example of using sand grids to construct roads over rough terrain.

Figure 2.3. Sand-Grid Road Construction.

2.3.1.2.3. When making road repairs with this material, place the initial 4-inch layer of sand grid in the crater parallel to the centerline of the roadway. Expand the sand grid, using shovels to fill the grid-edge sections to hold it in place. Cover the entire bottom of the cavity with grid material in this manner so it conforms to the shape of the repair, curving or cutting as necessary (see **Figure 2.4.**). Sections that do not fully expand add strength to the base. After positioning the first layer, fill the grid, working from one edge of the repair toward the center. Compact the cells level with the pavement, using a rubber-tire or steel-wheel roller or vibratory-plate tampers, and remove any excess material after compaction. If more than one layer is needed, follow the previous instructions for sand-grid road construction.

Figure 2.4. Sand-Grid Construction Details.

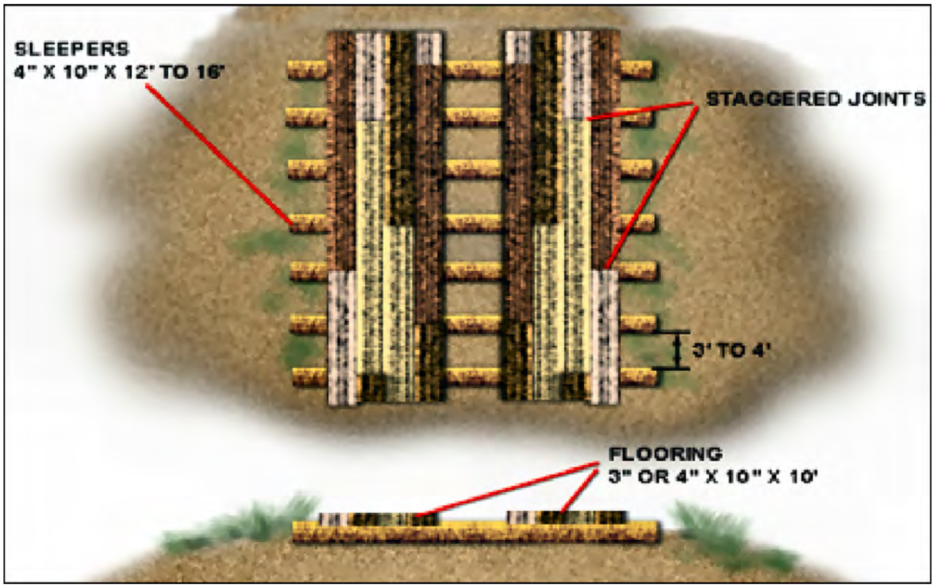


2.3.1.3. **Plank-Tread Roads.** Use plank-tread roads for crossing short sections of loose sand or wet, soft ground. This type of road may last several months if it is well-built and has an adequate base (see **Figure 2.5.**).

2.3.1.3.1. To construct a plank-tread road, first place sleepers 12 to 16 feet long perpendicular to the centerline on 3- to 4-foot centers, depending on the loads to be carried and subgrade conditions. If finished timber is not available, logs may be used as sleepers. Next, place 4- by 10-inch planks parallel to the line of traffic to form two treads about 36 inches apart. Stagger the joints to prevent forming weak spots. If desired, 6-inch curbs may be installed on the inside of the treads. When built with an adequate base, plank roads can last for several months. Planks 3 to 4 inches thick, 8 to 12 inches wide, and at least 13 feet long are ideal for flooring, stringers, and sleepers. When desired, 3- by 10-inch planks (rough, not finished) can replace the 4- by 10-inch timbers shown in **Figure 2.5.** Rough 3- by 8-inch and 3- by 10-inch planks can normally be cut to order.

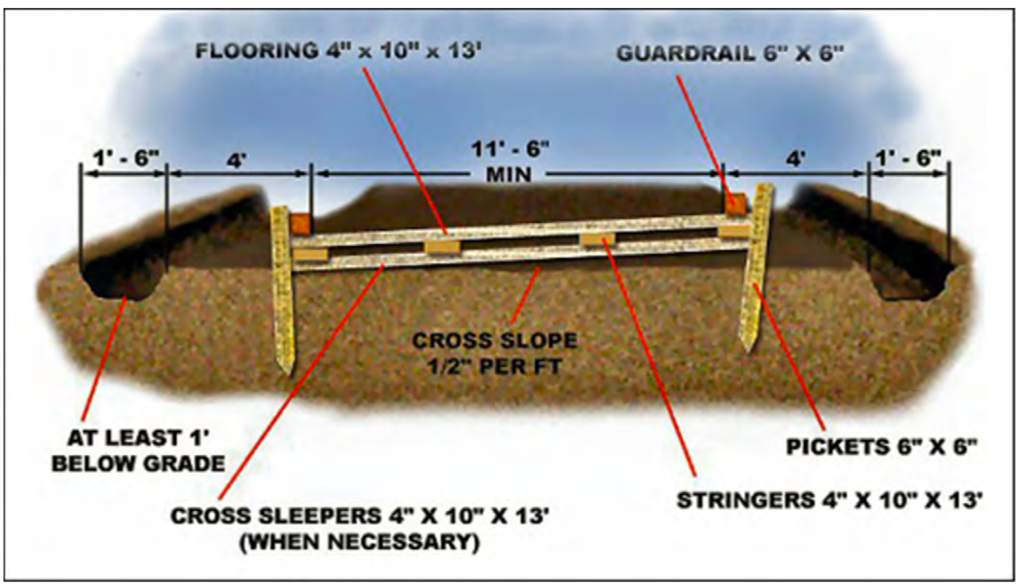
2.3.1.3.2. Position stringers in regular rows parallel to the centerline on 3-foot centers with staggered joints. Lay floor planks across the stringers with about 1-inch gaps when seasoned lumber is used. The gaps allow for swelling when the lumber absorbs moisture. Spike the planks to every stringer. Place 6-inch-deep guardrails on each side with a 12-inch gap left between successive lengths of guardrails for surface-water drainage. Install pickets along each side at 15-foot intervals to hold the roadway in line.

Figure 2.5. Plank-Tread Road Layout Plan.



2.3.1.3.3. To achieve proper drainage, construct the base for a plank road with a transverse slope, as shown in **Figure 2.6.**, instead of a center crown. To provide a smoother riding surface, put treads parallel to the line of traffic over floor planks.

Figure 2.6. Plank Road Construction Details.



2.3.1.4. **Airfield Landing Mats.** The demand for rapidly constructed airfields led to the development of several portable, metal landing mats. As metal airfield landing mats became a standard supply item, they were quickly put to use on beaches as well as airfields. They are still in use as expedients for crossing sandy terrain. Landing mat designs fabricated from aluminum alloys can support heavier loads than many other materials and have a lower weight per square foot as compared to timbers. They also provide smoother surfaces so that the smallest-wheeled vehicle using the road can obtain traction. The three most common types of matting employed in expedient road construction are pierced steel planking (PSP), M8A1, and AM-2 (see **Figure 2.7.**).

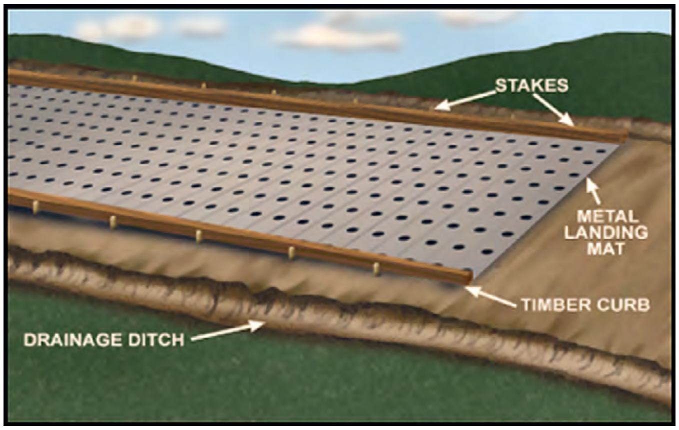
Figure 2.7. Common Landing Mat Variations.

2.3.1.4.1. When used on sand, place the metal landing mats directly on the sand to the length and width desired. Install the mat so that its long axis is perpendicular to the flow of traffic. If a width greater than the effective length of one plank is required, use half sections to stagger the joints. A second layer of the steel mat, laid as a treadway over the initial layer, increases its effectiveness. If PSP is used, place an impervious membrane under the mat to smooth and firm the subgrade, thus improving the road stability.

2.3.1.4.2. After extended use, landing mats tend to curl at the edges. This problem can be overcome by anchoring the edges properly. Screw-type earth anchors provide the best means of anchoring. Another method of securing the edges is to use a curb of timber on the outside edge of the road and either wire it tightly to buried logs laid parallel to the road or stake it as shown in **Figure 2.8.** In addition, the road surface must be void of high spots and ruts for matting to be effective. Such irregularities cause difficulties in assembling the matting pieces.

2.3.1.5. **Snow and Ice Roads.** In regions with heavy snowfall and where temperatures are below freezing for extended periods, expedient roads can be constructed over the snow. When a road is laid out over snow or ice, make grades and curves as gentle as possible and compact the snow until it is capable of supporting the weight of the vehicles expected to use it. Once proper compaction is achieved, add water to the compacted plane and allow it to freeze to produce a sounder wearing surface. Vehicle tire traction can be improved by spreading sand over the surface.

Figure 2.8. Landing Mat Anchoring Technique.



2.3.2. **Soil Stabilization Techniques.** In addition to expedient road construction procedures addressed previously, mechanical and chemical soil stabilization techniques can be used to bolster road surfaces during contingencies (**Figure 2.9.**). Many of these approaches can be effective for extended periods. Mechanically stabilized soil mixtures are widely used as surfaces for military roads to carry light traffic where difficult soil conditions exist. Chemical admixtures are often used to stabilize soils when mechanical methods are inadequate and replacing an undesirable soil with a desirable soil is not an option. Most chemical admixture stabilization projects involve the use of cement, lime, or fly ash. While both of these methods appear to be labor intensive, they are quite the opposite when compared to standard road construction methods. In terms of material, both processes are less costly than normal road construction involving asphalt or concrete. **Warning.** The use of cement, lime or fly ash to stabilize a soil with a high content of sulfates (as present in many Southwest Asia (SWA) countries) can lead to heave from ettringite formation. Engineers may need to have soil tested for sulfate content before selecting a stabilization agent.

Figure 2.9. Stabilizing a Tent Area in French Guinea.

2.3.2.1. **Chemical Mixtures Methods.** Although effective, there are hazards associated with chemical stabilizers. When working with these materials, refer to detailed information listed in the Material Safety Data Sheet (MSDS) prepared by the manufacturer. Generally, the hazard of airborne particles is reduced significantly in the open air on the construction site. General information is also provided in FM 5-410, *Military Soils Engineering*, Appendix C.

2.3.2.1.1. **Soil-Cement.** Soil-cement, also referred to as cement-modified soil and cement-treated aggregate base, is a dense, highly compacted mixture of soil or roadway material, Portland cement, and water. Almost any inorganic type of soil is suitable for soil-cement. However, granular soils are preferred over clay soils because they pulverize more easily and require less cement to achieve the required strength and durability. A well-graded granular soil will generally require 5 to 8 percent cement by dryweight of soil aggregate, while a soil that is sandy silt with 25 percent passing the No. 200 sieve will need 8 to 11 percent cement. In addition, granular soils are more desirable for this application since they tend to make the surface resistant to both the abrasive effects of traffic and the penetration of precipitation.

2.3.2.1.1.1. **Soil-Cement's Advantages.** Soil-cement's advantages include high strength and durability combined with low first cost, making it an economical material. About 90 percent of the material needed for soil-cement is already in place, keeping handling and hauling costs to a minimum. Like concrete, soil-cement continues to gain strength with age. Because soil-cement is compacted into a tight matrix during construction, the pavement does not deform under traffic or develop potholes like unbound aggregate bases. Soil-cement is capable of bridging over weak subgrade areas and is highly resistant to deterioration caused by seasonal moisture changes and freeze/thaw cycles.

2.3.2.1.1.2. **Installation Steps.** Tests must be performed to determine the proper cement content, compaction, and water requirements for the soil material used. Soil-cement can be mixed in either a central plant or mixed in place. However, during contingency situations involving expediency, mixing the material in place is often the obvious choice. For in-place operations, either clay or granular soils can be used. During a mixing-in-place operation, always follow the four basic soil-cement paving steps: spreading, mixing, compacting, and curing.

2.3.2.1.1.2.1. When the roadway has been shaped to grade and the soil loosened to a depth of 8 to 10 inches, the proper quantity of cement is spread on the in-place soil.

2.3.2.1.1.2.2. The cement is then thoroughly mixed into the soil and the required amount of water is added.

2.3.2.1.1.2.3. The mixture is then tightly compacted with rollers, shaped to the proper contour and rolled again to achieve a smooth finish. Finally, to supply and maintain the moisture needed for hydration, the soil-cement is sprayed with water and sealed with a bituminous mixture. Further information regarding soil-cement procedures can be found in HQ AFCESA Engineering Technical Letter (ETL) 01-06, *Contingency Airfield Pavement Specifications.* This document can be downloaded from the AFCESA web site:

https://www.my.af.mil/gcss-af/USAF/AFP40/Attachment/20070629/ETL%2001-6.pdf

2.3.2.1.2. **Lime.** Experience has shown that lime reacts with medium, moderately fine, and fine-grained soils to produce decreased plasticity, increased workability and strength, and reduced swell. Several soil classifications in the Unified Soils Classification System (USCS) are potentially capable of being stabilized with lime. Additional data on lime stabilization actions can be found in FM 5-410.

2.3.2.1.2.1. If the soil temperature is less than 60 degrees Fahrenheit and is not expected to increase for one month, chemical reactions will not occur rapidly. Thus, the strength gain of the lime-soil mixture will be minimal. Lime-soil mixtures should be scheduled so that sufficient durability is gained to resist any freeze/thaw cycles expected. If heavy vehicles are allowed on the lime-stabilized soil before a 10- to 14-day curing period, pavement damage can be expected. Lime gains strength slowly and requires about 14 days in hot weather and 28 days in cool weather to gain significant strength. Unsurfaced lime-stabilized soils degrade rapidly under traffic, so bituminous surface treatment is recommended to prevent surface deterioration.

2.3.2.1.2.2. Lime can be used either to modify some of the physical properties and thereby improve the quality of a soil or to transform the soil into a stabilized mass, which increases its strength and durability. The amount of lime additive depends on whether the soil is to be modified or stabilized. The lime to be used may be either hydrated or quicklime, although most stabilization is done using hydrated lime. The reason is that quicklime is highly caustic and dangerous to use.

2.3.2.1.2.3. When lime is added to a soil, a combination of reactions begins to take place immediately. These reactions are nearly complete within one hour, although substantial strength gain is not reflected for some time. The reactions result in a change in both the chemical composition and the physical properties. Most lime has a pH of about 12.4 when placed in a water solution. Therefore, the pH is a good indicator of the desirable lime content of a soil-lime mixture. The reaction that takes place when lime is introduced to a soil generally causes a significant change in the plasticity of the soil.

2.3.2.1.3. **Fly Ash.** Fly ash consists mainly of silicon and aluminum compounds that, when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compression strengths. Fly ash is a by-product of coal-fired, electric-power-generation facilities. The liming quality of fly ash is highly dependent on the type of coal used in power generation. Fly ash is categorized into two broad classes by its calcium oxide (CaO) content. They are: Class C and Class F. Refer to FM 5-410 for more information on fly ash stabilization.

2.3.2.1.3.1. **Class C.** This class of fly ash has a high CaO content (12 percent or more) and originates from sub-bituminous and lignite (soft) coal. Fly ash from lignite has the highest CaO content, often exceeding 30 percent. This type can be used as a stand-alone stabilizing agent. The strength characteristics of Class C fly ash having a CaO less than 25 percent can be improved by adding lime.

2.3.2.1.3.2. **Class F.** This class of fly ash has a low CaO content (less than 10 percent) and originates from anthracite and bituminous coal. Class F fly ash has an insufficient CaO content for the pozzolanic reaction to occur. It is not effective as a stabilizing agent by itself; but when mixed with lime or lime and cement, the fly ash mixture becomes an effective stabilizing agent.

2.3.2.1.3.3. **Lime Fly Ash (LFA) Mixtures.** LFA mixtures can contain either Class C or Class F fly ash. The LFA design process is a four-part process that requires laboratory analysis to determine the optimum fines (particles passing a Number 200 sieve) content and lime-to-fly-ash ratio. The optimum fines content is the percentage of fly ash that results in the maximum density of the soil mix. The initial fly ash content should be about

10 percent based on the weight of the total mix. The design fines content should be 2 percent above the optimum fines content. For example, if 14 percent fly ash yields the maximum density, the design fines content would be 16 percent. The moisture density relation would be based on the 16 percent mixture. LFA is constructed in layers not less than 4 compacted inches. Final thickness and actual proportions are set by the engineer. After LFA has been constructed, the surface must be kept moist until a bituminous curing cover is applied.

2.3.2.1.3.4. **Lime-Cement-Fly Ash (LCF) Mixtures:** The design methodology for determining the LCF ratio for deliberate construction is the same as for LFA except cement is added at the ratio of 1 to 2 percent of the design fines content. Cement may be used in place of or in addition to lime; however, the design fines content should be maintained. When expedient construction is required, use an initial mix proportion of 1 percent Portland cement, 4 percent lime, 16 percent fly ash, and 79 percent soil. Minimum unconfined strength requirements (see **Table 2.1.**) must be met. If test specimens do not meet strength requirements, add cement in 1/2 percent increments until strength is adequate. **Note:** As with cement-stabilized base course materials, LCF mixtures containing more than 4 percent cement cannot be used as base course material under Air Force airfield pavements.

Table 2.1. Minimum Strengths for Stabilized Soils.

Stabilized Soil Layer	Minimum Unconfined Compressive Strength psi[a]		
	Flexible Pavement		Rigid Pavements, All
	Air Force and Army	Navy	
Base Course	750	750	500
Subbase course, select material or subgrade	250	300 (cement) 150 (lime)	200
[a]Unconfirmed compressive strength determined at 7 days for cement stabilization and 28 days for lime or lime-cement-fly ash stabilization.			

2.3.2.2. **Mechanical Mixture (Sand Fiber) Method.** The Army Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi, developed this rapid-road-construction method to overcome sandy and soft soil deficiencies. Theroad construction procedure involves stabilizing sand with geofibers, also known as sand fibers. The effectiveness of this approach has been verified through extensive testing at the ERDC testing facilities.

2.3.2.2.1. Sand-fiber road stabilization technology involves mixing small amounts (0.8 percent by weight) of hair-like, 5-centimeter-long (2 inches) polypropylene fibers into moist sand with a rotary mixer (**Figure 2.10.**). The sand-fiber layer is then compacted with a smooth-drum vibratory roller. Next, a wearing surface is added by spraying a resin-modified emulsion or emulsified asphalt onto the road surface to bond the sand grains with the fiber filaments and protect the sand-fiber surface.

2.3.2.2.2. Using the geofiber construction method, military supply roads can be constructed quickly at remote sites, over beaches, or across desert sands with less equipment, manpower, and materials than other road-building methods require. Experiments conducted at ERDC indicate that roads constructed with this new technology can carry over 10,000 passes of heavy military supply traffic with very little or no maintenance required. Sand-fiber stabilization uses existing military construction equipment and requires no special construction skills. In addition, it can be used on a wide variety of sands and silty soils found around the world. **Table 2.2.** lists soil stabilization methods for specific applications. For additional information regarding geofiber soil reinforcement, obtain US Army Engineer Waterways Experiment Station (1999) Technical Report GL-99-03, *Discrete Fiber Reinforcement of Sands for Expedient Road Construction,* at **http://libweb.wes.army.mil**.

Figure 2.10. Blending Fibers With Soil.

Table 2.2. Stabilization Methods Most Suitable for Specific Applications.

Purpose	Soil Type	Method
Subgrade Improved load carrying and stress distribution characteristics	Fine granular	SA, SC, MB, C
	Coarse granular	SA, SC, MB, C
	Clays of low PI	C, SC, CMS, LMS, SL
	Clays of high PI	SL, LMS
Reduce frost susceptibility	Fine granular	CMS, SA, SC, LF
	Clays of low PI	CMS, SC, SL, LMS
Waterproofing and improved runoff	Clays of low PI	CMS, SA, LMS, SL
Control of shrinkage and swell	Clays of low PI	CMS, SC, C, LMS, SL
	Clays of high PI	SL
Reduce resiliency	Clays of high PI	SL, LMS
	Elastic silts or clays	SC, CMS
Base course stabilization Improvements of substandard materials	Fine granular	SC, SA, LF, MB
	Clays of low PI	SC, SL
Improved load carrying and stress distribution characteristics	Course granular	SA, SC, MB, LF
	Fine granular	SC, SA, LF, MB
Reduction of pumping	Fine granular	SC, SA, LF, MB, membranes
Dust palliative	Fine granular	CMS, SA, Oil or bituminous surface spray, APSB
	Plastic soils	CMS, SL, LMS, APSB, DCA 70
LEGEND:		
Where the methods of treatment are:		
APSB = Asphalt penetration surface binder	LMS = Lime modified soil	
C = Compaction	MB = Mechanical blending	
CMS = Cement modified soil	SA = Soil-asphalt	
DCA70 = Polyvinyl acetate emulsion	SC = Soil-cement	
LF = Lime fly ash	SL = Soil-lime	PI =Plasticity Index

2.3.2.3. **Geotextiles Technique.** Another technique available for improving the condition of soils besides mechanical blending and chemical stabilization involves the use of geotextiles (see **Figure 2.11.**). The term geotextile refers to any permeable textile used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system. Geotextiles are also commonly referred to as geofabrics, engineering fabrics, or just fabrics.

Figure 2.11. Using Geotextile During Road Construction.

2.3.2.3.1. Geotextiles serve four primary functions: reinforcement, separation, drainage, and filtration. In many situations, using these fabrics can replace soil, which saves time, materials, and equipment costs. In theater-of-operations horizontal construction, the primary concern is with separating and reinforcing low load-bearing soils to reduce construction time.

2.3.2.3.2. The design engineer attempts to reduce the thickness of a pavement structure whenever possible. Tests show that for low load-bearing soils (generally anything less than a 5 CBR value) the use of geofabrics can often decrease the amount of subbase and base course materials required. The fabric lends its tensile strength to the soil to increase the overall design strength. **Figure 2.12.** shows an example of this concept.

2.3.2.3.3. Swamps, peat bogs, and beach sands can also be quickly stabilized by the use of geofabrics. The normal solution is to remove the poor base material by a process commonly referred to as "mucking." However, this is not an option during most contingencies for a number of reasons. Specifically, the removal process is often very difficult and time-consuming. Furthermore, it can only be used if the area has sound, stable soil underneath the soft soil and a suitable fill material is available nearby. Consequently, during contingencies, a bridge of base course construction material is usually placed directly over the weak soil separated by a layer of geotextile material, as shown in **Figure 2.13.** The basic construction sequence for the direct fill process is shown in **Figure 2.14.** Specific geotextile application details are provided in FM 5-410 and UFC 3-220-08FA, *Engineering Use of Geotextiles*.

Figure 2.12. Comparison of Aggregate Depth Requirements.

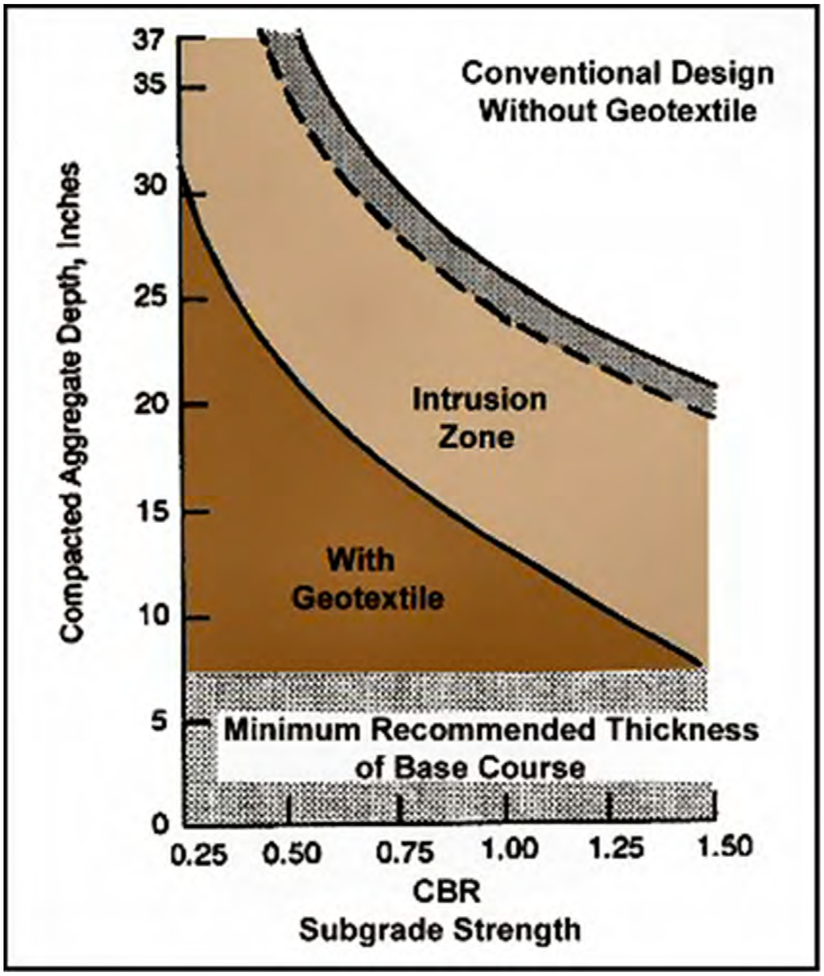


Figure 2.13. Using Geofabric to Separate Construction Materials.

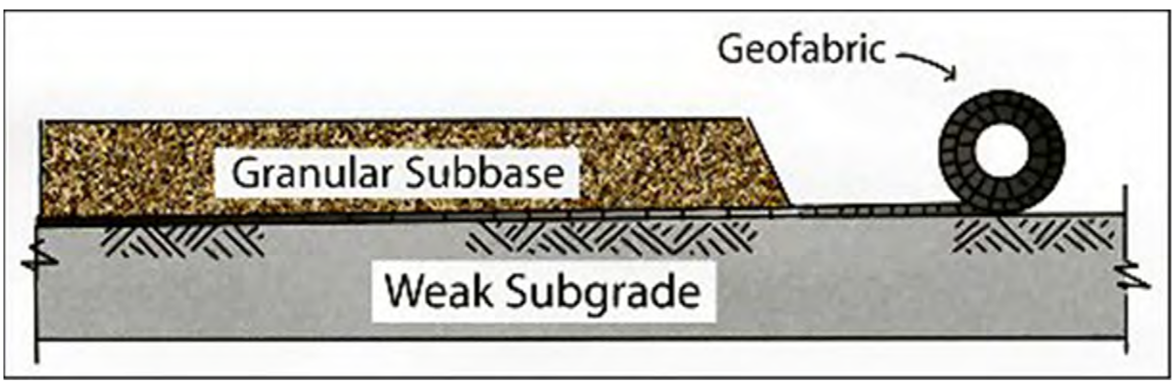
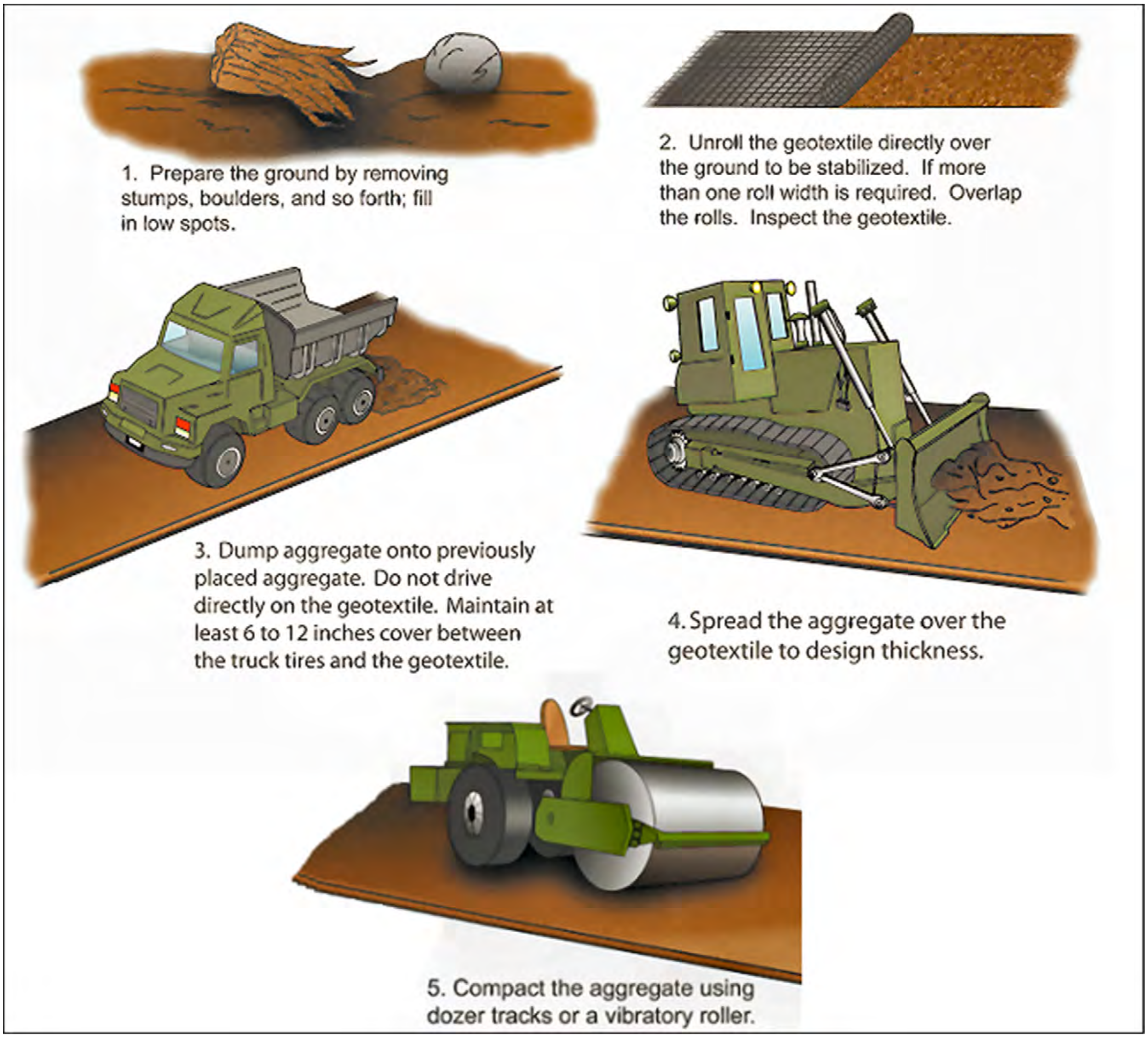


Figure 2.14. Basic Geotextile Construction Sequence.



2.3.2.3.4. **Choosing Geotextiles.** A wide range of geotextile fabric is available to meet various soil conditions. Selection of the proper geotextile will depend on the actual soil and hydraulic conditions. The general soil conditions and considerations listed in **Table 2.3.** should provide some insight into selecting the optimum material. Further information about geotextile uses is available in FM 5-410 and UFC 3-220-08FA.

2.3.2.4. **Other Surface Options.** A number of other materials can be used to construct expedient road surfaces. A few examples include rubble, bricks, concrete blocks, timbers, and loose aggregate or gravel. Detailed information on expedient road construction variations can be found in FM 5-430-00-1.

Table 2.3. Soil and Hydraulic Conditions.

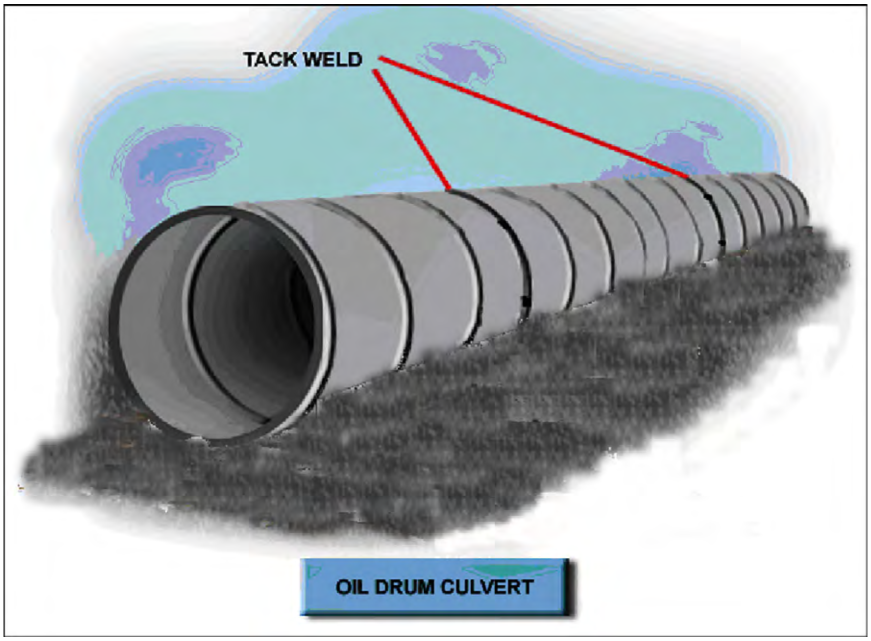
Soil Condition	Consideration
Graded Gravels and Coarse Sands	The use of very open monofilament or multifilament woven materials may be required to permithigh rates of flow anda low risk of blinding.
Sands and Gravels with Less than 20% Fines	This very "dirty" or si lty sand and gravel mate rial requires the use of open monofilament wo ven fabrics and need le-punched nonwoven materials with large openings to redu ce the risk of blinding. For thin, heat-bonded nonwoven geotextile s and thick needle-punched, nonwoven geotextiles, filtration tests should be performed.
Soils with 20% to 60% Fines	When silt or silty sa nd soils are invo lved, filtration tests should be performed on all fabric types.
Soils with Greater than 60% Fines	If dealing with silt or clayey silt type soils, heavyweight needle-punched and heat-bonded nonwoven geote xtiles tend to work best as fines will not pass. If blinding does o ccur, the permeability of the blinding cake would equal that of the soil.
Gap Graded Cohesionless Soils	With these types of soils, consider using a uniform sand filter with a woven monofilament as a filter for the sand.
Silts with Sand Seams	Consider using a uniform sand filt er over the soil with a woven geotextile to prevent mo vement of the filter sand; alternatively , consider using a heavyweight (t hick), needle-punched nonwoven directly against soil as water can flow latera lly through the geotextile should it become locally clogged.

2.4. Expedient Drainage Construction and Repair. Removing surface water and water runoff away from roads, buildings, and other structures is critical during disasters or after an attack. The use of culverts, ditches, and other drainage methods may be necessary to prev ent erosion of key building foundations and roadways or to clear floodwaters from housing and industrial areas.

2.4.1. **Expedient Culvert Designs:** Expedient culverts can be cons tructed from a wide varie ty of materials. A few of the more common variations include sand bags, pierced steel planks, and empty oil, gasoline, or asphalt drums. Culverts constructed of timber or logs are usable in the field as temporary measures until structures that are more permanent can be employed. In both of these instances, an area equal to the end area of anappropriately sized corrugated metal pipe (CMP) or concrete pipe outlet, on the same slope, can be used for hydraulic capacity.

2.4.1.1. **Oil Drum Culverts** (**Figure 2.15.**). When empty drums are used, the capacity of the culverts can be assumed to be equivalent to the same diameter CMP set at a comparable slope. **Note:** If using drums as culverts, take extreme care when using a cutting torch to remove the lids. Joints between drums should be welded solid. However, if this cannot be accomplished, tack welds can be used if provisions are made to seal the join ts to prevent the culvert water from saturating the surrounding fill material.

Figure 2.15. Expedient Oil Drum Culvert.



2.4.1.2. **Log or Timber Box Culverts.** When constructing a log or a timber culvert, the cover should be greater than the top width of the box (see **Figure 2.16.**). Joints should be as tight as practicable and, if plausible, covered with some type of sealing material (such as plastic sheeting, asphalt, or tar) to prevent water seepage. If such material is not available, caulk with leaves and brush. If logs are to be used, in order to obtain maximum structural strength, logs should be trimmed where required to ensure proper seating and securely fastened with spikes or driftpins (see **Figure 2.17.**). In order to reduce joint openings, always lay logs butt to tip. To prevent the movement of soil through log openings, double-layer the top logs with burlap or brush. This step also applies to culverts made of sandbags and pierced steel planks if a paved surface is not used (see **Figure 2.18.** and **Figure 2.19.**). **Note:** A minimum cover of three feet over a culvert of this type is required.

2.4.2. **Open-Ditch Design.** From an expedient construction perspective, the shape of a ditch is usually governed by the engineer equipment available. The road grader will probably be the most common heavy equipment item used. Triangular ditches are appropriate for most situations; they can be symmetrical or nonsymmetrical. If large quantities of runoff are probable, a trapezoidal ditch can be excavated. Do not be conservative when it comes to sizing drainage ditches; an oversized ditch will cause much less problems than one that is too small.

Figure 2.16. Expedient Log Box Culvert.

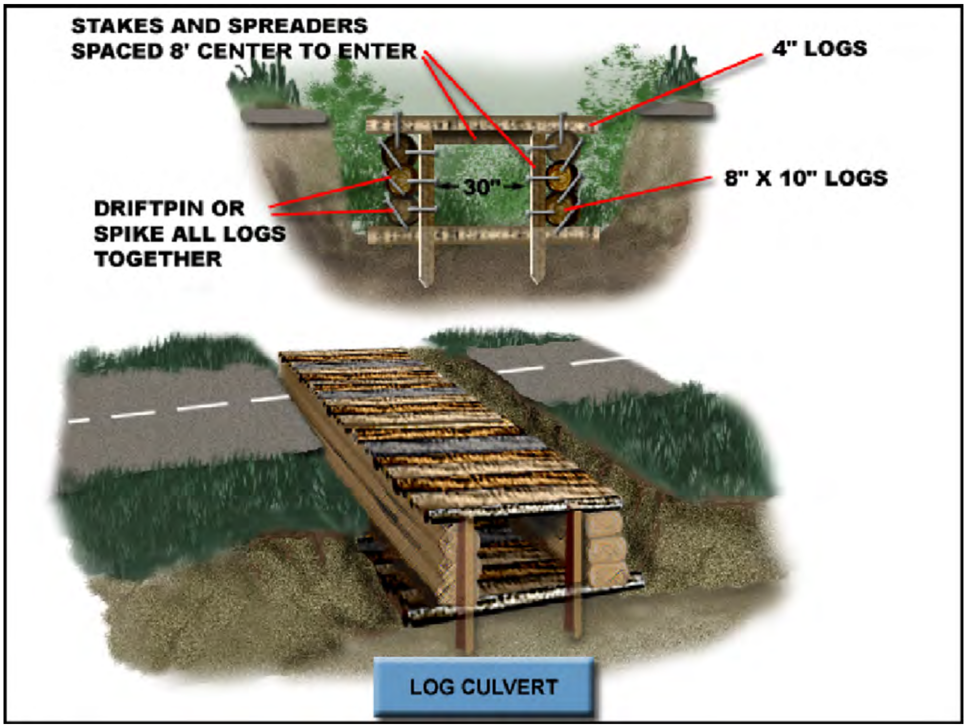


Figure 2.17. Spiking and Fastening a Log Box Culvert.

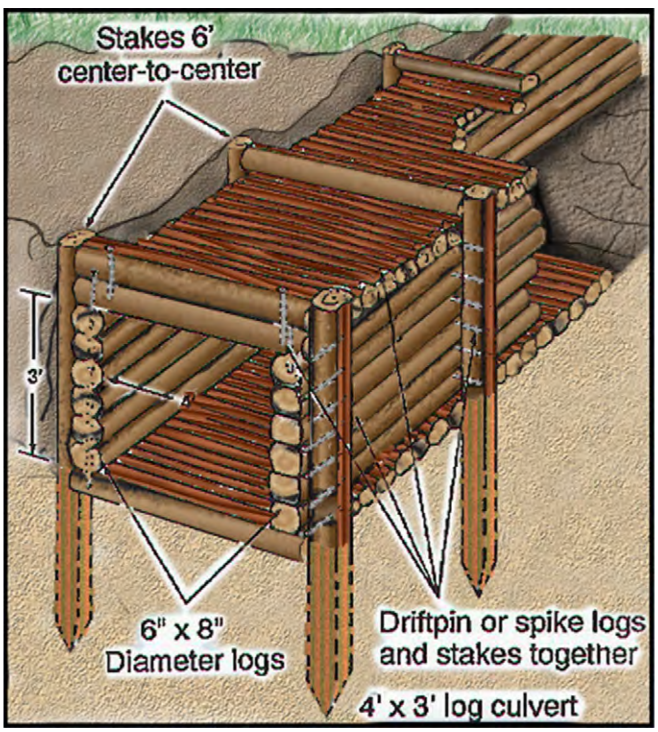


Figure 2.18. Expedient Sandbag Culvert.

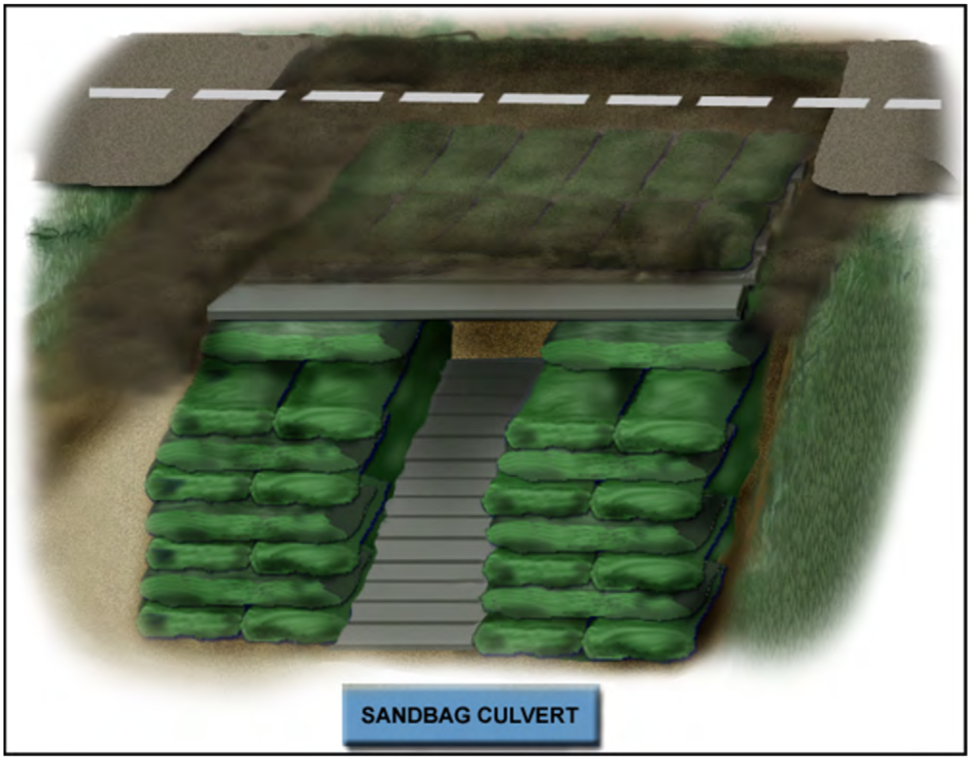
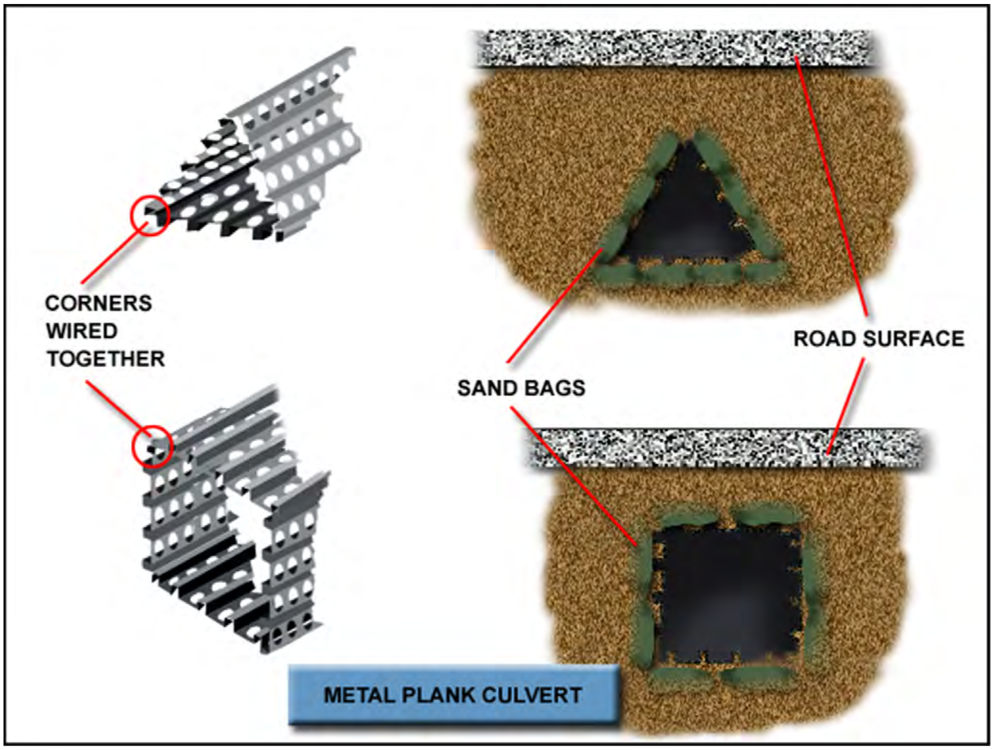


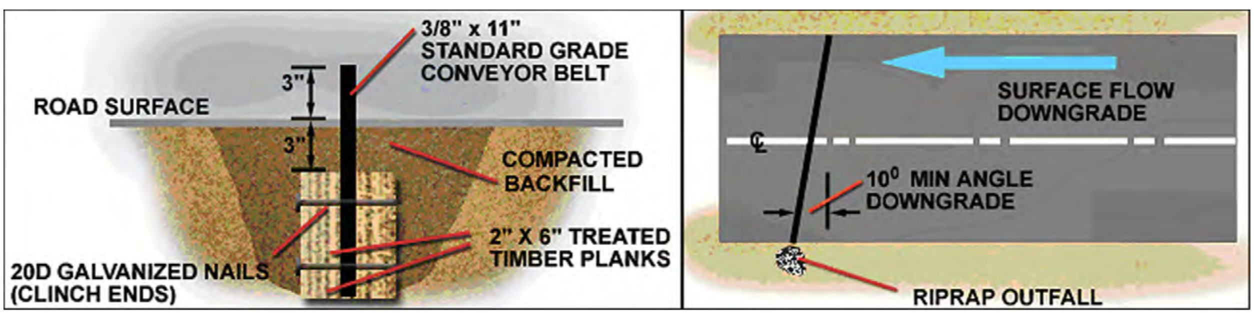
Figure 2.19. Expedient Metal Plank Culvert.



2.4.3. **Deflectors.** To remove water off the surface of an expedient road, a deflector can be installed. Deflectors are particularly effective on sloping roads and help to stop channeling and rutting of the road surface. A deflector is simply a piece of rubber belting 3/8- to a 1/2-inch thick fastened between treated timbers. An unserviceable arresting barrier tape could also be used if a flat rubber belt is not available. The timbers are buried at a slight angle across the roadway with only about 3 inches of the belt exposed (see **Figure 2.20.** and **Figure 2.21.**). As water runs down the surface of the roadway, it is intercepted by the belt and is dispersed off to the side. It is common practice to place riprap at the dispersal end of the deflector to prevent erosion of the shoulder and side slopes of the road.

Figure 2.20. Typical Deflector Installations.

Figure 2.21. Deflector Construction Details.



2.4.4. **Open Top Culverts.** The open top culvert (**Figure 2.22.**) is another way to remove surface water away from the surface of roads. This method consists of a "U" shaped wooden trough made of treated lumber. This trough is installed flush with the roadway surface and angled 30 to 45 degrees downgrade. The outlet end of this type of culvert should extend beyond the edge of the road, and riprap should be placed at the outlet end to prevent erosion. This type of culvert generally requires regular maintenance; consequently, it should only be used on roadways with minimum grades. If treated lumber is not readily available, an open culvert can also be fabricated using natural material as shown in **Figure 2.23.** where logs were employed.

Figure 2.22. Typical Open Top Culvert Example.

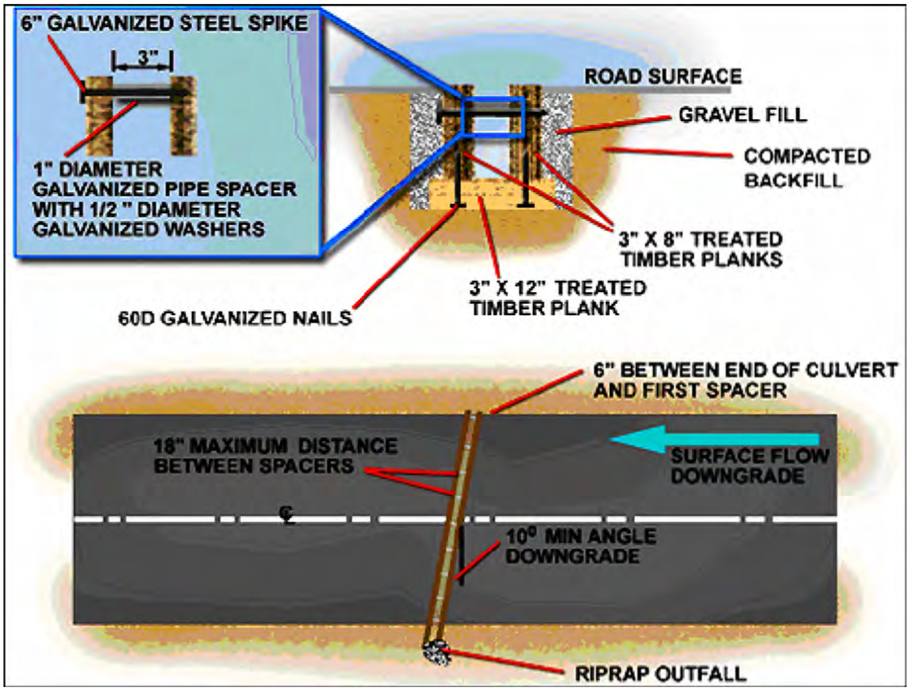
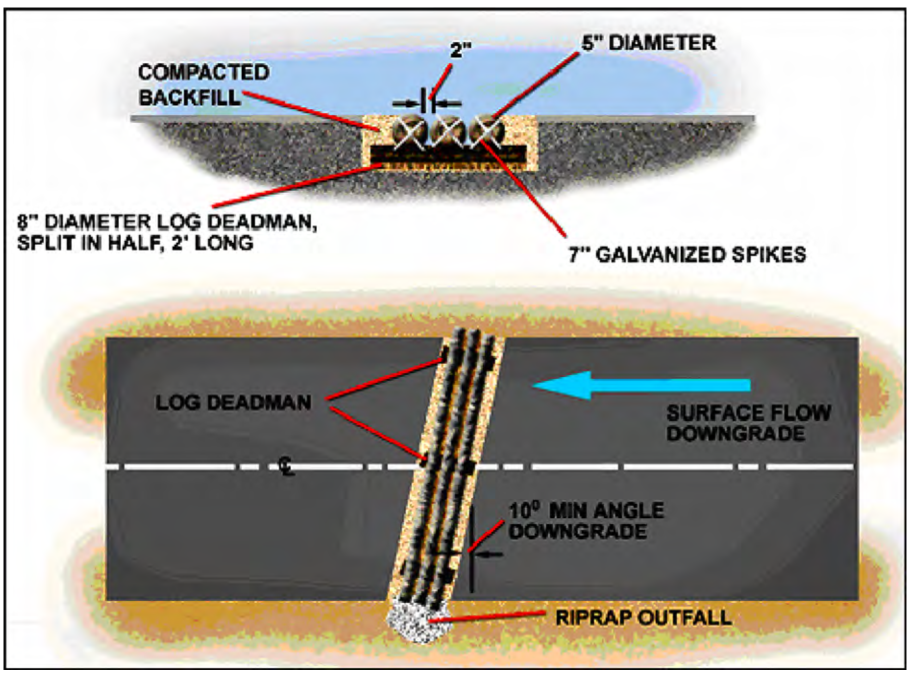


Figure 2.23. Open Culvert Built Using Logs.

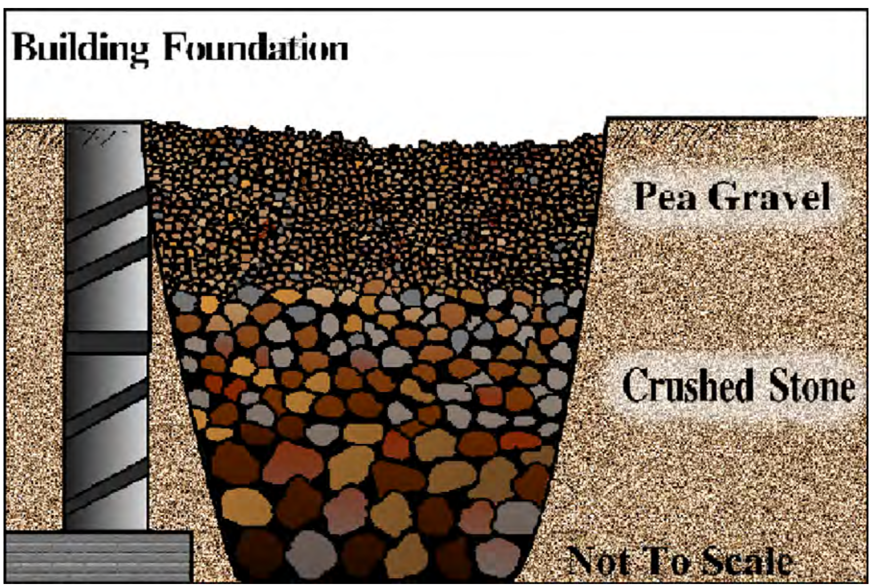


2.4.5. **French Drains.** The purpose of a French drainage system is to carry unwanted freestanding water away from a building. French drains, also known as blind drains, are commonly installed near the perimeter of a structure at the lowest point where standing water is found. The system may terminate at any point where the water will not drain back toward the building. Installing a French drain is usually a simple, but labor-intensive, project. However, obstacles such as tree roots, boulders, and underground utilities, can make the project difficult and time-consuming.

2.4.5.1. French drains are normally shallow systems that function on the principle of gravity. As such, to be effective, the drain must slope downward with a minimum recommended slope of 1/4 inch per foot. If the adjacent ground grade runs upward along the drain path, dig deeper to maintain a downward slope.

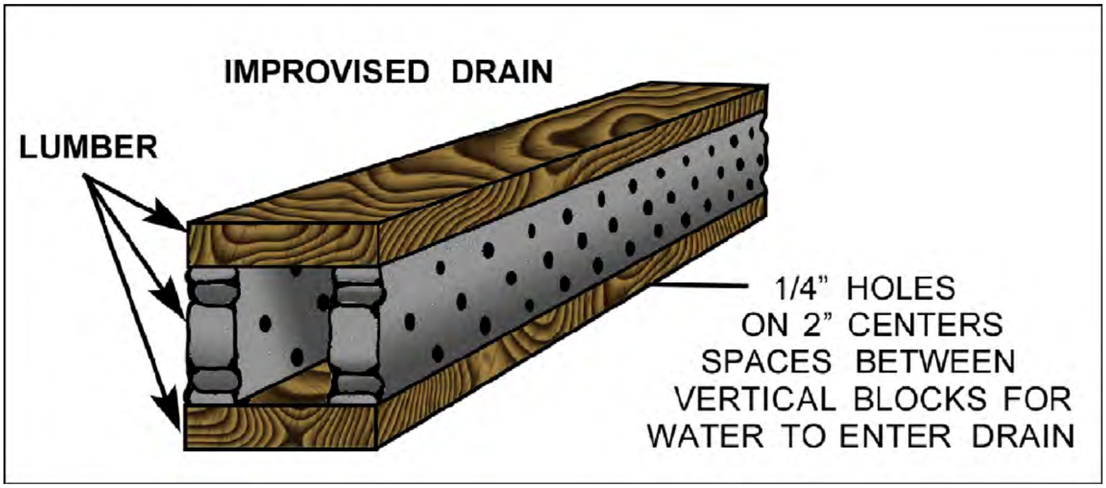
2.4.5.2. In general, French drains are constructed by filling a ditch or trench with broken or crushed rock (see **Figure 2.24.**). The top surface of the rock may be left exposed so the trench will act as a combination drain or the rock may be covered by a relatively impervious soil so that no surface water can penetrate. The latter is the general practice. Normally, French drains are not recommended for permanent construction because they have a tendency to silt up with prolonged use. In field construction, such drains are often used as a substitute for perforated or open joint pipes because of logistical limitations on piping or on filter materials suitable for use with such piping. However, it is advisable to use a French drain with a perforated land drain in the bottom, which may also be wrapped in a layer of this geotextile fabric to ensure longer life by stopping any fines from clogging the system. In areas with severe drainage problems, multiple perforated pipes can be run together to act as water collectors or interceptor drains. This way, water is carried away more quickly when the surrounding earth is saturated.

Figure 2.24. Open French Drain Without Pipe.



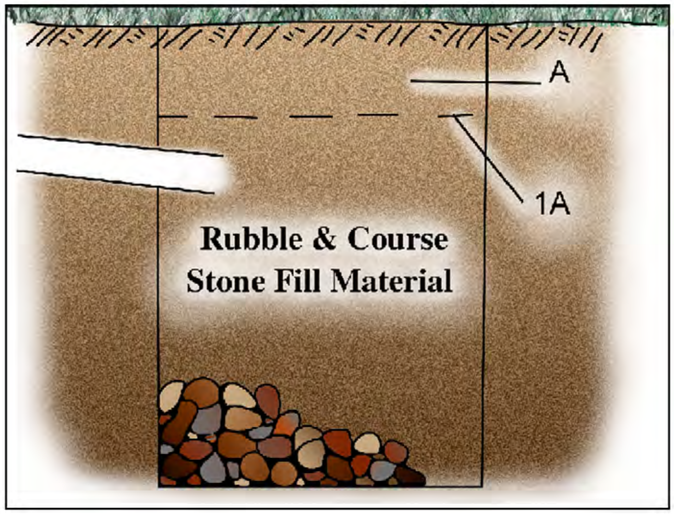
2.4.5.3. **French Drain Construction Details.** The basic procedure for installing a French drain that includes perforated pipe is as follows. However, keep in mind, a system can also be installed without piping and geotextile fabric, but its longevity may be greatly reduced due to silt transfer. From the beginning point of the drain, dig a trench about 12 inches deep and approximately 8 inches wide. If the ground slopes upward, dig deeper from the starting point to maintain a downward slope. Line the cavity with a geotextile, leaving sufficient excess to allow it to overlap the subsequent piping and fill material. Next, pour in about 2 inches of rock (pea gravel or crushed stone). Lay a 4- to 6-inch perforated pipe over the rock with the perforations facing down. If perforated pipe is not available, fabricate a substitute from lumber as shown in **Figure 2.25.** Once the piping has been installed, place another 2 inches of rock in the opening to completely cover the pipe and fold the remaining geotextile over the stone in order to encapsulate the drain field. Lastly, back fill with soil (about 2 inches) and plant grass. **Note:** Water entering the trench will have to run to a suitable drain-off point, and in most cases, this is a soakaway or watercourse. However, rainwater should never be discharged into a cesspool or septic tank, and foul drainage should never be discharged into a French drain or soakaway.

Figure 2.25. Improvised Drain Line.



2.4.6. **Soakaway:** A soakaway is simply a hole in the ground filled with rubble and coarse stone with a drainage pipe laid into it to aid in removing surface (rain) water from other areas. The soil in which the soakaway is placed must be granular with good drainage properties. A soakaway should not be used in clay soils. Most local authority regulations dictate soakaways be located at least 15 feet from any habitable building. The pipe flowing to them should be at least 3 inches in diameter, however, a 4-inch pipe diameter is the recommended size. This pipe should be laid to a fall of 1 in 40. The size of the soakaway should be a minimum of 3' x 3' x 3' below the bottom of the incoming pipe. The stone fill should surround the pipe and finish approximately 4 inches above it. As indicated in **Figure 2.26.**, an impervious layer should then be placed on the stone. Materials such as thick polyethylene, tarpaulin, or even a bed of concrete (A1) are recommended. Topsoil can then be placed on top of this layer to restore the garden level (A).

Figure 2.26. Typical Soakaway.



2.4.7. **Vertical Wells.** Vertical wells are sometimes constructed to permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer of soil. Additional wells are driven if drainage is obstructed or the pocket is drained with an easily maintained lateral sub-drain system. Vertical wells are often used in northern latitudes to permit fast runoff from melting snow to get through the frozen soil and reach a pervious stratum. Under such conditions, the bottoms of these wells are treated with calcium chloride or a layer of hay to prevent freezing.

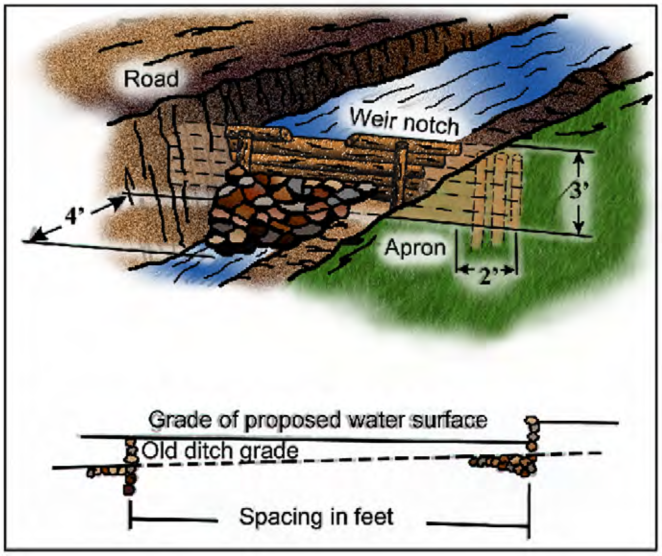
2.5. Drainage System Erosion Control and Maintenance. Erosion presents many difficult problems in designing and maintaining open channels. Erosion tends to change the shape of channels, which can cause troubles near structures such as roads, bridges, and culverts. Additionally, erosion presents problems when the displaced material is deposited in undesi red locations. The primary cause for erosion is the velocity of the water in the channel. The principle method for preventing erosion is to lower the velocity in the channel below the soil erosion velocity.

2.5.1. **Controlling Velocity.** Velocity is dependent on the slope of the channel. If the slope is increased, the velocity increases. One method of decreasing the velocity of the water in a channel is to decrease the slope. Channel velocity is also affected by the shape and depth of the channel. Making the ditch wider and shallower increases the surface area. The larger surface area causes greater friction and lowers the channel velocity. Since constructing a new ditch at a different slope is impractical, an effective alternative is to construct a check dam. Check dams are the most common structure used to reduce velocity in ditches that have longitudinal grades not exceeding 8 percent. They work by decreasing the slope of the water surface. Eventually soil is deposited on the ditch bottom and the ditch slope itself is decreased. Check dams should be considered when the slope ranges between 2 and 8 percent. Channels with slopes of 2 percent or less generally do not require extensive erosion controls. Usually with slopes in excess of 8 percent, it is more economical to pave the ditch with asphalt.

2.5.2. **Constructing Check Dams.** Check dams may be constructed of timber, sandbags, concrete, rock, or similar materials. They should extend at least 24 inches into the bottom and sides of the ditch, and the ditch top should be at least 12 inches above the top of the dam. The effective height of the check dam should be at least 12 inches, but not more than 36 inches. An apron of rubble or riprap should extend at least 4 feet from the face of the check dam on the discharge side to prevent erosion.

A weir notch must be cut in the top of the check dam with a capacity large enough to discharge the anticipated runoff to prevent water from cutting around the edges of the dam. Figure 2.27. shows two views of a check dam.

Figure 2.27. Typical Check Dam With Weir Notch.



2.5.3. **Check Dam Maintenance:** Erosion around the dam is the most common problem associated with check dams. The primary cause for this situation is that the weir notch is too small or is clogged with debris causing water flow over the top of the dam. This situation results in erosion where the dam is anchored into the ground (see Figure 2.28.), and if left uncorrected over time, will often result in more damage to adjacent structures than if the dam was never installed.

2.5.4. **Using Riprap and Rubble.** By increasing the effective roughness of a ditch, ditch soil erosion is decreased. One easy way of doing this is with riprap and rubble (Figure 2.29.). This method involves placing rocks or rubble in the ditch bottom to provide a protective cover over the soil. Normally, rocks should be larger than 6 inches to assure stabilization. Furthermore, they should be hand-placed and compacted individually in at least two layers. The riprap not only prevents erosion, but will also tend to decrease the velocity in the channel. This makes it useful for lowering velocities in sections of channel when making transitions to soil ditches from paved or other high-velocity ditches.

Figure 2.28. Dam Erosion Caused by Weir Notch Debris.

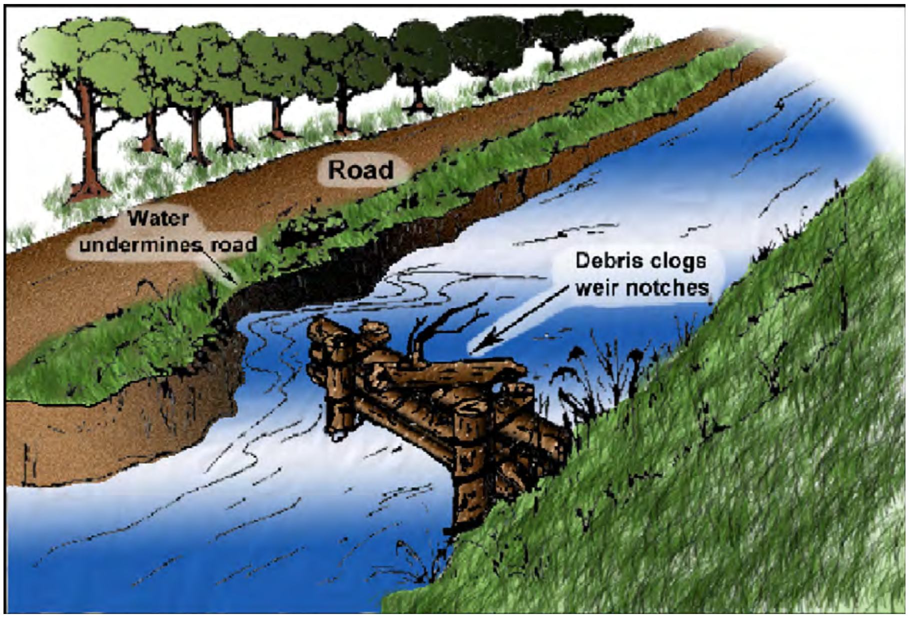
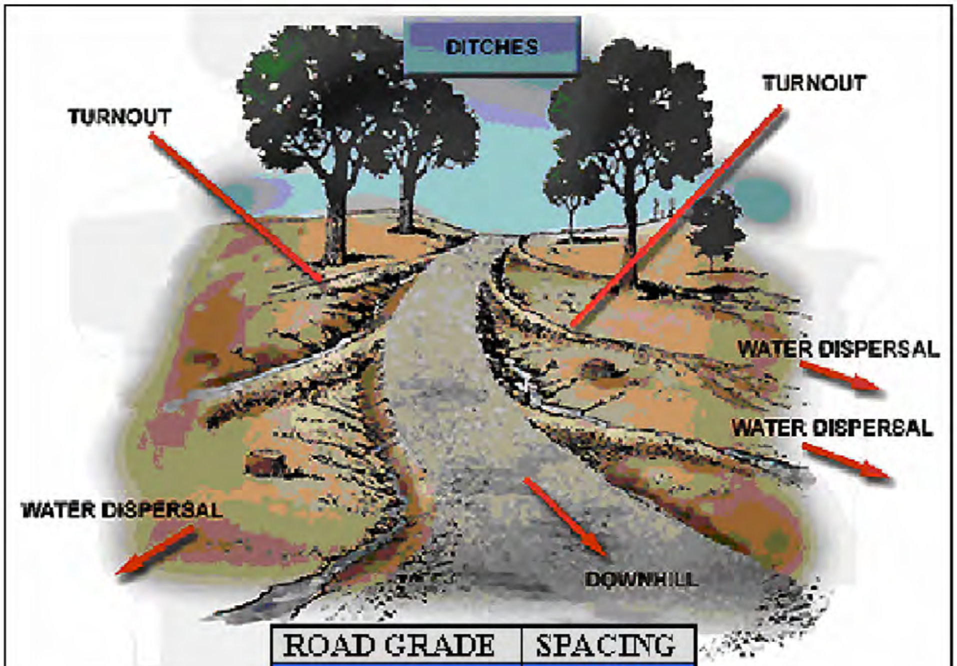


Figure 2.29. Riprap-Lined Drainage Ditches.

2.5.5. **Using Turnouts on Roadside Ditches.** If hilly terrain is encountered during the construction of expedient roads, erosion in the supporting drainage ditches may be a problem. As addressed previously, one method of fighting such erosion involves using riprap, but the use of turnouts might be more effective. Turnouts are channels cut from the roadside ditches to adjacent areas that can handle larger runoff quantities. Attempt to have collected water spread over an open land area. Refrain from diverting the water directly into nearby streams or lakes. **Figure 2.30.** shows a typical turnout arrangement and a chart that indicates the spacing of turnouts in respect to the grading of the road.

Figure 2.30. 2B22BTurnout Layout and Spacing Requirements.



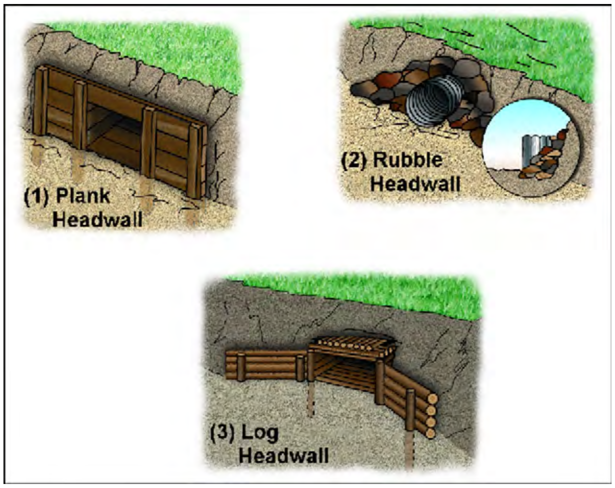
ROAD GRADE	SPACING
2%	500'
5%	300'
10%	200'
15%	100'

2.5.6. **Constructing Headwalls and Wingwalls.** Headwalls and wingwalls are constructed to prevent and control erosion, guide water into a culvert, reduce seepage, and hold the end of a culvert in place. **Figure 2.31.** illustrates three types of expedient headwalls. Headwalls, also known as retaining walls, are always employed at the upstream end of a culvert. Nevertheless, they can also be used downstream where steep grades are involved to support and protect the soil mass at the end of the culvert and to hold the culvert sections in place. They should be constructed of materials as durable as the culvert. Sandbags or rubble can be used in emergency situations.

2.5.6.1. **Headwalls.** The inlet end of the pipe should be extended so that a minimum-sized headwall is required. Headwalls should not protrude above the shoulder grade and should be located at least two feet outside the shoulder to avoid becoming traffic hazards.

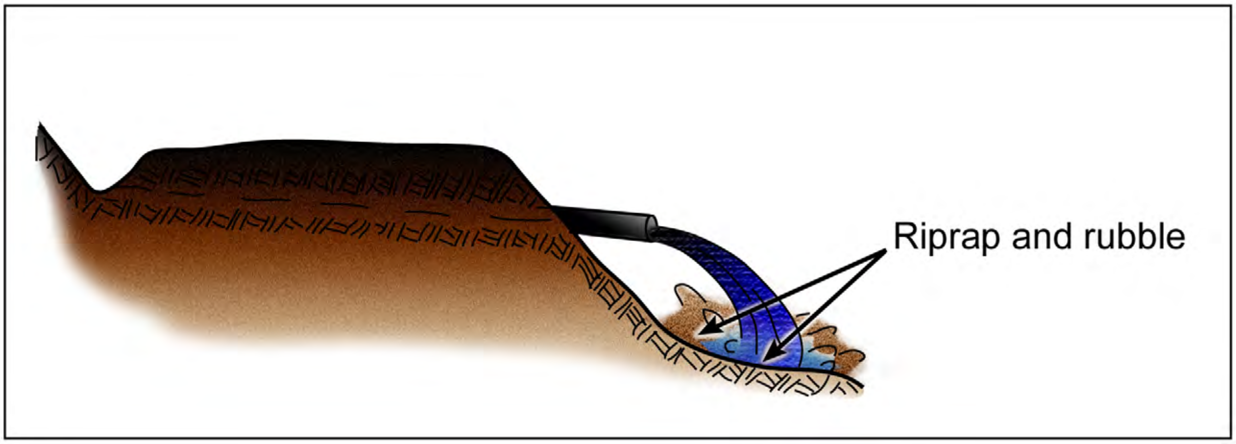
2.5.6.2. **Wingwalls.** Wingwalls are required to channelize water and prevent washing out of headwalls. They are set at an angle to the headwall to further support the surrounding fill and help direct the water flow. Their height should prevent embankment material from spilling into the waterway. The log headwall, shown as (3) in **Figure 2.31.**, includes wings.

Figure 2.31. Expedient Headwall Examples.



2.5.6.3. **Alternatives.** Headwalls and wingwalls are costly to build in both time and materials. When possible, avoid this effort by extending the outlet a minimum distance of two feet beyond the toe of the fill. In addition, the area directly beneath the projecting culvert should be well protected by erosion-resistant material such as sandbags or rock riprap. Riprap should consist of rock not less than 6-inches in diameter. Riprap should be two layers deep on the sides of the channel. Riprap under the culvert outfall should be at least three layers deep (see **Figure 2.32.**).

Figure 2.32. Riprap and Rubble Use When There Is No Headwall.



Chapter 3

EXPEDIENT STRUCTURAL REPAIRS

3.1. Introduction. Expedient structural repair techniques are employed by Air Force engineers to protect fixed assets following a disaster, wartime or terrorist attack, or during humanitarian assistance activities. After a wartime or terrorist attack, emergency building repair is generally limited in scope and emergency repairs are considered adequate when they allow mission-critical functions to continue. During peacetime, an emergency building repair may be required as a result of a major disaster or emergency. The type and extent of the disaster or emergency will, to a large degree, dictate both the type and extent of the recovery response. Tornadoes and hurricanes are two of the more common natural disasters that affect military installations. In the past, Altus, Homestead, and Tinker Air Force Bases suffered heavy damage that was similar to that of an airfield attack from these weather phenomena. Installations and local communities can also experience fires, floods, and the affects of volcanoes. The devastation from Hurricane Katrina at Keesler Air Force Base in 2005 (**Figure 3.1.**) reinforces the necessity for engineers to have the skill-sets required to expediently repair the damage generated by such storms.

Figure 3.1. Building Damage From Hurricane Katrina at Keesler AFB (2005).

3.2. Overview. This chapter concentrates on common techniques used to make expedient or emergency repairs to damaged structures—either civilian or military. Emergency repairs of critical facilities normally involve debris removal; demolition and/or shoring and expedient structural patching of roofing, structural openings, and exterior sheathing. The topics presented in this chapter consist of repair considerations, area clearing and safing practices, debris clearing operations, structural shoring, and facility expedient damage repair.

3.3. Repair Considerations. Expedient repair of facilities must be viewed from a common sense perspective. The following considerations should form the basis for facility repair activities.

3.3.1. **Safety.** Wartime and contingency environments are hazardous enough without endangering personnel through unsafe acts during repair activities. Structures may be weakened, live electrical wires may be down, explosive gas vapors may be present, chemical or biological contamination may be prevalent, and unexploded ordnance may litter the installation. Air base medical facilities may be crowded with casualties, and civil engineer (CE) manpower will probably be at critical levels. These conditions make it essential that resources are not further taxed by injuries caused through neglect of safety practices. Enthusiasm for getting the job done must be tempered with a prudent assessment of the risks. Time should be taken to make a preliminary survey of any suspect structures before any repairs are attempted. Also, when civil engineers provide assistance to off-base civilian facilities during a major disaster, they may be faced with various types of structures and hazards that are not common to their installation environment.

3.3.2. **Expediency.** All engineer efforts immediately following an emergency should be limited to minimum-essential repair of crucial facilities. Work performed should concentrate on functional rather than cosmetic repair. All structural repair efforts should be geared toward making a facility safe for occupancy and providing minimal protection from the elements.

3.3.3. **Mission.** The importance of the facility to the overall base mission determines the repair priority. Damaged facilities housing activities that are not essential to the base mission and do not present a hazard should be left as they are until time and resources permit conventional repairs.

3.3.4. **Practicality.** Considerations of other related repair activities affecting the facility should be taken into account. For example, if the facility provides service to aircraft and all access pavements are so severely damaged that they cannot be made usable for days, the structural repair can wait. Similarly, if the supporting utility systems to a facility are far beyond emergency repair, the structural portion of the repair effort can be delayed. On the other hand, lack of full utility service does not mean a building will be totally useless. A facility with partial utility service, electricity but no water for example, can still be used for its wartime purpose. The damage control center will have to make the decision as to the practicality of repair.

3.3.5. **Flexibility.** Flexibility is essential to any expedient repair effort—including ones of a structural nature. During war, expect repair priorities to change; engineer efforts must adjust accordingly. As might be expected, no two attacks will be identical; therefore, no two sets of structural repair taskings will be identical. Even during peacetime contingencies, engineer forces must not get locked into a standard set of facility priorities and spend a lot of time on minor repairs to the detriment of other more pressing requirements. For example, emergency repairs to a power generating plant may prove more important at some point in time than minor repairs to either an installation command and control (C2) center or other normally high-priority facility.

3.4. Area Clearing and Safing Practices. Area clearing and safing are important considerations when accomplishing any type of repair, but they are especially important with regard to expedient repairs following an emergency. Below are some common safety considerations and hazards that may be encountered.

3.4.1. **Safety Considerations.** Working smartly and safely is vitally important during area clearing operations. Disease-causing contaminants and structural damage could present some unusual health and safety problems for workers.

3.4.1.1. **Disease-Causing Contaminants.** Some buildings affected by conventional attacks, hurricanes, or contaminated floodwaters have walls, insulation, floors, and ventilation systems that can become breeding grounds for disease. Building materials can exhibit a wicking effect that draws water into and up the walls—as much as 3 feet above the water line. Even if workers do not become contaminated while repairing the facility, the occupants working in the buildings afterwards may quickly become seriously ill as the pathogens grow and become airborne. If time is available, make sure that the work area and critical facilities are free of contaminants, even if it requires ripping out wallboard, floor covering, and insulation. Consider hosing off contaminants with clean water or disinfectant at the work site.

3.4.1.2. **Structural Damage.** As emergency repairs are underway, efforts may grind to a halt should the building incur further consequential structural damage by wind and water after the initial onslaught. When sheetrock becomes wet, it loses strength and becomes heavier. The additional weight and loss of strength can cause further damage or collapse. If repairs are delayed, provide temporary protection and early cleanup to avoid additional damage. Shoring procedures that are covered in paragraph **3.6.** may also be necessary.

3.4.2. **Hazards.** Whether on or off base, not all hazards are identified and not all hazards are quickly cleared. Problems could arise when setting up for emergency repairs even after first responders have been through the facilities.

3.4.2.1. **Electrical Hazards.** Electrical wires are usually a problem following bomb damage, hurricanes, tornados, or floods. The wires are vulnerable and are easily knocked down. They can be especially hard to see at night and may not have been made safe by others. A generator powering a nearby work site can send power through damaged electrical systems and reenergize wires at the work site. When working in this type of environment, be on the lookout for loose wires and make sure that main power panels are off before entering a building for emergency repair. This is especially important when working on metal roofs or metal structures situated near damaged electrical lines. The power distribution system damage depicted in **Figure 3.2.** is typical of what one might expect to encounter after a larger category hurricane.

Figure 3.2. Hurricane Damage on St. Thomas, Virgin Islands (1995).

3.4.2.2. **Gas Hazards.** Gas explosions and fires can cause fatalities. Containers and tanks can be displaced by winds and floods. Compressed gas tanks and drums carrying chemicals are often found in facilities. These containers can easily penetrate building walls as they are moved about by high winds and flood waters. Be alert for leaking gas from tanks or ruptured utility lines, and pay particular attention to smells when around buildings. An extremely offensive, garlicky odor is usually associated with mercaptans, a class of sulfur-containing compounds added to natural or bottled gas. Even moderate damage can turn deadly when leaking gas is involved. An ozone smell or a peculiar odor suggesting that of weak chlorine may indicate that there are arcing electrical wires.

3.4.2.3. **Biological Hazards.** Biological hazards can be a problem after an attack. An example of this hazard would be a terrorist use of anthrax or smallpox. Natural biological hazards are also a problem for civil engineers conducting emergency repairs after floods, hurricanes, and tornadoes. Hazardous wastes can also be a major problem after floods and other natural disasters. Floodwaters or debris may expose rotting animal carcasses and sewage that contain pathogenic microbes, viruses, bacteria, and fungi.

3.4.2.4. **Animal and Insect Hazards.** Live animals and insects can be just as dangerous as the effects of dead animals during floods. Animals, reptiles, and insects often take refuge within buildings that have been damaged. Snakes and venomous insects can be especially problematic in coastal areas affected by floods and hurricanes.

3.4.2.5. **Asbestos and Lead Hazards.** Exposure to asbestos and lead can be a problem, especially when the work area has been badly damaged by an explosion or windstorm. Flying debris or blast waves can expose enclosed areas of buildings where brittle asbestos was previously concealed. Previously encapsulated asbestos shingles, wallboard, plaster, insulation, or stucco can fracture and disperse asbestos fibers (see **Figure 3.3.**). While recent base control and removal efforts may limit exposure to asbestos on the installation, off-base facilities could cause serious exposure problems.

Figure 3.3. Examples of Asbestos Use in Construction.

3.5. Debris Clearing Operations. A major disaster or enemy attack could generate vast amounts of debris (**Figure 3.4.**). When clearing debris from work areas and facilities, provide enough room around the facility to allow access for high-reach trucks, cranes, ladders, or scaffolding that may be required during the repair. Make sure utility and telephone cables are removed or completely isolated from the work area. Wires, cable, metal fences, pipes, and roofs can become energized and cause electrocution if contacted by hot power lines. At times it is safer to remove damaged building parts when it is extremely dangerous to repair the component. This is often the case with heavy hangar doors when dislodged from their tracks after an explosion or windstorm. Doors of this type normally require special equipment and training to allow recovery or repair. However, large doors or smaller hangar door sections may be valuable as temporary replacement wall sections if equipment is available to safely move them. Always clear out hazardous materials and debris, especially wet debris. If immediate repairs cannot be made to walls or roofs with plywood, protect the area with tarps and/or plastic sheeting. Keep in mind that little adjustments can make the job much more manageable. For example, cleanup is easier when debris can be tossed through a blown out wall or window before repairs are made.

Figure 3.4. Debris Clearing After Hurricane Andrew at Homestead AFB (1992).

3.5.1. **Debris Removal Priorities.** The priorities for debris removal will vary depending on base mission and type of disaster. The Emergency Operations Center (EOC), or the on scene commander in the case of military response to a civilian emergency, assigns debris removal priorities. In the instance where damage is limited to a military complex, debris removal personnel should expect the EOC to assign the highest priorities to the areas most critical to the mission.

3.5.2. **Debris Removal Resources.** As might be anticipated, the type of equipment required to clear an area is related to the size and amount of debris. Large pieces of wreckage will necessitate the use of heavy equipment such as bulldozers and cranes. If equipment is scarce, areas with large amounts of smaller-size debris may be cleared with hand tools. The following equipment items can be effective in debris clearance operations.

3.5.2.1. **Crane.** For removing extremely large chunks of debris, a crane may be the only suitable piece of equipment. A crane can clear destruction on upper floors of a structure beyond the reach of a excavator or front-end loader.

3.5.2.2. **Bulldozer.** A bulldozer has the power to push large pieces of debris out of an area and can quickly clear large areas of smaller debris (see **Figure 3.5.**). One skilled dozer operator can clear an area that would require several hours of labor if done by hand. However, bulldozers may be in short supply if runway repair is required.

Figure 3.5. Debris Clearing After Volcano Eruption in the Philippines (1991).

3.5.2.3. **Front-End Loader.** Front-end loaders are especially useful in loading debris on dump trucks and other vehicles for removal from the site. They also are adequate for clearing paved areas and streets of large amounts of small debris.

3.5.2.4. **Dump Truck.** Dump trucks haul debris to disposal sites; however, after an attack, like bulldozers, they are essential vehicles in airfield damage repair activities and may be available only in limited numbers for debris removal. Other suitable vehicles, such as cargo trucks and tractor-trailer units, can sometimes substitute for them.

3.5.2.5. **Sweepers.** Once larger debris is removed from an area, street sweepers are employed to clear smaller items from aircraft operating surfaces and primary access streets. If sweepers are not used, small metal items left on roadways and working areas can cause tire damage to equipment involved in cleanup operations. Time spent repairing and replacing flat tires on these vehicles only serves to further delay the overall recovery effort.

3.5.2.6. **Towing Devices.** Steel cable, chains, hooks, and similar items can be fashioned into towing devices for debris removal.

3.5.2.7. **Hand Tools.** Various types of hand tools are useful in debris clearance. Chainsaws and axes can be used to cut fallen trees into smaller sections for easier removal. Shovels are useful in loading smaller debris on vehicles for transport to a disposal site. Brooms and rakes can be used to clear surface areas of scattered debris.

3.5.2.8. **Manpower.** The amount of CE manpower required to clear an area of debris will be based upon the availability of the labor-saving equipment discussed in the previous paragraphs. Obviously, if mechanical equipment is available, fewer personnel will be needed for cleanup. However, personnel assigned to cleanup detail must be skilled in the operation of equipment. Less equipment means a greater number of persons required, but their skill levels need not be as high. During recovery operations on a military installation, in all likelihood, the EOC will task other installation agencies, whose post-attack missions may not be critical to aircraft generation, to supply augmenters for debris removal efforts. In such instances, CE personnel will have to supervise these individuals during debris removal activities and provide them with necessary tools and protective gear such as gloves. Also, remember the augmentees may not be cognizant of the dangers involved with debris removal nor be trained in explosive ordnance reconnaissance; therefore, their taskings should be assigned with these limitations in mind.

3.5.3. **Debris Removal Operations.** The debris removal operation is dictated by available equipment, manpower, and common sense. In the period immediately following a disaster or enemy attack, the EOC or on scene commander will make decisions regarding how debris removal operations should proceed. Debris in nonessential areas will be left until additional resources become available unless it hampers recovery operations or poses a safety hazard. Personnel will be assigned debris clearance tasks, and equipment will be allocated on a priority basis.

3.5.3.1. **Removal Preparations.** This step consists of establishing debris removal crews, positioning equipment for removal activities, attaching cables and other devices to large pieces of debris, breaking or cutting up larger debris pieces for ease of removal, and similar actions. Any debris salvageable for recovery operations should be set aside.

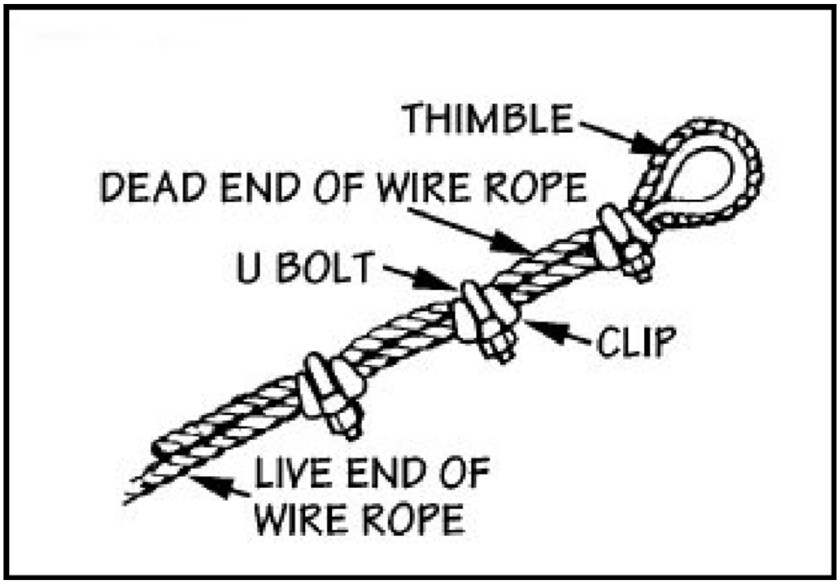
3.5.3.2. **Removal and Disposal.** Under certain circumstances, the debris may be pushed into craters, or prepared holes, and buried. When debris is not buried or otherwise disposed of at the scene of destruction, it is moved to a central location where it is loaded into dump trucks or other vehicles for transport to a remote location for burial or burning. The local environmental flight should be consulted before establishing any landfill or debris-burning operation.

3.6. Structural Shoring. Once debris has been removed and safe access is assured, the first concern in structural repairs should be shoring any weakened areas to restore a minimum degree of structural integrity to the facility. Immediately after an attack or natural disaster, there may not be time to make a detailed engineering analysis on structural soundness. Instead, rely on field experience, facility appearance, common sense, and instinct. If a facility appears beyond repair, demolition is probably in order. On the other hand, once it is determined to "save" a facility and the areas in need of repair have been identified, there are numerous shoring and patching repair options available. Most require relatively common engineering materials readily available on base or from off-base vendors. Examples include guying, bracing, jacking, splinting, tension ties, stitching dogs, and welding.

3.6.1. **Guying.** Guys are usually fashioned from wire rope and tensioned by turnbuckles, if available. Guy wires are commonly found providing stabilizing support for power poles and tall antennas. Guys are normally installed to function in opposing pairs to provide lateral restraint from such forces as wind or ice loading. They are particularly effective when damage has been sustained to end walls or sidewalls, yet roof members have been essentially untouched. Depending upon the situation, they can be installed either inside or outside a facility. The number of pairs required will depend upon the situation at hand, based upon the size of the facility being shored and extent of damage sustained.

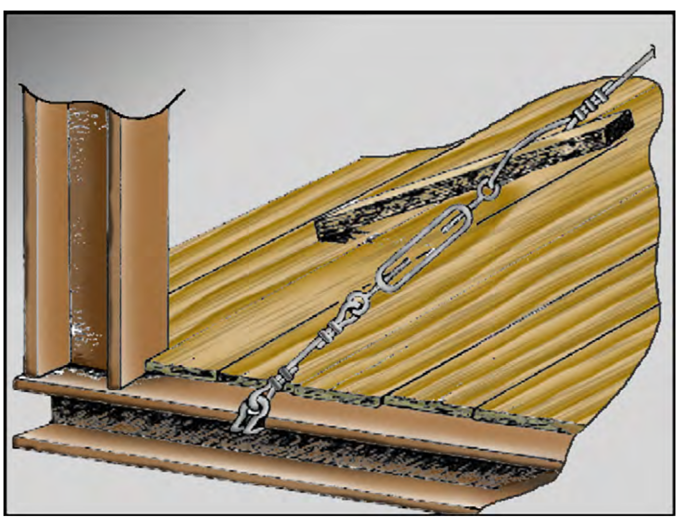
3.6.1.1. Although a number of different wire rope fittings are available commercially, by far the most common means of attachment of wire rope guys is the use of wire rope clips (**Figure 3.6.**). When properly installed, clips can provide up to 80 percent of the rope's strength. The size of the wire rope dictates the number of clips used and their spacing. A good rule of thumb is to use a minimum of three clips spaced about 3- 3/4 inches apart for 1/2- or 5/8-inch rope, and four clips spaced 4- 1/2 inches apart for 3/4- or 7/8-inch rope. These standard practices prevent kinking of the rope and fraying of the cable due to friction when it is connected to a turnbuckle or other attachment. Also, note how the clips are attached to the rope. The bend of the U-bolt compresses the dead end of the rope, whereas the clip compresses the live end of the rope. The live end of the rope leads back to the structure that is being guyed.

Figure 3.6. Installation of Wire Rope Clips.



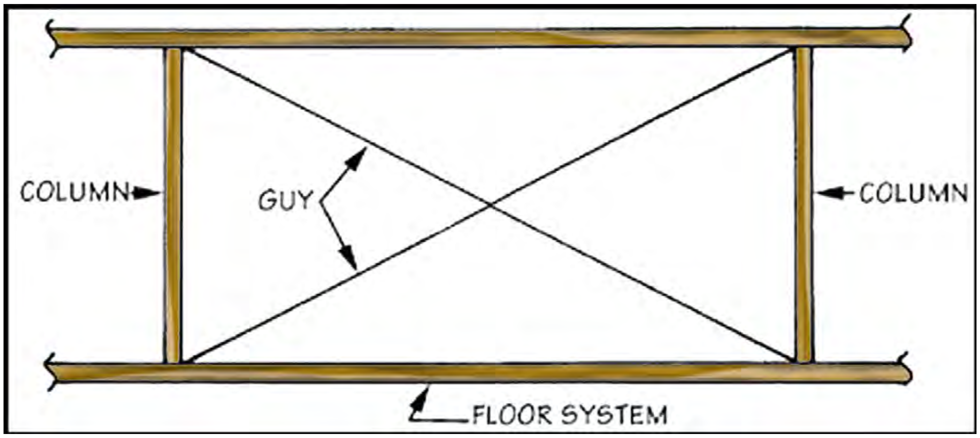
3.6.1.2. **Figure 3.7.** illustrates a typical guy wire connection to a structure. The wire rope is attached to a turnbuckle that is attached to the building. This particular example shows a connection to a steel beam using a beam clip. A beam clip is merely a C-shaped connector that can be fabricated in the shop, if necessary. Other connections to a structure are possible using eye bolts and even wrapping the rope around the structural member to be stabilized. Note the use of the 2" x 4" board as a brace to prevent the guy wire from twisting as the turnbuckle is tightened. If an external guy is to be used, one end of the guy must be connected to a solid, immovable object, commonly referred to as a "deadman." The deadman can be a nearby foundation, another part of the structure to be guyed, screw-anchors similar to what linemen use for pole guying, or even a piece of unserviceable equipment, provided it is heavy enough.

Figure 3.7. Typical Guy Wire Connection to a Structure.



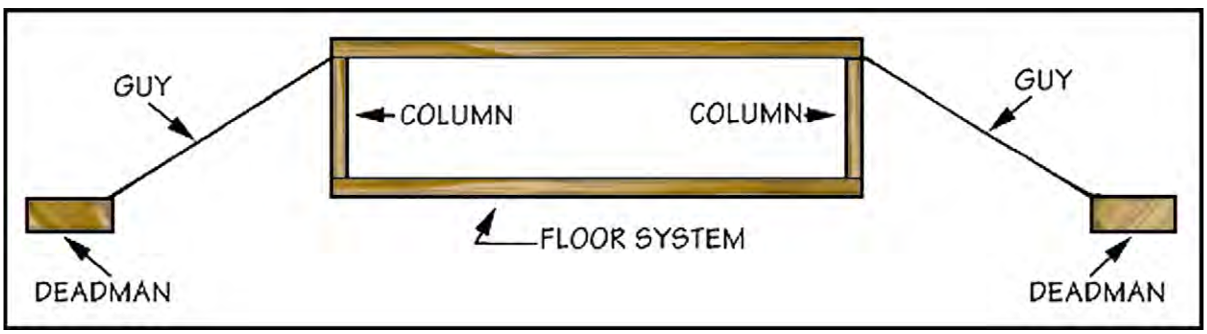
3.6.1.3. As mentioned earlier, guys can be installed either internally or externally. **Figure 3.8.** illustrates an internal configuration. Keep in mind that guys must be tightened in pairs and concurrently to avoid placing too much stress on the structure's frame at any particular point. However, caution must be used to prevent overtightening; the intent is to take all the sag out of the wire ropes.

Figure 3.8. Internal Guy System.



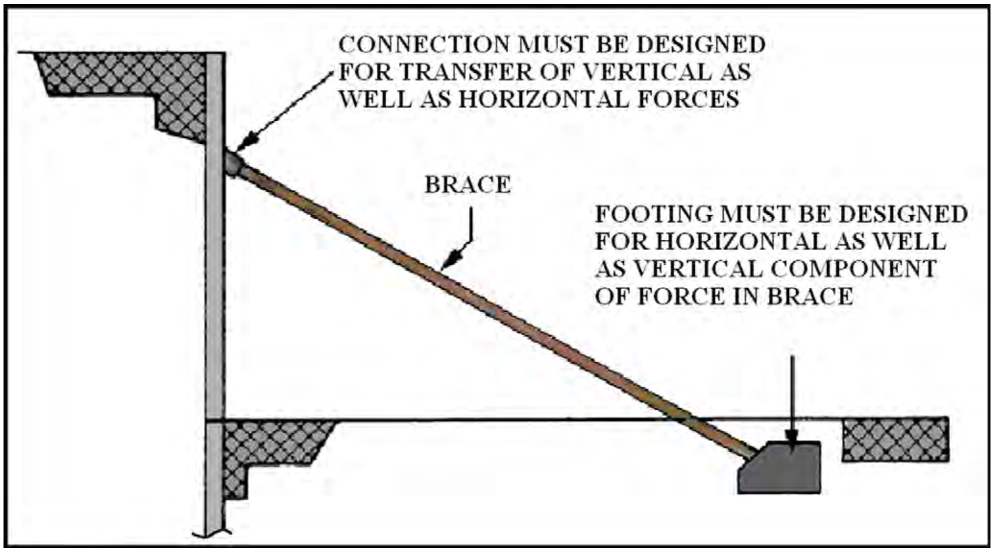
3.6.1.4. The external guy configuration is also installed in pairs (see **Figure 3.9.**). The major difference is instead of using the structure itself as the end points for the guys, external anchors or deadmen are used. The stabilization effect is essentially the same.

Figure 3.9. External Guy System.



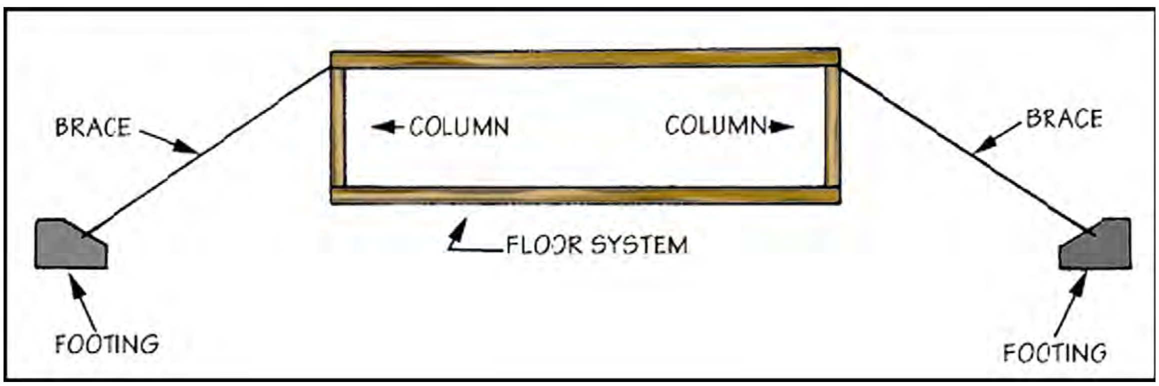
3.6.2. **Bracing.** Braces are compression members usually made of structural steel and heavy timbers (**Figure 3.10.**). Like guys, they can be installed eitherinternally or externally. Depending upon the situation, they can be placed in opposite pairs or used individually. Regardless of the method used, ensure adequate connections to the structure are made. If not well attached, the probability that the bracing will slide out of position is great, risking further facility damage or collapse. Footings for bracing require the same attention; they must be of sufficient mass so they will not move when force is applied. Do not expect a brace that is just shoved into the ground to hold. If necessary, build an expedient footing out of rubble, heavy metal, or timber if another part of the structure's foundation, or the foundation of an adjacent building is not available.

Figure 3.10. Typical Brace Configuration.



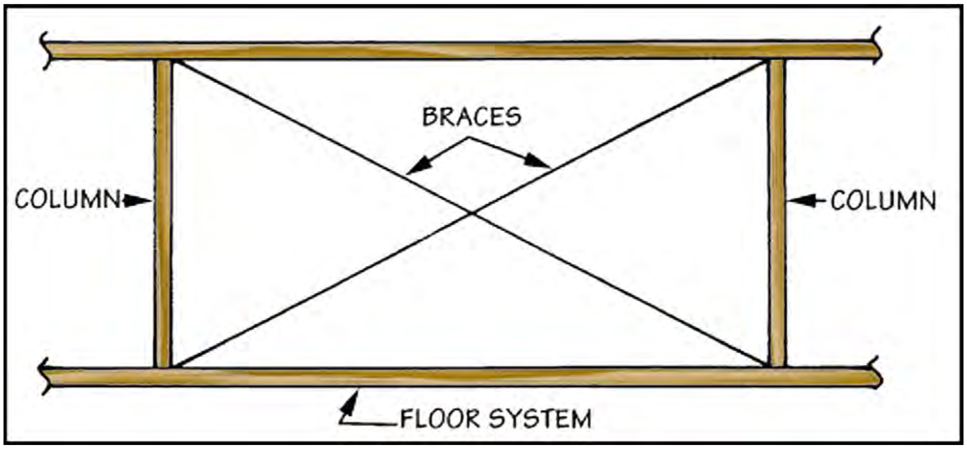
3.6.2.1. In most cases, braces will have to be installed in pairs, as shown in **Figure 3.11.** Like guy wires, more than one pair of braces may be required. This will be an on-site decision, generally driven by the size of the building being shored and severity of damage incurred.

Figure 3.11. Externally Opposed Braces.



3.6.2.2. Internal braces are depicted in **Figure 3.12.** and are also normally installed in pairs. Remember, braces must be firmly attached to the facility to prevent slipping out of position when pressure is applied.

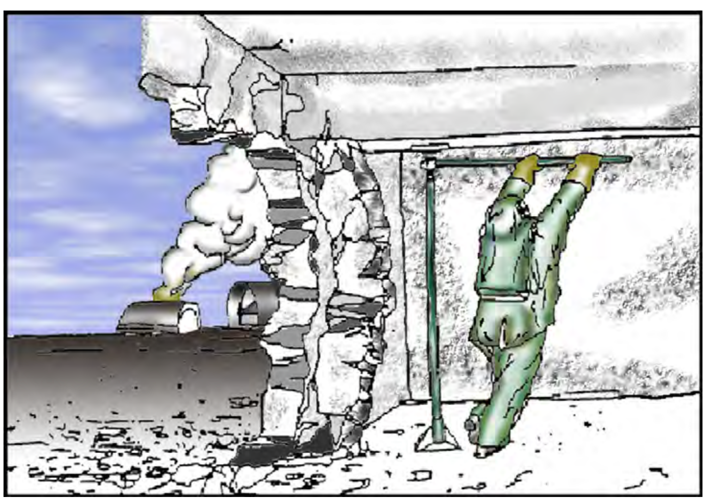
Figure 3.12. Internally Opposed Braces.



3.6.3. **Jacking.** Guying and bracing usually are used to stabilize a facility from lateral movement, keeping it from moving side to side. In some cases, the structural integrity of a facility may be jeopardized due to damaged structural members that are more directly affected by vertical loads—in other words, the effects of gravity. In such situations, there may be deflected or cracked beams/girders that need vertical support or damaged columns that will eventually need replacement. Shoring jacks help provide expedient solutions for these types of problems.

3.6.3.1. Shoring jacks are placed immediately under the point of deflection, or adjacent to the damaged column, and extended until they are firmly wedged into position (**Figure 3.13.**). Any debris around the base of the jacks must be cleared away so that the jacks are positioned squarely on the facility floor. While not shown in the figure, it is also advisable to brace the jacks once they are in position. This can be accomplished by welding two steel plates on the jacks at 90 degrees to each other. The plates should have 3/4-inch holes drilled in them. Standard 2" x 4"s are then bolted to the plates at one end and nailed at the other end to short pieces of 2" x 4" stock that have been attached to the floor of the facility using explosive actuated fasteners or suitable threaded concrete fasteners.

Figure 3.13. Shoring Jack Installation.

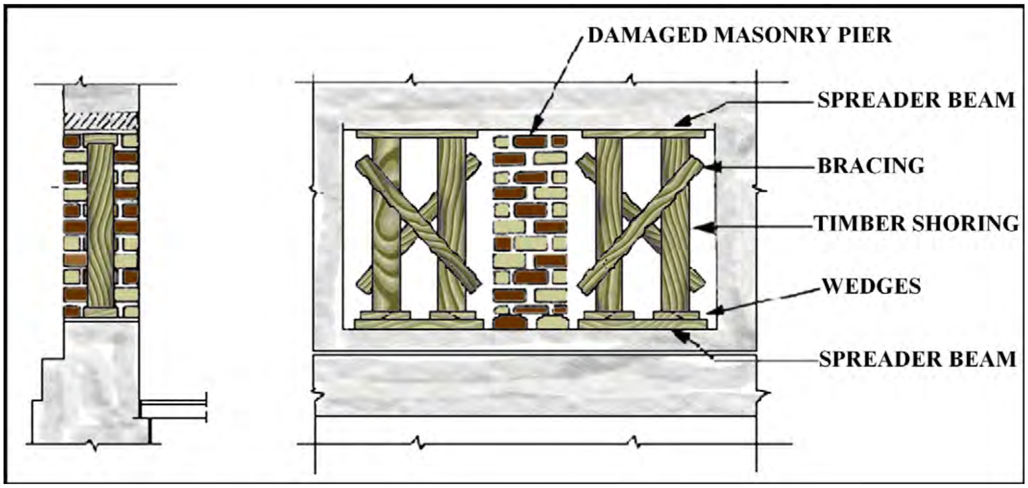


3.6.3.2. In most cases, shoring jacks will be in short supply and too valuable to leave in damaged facilities. An alternative to leaving the jacks is using timbers as supporting members, as shown in **Figure 3.14.** Wood and timber are extensively used to shore damaged structural components because of their availability and economy. A variety of elements can be employed, ranging from tree logs, sawed timbers, and utility poles to industrially made items with different cross sections, such as planks, boards and beams. The procedures for installing timbers are similar to jacks, but are somewhat more manpower intensive. After clearing debris from the work area, a shoring jack is placed immediately adjacent to the location where the timber is going to go. The jack is then raised until it reaches the desired height, or it can no longer be extended. Measure the distance from the top of the jack to the floor and cut the timber 1/2-inch shorter than the measurement. Once cut, the timber is raised into position and several wedges are pounded into the 1/2-inch gap between the top of the timber and the damaged beam; this secures the timber into position. The shoring jack is then lowered and removed. The final step is to brace the timber in two directions, similar to what was done earlier with nails and 2" x 4" stock.

3.6.3.3. Timber shoring can also be used for expedient repair of damaged load-bearing walls with openings, such as windows or doors. The use of timber to take the vertical load from a damaged masonry pier between two windows is shown in **Figure 3.15.** Note that bracing is used between the vertical timbers in each window opening. This common construction technique increases the efficiency of the timbers by reducing their potential for buckling under any increases in load. Also, spreader beams have been placed at the top and bottom of the timbers where they meet the window frames. These beams spread the vertical load over a larger surface area, decreasing the chance of punching through or shearing the window frame. Spreader beams can be made from planks, boards, or even steel plates. The wedges shown are used to secure the vertical timbers in position. One final note concerning the use of timbers; if heavy timbers are not readily available, be resourceful. Other facilities that have been damaged beyond repair may contain salvageable timbers. Also, consider nailing, gluing, bolting, or banding 2" x 8" or 2" x 10" stock together to form usable substitutes.

Figure 3.14. Timber Column Use.

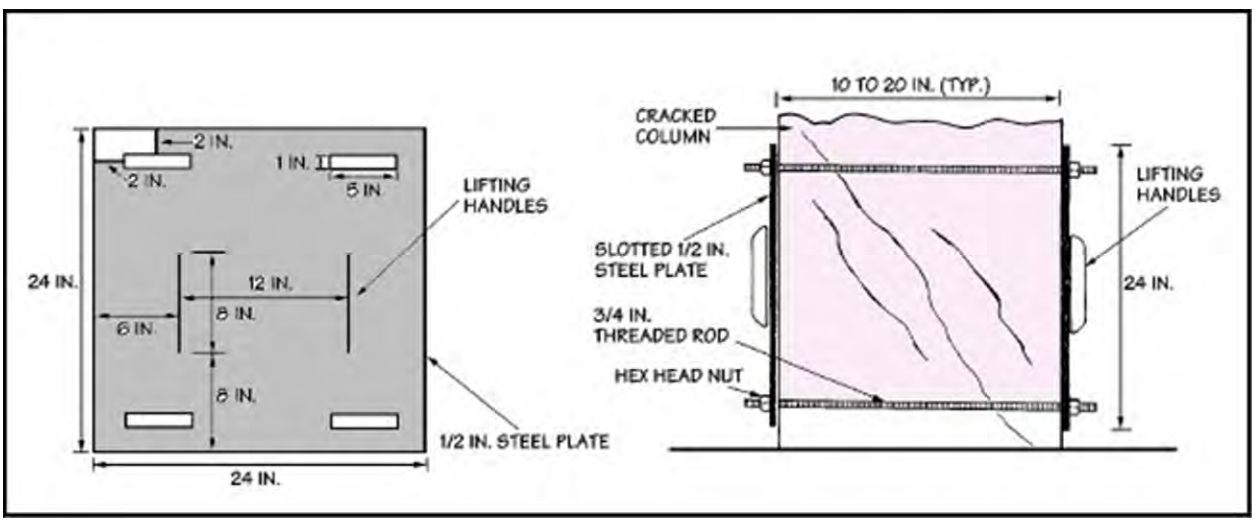
Figure 3.15. Support of Damaged Load Bearing Walls With Openings.



3.6.4. **Splinting.** Another method of providing basic structural integrity involves the splinting of columns, particularly the reinforced concrete type, that have not been seriously damaged but show signs of cracking or minor fracturing.

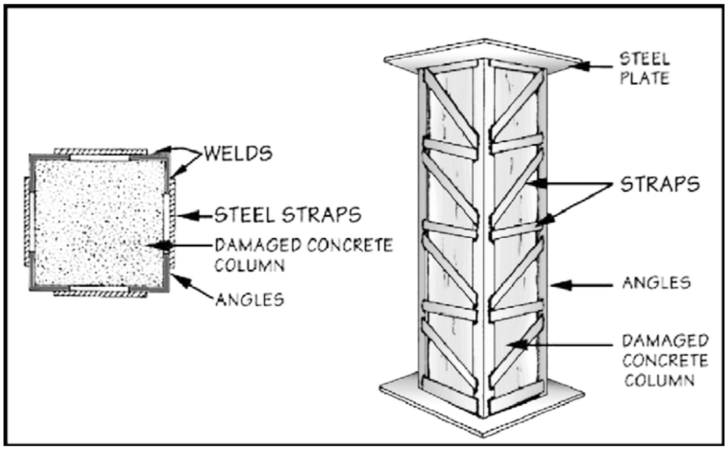
3.6.4.1. One technique involves "sandwiching" the damaged column between two steel plates connected by threaded rods. The plates have slotted holes so they can be fitted to various sized columns. In this repair, splints are placed around the column at the location of the crack(s) to provide a lateral restraining force (see **Figure 3.16.**). If cracks are at several locations on the column, multiple splints can be used. This repair is preferable to column replacement when a damaged column is still capable of carrying a significant load, because it requires less manpower and is a faster repair. However, if a column is severely damaged and appears near the point of collapse, column replacement using jacks or timber supports should be used.

Figure 3.16. Steel Plate Splint.



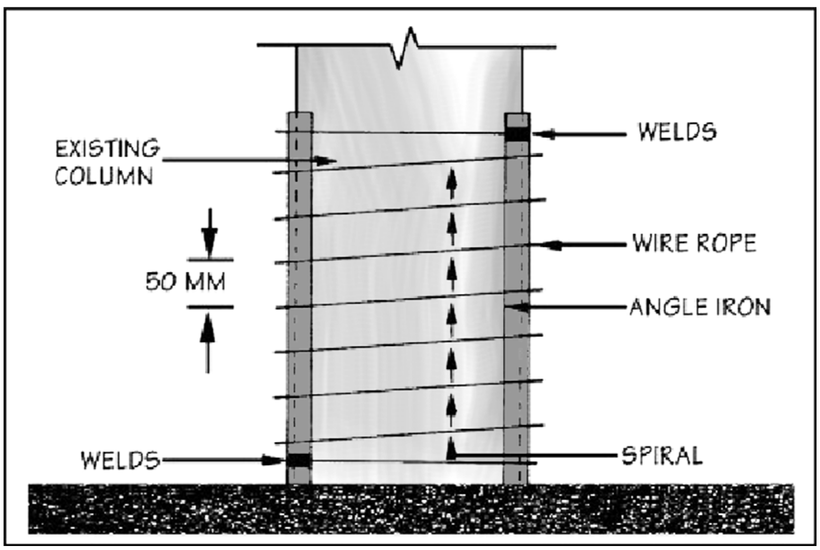
3.6.4.2. A second splinting technique involves placing angle iron at the corners of a damaged column and connecting the angles with steel straps (see **Figure 3.17.**). Steel plates should be provided at the ends of the angles to a void load-bearing problems at the bottom of the column whe re it is attached to the slab.

Figure 3.17. Use of Steel Angles at Corners of a Damaged Column.



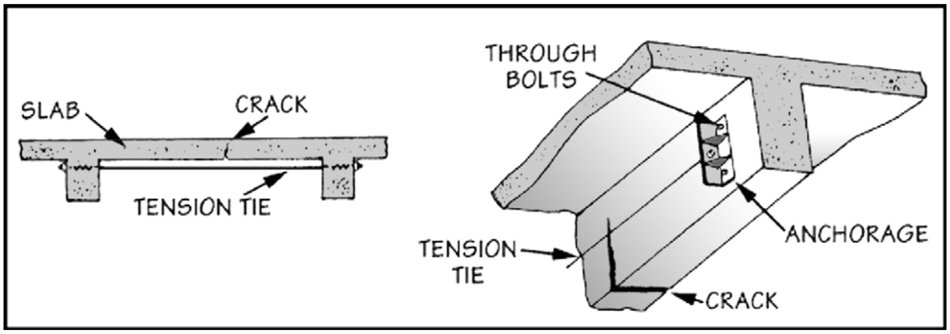
3.6.4.3. A third method of splinting again uses angle iron at the corners of the damaged columns, but the angle irons are joined together with wire rope or similar cabling (see **Figure 3.18.**). One end of the wire rope is welded to the top of one of the angles, and the rope is tightly wound around the column. The other end of the wirerope is welded to one of the angles at the base of the column. Additional welds may be made at various points to better secure the cable to the angle iron.

Figure 3.18. Use of Wound Spiral to Repair Column.



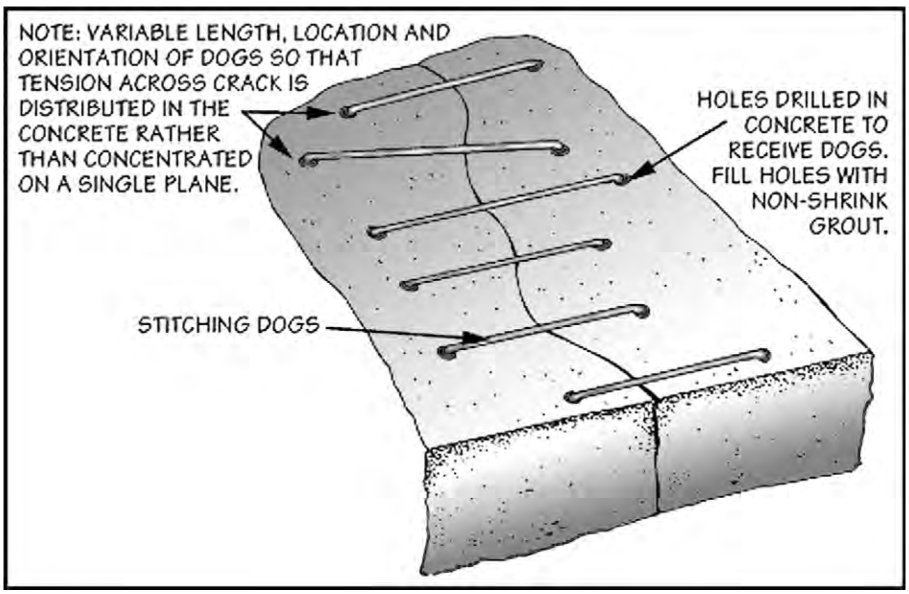
3.6.5. **Tension Ties.** Some facilities at overseas locations are essentially all reinforced concrete construction. In such cases, slabs and beams will be of unitary construction, meaning that they are formed, reinforced, and poured as a single unit. After an attack or na tural disaster, some of the slabs and beams may develop minor cracking. Tension ties are a method of providing a compressive force on the slabs and beams that aids in the prevention of further cracking (see **Figure 3.19.**). For slab repair, a threaded rod is anchored to the beams on both sides of the cracked area of the slab. For beams, anchor plates are bolted to the beam on both sides of the crack and a threaded rod is placed parallel to the beam, connecting the two anchor plates. Tightening the nuts on the threaded rod induces a compressive force into the beam or slab, thereby restricting further cracking.

Figure 3.19. Tension Ties.



3.6.6. **Stitching Dogs.** Yet another method of restoring structural integrity into a cracked concrete slab is the use of "stitching dogs." These dogs are steel bars, normally rebar, formed into a U-shape and placed over the crack, rather like staples, as shown in **Figure 3.20.** The dogs should be of random length and variably spaced along the crack. The holes that the dogs are inserted into must be well grouted to ensure a tight fit.

Figure 3.20. Stitching Dogs.



3.6.7. **Welding.** Welding steel sections back into place to restore the stability of a steel framework is a common shoring method. Welding repairs will usually be limited to a relatively small section of a facility. To attempt more than this as an expedient repair will take too much time and effort. For the most part, such repairs will involve erecting scaffolding, positioning steel plate and structural shapes, and accomplishing the welding.

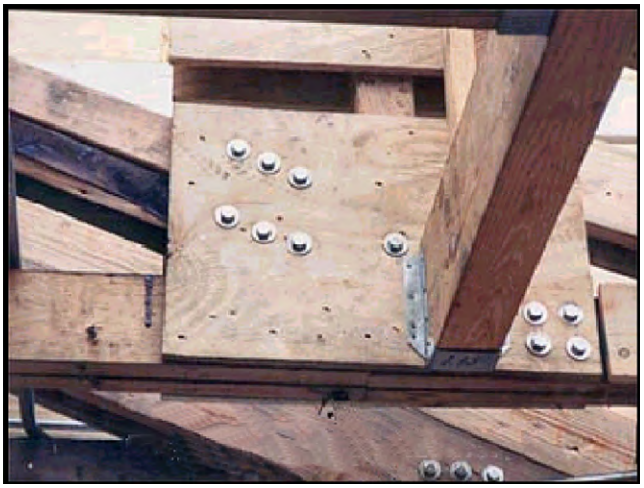
3.7. Expedient Repair of Damaged Facilities. Once basic structural integrity has been restored through structural shoring, steps can be taken to protect personnel and essential equipment from the elements. This usually involves patching holes in walls, roofs, and floors. Before expending resources to patch these holes, determine if urgent, immediate patching is required. Local climate and prevailing weather are major factors. If the weather is warm and rainfall is not a detrimental factor, some openings may be left exposed temporarily without significant impact. On the other hand, if patching is required, there are several different types of materials and expedient techniques that can be used.

3.7.1. **Roof Repairs.** It is important to recognize that some roofs and support systems perform various functions. While some are simply a weather cover, others act as part of a structural frame or diaphragm. Analyze failed sections and holes in the roof to determine the needs for emergency repair. Initial efforts must focus on safety. Ensure that bracing and shoring are adequate. Secondly, eliminate hazardous hanging materials (i.e., lights, wires, cable trays, mechanical ducts, etc.) below the roof and assess the extent of damage to the roof support system. The third and any subsequent efforts are to cover the hole, replace damaged sections of roof covering, and strengthen the support system as necessary.

3.7.1.1. **Damage Assessment.** Once the emergency has subsided, inspect both the top and bottom portions of the roof to make sure that the areas are sound. Be aware that even though roof structural members and the deck are intact, emergency repairs may still be needed. One example is that even after hurricane winds subside, persistent rains can cause severe damage or building collapse. Many roofs are covered with insulation boards. High winds can leave the decking intact but blow off felts and expose insulation boards. Some insulation boards soak up rain like a sponge. The additional dead load from the water-soaked insulation, as well as ponding of trapped water, can collapse structures, especially warehouses and large hangars. If the supporting members are damaged, shore and brace the trusses and repair damaged supports.

3.7.1.2. **Fire-Damaged Roofing Components.** Fire-damaged wood structural members must be checked for structural integrity. Scrape the charred wood off the member in various sections to check for the extent of damage. Fire-damaged wood can remain in place if it retains most of its structural integrity. The amount of remaining strength will depend on the extent of charring or exposure to high temperatures. There is no definitive, in-place test to determine if fire-damaged wood is still structurally sound. An engineering test and analysis are normally required. If the structure was modified after construction, such as installing an overhead rail, then a structural analysis is needed to determine if fire-damaged members are adequate. Charred wood should only be used if at least 90 percent of the wood cross section is not charred; and charring itself does not extend more than 1/16 inch into the wood. Emergency repair of fire-damaged trusses normally involves scraping off the charred material and sistering a similar piece of wood onto the damaged section, splinting the damaged area between two sound pieces of wood, using gusset plates (see **Figure 3.21.**), or using a combination of these procedures.

Figure 3.21. Gusset Plate Repairs.



3.7.1.3. **Weather Tightness.** Once the structural integrity is assured you can begin returning the weather tightness to the structure. From an expedient aspect, it will be difficult to completely seal off the building from weather, but most of the ill effects of bad weather can be kept out. Keep in mind that many roof systems are interchangeable. An example is that metal and wood roof systems can be used with wood, metal, or precast concrete buildings. Sheets of plywood can be nailed over the opening. Sheet metal, plastic sheeting, and even canvas can be used in lieu of plywood. For flat roofs, sheets of plywood can be fabricated into a patch a bit larger than the hole and nailed in place. If the roof is concrete, explosive actuated fasteners or suitable threaded concrete fasteners could be used to attach the plywood patch. If available, rolled roofing can then be nailed to the patch for added weather protection. **Figure 3.22.** shows personnel providing expedient roof protection, in the form of plastic sheeting, on a housing unit at Homestead AFB after Hurricane Andrew's assault in 1992. Once any covering is in place, positive drainage must be maintained to divert rainwater and prevent ponding. This could involve stacking sandbags above the repair to divert the water or changing the slope at the repair itself. For larger areas, raise the center of the tarp or sheeting to divert water.

Figure 3.22. Using Plastic to Cover a Damaged Roof.

3.7.1.4. **Metal Roof Repair.** Metal roofs are repaired the same way as metal wall systems. When possible, remove the damaged surface material and replace with new or cannibalized material. Overlap the good metal roofing with the replacement metal roofing by at least a matching corrugation or rib section. Catch as many purlins as possible for support and tack in place with sheet metal screws along the edges. Use caulk or construction adhesive on the upslope side for additional water protection. For large holes where purlins are too badly damaged to allow fast repair, and where reuse and immediate coverage is required, expediently patch the hole with similar materials, but provide at least 24 inches of overlap to distribute loadings. Add purlins later as time allows.

3.7.2. **Wall Repairs.** For the most part, wall repairs are similar to roof repairs, except they should be somewhat easier since the requirement to lift all materials to roof height is eliminated. Damage to walls can be covered with standard materials such as plywood, sheet metal, tarpaulins, and plastic sheets (**Figure 3.23.**). Before beginning a wall repair, ensure the structure is strong enough to withstand pounding from additional winds when using tarps or plastic sheeting. Shore and brace the structure as described previously in paragraph **3.6.**, if required. Secured tarps can provide good protection from rain and can withstand greater wind loads than plastic sheeting. **Note:** Usually large tarps and high-strength plastic sheets must be special ordered but are generally available as a construction material item. Coordinate with federal and state emergency management officials or MAJCOM personnel to obtain large tarps and sheeting. For overseas humanitarian deployments, the US Agency for International Development (USAID), Office of Foreign Disaster Assistance (OFDA) can often provide special sheeting for shelters.

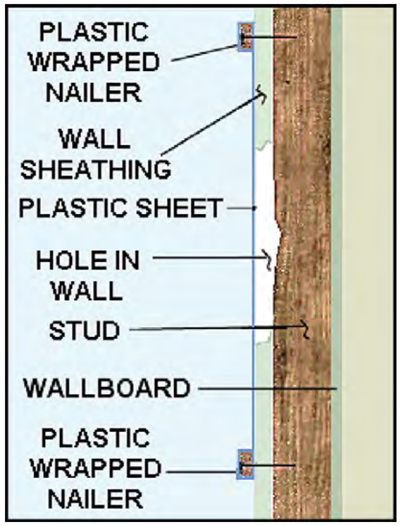
Figure 3.23. Temporary Tarpaulin Protection.

3.7.2.1. **Plastic Sheeting Protective Techniques.** When plastic sheeting is used to cover a hole, size the nailing strips and plastic based on the size of the hole. Normally, the required materials are: nailing strips that are at least 1" x 2" furring strips (or 12-gauge metal strips that are 1" wide), plastic sheeting that is at least 6-mil plastic or reinforced sheeting (10-mil plastic or plastic with woven fiber is preferable), and fasteners of sufficient length to penetrate the sheathing (or at least 1- 1/2 inches into the stud). Avoid black, recycled plastic sheeting if the repair will be exposed to harsh elements for more than a month due to the high rate of deterioration. Use nails, staples, or screws in wood and self-tapping metal screws to fasten into metal siding. To accomplish the repair, wrap plastic sheeting around nailing strips and nail the strips around the hole as a rectangular frame to provide a tight plastic surface. When possible, provide 6 to 12 inches of plastic overlap around the edges of the hole. For holes in plywood (or other nailable substrate) cut the nailing strips 12 to 24 inches wider than the hole and cut the plastic sheeting yet another 24 inches wider. For holes in a non-nailable substrate, locate the nailing strips over the closest undamaged wall-framing studs. Cut the plastic sheeting 24 inches wider than the nailing strip. Wrap 12 inches of plastic around both the top and bottom nailing strips. When installed, the plastic should be flat against the building with the wrapped nailing strip on the outside. Position the strips and fasten in place to the wall (or studs for non-nailable surfaces), stretching tight vertically (see **Figure 3.24.**). Note that both plastic sheets and tarps only provide protection against the elements. More substantial structural repairs are often necessary.

3.7.2.1.1. If there are no intermediate studs to nail into for support, use adhesive and tape to secure the top and bottom edges. If there are damaged intermediate studs, sister new studs to the damaged studs to allow nailing strips to be fastened.

3.7.2.1.2. Repair any miss-cuts or tears in the plastic with flexible duct tape. Use caulk to fill in larger gaps between the nailing strips and wall surface. For metal skin walls with deformations, use expanding foam to fill in gaps as necessary between the metal and the nailing strip.

Figure 3.24. Typical Plastic Sheeting Wall Repair.



3.7.2.2. **Emergency Wall Repairs on Wood Frame Structures.** Wood-framed walls are typically the easiest wall systems to repair. Depending on the size of the hole, the repair may be made by replacing the damaged area in kind, replacing a wall section, or providing a structural or non-structural patch. Explosions, projectiles, or debris can create similar damage in wood-framed walls. The repair requirements will vary by the size of hole, location, and wall function. Smaller holes with little damage to framing members can usually be fixed with a sheathing material (plywood, fiberglass, metal sheet, etc.) or plastic sheeting. Plywood or Oriented Strand Board (OSB) sheets are normally used. Holes larger than 3 feet in diameter usually require some reframing and new plywood/OSB. Still larger holes usually require the wall section to be replaced with new framing and plywood/OSB on the outside of the wall. If the damaged wall is a shearwall, a cross wall that provides lateral support, or a load-bearing wall, a structural frame wall having plywood on both sides may be required.

3.7.2.2.1. **Small Hole Repair.** Use plywood or OSB sheathing to repair small holes (less than 3 feet in diameter) when the substrate is nailable. If possible, provide at least a 6-inch overlap over the undamaged siding. If more weather protection is needed than provided by plastic sheeting, use sheathing. When the substrate is not nailable, cut the sheathing to fit between the closest studs on both sides of the hole. Position sheathing over the hole and fasten into a stud or nailable substrate. Be sure to caulk along the edge of the sheathing before fastening in place.

3.7.2.2.2. **Large Hole Repair.** Remove damaged framing for larger holes, but be particularly careful around any load-bearing joists, beams, or wall top plates. Replace damaged or missing framing and blocking. Where sheathing is missing and framing is damaged, the wall usually requires repair or replacement of damaged framing and new sheathing. After shoring and bracing adjoining walls and ceiling, replace any missing studs and top and bottom plates. Attempt to maintain normal stud spacing at 16 inches on center. For partially split or gouged studs (i.e., 60 to 80 percent of the damaged stud cross section remains) and where some sheathing is still present, sister another stud to the damaged stud to strengthen it. Apply construction adhesive between the damaged stud and new stud for additional strength. To add strength to walls that must withstand additional wind loads, apply construction adhesive on stud surfaces and then nail the members together.

3.7.2.2.3. **Sheathing Repair.** One emergency repair where sheathing is required is during repair of a structural wall, particularly where shearwalls have failed. As seen in **Figure 3.25.**, shear failure in plywood can be either localized to a small area that appears as a tearing pattern in the plywood, or involve a complete failure where the sheathing itself is dislodged. When sheathing is entirely missing, add new material as necessary. To do this, remove damaged wall covering and/or sheathing back to the nearest exposed stud. Apply 1/2-inch nominal sheathing to the studs for most walls. However, for shearwalls, use 3/4-inch plywood when available. If additional nailing surface is needed for securing the new sheathing, add another stud to the exposed stud. When the wall must act as a hold down for the roof, nail the sheathing at 6 inches on center vertically and horizontally, except on the top and bottom plates where nailing is at 4 inches on center. Be sure to block the wall at sheathing edges if it is taller than the sheathing. For additional strength and less nailing, apply construction adhesive (meeting requirements of APA AFG-01) on framing members near edges. Also, if the repair will be exposed to heavy rains, cover with plastic sheeting and/or caulk butt joints. For shearwalls wider than 4 feet, apply plywood horizontally on both sides of the wall. When dealing with shearwalls between floor levels, if possible do not align plywood butt joints with any of the floor joints. Instead, stagger end joints and block all edges that require nailing. For other walls, except shearwalls, apply sheathing vertically or horizontally per standard nailing procedures. **Note:** Some failed shearwalls may have been constructed with vertical sheathing. If new building standards require three-by (3x) lumber at edges, consider running the plywood horizontally and block at all horizontal edges. Blocking provides additional stiffness support to shearwalls.

3.7.2.3. **Emergency Wall Repairs on Masonry Structures.** Emergency repair of masonry walls is usually more time-consuming, strenuous, and equipment and material sensitive than emergency repairs to wood walls. Masonry walls are usually block and/or brick; however, masonry buildingscomposed of rock and mortar walls may be encountered at some overseas locations. Use extra caution when performing emergency repairs on masonry walls. Failed masonry walls are normally more dangerous to work with than most other walls for several reasons. This added danger is caused by factors such as the increased dead weight of the building materials, the brittle nature of masonry products, and the limited ability to determine the actual extent of damage by simply viewing the apparent damage. In fact, it may not beknown how or even if the wall is reinforced or what is holding the cracked areas together.

3.7.2.3.1. **Damage Assessment Considerations.** Consider the following when assessing masonry wall damage. While a crack may appear to be small, the wall may still fail if there is inadequate reinforcing steel to hold the crack together. Reinforcing steel is usually in select cells. Determine if a crack crosses reinforced cells and if the cells are still solid. If the cells do not contain reinforcing steel, determine if the crack is being momentarily held in place by friction from dead loads. If such is the case, a small shift in the weight of a structure or ground tremors (i.e., seismic shaking from nearby movement of heavy equipment) can cause release and catastrophic collapse. Keep in mind that removal of debris, rain, snow, or wind can also cause shifting in multistory structures and subsequent collapse. Two additional factors associated with masonry walls that must be assessed include determining if the wall can be shored to maintain lateral support when pilasters are damaged and determining if the wall's floor/roof attachments are damaged or have failed.

Figure 3.25. Examples of Sheathing Damage.

3.7.2.3.2. **Masonry Wall Variations.** Emergency repairs to masonry structures usually depend on whether the wall is a structural wall or a non-structural infill wall (**Figure 3.26.**). Structural walls can be infill walls that provide lateral support or shearwalls built into a concrete or steel moment frame building. Also, structural walls can be supporting walls (and pilasters) that provide lateral and vertical support for the roof and other floors. Non-structural walls are usually constructed as infill walls that have wall ties to flexible frames, or they may use tracks or offset walls that extend past the exterior frame and wrap around it without providing lateral support. If a structural wall is damaged, emergency shoring and bracing may be required along with repair. Once strengthened, the wall should be closed up with injection grout or some other means of confinement as discussed in this chapter. Emergency repairs for non-structural walls depend on the damage. Typical repairs usually involve removing and replacing damaged material and patching the open area with appropriate sheathing.

Figure 3.26. Damaged Brick Infill Wall.

3.7.2.4. **Small Hole Repair in Structural Walls.** The simplest emergency repair to a masonry wall is repairing a small hole that has been punched through the wall involving no damage to the rest of the structure. Usually, this will occur from debris being thrown through the wall from an exterior blast or high winds. The repair method for small punched holes in masonry structures varies according to the type of wall involved. The emergency repair method for small holes cleanly punched through a non-structural masonry wall, where only a few blocks are missing, is to simply fasten a patch of wood sheathing over the hole. Cut a sheet of sheathing (plywood or OSB) that is large enough to extend several inches past the next undamaged blocks' grout joints around the hole. When positioning the patch on the outside of the wall, apply construction adhesive to the edges of the sheathing. Next, drill holes through the sheathing and into the undamaged grout joint (or a block with a filled cell); secure the sheathing in place with bolts, washers, and lead or expanding anchors. Do not use this repair method if there are loose blocks or cracks around the hole; rather, tie the wall together with sheathing on both sides. When only a block or two are missing, it is usually easier to knock out the damaged material, square up the opening to size, and fill the void using new blocks and a fast-setting cement or epoxy grout mortar (see **Figure 3.27.**).

Figure 3.27. Correcting Damage With New Material.

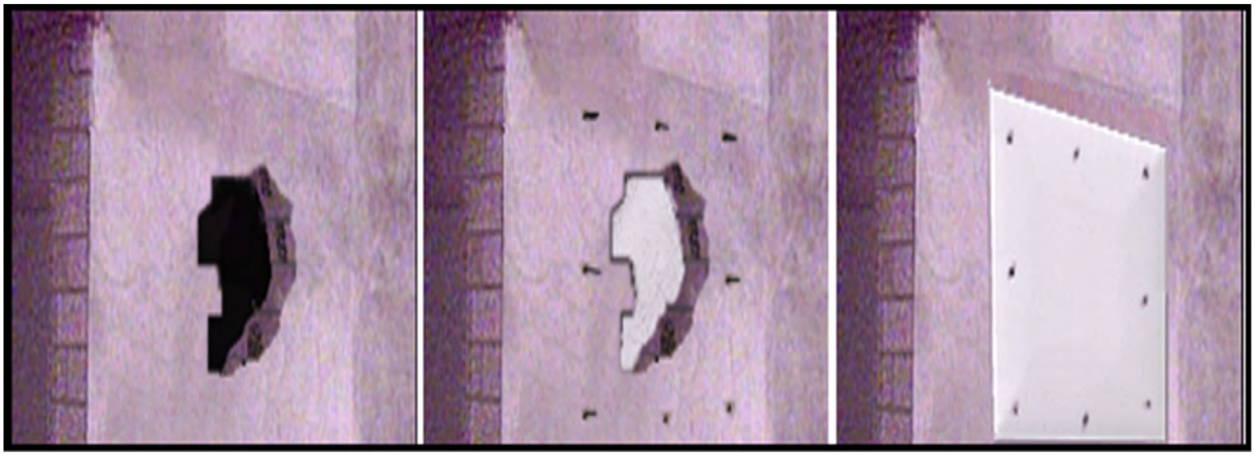
3.7.2.5. **Large Hole Repair in Structural Walls.** Structural masonry walls with larger holes (i.e., larger than about five blocks high and four blocks wide) or failed sections are very dangerous (see **Figure 3.28.**). It is usually better to shore and brace the roof or floors above the failed area and then work somewhere else in the facility. However, moving to another section of the building should not be attempted until the extent of the structural damage has been thoroughly analyzed. Failed sections in one part of a masonry building can often lead to a progressive collapse in the rest of the structure when wind, rain, vibration, or shifting loads are involved. **Figure 3.29.** is an excellent example of a progressive structural failure after an earthquake. There are few options for making emergency repairs for larger holes in structural masonry walls. For a wartime repair of a larger hole in a shearwall or support wall, shore and brace the area around the wall, square up the hole, provide necessary bracing, and cover the hole. Leave the shoring in place if there will be continued blast or seismic shaking; cribbing is more stable than using a single support post. After shoring the area, square the hole, brace the hole with double 2" x 8" headers and side braces, and use double 2" x 4" cross bracing. Cover over each side with 1 or 2 layers of 3/4-inch plywood (depending on the expected shear loads). Cut sheets to run horizontally, and allow at least 8 inches of overlap onto good masonry. Position sheets and drill holes through the masonry to align with the holes in the plywood. Tie together with threaded rods, washers, and nuts. When possible, use 2" x 4"s between opposing bolts to prevent the tie rods, washers, and nuts from tearing through the plywood.

Figure 3.28. Extensive Structural Wall Damage at Homestead AFB. (1992)

Figure 3.29. Progressive Structural Damage in Guam (1999).

3.7.2.6. **Structural Wall Confining.** When broken blocks cannot be replaced for a small hole in a structural masonry wall, confining the wall is a safe option. This repair should be limited to small holes with 7 or 8 blocks missing and where there is no extensive cracking around the hole. Use at least 4- or 3-gauge sheet steel (i.e., about 1/4-inch thick) on both sides of the hole. Cut the steel to provide about 8 inches of overlap between the steel and the undamaged block. Drill through the sheet steel about 4 inches from the edges in the corners and midpoint on each side. Next, drill through the masonry so it will align with the holes in the sheet steel. Next, run a bead of construction adhesive around the hole on both sides before fastening the sheet steel together with threaded rods, washers, and nuts (see **Figure 3.30.** graphic sequence).

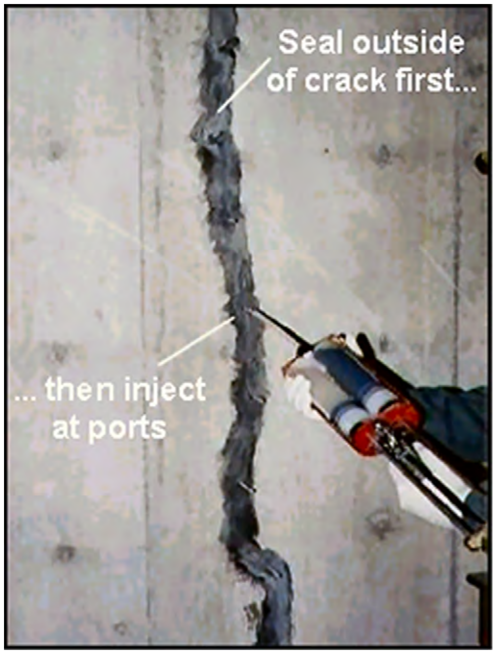
Figure 3.30. Masonry Wall Confining Sequence.



3.7.2.7. **Large Hole Repair in Non-Structural Walls.** Non-structural walls with large holes (i.e., up to about five blocks high and four blocks wide) can usually be repaired with a sheet of plywood, a couple of 2" x 8" braces, and a header. Knock out or saw-cut loose block on the top and sides of the hole to provide fairly straight edges (i.e., square up the hole). Cut one or two 2" x 8"s for a header to fit the top of the squared hole (if overseas and metric blocks are used, use a wider header or add 3/4-inch plywood cut as wide as the block and nailed to the top of the header). Next, cut two side braces about 1/8 inch longer than the distance from the bottom of the hole to the bottom of the header and place one end of the braces at the bottom of the hole on each side and drive the top of the braces in place to hold up the header. Once in position, toe-nail the top of each header. Lastly, cut sheathing and fasten in place in the same manner as described for covering a small hole. If desired, and for additional rigidity, apply 1/2-inch sheetrock on the inside facing. Additional expedient masonry wall repair procedure options, such as pressure injected epoxy and structural steel bracing, are provided in the *Expedient Structural Repair Course* on the Air Force Civil Engineer Virtual Learning Center web site at **https://afcesa.csd.disa.mil**.

3.7.2.8. **Crack Repairs on Reinforced Walls.** When replacing a reinforced masonry or concrete wall is not feasible, an acceptable repair is to fill the cracks with a structural grout or epoxy. In most cases, epoxy injection works best (see **Attachment 2**, Crack Repair Using Epoxy Injection Method). The epoxy injection method can be used to repair cracks as narrow as 0.002 inch if the reinforcing steel has not been stressed beyond its elastic limit. If necessary, seal the top of the crack with the same epoxy troweled in place or use metal plates. This type of repair generally consists of drilling holes at close intervals along the cracks, in some cases installing entry ports, and injecting the epoxy under pressure. However, for small cracks, cartridges can be used with handguns (see **Figure 3.31.**). For massive structures, an alternative procedure consists of drilling a series of holes, usually 7/8 inch in diameter, that intercept the crack at a number of locations. Typically, holes are spaced at 5-foot intervals.

Figure 3.31. Epoxy Application.



3.7.3. **Window Repair.** In an expedient sense, there are not too many fixes for damaged windows. Attempting to replace glass is much too long an effort and during a conflict or earthquake, is almost self-defeating since it will probably all be lost again in the next attack or aftershock.

3.7.3.1. **Repair Options.** Normally, placing plywood over the window opening is sufficient. If the facility must remain occupied and requires daylight, then rigid plastic sheets can be used to maintain a visible opening. Plexiglas sheets are usually used for this repair. Use polycarbonate sheets if additional protection is required. Either way, it is important to first bond the rigid sheet to the building using construction adhesive, and then clamp it to the building using a simple wooden or metal frame and screws.

3.7.3.2. **Repair Procedures.** Do not drill or fasten through the sheets if there will be additional blasts or high winds. Instead, hold them in place with a wooden (or metal) frame. Cut the rigid sheets 2 inches wider and taller than the opening. Use 2" x 4"s or 2" x 6"s to frame the opening, sizing the frame to fit outside the dimension of the opening. Once the frame is configured, apply a continuous bead of construction adhesive to the edge of the opening to set and hold the sheet in place. Sandwich the rigid sheet between the building and the frame and clamp in place by fastening the frame to the building with screws or other appropriate (removable) fasteners.

3.7.4. **Door Repair.** Damaged door openings that must remain accessible for entry and exit are usually shored and framed to keep the opening safe. To protect the opening against further damage from wind, weather, or blast forces, use expedient measures such as stacking sandbags at the opening. This is especially important when the wall is a structural wall and has been damaged.

3.7.4.1. **Repair Priorities.** The first priority for an emergency repair of a door opening in a structural wall is to maintain the wall's structural integrity. Shore the opening at the top, bottom, and sides. Use spreaders at the top and bottom of the door to take the place of cross bracing. If blast or wind protection is required, use sandbags stacked at the entrance and along walls (see **Figure 3.32.**).

Figure 3.32. Sandbagged Entrance.

3.7.4.2. **Weather Tightness.** If weather tightness and further strengthening are required, construct a separate door. Tack the door framework to the opening to avoid causing additional stress on any weakened structures. Make sure the connections to the building are relatively weak. Rely on sandbag berms or other expedient berm structures for protection against blast.

3.7.4.3. **Sliding/Roller Doors.** Hangars, warehouses, and maintenance facilities are often critical facilities. Other than for hardened aircraft shelters, these types of facilities have doors that are quite vulnerable to exterior blast and high winds. Typical hangar-type doors are bottom rolling (sliding doors), which have top guide tracks and bottom rollers on support tracks. Different types of large doors can be used on large facilities when blast protection is not a problem or when snow and ice are a problem. Lightweight doors are often used on newer permanent or deployable hangars and warehouses. Deployable hangars and some newer hangars, maintenance facilities, and warehouses may have vertical lift, clamshell, canopy, or folded-fabric lift (panel) doors.

3.7.4.4. **Heavy Metal Door Repair.** Full metal, bottom-rolling doors that have come loose from their tracks usually cannot be expediently repaired. Limit repairs to patching holes. If the rollers and top tracks are not damaged, some doors can be jacked up and pushed back on tracks. The following failures require door removal and/or track repair: (1) rolling doors come loose from the top rail; (2) the doors have fallen inward from the top when wind or blast pressures have racked the building or collapsed the metal overhead track system, (3) high winds or floods lifted or pushed the doors off the bottom track; (4) the door has hung up on the upper track and torqued the wall and supporting framework. **Warning:** When dealing with very large metal rolling doors such as those on hangars, emergency repair is usually not feasible except by trained heavy repair teams supported by cranes and other special equipment. Also, check on the door and framing specifications before considering the repair of top rails using standard shapes of A36 (36,000-psi) steel. Large steel hangar door structures often use 50,000-psi steel and special fittings. If an A36 structural shape is used and the original specification was for 50,000-psi steel, the door framing and tracks will be grossly undersized for the load.

3.7.4.5. **Lightweight Metal and Fabric Door Repair.** Because of their design, lighter weight doors, such as vertical lift, clamshell, canopy, and folded-fabric lift doors, can usually be repaired in an emergency without the use of heavy equipment. Two deployable fabric door examples are shown in **Figure 3.33.** The first example is a B-1 hangar that uses folded-fabric lift doors with lightweight framing door guides. In the clamshell hangar example, lightweight framing and tubing are used as the superstructure.

Figure 3.33. Lightweight Fabric Hangar.

3.7.4.5.1. **Structural Repairs.** Bent framing on these types of structures can usually be straightened, bolstered with additional piping, or replaced with similar common materials. Also, damaged tracks can often be straightened or detached/cut out and replaced using similar materials.

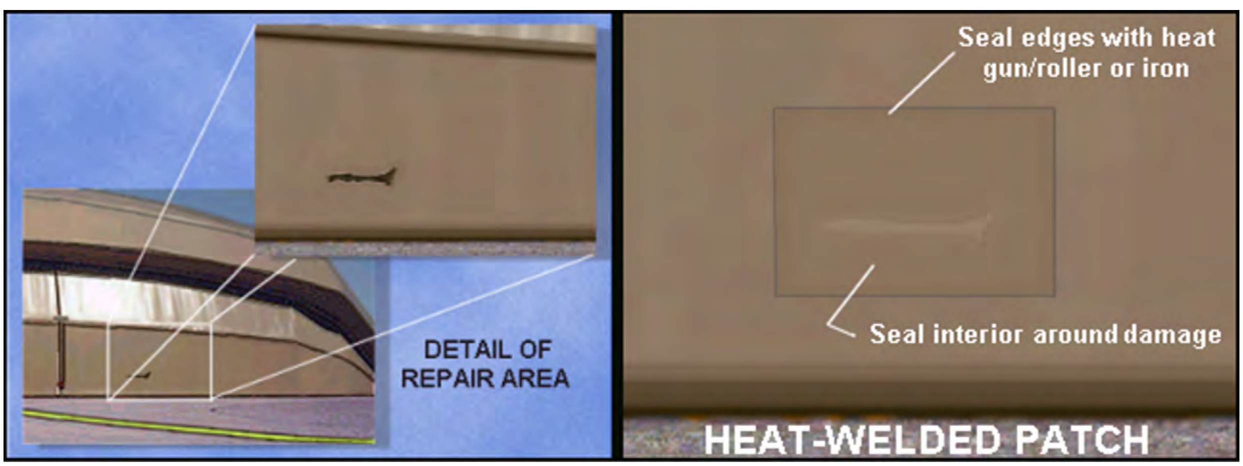
3.7.4.5.2. **Surface Skin Repairs.** Holes in lightweight rigid composite panels are usually repaired with a patch of 14-gauge sheet metal fastened over the hole. Use construction adhesive and sheet metal screws, screw-in shields, or expanding sleeve anchors, whichever is appropriate. Fabric panel systems can usually be quickly repaired. Coated fabric systems are used with many portable shelters, deployable hangars, and maintenance shelters. The most common coating is PVC-coated polyester. It is used with many clamshell-type structures and fabric hangars. Larger structures may use a tensile fabric design. Emergency repairs must maintain structural integrity of these larger structures. Emergency fabric repair kits are usually available from the manufacturer. If one is not available, consult with Fuel System Maintenance or Fabrication shops, as some of their shop methods and equipment are similar to manufacturers' recommended methods and equipment. Depending on whether the material is a cover fabric or tensile fabric, there are usually two repair methods for fixing pierced fabric sections in walls and overhead doors: the FabricClamp and PVC-Coated Polyester Fabric system.

3.7.4.5.3. **Fabric Clamp Repair.** Fabric clamp systems are most often used for folded fabric-lift doors (**Figure 3.34.**). The steps involved begin with loosening screws on the fabric-clamp strips above and below the torn section. Next, cut the repair fabric large enough to overlap the tear by at least 2 inches on each side. Once the repair patch is properly sized, extend the repair fabric under and between the two clamp strips. Then, retighten the clamp strips, trim off excess material, and tack down the fabric edges with adhesive or double-sided tape. Lastly, trim off or glue together any loose fabric that is under the patch and around the tear.

Figure 3.34. Typical Fabric Clamp Repair.

3.7.5. **Repair of PVC-Coated Polyester Fabric Systems.** These systems are used with several generations of shelters and hangars. The manufacturer for each system usually provides repair criteria; however, if criteria are not readily available, follow the general guidance here. Repairs usually require either a heat-welded patch (with either a heat gun or bonding iron and a roller) or a solvent-welded patch (with solvent). For coated fabric systems that have a slick, Teflon-like coating on the exterior surface, patch the hole from the inside using a piece of fabric and adhesive. As with the Fabric Clamp method, work with Fuel System Maintenance and Fabrication shop personnel to repair these types of fabrics. Begin the repair by cutting and positioning a fabric patch over the torn section. For tensile fabric systems that distribute load, cut the patch to extend at least 12 inches past each damaged edge, unless the manufacturer has other recommendations. For simple cover systems, cut the patch to extend 2 to 4 inches past each damaged edge. For heat-welded patches, provide heat between the fabric and the patch. Hold a piece of plywood on the inside surface and use the roller on the outside of the heated patch to roll the material together. Roll out air bubbles, keeping the temperature just under the point where smoke develops on the patch or the two fabrics will melt. When done properly, the result should look similar to that in **Figure 3.35.**

Figure 3.35. Typical Heat/Solvent -Welded Patch Repair.

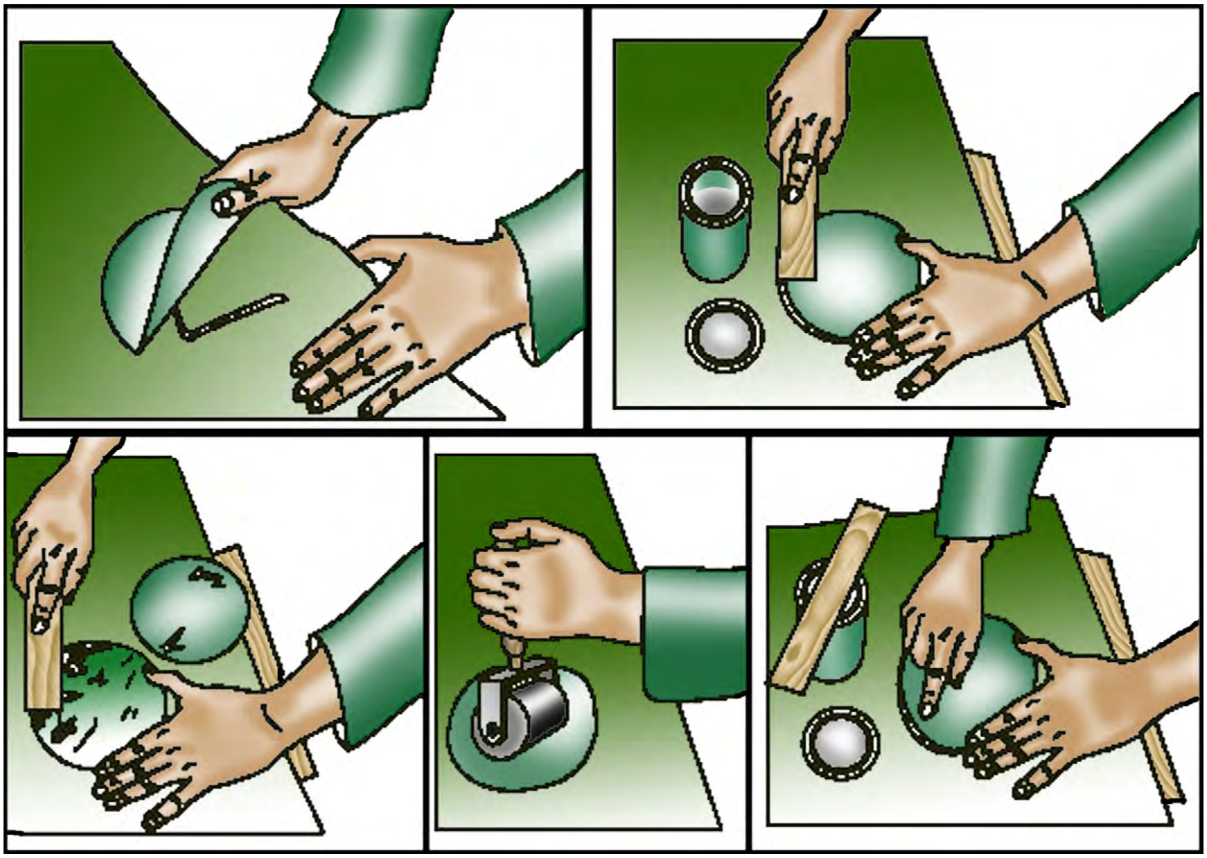


3.7.6. **Cement and Sealer Fabric Repair.** Other fabric-based deployable structures, such as the TEMPER tent and Medium/Small Shelters, are all sheathed with a fabric outer covering over rigid framing. When damage to these units occurs, it is not always possible or practical to make sewn repairs. This is especially true when a tent is erected and the damage is minor. If a hole or tear is fairly small and it is not located near a seam, an edge, or hardware, a cemented patch or dab of adhesive can be used to repair the damage. When a stovepipe shield is slightly damaged, sealer can be used to repair the damage. There are specific repair kits available that have been developed by each product manufacturer to correct minor damage. Typical repair procedures for minor holes and tears are described below.

3.7.6.1. **Small Hole Adhesive Repair.** A dab of adhesive is used on a hole in a tent that measures 1/8 inch or less across. To seal a small hole, first use a wire brush to clean the area around the hole and raise the nap of the fabric. Next, simply use a small stick or paddle to put a dab of adhesive on the hole, working it into the fabric while being sure to bridge the damage with the adhesive to ensure a complete seal.

3.7.6.2. **Large Hole/Tear Adhesive Repair.** Cemented patches are used to cover holes and tears that are more than 1/8 inch, but less than 4 3/4 inches across. Putting a cemented patch on a tent is similar to patching a bicycle tire. To apply a cemented patch (see **Figure 3.36.**), first obtain the following items (if not included in the repair kit): a ruler, chalk, wire brush, flat board, paddle, roller, tent-patching adhesive, and a piece of clean matching canvas. Next, measure the damage and cut a round patch from a piece of matching canvas, making sure the patch is large enough to extend 3/4 inch beyond the damage in all directions. Then, place the board under the damage for support. On an erect tent, another individual will be needed inside the tent to hold the board against the damage. Center the patch over the damage and draw a circle with chalk around the patch, then remove the patch. Use a wire brush to clean the fabric and raise the nap of the material inside the circle and the patch itself. Now, position the patch facedown over the damage and use the paddle to coat the patch evenly with adhesive. Let the adhesive overlap the edge of the patch a little so that it forms a circle on the tent Next, remove the patch, flatten out the canvas and the edges of the hole or tear as much as possible and fill in the circle with a coating of adhesive. Let the adhesive dry, then apply a second coat of adhesive to the tent and to the patch. Now, wait 10 to 15 minutes for the adhesive to become tacky (test the patch by touching it). The patch is ready to use when it is sticky. Once the adhesive reaches this point, center the patch face up on top of the damage and press the two sticky surfaces together. Use a roller to press the excess adhesive and the air bubbles from under the patch. Roll first in one direction and then in the opposite direction. If no roller is available, use the can of adhesive as a roller. Be sure to tightly seal the can first. Lastly, dip the tip of one gloved finger in the adhesive and run the finger around the edge of the patch to seal the edge with adhesive and prevent fraying. **Note:** With some fabric (e.g., TEMPER tents), large tears must be sewn together prior to the application of adhesive or sealer. **Caution:** Seam sealer and solvent are extremely flammable and contain toxic fumes. Do not smoke or use seam sealer/solvent near an open flame. Use seam sealer and solvent with goggles and gloves. When indoors, wear a respirator, or use in an open, well ventilated area, away from sources of combustion. Death or severe injury may result from explosion or fire. Inhalation of fumes may cause toxic sickness.

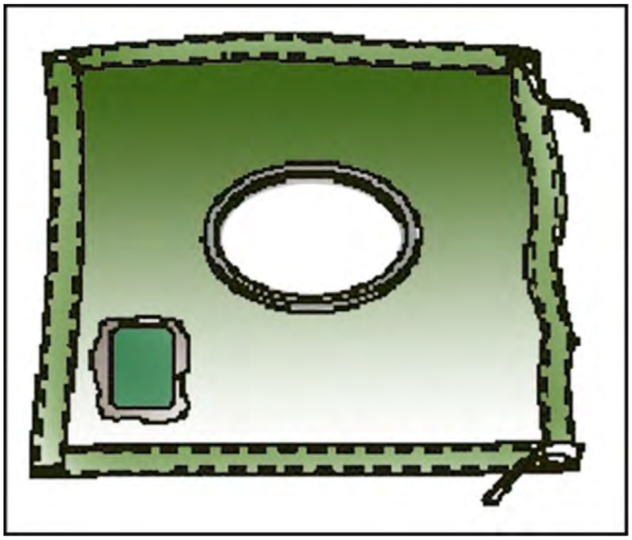
Figure 3.36. Large Hole/Tear Adhesive Repair Steps.



3.7.6.3. **Sealer Repairs for Small Holes and Tears in Stovepipe Shields.** Holes and tears in stovepipe shields can be repaired with sealer. The kind of repair used depends on the extent of the damage, as described below. A layer of silicone sealer is used to repair holes or tears that measure 2 inches or less across. To make this repair, obtain cleaning materials, a dry rag, a can of silicone sealer (MIL-A-46106), and a paddle. Then clean and dry the damaged area thoroughly. Next, spread a 1/16-inch-thick layer of sealer on both sides of the shield, covering the hole or tear and at least 1/2 inch on each side of the damage. Smooth out the layer as evenly as possible. Brace the shield so that the sealer does not touch anything while it is wet, and allow the repair to dry for 4 hours on a sunny day with low humidity or 6 hours on a humid day. Do not move the tent while the sealer is drying.

3.7.6.4. **Sealer Repairs for Large Holes and Tears in Stovepipe Shields.** A patch attached with silicone sealer is used to repair holes and tears more than 2 inches across in stovepipe shields. To make this repair (see **Figure 3.37.**), first obtain the following items (if not included in the repair kit): ruler, cleaning materials, a dry rag, a craftsman's knife, a piece of matching patch material, a can of silicone sealer, and a paddle. Begin the process by cleaning and drying the damaged area thoroughly. Next, measure the damaged area and cut a patch from material salvaged from a shield that could not be repaired, making sure that the patch is large enough to extend 1 inch beyond the damage on all sides. Now, spread a layer of sealer on either the patch or the shield and press the patch in place at once. Finally, spread sealer 1 inch over all edges of the patch to eliminate fraying. Do not move the shield for 4 to 6 hours.

Figure 3.37. Larger Hole Sealer Repair.



3.7.6.5. Additional details on fabric repair procedures can be obtained in the following documents: FM 10-16, *General Fabric Repair*; T.O. 35E5-6-1, *Tent, Extendable, Modular, Personnel (TEMPER)*; T.O. 35E5-6-11, *Alaska Small Shelter System*; and T.O. 35E-6-21, *Californian Medium Shelter System*.

3.8. Conversion of Alternate Facilities. There may be some facilities which are damaged beyond expedient repair capabilities. If such a facility is vital to the air base mission, another facility must be converted to meet the uninhabitable facility's role. To effectively convert another facility, engineers must be aware of the function of the destroyed structure. Equipped with this knowledge, potential alternate facilities can be evaluated in terms ofsize, utilities support, and other special functional requirements. To select or recommend the best facility for conversion, the base civil engineer (BCE) should consider two factors. First, what other structures on the installation come closest to meeting the requirements for an alternate facility? Second, how much work will be required to convert the facility to meet its intended use? If there are no special considerations, the structure meeting the functional requirements and taking the least amount of time to convert should be selected.

Chapter 4

EXPEDIENT REPAIR OF WATER AND WASTE SYSTEMS

4.1. Introduction. Timely repair of water and waste systems is essential after a disaster or enemy attack for obvious health, hygiene, and operational reasons. Since it is impossible to predict the extent of damage to these systems during a disaster or attack, specific priorities need to be established after an incident. Facility priorities listed in base recovery plans are generally a sound starting guide. However, the Emergency Operations Center (EOC) normally dictates repair priorities during emergencies. Bottom line—service to crucial base functions must be restored quickly. If necessary, some creative engineering and cannibalization of non-critical systems may be required to establish or keep priority water and sanitation systems operating.

4.2. Overview. This chapter primarily focuses on expedient water and waste systems repair. Additionally, gas line and POL system repair is briefly discussed. Although some expedient repairs to water and waste systems end up being permanent, most repairs are temporary measures that provide limited support for short periods. The topics presented in this chapter address expedient repair of water distribution, water treatment, water storage, expedient water sources, sewage disposal, gas line, and POL systems.

4.3. Water Distribution Systems. Water is an important utility requiring quick restoration following a disaster or hostile attack. Water systems normally have a high priority for repair due to firefighting requirements, decontamination purposes, personal consumption, cooking uses, and both general and medical hygiene. The major components of any water supply system are source, treatment, storage, and distribution. Of these, the distribution network is the most extensive component of the installation water system and is where most expedient repairs are affected.

4.3.1. **Anticipated Damage and Effects.** Subterranean construction protects the distribution network from certain types of disasters. Its widespread layout can make it more vulnerable to other emergencies.

4.3.1.1. High wind associated with a hurricane or tornado is not likely to break underground water mains, but a major enemy air attack is almost certain to disrupt some part of the dispersed layout of the distribution network. Damage to the distribution system is normally confined to pumps, valves, and water mains. Water mains may be broken in several locations resulting in easily recognizable leaks (**Figure 4.1.**) as well as numerous hidden leaks producing delayed damage in the form of undermined streets or structures.

4.3.1.2. A water system is easily contaminated when water mains and sewers in close proximity are fractured. If the water mains and sewers are on a steep gradient, sewage may enter the water mains with enough head to flow to the consumers' taps below. Contamination may result when broken mains reduce pressure within the system, heavy draft for firefighting, valve closures, and supply failures occurring during enemy attack or sabotage. Contamination may also be caused by filth entering open mains through open ends or fractures during repair operations. The more common diseases attributed to contaminated water are typhoid fever, cholera, and dysentery. Diarrhea may also be caused by contaminated water. An epidemic of any of these seriously hampers military operations.

Figure 4.1. Obvious Water Line Break.

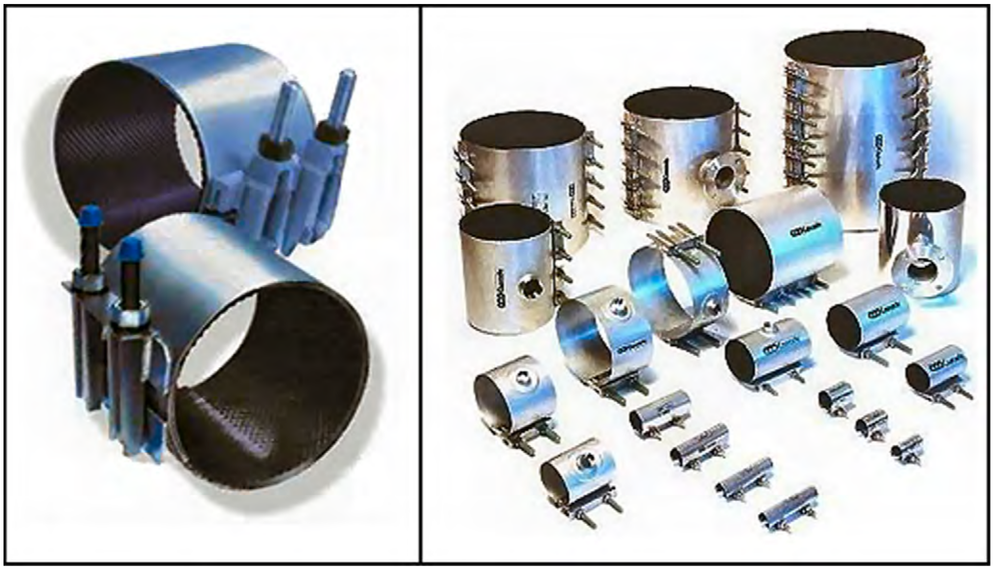
4.3.1.3. During periods of conflict, a retreating enemy or terrorists may deliberately contaminate water supply systems by placing bone oil, refuse, bodies, lubrication oils, or other materials in wells, springs, reservoirs, tanks, or the distribution system. Consequently, measures should be taken to secure easy access points such as well points, pumping stations, and storage vessels.

4.3.2. **Expedient Repair Procedures.** As soon as the situation permits, work should be started on restoring water supply since water supply systems often have a higher priority in rehabilitation than other utilities. Time is normally a limiting factor during base recovery, and rapid completion of the job is by far more important than economy of labor, materials, and equipment. In making improvised repairs, any suitable material or equipment available is used to meet the immediate need. A repaired water main does not have to be leak-proof to be functional. Expedient repairs are improved as time and supplies allow. Water distribution systems include pipe from 1-1/2 to 24 inches in diameter and may consist of PVC rigid plastic pipe, steel, asbestos cement, cast iron, and ductile iron. Water pressure ranges from 60- to 120- psi. Most distribution lines are considered repairable and, therefore, efforts should concentrate on quickly reestablishing major feeder lines. As a general rule, system components, such as pumps, hydrants, valves, and purification units, are not considered expediently repairable due to the time required to accomplish a fix. Suggested repair procedures for water supply systems are listed below.

4.3.2.1. Identify the Problem. The first corrective action is to identify the extent of the problem. Pipes and mains, valves, and pumping stations can be located from existing utility drawings. If available, local technicians should be able to assist greatly in this effort. Multi-frequency pipe locators and similar equipment can be used to locate otherwise hidden lines.

4.3.2.2. Select Repair Materials. Repairs can be accomplished with cast-iron pipe with mechanical couplings or by using iron or steel pipe. Steel pipe is preferable to cast-iron pipe because it is stronger and lighter, can be fabricated in longer lengths, has fewer joints, and is easier to transport and handle. Fire hoses may also be used for temporary bypasses. Schedule 40 PVC piping can also be used as feeder lines. Plastic piping, which normally comes in 10-foot lengths, is very easy to assemble and modify. Mechanical couplers are generally desirable because they are quickly installed and resist vibration and settlement. The most common couplers are the full circle and closed circle types. The full circle or open side couplers (**Figure 4.2.**) are the most preferred and recommended for water, sewer, and POL line repairs. The closed circle or closed side coupler is used primarily for steam line repairs. If normal repair materials, such as couplers, are not available to repair a broken pipe or leaking joint, other expedient line repair techniques are still available.

Figure 4.2. Typical Full Circle Couplers.



4.3.2.3. **Implement Repairs.** Expedient repair to water distribution systems basically consists of piping. In essence, replace or repair piping systems with locally available materials or materials obtained by dismantling non-critical systems for components. First responders will normally attempt to isolate and/or bypass damaged lines. Once the damage has been assessed, make temporary repairs to control water wastage, maintain essential flow, and permit the reopening of valves.

4.3.2.3.1. **Repairing Water Main Breaks and Leaks.** Water main repairs should be repaired as quickly as possible. The type of repair technique that is used depends on the type of leak in the water main. Use the procedures in **Table 4.1.** as a guide for repairing water main breaks and leaks.

Table 4.1. Checklist for Repairing Water Main Breaks and Leaks.

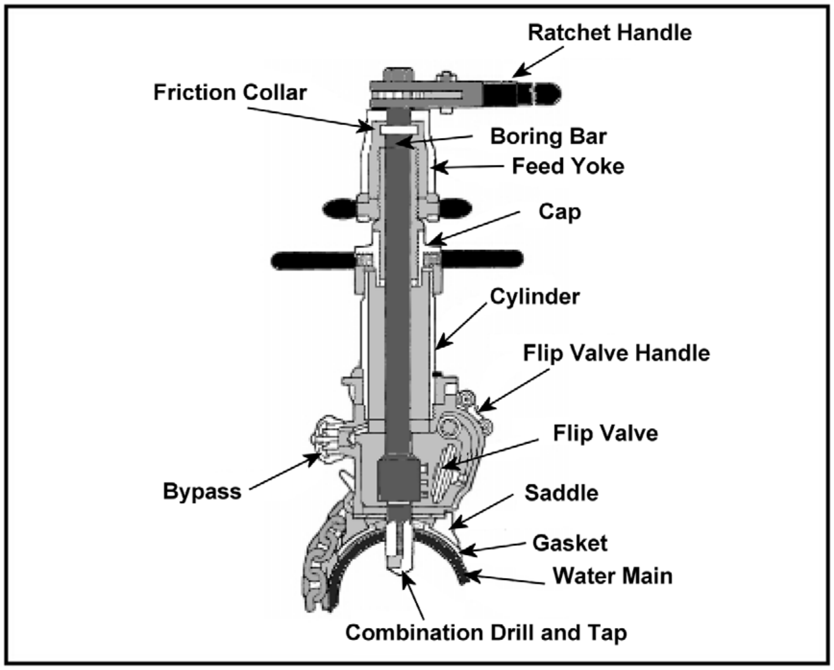
Problem Type	Repair Procedure
Small Holes	Use wood plugs to stop small holes temporarily. (Replace wood plugs with permanent metal plugs at a later date.) Temporary wood plugs can also be used to plug the ends of pipes up to 8 inches in diameter. Brace the plugs to withstand the pressure in the main.
Joint Leaks	Repair joint leaks by recaulking the joint if caulking was previously used in the joint.
Cracks in Main	Cracks in mains usually require that the valves be shut off in the affected area, especially in severe main breaks. Notify the fire fighting authorities in case of main shutoff. Repair leaks in mains using split sleeves or mechanical couplings. Split-sleeve and mechanical-joint repair fittings offer the best method for quick, effective repairs. Several companies manufacture split-sleeve and mechanical-joint repair fittings. Split-sleeve repair method: Insert a split sleeve over fracture or hole. Split-sleeve fittings can be installed underwater if necessary. Mechanical-joint repair method: Cut out a section of the cracked pipe and replace it with a piece of pipe and mechanical couplings. Mechanical couplings are manufactured by several companies for various types of repair jobs. Consult the manufacturer's instructions for installation methods to make the proper selection and installation. If the break is too long for a short insertion piece, insert a whole length of pipe. When a water main is opened for repair, flush and disinfect it before returning it to service.

4.3.2.3.2. Tapping Water Mains. After a disaster or during a contingency, it may be necessary to tap into water mains to make expedient repairs or reroute essential service. Water mains are usually cast iron, 8 inches or more in diameter. If the involved main is less than 8 inches in diameter, taps should be 2 inches or smaller. Use the steps in **Table 4.2.** and the illustration in **Figure 4.3.** to tap the water main.

Table 4.2. Steps to Tap a Water Main.

Water Main Tapping Procedures	
Step 1	Dig to expose pipe at thepoint where tap is to bemade. Dig as close tothe top of water main as possible.
Step 2	Clean all dirt and rust off pipe at that point.
Step 3	Place gasket of water main self-tapping machine on pipe, and set saddle of machine on the gasket.
Step 4	Wrap the chain around the pipe, and tighten it to clamp water main self-tapping machine to the pipe.
Step 5	Remove cap from the cylinder ofmachine, and place combination drill and tap in boring bar
Step 6	Reassemble machine by putting boring bar through cylinder and tightening cap.
Step 7	Open flap valve between the compartments and start drilling hole by applying pressure at feed yoke and turning ratchet handle until drill enters the main.
Step 8	When tap starts threading the hole, back off the feed yoke to prevent stripping threads.
Step 9	Continue to turn boring bar until the ratchet handle can no longer be turned without extra force.
Step 10	Remove tap from the hole by reversing the ratchet. Then,back the boring bar out by turning it counterclockwise.
Step 11	Close the flap valve between upper and lower compartments.
Step 12	Drain water from cylinder through the bypass.
Step 13	Remove cap and drill tool. Place a corporation stop in the boring bar, ensuring that the stop is closed.
Step 14	Repeat steps 6 and 7.
Step 15	Turn ratchet handle to thread corporation stop into the pipe.
Step 16	Repeat Step 13.
Step 17	Remove cap from the cylinder, and unbolt boring bar from the corporation stop.
Step 18	Remove lower chamber from the pipe.
Step 19	Inspect for leaks. If corporation stop leaks, tighten it with a suitable wrench

Figure 4.3. Water Main Tap.



4.3.2.3.3. **Making Temporary Repairs in Water Pipes.** Although expedient repairs may not eliminate all leaks from water distribution pipes, small leaks should be repaired when the tactical situation or mission permits. Before making any repairs, shut off the water and relieve the pressure from the system. Pipes can be temporarily repaired using the following methods.

4.3.2.3.3.1. **Rubber Hose or Plastic Tubing.** Cut the pipe on either side of the leak with a hacksaw or pipe cutter. Remove the damaged pipe section and replace it with a length of rubber hose or plastic tubing. To do this, slip the ends over the pipe and fasten them with hose clamps. The inside diameter of the hose must fit the outside diameter of the pipe.

4.3.2.3.3.2. **Sheet Rubber.** Wrap the leaking area with sheet rubber. Place two sheet-metal clamps on the pipe (one on each side). Then, fasten the clamps with nuts and bolts.

4.3.2.3.3.3. **Electrician's Friction Tape.** Wrap several layers of friction tape around the hole or crack, extending the tape about 2 inches above and below the leak.

4.3.2.3.3.4. **Wood Plugs.** Similar to water main repairs, small holes in other water pipes can also be filled with wood plugs. Drive a wooden plug into the hole after it is drilled or reamed. The plug will swell as it absorbs water, preventing it from being blown out by water pressure.

4.3.2.3.4. Installing Temporary Piping or Hoses. These repairs may involve plugging or capping fractured mains or shunting water around breaks with a fire hose connected to the fractured pipe or fire hydrants. Expedient repairs could also consist of new piping laid on the ground. Replace temporary piping and hoses with more permanent repairs as soon as possible because they may interfere with traffic, are likely to freeze in cold weather, and may not provide sufficient supply. **Figure 4.4.** and **Figure 4.5.** give examples of typical service and waterline connections that may require repair.

Figure 4.4. Service Connections to Existing Mains.

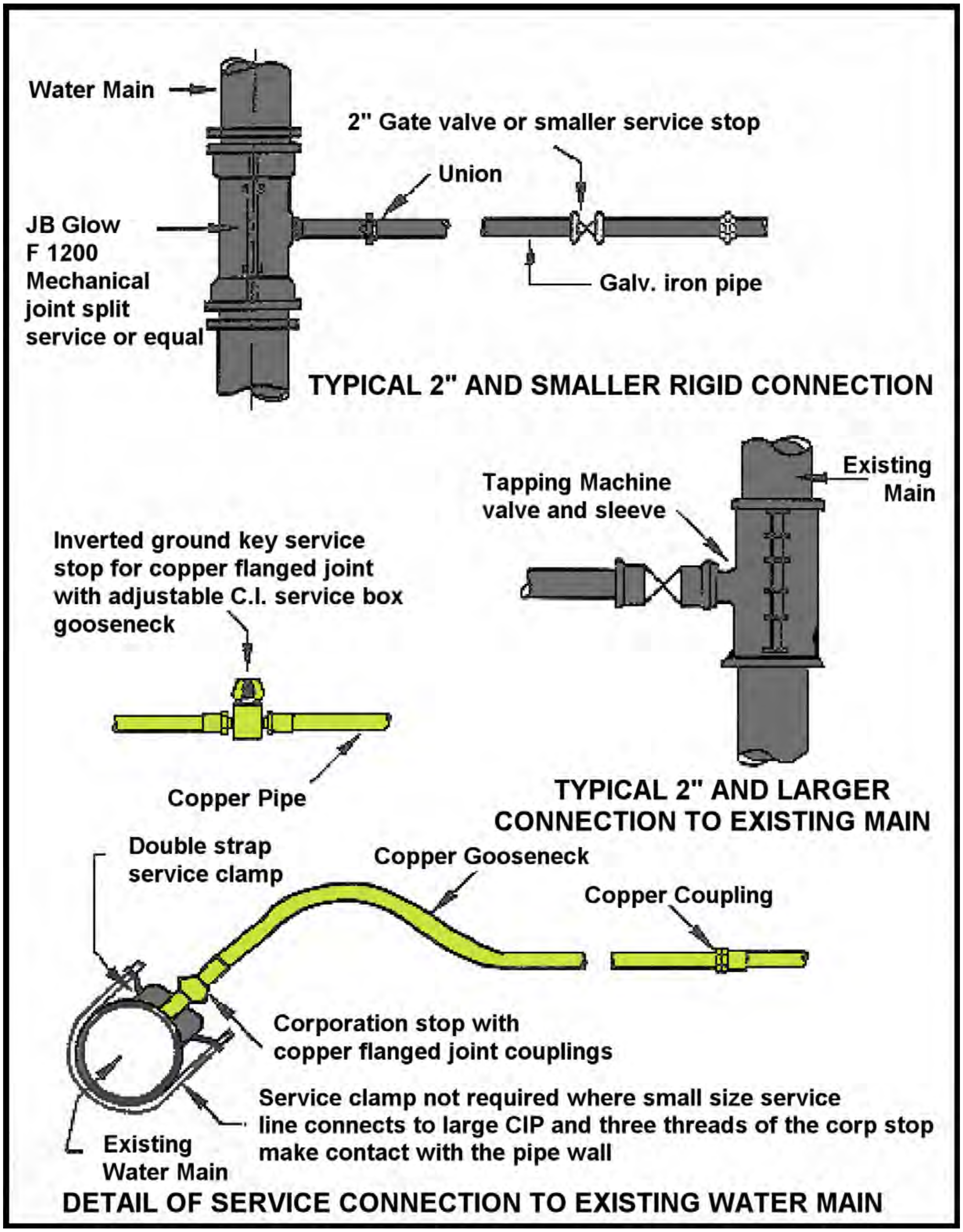
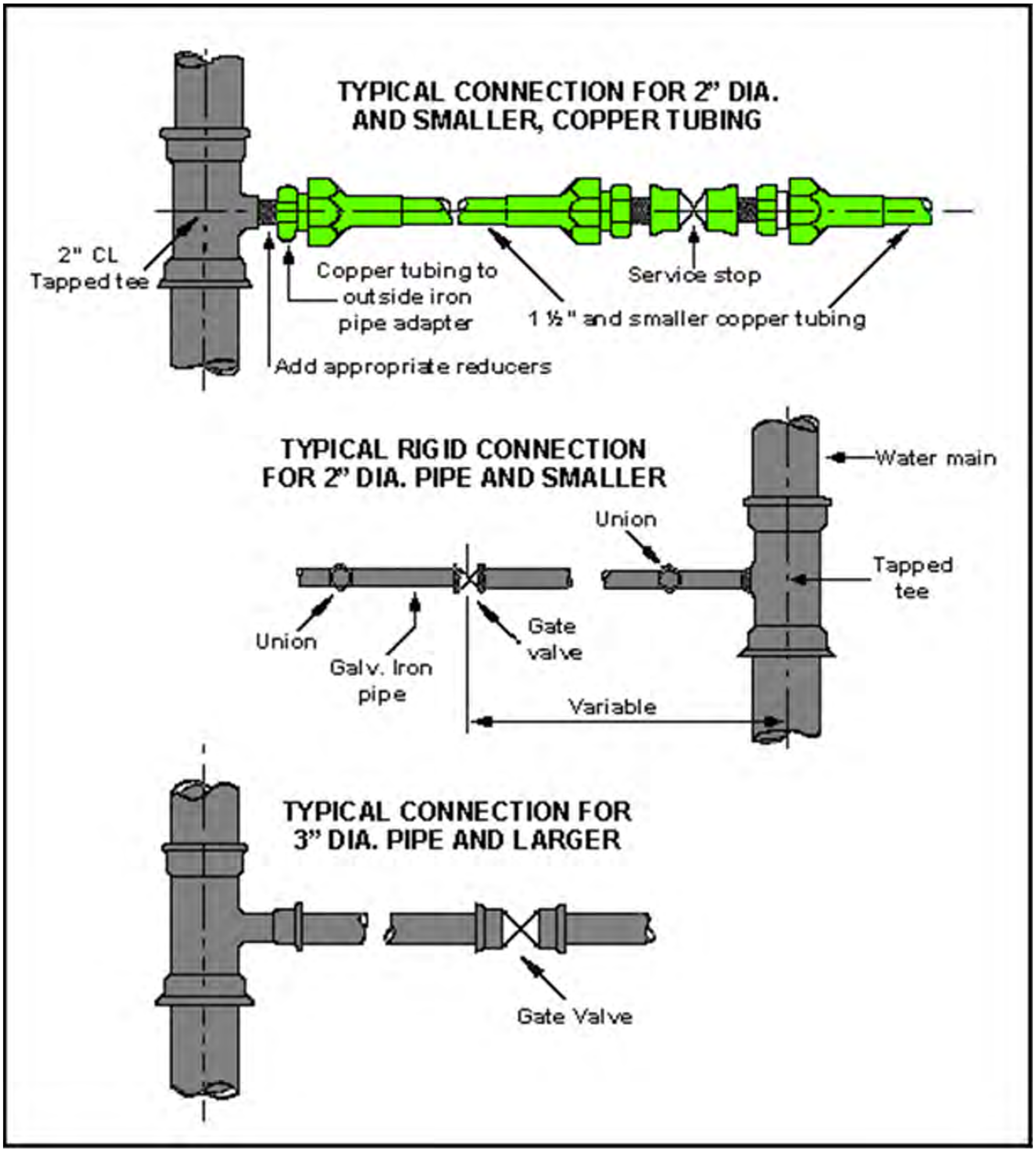
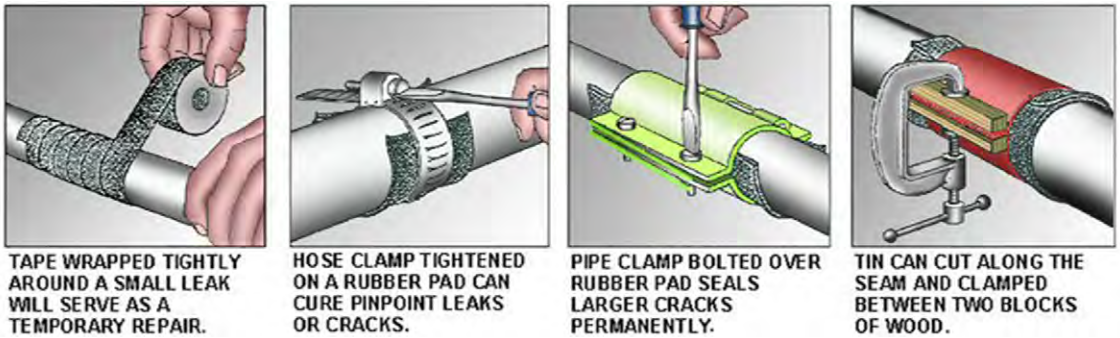


Figure 4.5. Typical Waterline Connections.



4.3.2.3.5. Repairing Burst Water Lines. Four examples of ways to repair a burst water line are shown in **Figure 4.6.**

Figure 4.6. Expedient Pipe Repair Techniques.



4.3.2.3.6. Using Dissimilar Materials. During expedient repair, the goal is delivery. As such, the piping size must be based upon the sizes that the pumps will accommodate and the materials available. During contingency operations proper fittings, material, and tools may not be available. Therefore, the field engineer may have to improvise using dissimilar materials to effect temporary repairs. **Figure 4.7.** through **Figure 4.9.** illustrate a few ways to accomplish pipe repairs when working with limited resources or dissimilar materials. Regardless of what type of expedient repairs are performed, the total system will need to be disinfected when the repairs are completed.

Figure 4.7. Joining No-Hub Cast-Iron Pipe.

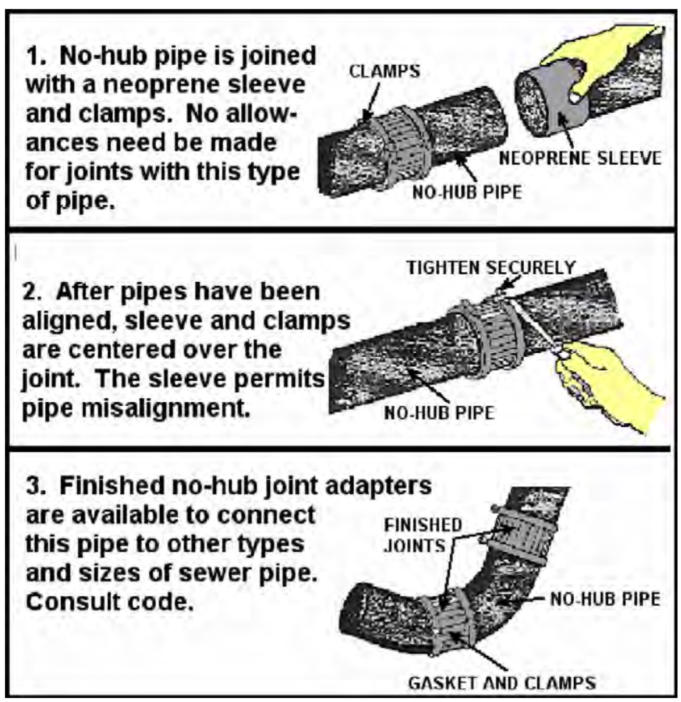


Figure 4.8. Working With Flexible Plastic Pipe.

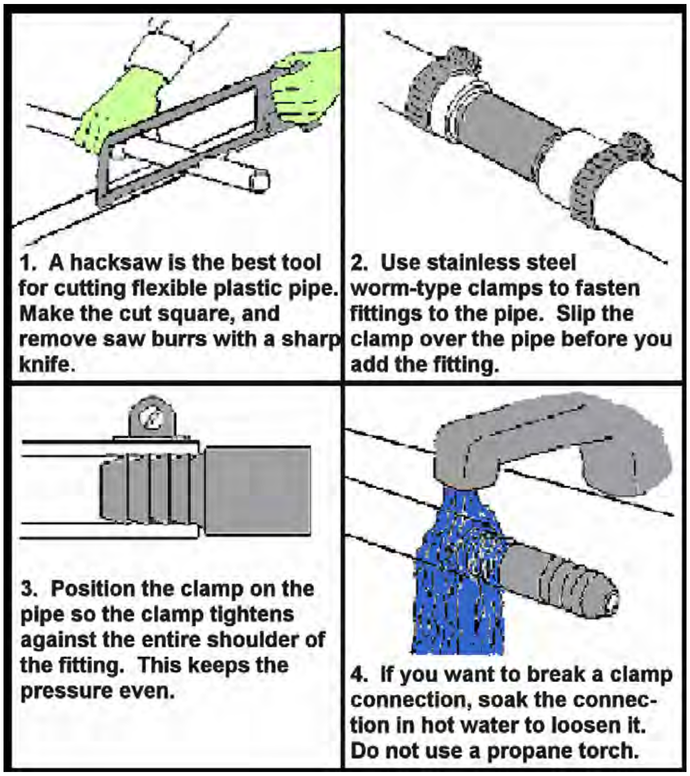
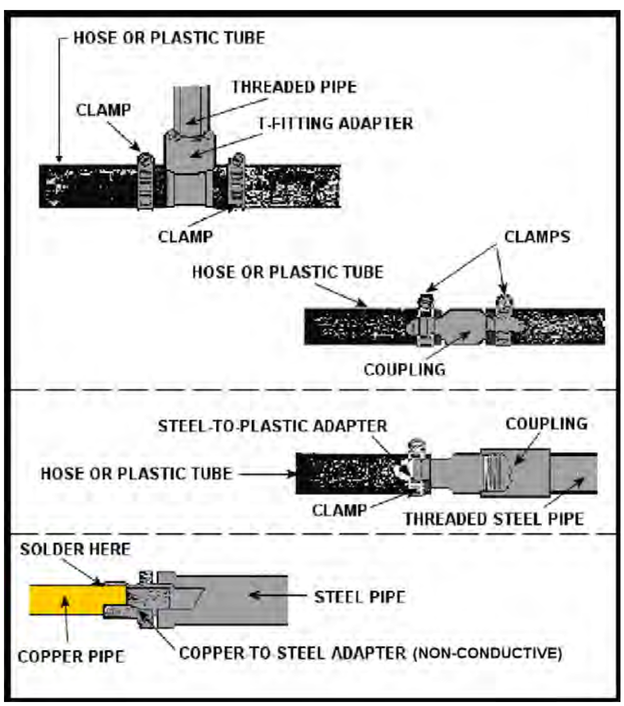


Figure 4.9. Dissimilar Materials Jointing.



4.3.2.3.7. **Thawing Frozen Systems.** Pipes may freeze in temperat e as well as frigid zones. In frigid climates, freezing presents a major problem to a water distribution system, and pipes are normally insulated and heated. If a building's temperature falls below freezing, inside pipes may also freeze causing the pipe to break at the weakest point. The best way to avoid frozen pipes is to insulate or wrap lines with electrical heat tape. In areas where the ground is permanently frozen, water pipes are placed in heated conduits. Pipes are typically buried below frost penetration depth in temperate climates where freezing is only a seasonal problem. Even with proper protection, some pipes may still freeze. The paragraphs below discuss some pipe-thawing procedures.

4.3.2.3.7.1. **Electrical Thawing of Wrought-Iron and Cast-Iron Pipe.** Electrical thawing is quick and relatively inexpensive. The electrical circuit for the thawing operation consists of a source of current (a DC generator, such as a welding unit, or a transformer connected to an AC outlet), a length of the frozen pipe, and two insulated wires connecting the current source and the pipe. As current flows through the pipe, heat is generated and the ice within the pipe begins to melt. As the water starts to flow, the rest of the ice is progressively melted by contact with the flowing water. The wires from the current source may be connected to nearby hydrants, valves, or exposed points at the ends of the frozen section. The amount of current and voltage required to thaw various sizes of wrought-iron and cast-iron pipe are given in **Table 4.3.** The time required for electrical thawing varies from 5 minutes to over 2 hours, depending on the pipe size and length, the intensity of freezing, and several other factors. The best practice is to supply current until the water flows freely.

Table 4.3. Current and Voltage Required to Thaw Wrought-Iron and Cast-Iron Pipes.

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

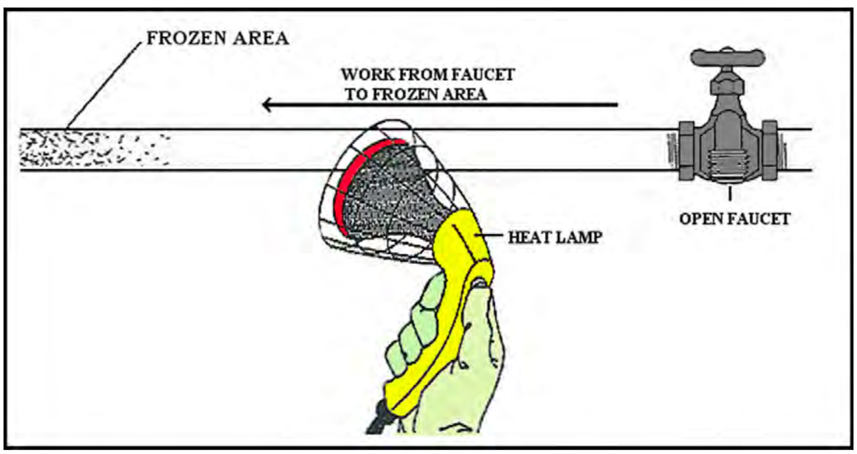
4.3.2.3.7.1.1. **Precautions.** In general, do not use a current higher than the one listed in **Table 4.3.** for a particular pipe size. When in doubt, use a lower current for a longer period of time. Select contact points on the pipe as close as possible to the frozen section and make sure the contact points are free of rust, grease, or scale. Remove any meters, electrical ground connections, and couplings to the building plumbing from the line to be thawed. If the pipe joints have gaskets or other insulation, thaw the pipe in sections between the joints or use copper jumpers to pass the current around the insulated joints.

4.3.2.3.7.1.2. **Procedures.** To thaw pipe with a welding generator or similar DC source, set the generator to the correct amperage for the pipe to be thawed and connect leads to the pipe. For an AC source, transformers are required to adjust the amperage of the AC circuit to the pipe being thawed. Consult an electrical engineer for the best transformer arrangement. To keep hazards to a minimum, a competent electrician generally sets and connects transformers, makes the connections, and assists throughout the thawing procedure. Where frequent thawing is necessary at different points, the transformers may be mounted on a trailer for ready use.

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

4.3.2.3.7.3. **Thawing With a Heat Lamp or Blow Torch.** A heat lamp or blowtorch is a good method for thawing aboveground pipes, but there is a risk of fire—especially with plastic pipes. Use the following steps to thaw frozen pipes when using a heat lamp or blowtorch: (1) open the faucets in the line; (2) apply heat from the heat lamp or blowtorch at one end of the pipe and work along the entire length of the pipe (**Figure 4.10.**); (3) continue to heat the pipe until the water flows freely. **Caution:** Do not overheat the pipes, because soldered joints will break loose if the solder melts.

Figure 4.10. Thawing Frozen Interior Pipes.



4.3.2.3.7.4. Thawing with Boiling Water and Thaw Pipe. Follow the steps in **Table 4.4.** and use the illustration in **Figure 4.11.** to thaw frozen exterior pipes.

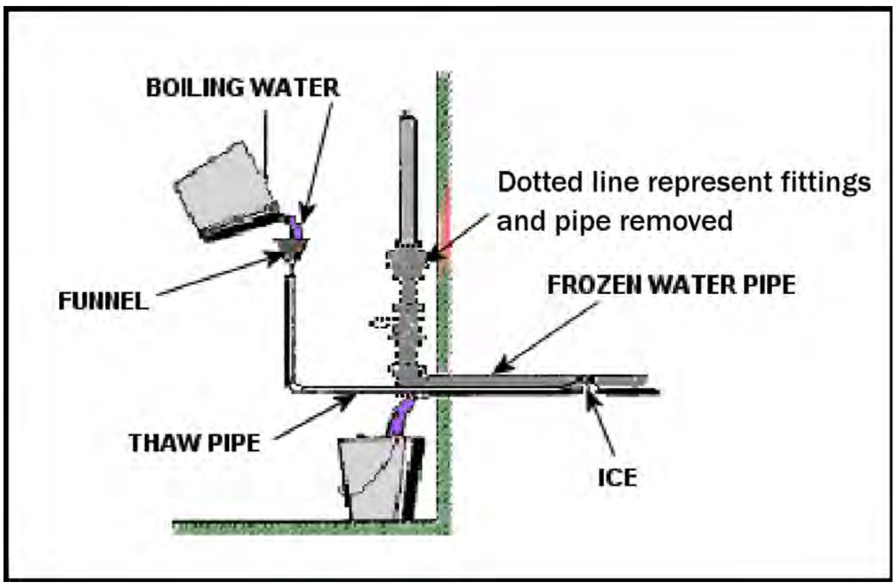
4.3.2.3.7.5. Other Thawing Methods. Pipes can also be thawed by wrapping them with burlap or other cloth and pouring boiling water over the wrappings, thus transmitting heat to the frozen pipe. In some cases, a small pump may be used to clear a piece of pipe. However, excessive pump pressure can cause a backup; therefore, this procedure must be carefully monitored. When indoor pipes freeze due to failure in the heating plant, the heating plant must be repaired. A high temperature should be maintained in the building until the pipes thaw.

4.3.2.3.8. Disinfecting the Piping System. After repairs are made to water supply pipes, clean and disinfect plumbing pipes and other parts of a water supply system carrying drinking water before use. Flush the system to remove dirt, waste, and surface water. Disinfect each unit with a chemical such as a solution of hypochlorite or chlorine according to established disinfection standards and procedures. Normally, there is little danger of contamination, and disinfection is not required if leaks or breaks are repaired with clamping devices while the mains remain full of pressurized water.

Table 4.4. Steps to Thaw Frozen Underground Pipes.

Pipe Thawing Procedures	
Step 1	Remove the pipe fittings.
Step 2	Insert small thaw pipe or tube into the frozen pipe as shown in **Figure 4.11.**
Step 3	Add an elbow and a piece of vertical pipe to outer end of the thaw pipe.
Step 4	Place a bucket under the opening to the frozen pipe.
Step 5	Insert a funnel into the open end of the vertical pipe.
Step 6	Pour boiling water into the funnel and, as the ice melts, push the thaw pipe forward.
Step 7	After the flow starts, withdraw the pipe quickly. Allow the flow to continue until the thaw pipe is completely withdrawn and cleared of ice.

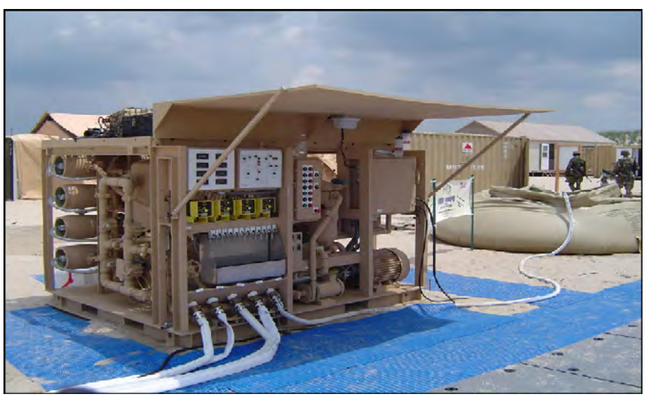
Figure 4.11. Thawing Frozen Exterior Pipes.



4.4. Water Treatment Systems. The expedient restoration of water treatment capabilities may consist of repairs to an existing treatment plant or the installation of portable water treatment units. The importance of restoring the water treatment facility will depend upon the quality of the installation water source following an emergency. If the source is relatively free of contaminants, treatment plant repairs or setting up of portable treatment equipment may be of less importance than other installation repairs. If water treatment is necessary and the treatment plant is beyond repair, or the installation does not possess a treatment facility, it may be necessary to use expedient water treatment equipment. The most common expedient water treatment system available to civil engineer forces is the reverse osmosis water purification unit (ROWPU). The ROWPU purifies water by forcing water under high pressure through a series of membranes to eliminate impurities. The ROWPU is capable of removing dissolved minerals from water. Disinfection treatment is accomplished only after processing through the membrane filter elements since chlorine causes acute damage to the filter elements. The production capability of the ROWPU will be reduced by high temperatures of the feedwater source. Although ROWPUs come in several sizes, the Air Force currently uses both the 600-GPH unit shown in **Figure 4.12.** and the 1500-GPH unit shown in **Figure 4.13.** For more information on ROWPU operations, refer to AFH 10-222, Volume 9, *Guide to Reverse Osmosis Water Purification Unit Installation and Operation.*

Figure 4.12. 600-GPH Reverse Osmosis Water Purification Unit (ROWPU).

Figure 4.13. 1500-GPH Reverse Osmosis Water Purification Unit (ROWPU).



4.5. Water Storage Systems. The water storage system on an air base or beddown location may consist of underground reservoirs, elevated water tanks, open reservoirs, and temporary storage facilities like those in **Figure 4.14.** The most severe damage to the storage system could be a rupture causing loss of the stored water. Another consideration is sabotage by clandestine groups. Whenever possible, water storage facilities should be postured well within the secure area of the installation or beddown setting. Ruptures or other damage to existing storage facilities can be sealed from the inside using rubber patches, epoxy, or wooden dowels if the holes are small. When conventional installation water storage facilities are damaged or additional storage space is required, swimming pools and similar watertight facilities make excellent alternate reservoirs. Other expedient water storage alternatives include: flexible bladders ranging in size up to a 50,000-gallon capacity, water distribution trucks, water trailers, lyster bags, 5- and 10-gallon igloo water coolers, and 55-gallon drums. An aboveground reservoir can be constructed using sandbags or earthen berms lined with plastic sheeting to make it watertight. Bear in mind that a considerable amount of water is stored within the pipelines themselves. For example, a 6-inch pipeline, two miles long contains approximately 16,000 gallons when full. Using shutoff valves to quickly isolate undamaged sections of the distribution system could mean substantial amounts of water saved within the pipes for future use.

Figure 4.14. Temporary Water Storage Facilities.

4.6. Expedient Water Sources. The source of water for an air base or beddown location may be as varied as a commercial supplier, a ground water source, or a surface water source (**Figure 4.15.**). Damage to a commercial water supply during an emergency will normally consist of a ruptured or blocked supply line that results in either reducing or eliminating the base water supply. Ground water sources, water pumped from below the surface, are probably the least vulnerable supply sources. It can be assumed most natural disasters or hostile attacks would not destroy this type of water source. However, some emergencies can cause damage to the well and pumping systems that give access to this source. Specifically, wells could be partially filled with debris, well walls and pumping facilities damaged or destroyed entirely. Various types of emergency situations can affect surface water sources also. Water-borne debris associated with a flood or hurricane might block water inlets to the system; nuclear, biological, or chemical contaminants used during an enemy attack could make the source unusable; or conventional enemy munitions may diminish, divert, or stop access to a river or lake. Other sources of water available to the civil engineer force are sometimes overlooked. In cold weather regions there are vast amounts of "solid" water available in the form of snow and ice. Snow and ice melting devices can be fabricated and used to provide excellent water supplies from glaciers and other ice formations. Base swimming pools, ornamental pools, and similar facilities often contain substantial amounts of water, which can be used during emergencies. **Table 4.5.** through **Table 4.8.** show the characteristic advantages and disadvantages associated with supplying and using water in the four major climatic regions of the world.

Figure 4.15. Sourcing Water for Earthquake Victims (Turkey 1999).

Table 4.5. Temperate Regions.

Advantages	Disadvantages
Abundant Resources Lakes Streams Rivers Existing Wells Local Water Systems	Chemical, Biological, Radiological, and Nuclear munitions easily contaminate surface sources. Natural contamination is possible by organic, disease-bearing organisms, and inorganic salt.
Sources are convenientto locate, develop, and access. Water sources can be purified at small unit level. Drinking water does not require cooling.	Environmental pollution from local development such as septic fields may contaminate ground water.

Table 4.6. Tropical Regions.

Advantages	Disadvantages
Water sources available are more scattered than temperate regions. They include: Lakes Streams Rivers Existing Wells Local Water Systems Water sources can be purified at small unit level.	Chemical, Biological, Radiological, and Nuclear munitions easily contaminate surface sources. Dense vegetation may make access difficult. The presence of waterborne diseases and parasites capable of transmitting disease may make water unsuitable for bathing and laundry use until disinfected. Higher water use is needed because of high humidity and heat.

Table 4.7. Frigid Regions.

Advantages	Disadvantages
Water sources may be abundant, but frozen. Sources include: Lakes Streams Rivers Existing Wells	Expect increased consumption to prevent dehydration. Water purification, storage, and distribution systems must be protected against freezing. Snow and ice are impractical to melt for other than very small units due to the excessive fuel needed for melting.

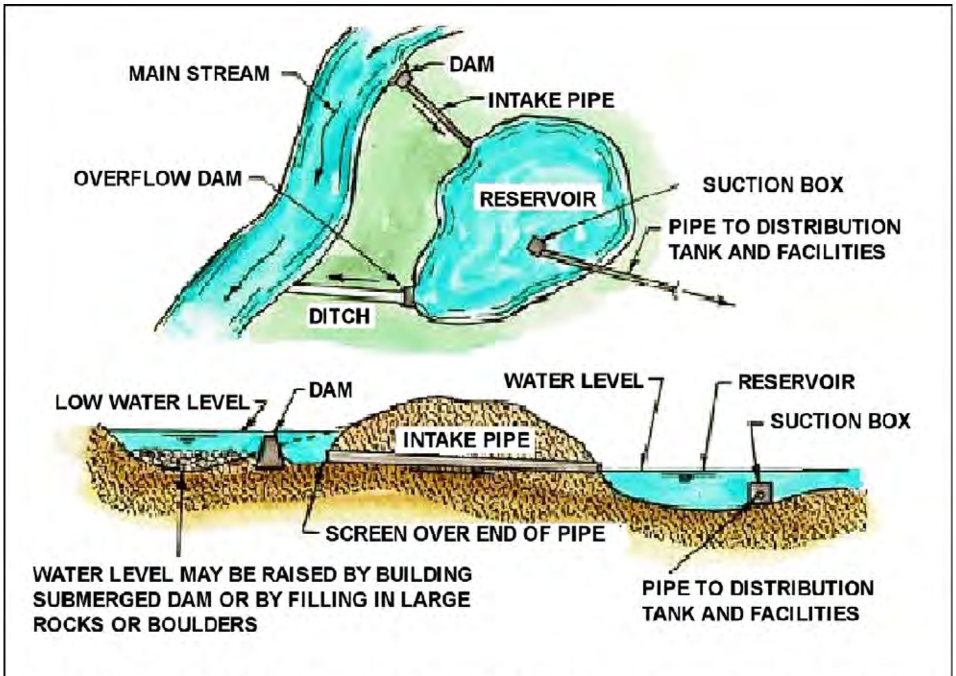
Table 4.8. Desert Regions.

Advantages	Disadvantages
None.	Surface fresh water almost nonexistent. Available water sources are limited and widely dispersed. Anticipate increased water use to prevent heat casualties. Limited supplies may dictate the tactical scenario. The lack of water abundance makes an extensive storage and distribution system vital.

4.6.1. **Water Sources Development.** Once water sources have been identified for a beddown location, the field engineer must further develop and maintain these sources for use. General tasks involved in this process include, (1) developing water points by creating ponds and lakes across streams, deepening and reinforcing existing water collection areas; (2) providing drainage to prevent contamination of water sources from storm runoff; (3) constructing physical protection structures for water sources; (4) constructing and improving roads from water points and well sites to the main supply routes; (5) maintaining, repairing and building semi-permanent and permanent water utilities at existing installations; and (6) repairing and constructing water storage and distribution systems.

4.6.2. **Surface Water Resources.** Surface water from rivers, streams, lakes, or springs is the most common sources of water supply. Surface water sources must be treated according to established water treatment procedures and standards to ensure water is potable before use. Refer to AFH 10-222, Volume 9 for water treatment procedures. The capacity of small streams to meet supply requirements may be increased by the construction of small dams or reservoirs. Expedient structures for this purpose are shown in **Figure 4.16.** through **Figure 4.18.** In regions such as tropical islands where there is abundant rainfall and rapid surface runoff, rainwater is the primary source for the inhabitants, however, the quantity of water available may not be sufficient to supply the needs of both the civilian population and the military. Rainwater as a source may be sufficient for small units for limited operations, but it should not be considered if other more reliable sources are available.

Figure 4.16. Expedient Dam and Reservoir Layout.



The intake pipe should be of a size to bring about 1-1/2 times the maximum hourly demand of the water system. The reservoir should be able to store at least one day's supply of water for the system.

Figure 4.17. Typical Small Expedient Dam.

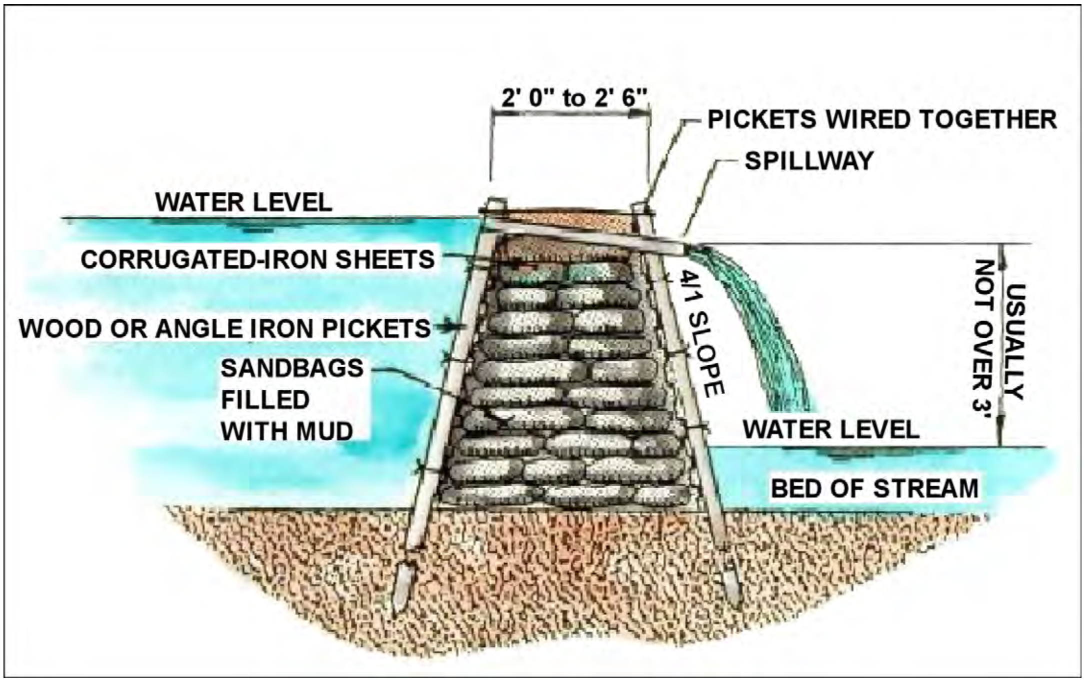
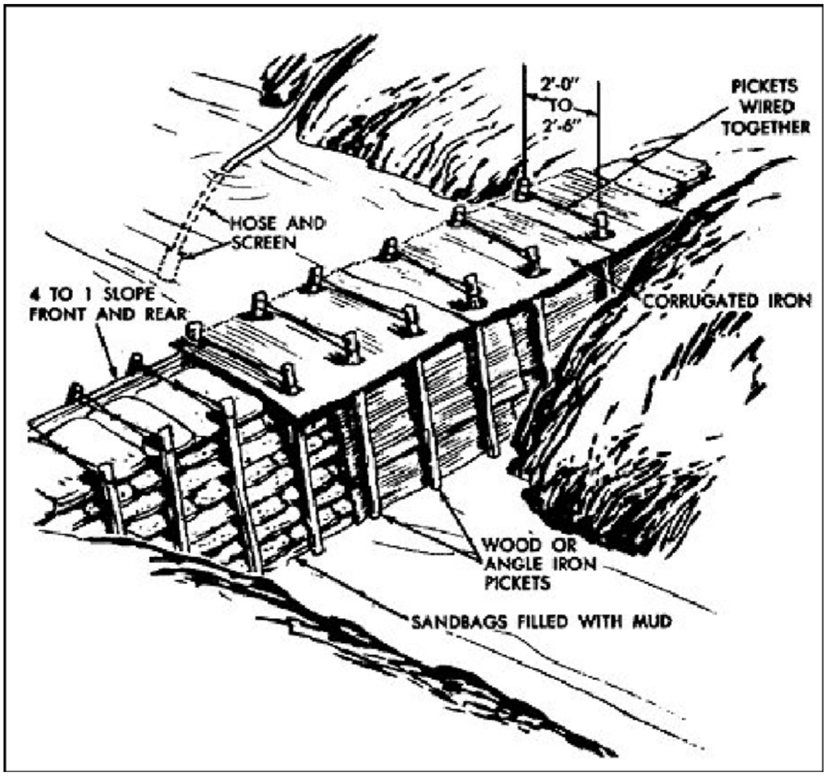


Figure 4.18. Improvised Dam for Impounding a Small Stream.



4.6.3. **Water Intakes.** Once the natural water resources are confined in a reservoir the water must be delivered to the point of usage. This is generally accomplished by pumps or gravity pipelines. Intakes are used as a means of obtaining water from its source. Water at the intake point should be as clear and deep as possible. Screens are installed on all intakes regardless of how clean the water appears. Screens used at surface sources serve to keep fish and debris out of the water system. Special attention must be given to the intake. If a lot of muck or silt is on the bottom of the water source, a floating type intake is best. On the other hand, if bottom of the water source is a bed of sand or gravel, a surface intake with a screen may be equally effective and easier to use.

4.6.3.1. **Floatable Intakes.** Floats made of logs, lumber, sealed cans, or empty fuel drums can be used to support the intake strainer in deep water. They are especially useful in large streams where the quality of the water varies across its width or where the water is not deep enough near the banks to cover the intake strainer. An adequate depth of water can cover the intake point by anchoring or stationing the float at the deep part of the stream. The intake hose should be secured to the top of the float, allowing enough slack for movement of the float. If support lines are used to secure the float to the banks, the position of the float can be altered to correspond to changes in depth by manipulation of the lines. The chief advantage of a float intake is the ease with which the screen can be adjusted. **Figure 4.19.** and **Figure 4.20.** illustrate two types of improvised intake floats. **Note:** The strainer on the suction hose of a floating intake should be placed at least 4 inches below the water level. This precaution reduces the possibility of the strainer becoming clogged with floating debris, or the loss of prime owing to air entering the suction line.

Figure 4.19. Drum Float Type Water Intake.

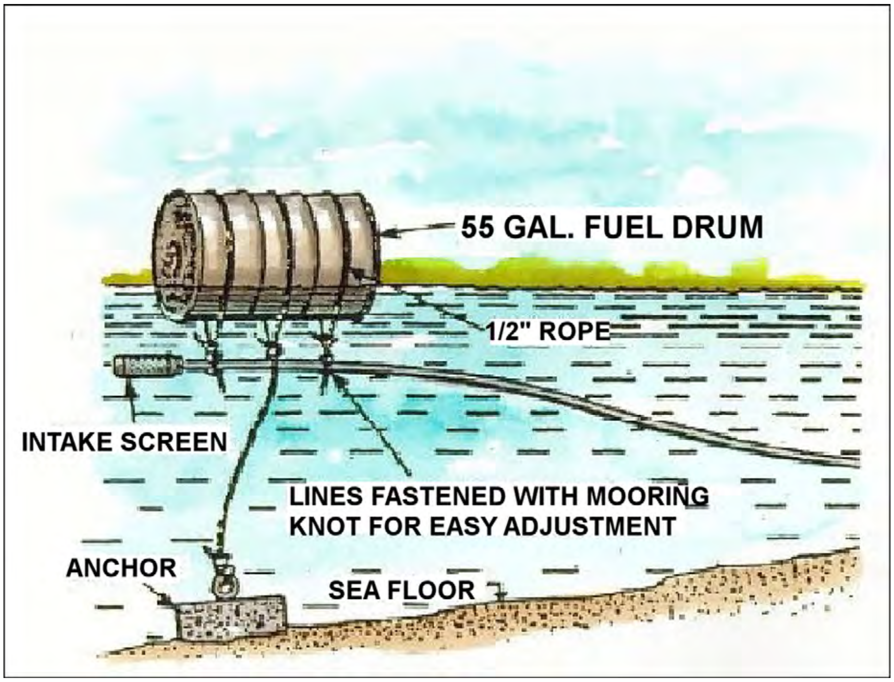
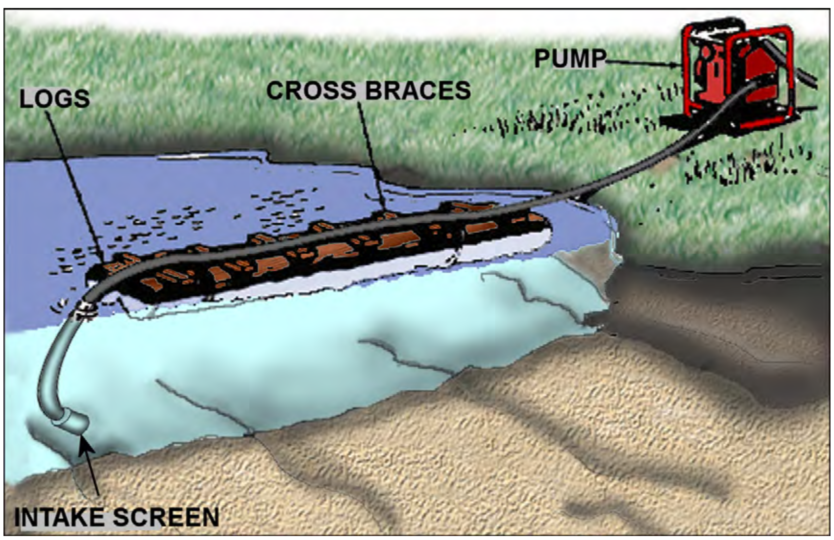
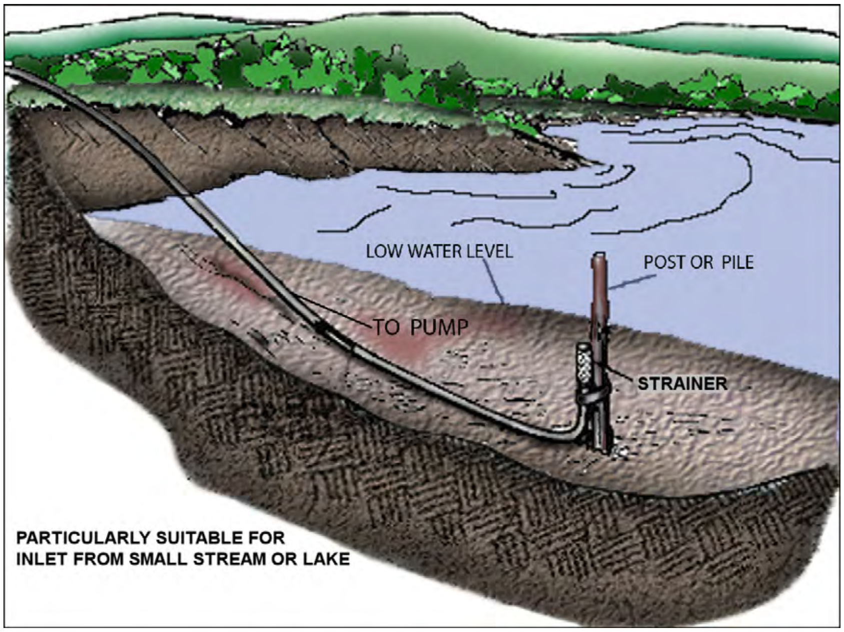


Figure 4.20. Log Float Type Water Intake.



4.6.3.2. Rock and S take Supported Intakes: If the stream is not too sw ift and the water is deep enough, an expedient intake may be prepared by placing the intake strainer on a rock. This will prevent clogging of the strainer by the streambed and provide enough water overhead to prevent the suction of air into the intake pipe. If the water source is a sm all stream or shallow lake the intake pipe can be secured to a post or pile as shown in **Figure 4.21.**

Figure 4.21. Stake Supported Water Intake.



4.6.3.3. **Pit Supported Intakes.** When a stream is so shallow thatthe intake screen is not covered by at least 4 inches of water, a pit should be dug and the screen laid on a rock or board placed at the bottom of the pit. Pits dug in streams with clay or silt bottoms should be lined with gravel to prevent dirt from entering the purification equipment (**Figure 4.22.**). The screen is surrounded by gravel that prevents collapse of the sides of th e pit and shields the screen from damage by lar ge floating objects. The gravel also acts as a coarse strainer for the water. Enclosing the intake screen in a bucket or other container as shown in **Figure 4.23.** may provide a similar method.

Figure 4.22. Typical Gravel Pit Intake.

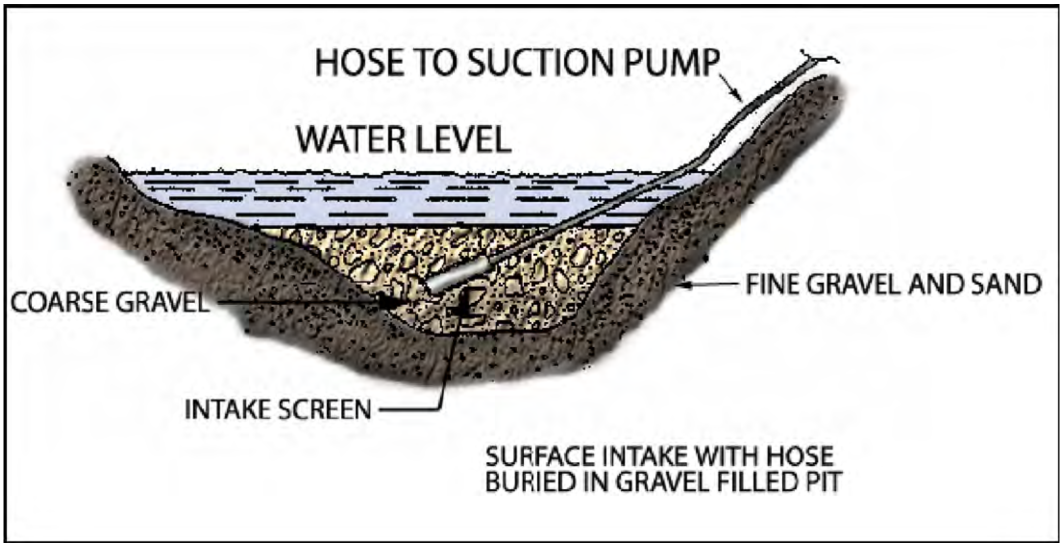
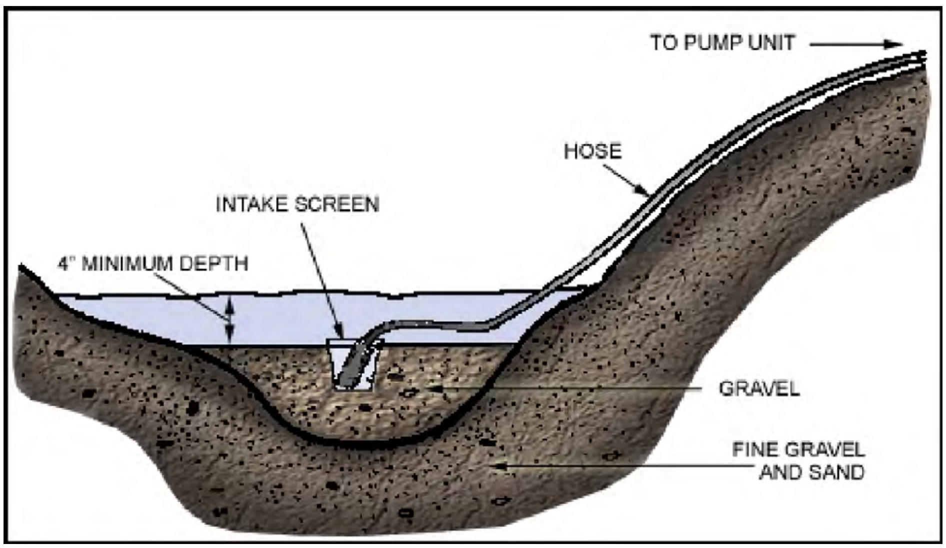


Figure 4.23. Bucket Use with Gravel Pit Intake.



4.7. Wastewater (Sewage) Systems. Improper disposal of sewage in the aftermath of a disaster or enemy attack will compound base recovery problems. If the sewage enters a water supply, an outbreak of intestinal diseases such as typhoid, cholera, dysentery, and diarrhea, is almost certain to occur. To prevent such outbreaks, civil engineer forces may have to repair damage to existing sewer systems as well as provide temporary sanitation facilities. The priority of these repairs will be based on an estimate of potential hazard to the installation population.

4.7.1. Classification of Air Base Sewage. Sewage may be divided into several classifications according to its source. These classifications will decide the immediate need for sewer rehabilitation. The two primary types of sewage on most installations are domestic sewage and storm sewage.

4.7.1.1. Domestic Sewage. Domestic sewage is the waste from toilets, lavatories, urinals, bathtubs, showers, laundries, and kitchens. Proper disposal of this type of sewage should receive first consideration in expedient repair operations.

4.7.1.2. Storm Sewage. Storm sewage is the inflow of surface runoff during or immediately following a storm or heavy rain. Disposal of storm sewage following a disaster is not a high priority unless it hinders base operations or endangers lives by flooding critical areas. Since storm sewers are designed to catch runoff whether it is natural or man-made, they will also catch and collect toxic chemicals introduced accidentally or on purpose. For this reason, civil engineers should be prepared to establish blocking points at critical locations to prevent the spread of hazardous materials. Storm sewers may be blocked using commercially available plugs or sandbags.

4.7.2. Sewage System Operation. The major components of the sewage system consist of facilities for collecting, pumping, treating, and disposing of sewage. The basic collecting system consists of a series of branch, lateral, main, and trunk sewers leading from various installation structures. Raw sewage moves through the collection system to a central point for treatment and eventual disposal. At any point along the system where gravity is not sufficient to move the sewage, a pump or lift station may be required. Sewage treatment plants vary in complexity according to the characteristics of the influent and the degree of treatment required prior to discharge. Effluent standards, set by national and local regulations, determine the degree of treatment.

4.7.3. Anticipated Sewer Damage. Common problems with the sewage system during typical disasters such as floods and hurricanes are complete inundation of the system by excessive amounts of water and blockage of parts of the system by debris. In the extreme, earthquakes or enemy attacks can cause complete destruction of treatment plants and lift stations as well as ruptures of sewage lines. Damage sustained during hostile attacks will probably be collateral in nature since the sewage system is not normally a preplanned target. Specific damage could consist of the following:

4.7.3.1. Sewers. Deliberate demolition to sewers by an enemy is usually limited to junction manholes or large mains. Stoppages caused by debris being blown and washed into sewers can be expected.

4.7.3.2. Pumping Stations. During conflict, pumping stations may be deliberately damaged because they are key points, are more accessible, and are most difficult to repair. They are not likely to be damaged seriously by bombs or artillery fire since they offer a relatively small target. However, flooding during either tropical storms or tornados can prove consequential.

4.7.3.3. Treatment Units. Treatment units may be damaged during a conflict by the demolition of machinery and other key equipment. However, they are not normally high-value targets due to their small size and the ability to achieve effective treatment results by other means.

4.7.3.4. Cesspools and Septic Tanks. Damage to cesspools and septic tanks from sabotage or bombing is relatively unimportant. Destruction of a cesspool or septic tank would affect only one or a small number of properties. Their wide dispersal provides a large measure of safety.

4.7.4. Effect of Damage. Human wastes must be properly disposed of in order to protect personnel. If sewage enters a water supply, an epidemic outbreak of intestinal diseases such as typhoid, cholera, dysentery, and diarrhea is almost certain to follow. Existing sewer systems may have to be rehabilitated to prevent such mission-impacting outbreaks.

4.7.5. Expedient Repair Procedures. Expedient sewer repairs should consist only of the minimum work required to prevent the outbreak of disease. For example, if the ruptured sewer line results in sewage leakage into an occupied area and does not threaten water sources, repairs can be delayed until emergency conditions subside. When damage is too widespread for expedient repair, civil engineers must resort to proven field sanitation methods. Development of temporary latrine facilities is addressed in **Chapter 6** of this pamphlet. The rehabilitation of a sewage disposal system requires the following actions.

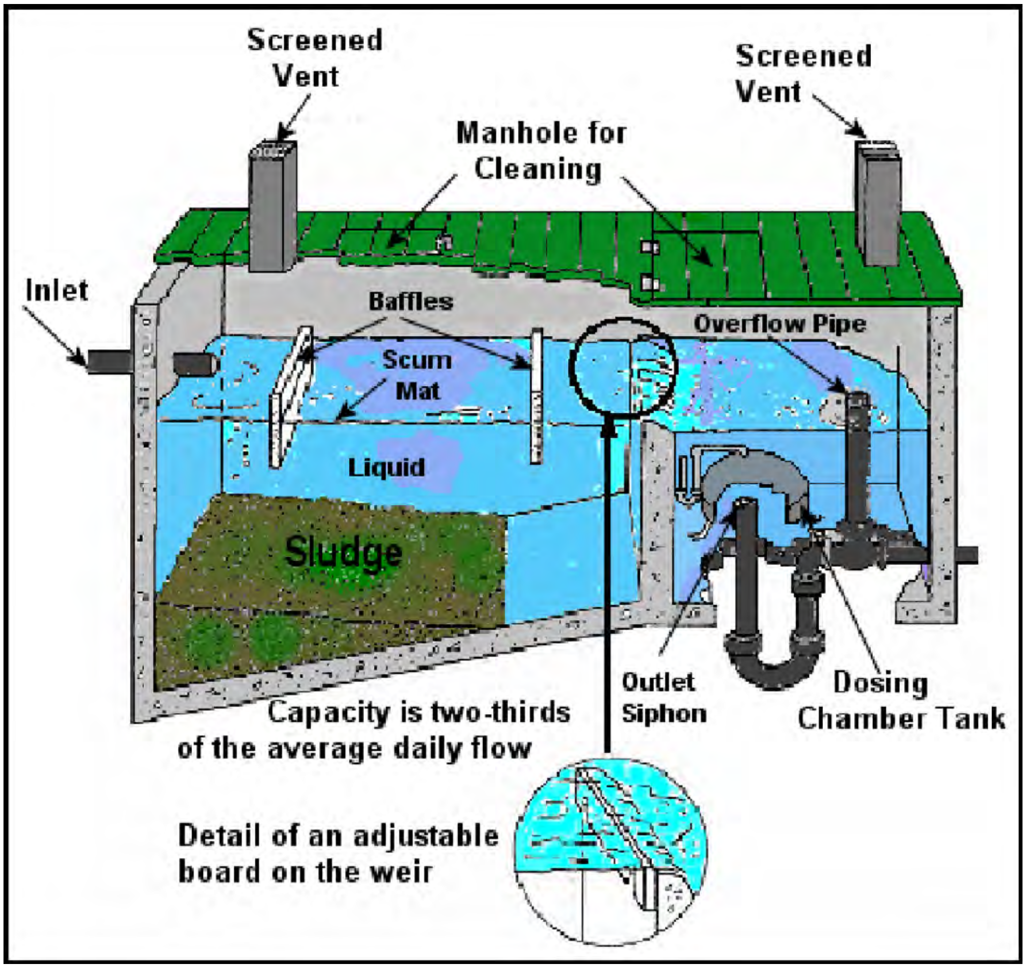
4.7.5.1. Sewers. Sewer lines are the most essential item in a sewage disposal system. If the situation is critical, service can be restored temporarily by pumping from an upstream manhole, around the damaged section, and into a downstream manhole. If the sewer is completely stopped or badly damaged, an open channel can be built. Where storm and sanitary sewers are separate, it may be possible to divert sanitary sewage through a storm sewer to a suitable outlet.

4.7.5.2. Pumping Stations. When sewage pumping stations cannot be repaired expeditiously using available replacement parts or parts cannibalized from other stations, portable pumps should be substituted. If pumps are not available, consider rerouting past the lift station with pipe or open channels using gravity flow.

4.7.5.3. Treatment Plants. It may be necessary to bypass severely damaged treatment plants. Settling and digestion tanks and filters can usually be repaired with standard construction materials. Sludge beds are practically indestructible. Machinery must be repaired by cannibalization or improvised methods. If compressed air is used in an activated sludge process, replacement of air compressors is difficult at best. However, the activated sludge plants can be operated as sedimentation or septic tanks. Such treatment, together with chlorination, provides a reasonable degree of purification. Further information about expedient septic systems is provided in **Chapter 6** of this pamphlet.

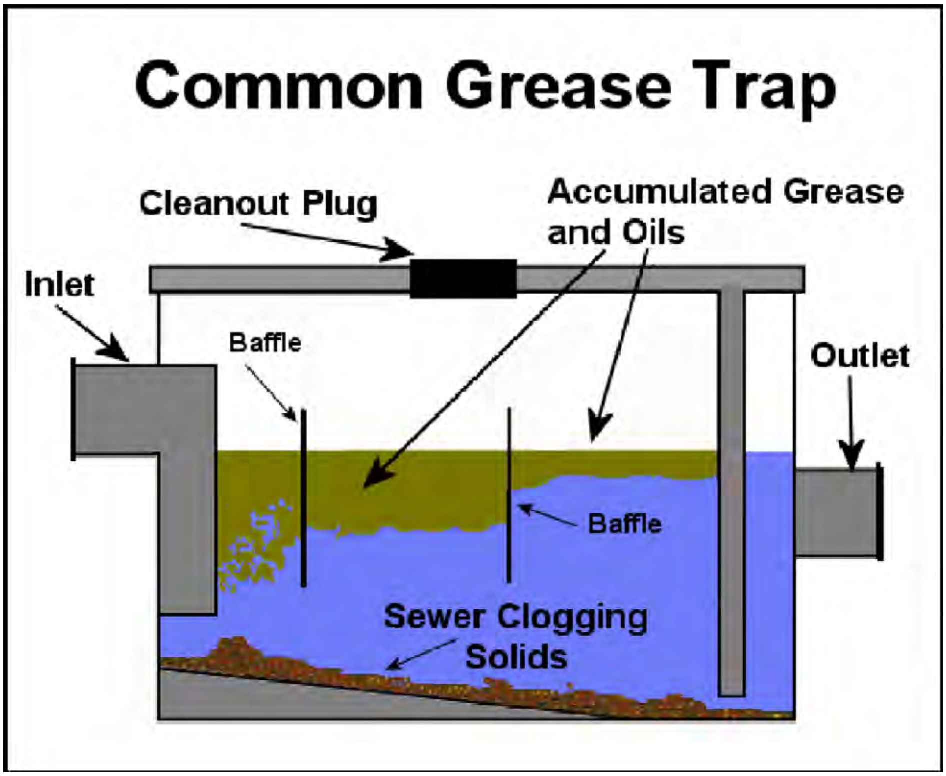
4.7.5.4. Septic Tanks. Septic tank systems (**Figure 4.24.**) are used to treat and dispose of wastewater from buildings where it is not feasible to provide a community wastewater collection and treatment system. A septic tank speeds up the decay of raw sewage. It may be made of concrete, stone, fiberglass, or brick (lumber is used when other materials are not available), in box-section form, and it should be watertight. The septic tank should have a manhole and cover to give access for cleaning and repair and must be designed to hold 70 percent of the peak water demand of that facility for 24 hours and not less than 16 hours. Contingency rapid repair of a septic tank would normally be low priority since other options are usually available. However, if a septic tank is severely damaged and totally inoperable and other prudent options are not available, an expedient-type septic tank can be constructed using procedures provided in **Chapter 6** of this pamphlet. Otherwise, expedient repairs would probably be limited to unclogging pipes, pumping out tanks, and improving or expanding drain fields.

Figure 4.24. Typical Septic Tank.



4.7.5.5. **Grease Traps.** Grease traps come in countless shapes and sizes, but their operation is basically the same. Just as the name suggests, a grease trap catches grease (animal fats and oils) from kitchen wastewater. Although there are many different models, grease traps are typically placed in the flow line of the building's sewer system to catch grease and fats from kitchen and scullery sinks, preventing clogs in the waste pipes. Expedient repair of grease traps is usually limited to unclogging inlet pipes and repairing or replacing damaged traps. Service personnel should be trained to perform routine cleaning and maintenance of grease traps installed in their area(s). **Figure 4.25.** provides a layout of a typical grease trap.

Figure 4.25. Typical Grease Trap Layout.



4.7.5.6. Additional details on water supply and wastewater systems repair procedures can be obtained in the following documents:

4.7.5.6.1. **Water Systems:** UFC 3-230-02, *Operation and Maintenance: Water Supply Systems*, and MIL-HDBK 1005/7A, *Water Supply Systems.*

4.7.5.6.2. **Wastewater Systems:** UFC 3-240-07FA, *Sanitary and Industrial Wastewater Collection: Gravity Sewers and Appurtenances*; UFC 3-240-08FA, *Sanitary and Industrial Wastewater Collection: Pumping Stations and Force Mains*; and MIL-HDBK 1005/16, *Wastewater Treatment System Design Augmenting Handbook*

4.8. Natural Gas Systems. Damage to a natural gas system must be dealt with rapidly to prevent and contain potential accidents like the one shown in **Figure 4.26.** The most expedient method of dealing with gas system leaks is to shut off the gas supply at main feeder points. Since gas is often not essential to installation operations, selective system isolation can usually be used until time and resources are available to make the necessary permanent repairs.

Figure 4.26. Ruptured Natural Gas Line Fire.

4.8.1. Emergency Cut-Off Procedures. If it is not possible to shut the gas off through the use of existing valves, gas main bags or gas stoppers, as shown in **Figure 4.27.**, may be required. Gas main bags are canvas or rubber bags which can be inserted into a gas main and inflated until they fill the pipe and halt the gas flow. The gas stopper consists of oiled or rubber-coated canvas stretched over a flexible steel frame. The edge of the stopper forms a seal with the interior of the gas main thereby stopping the gas flow. To seal a main with a gas bag, the rubber or canvas bag is inserted through a hole in the main (a hole created by damage, removal of a riser, or access port). If the interior of the pipe is coated with tar or oil, canvas bags are necessary. The bag is then inflated through a piece of attached tubing until it fills the pipe and stops the gas flow To use a gas stopper, the frame is squeezed together and inserted into the hole in the gas main. After the stopper is in the pipe, it is restored to its circular shape through the use of wire levers attached to the frame. The gas stopper can then be adjusted to shut off the gas flow. In larger mains, it is safer to use both bag and stopper.

Figure 4.27. Typical Gas Main Bag Kit.

4.8.2. Expedient Repairs of Gas Systems. As mentioned earlier, it is best to simply cut off gas systems and make permanent repairs later when the emergency has subsided. However, certain conditions may call for some immediate expedient repairs to prevent danger to personnel or to provide limited gas service.

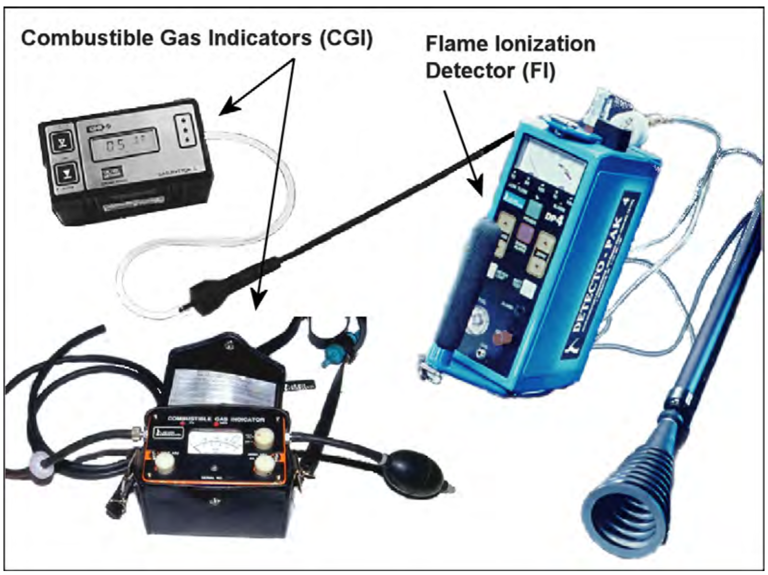
4.8.2.1. Venting of Gas Accumulations. After the main gas supply is shut off, immediately check buildings and other areas for the presence of dangerous gas accumulations. The presence of gas can be detected through the use of special gas detection devices such as a combustible gas indicator or, when no detection instrument is available, by an individual's sense of smell. The sense of smell cannot always be depended on to detect leaks because gas can lose its odor while traveling through the ground. Any accumulations should be vented to the outside to reduce the potential for asphyxiation or explosion.

4.8.2.2. Repair of Broken or Punctured Gas Pipes. There may be conditions following an emergency when gas must be supplied to certain facilities for essential operations. For example, the dining hall may have no alternate method of preparing food for the recovery force, or the hospital may need hot water for crucial medical services and have no other source of energy for water heaters. During periods of cold weather, gas may be the only source of heat for certain mission-critical installation facilities. Under any of these conditions, leaking or ruptured gas lines may require patching. If the leak is small and involves low-pressure gas pipes, a sealant may be used in conjunction with a pressure mold to close the opening. The sealant should be a product which does not break down in the presence of natural gas. Larger leaks and pipe breaks can be repaired using various types of mechanical clamps.

4.8.2.3. Safety. The potential for asphyxiation or explosion during encounters with gas leaks makes it imperative that the repair crew exercise extreme caution. Personnel should not enter confined areas with high gas accumulations unless they are equipped with self-contained breathing apparatus. No open flame from cutting torches, cigarette lighters, or similar devices will be used in a gaseous environment. Additionally, the repair crew must be careful not to generate sparks in the vicinity of a gas leak. A good rule of thumb is not to enter any area where the mixture of air and gas is at, or approaches, the lower explosive limits. Taking a few extra minutes to properly vent the area will greatly reduce the danger to personnel.

4.8.2.4. Leak Detection Measures. Natural gas can be detected through the use of special gas detection devices such as the ones shown in **Figure 4.28.** There are also other methods to detect gas leaks—like heavy insect activity (swarming), hissing sound, unusual improvement or deterioration in surrounding vegetation, and odor. Although natural gas is odorless, gas companies inject odor additives into the system to warn the public and aid in leak identification. These additives produce a rotten egg or sulfur odor when released into the air. However, be aware that a lack of odor is not a reliable indicator of the absence of a gas leak. The odor of the gas could be filtered out as the gas passes through certain soils or the odor may be modified by other vapors within a sewer system. Therefore, reports of gas leaks should be investigated using leak detection devices such as a Combustible Gas Indicator (CGI) or Flame Ionization Detector (FI). An effective way to pinpoint the location of small leaks on exposed lines involves using a spray bottle of soapy water. The soapy liquid will bubble when it comes in contact with a leak.

Figure 4.28. Common Gas Leak Detection Devices.



4.9. POL Systems. An installation's petroleum, oils and lubricants (POL) system is a key utility that has two primary components: storage facilities and distribution systems.

4.9.1. Storage Facilities. Most installations have several days of storage capacity for major fuel products. POL storage methods vary considerably from installation to installation. At some CONUS installations, there are large fixed storage tanks located aboveground (**Figure 4.29.**). Conversely, POL storage tanks at most overseas locations are both dispersed and covered by a protective layer of soil. In both instances, engineer forces will only be able to accomplish expedient repairs if the involved damage is superficial.

Figure 4.29. Altus AFB POL Tank Farm.

4.9.2. Distribution System. The POL distribution consists of pumping stations, pipelines, and dispensing points. The nature of construction of the POL distribution system makes it relatively safe from natural disasters other than flooding. The major damage that a POL distribution system might receive would more likely result from an enemy attack during wartime. The impact of damage will be reduced at installations where the distribution system is interconnected. As a protective measure, most control valves at a number of overseas locations have been installed in pits in order to limit their exposure to direct impact during an attack.

4.9.2.1. Pumping Stations. POL pumping stations are not easy targets to hit, however, and would not be considered primary targets during an enemy attack. Some losses to pumping capability should be expected from collateral damage but it is likely that some capacity to pump fuel will be retained.

4.9.2.2. Pipelines. POL pipelines are essentially all welded steel. They are the most survivable POL system component. However, since the distribution system piping is the most extensive element of the POL system, it is the most likely element to be damaged. The impact of such damage will be reduced at installations where the distribution system is looped.

4.9.2.3. Dispensing Points. Dispensing points range from vehicle fill stands to concrete-encased aircraft hydrant refueling systems. The fill stands service POL tank trucks for refueling aircraft at most locations. Damage to fill stands can be expected as a collateral effect of weapons detonation. Hydrant refueling systems, however, because of their "hardness," should remain relatively intact.

4.9.3. POL Repair Actions. Damage to the POL system is compounded by the volatile nature of the system contents. Engineers will have to think in terms of expedient repairs to water systems and use whatever spare parts and materials currently exist in bench stock or special levels. However, unlike water systems, POL repair crews will have to be especially concerned with toxicity, flammability, and compatibility issues. Primarily for Pacific theater installations, the POL rapid utility repair kit

(RURK) provides a means of quickly repairing valve and line failures resulting from an attack or disaster. For additional information on the POL Utility Repair Kit or the Contingency Fuel Recovery System, refer to the associated Qualification Training Package (**Figure 4.30.**).

Figure 4.30. POL Qualification Training Packages.

Chapter 5

EXPEDIENT REPAIR OF HVAC AND ELECTRIC SYSTEMS

5.1. Introduction. Air bases need viable power source to support mission operations. Electrical power is essential to daily activities; and, to a lesser degree, Heating, Ventilation, and Air Conditioning (HVAC) systems are also necessary. Obviously, having effective heating and air conditioning for personal comfort has a minimum impact on aircraft sortie generation. However, in today's operating environment, a large number of mission-critical systems and electronic equipment require stringent climate control. For example, many command and control centers are self-contained operations that cannot function without independent electrical or HVAC support. In these situations, adequate HVAC systems are critical to mission accomplishment.

5.2. Overview. This chapter focuses on expedient HVAC and electrical repair options during contingency situations. Specific topics include recovery concepts and expedient repair of heating, air conditioning, and electrical distribution systems. Each of these areas deals with hazardous materials and may require work on or near energized circuits; therefore, only trained technicians are allowed to accomplish HVAC and electrical system repairs and modifications, while strictly complying with Air Force electrical safety criteria. Electrical safety requirements in AFI 32-1064, *Electrical Safe Practices,* and UFC 3-560-01, *Electrical Safety O&M,* are mandatory and outline the type of arc thermal performance value (ATVP) rated PPE to wear when working on or near energized circuits, when work on or near energized circuits is authorized, and who is the energized work authority. Table 4-2 in UFC 3-560-0 defines hazard./ risk category classifications for work tasks. In addition, due to the complexity of these systems, the scope of this document is to provide only basic expedient repair guidelines for use during emergencies. Additional information is provided in the references listed in **Attachment 1**.

5.3. Heating Systems. In general, heating systems carry heat from the point of production to the place of use, and their design can be complex with many variations. They are usually classified by the medium used to carry the heat from the source to the point of use, such as hot water, steam, and forced-air systems.

5.3.1. **Heating Systems Repair.** Depending upon weather conditions at the time of a disaster or attack, repairing damage to the heating system can range in importance from critical to insignificant. The extent of damage can span the gamut from nothing whatsoever to total destruction. However, unless the installation is undergoing a period of severe cold, repairs to heating systems servicing non-mission-essential facilities can probably be delayed through the use of space heaters and the wearing of additional clothing. However, if repairs must be made, concentrate on minimum efforts necessary to return some measure of heat to base facilities. It is not necessary to attain pre-disaster comfort levels following an emergency. A partial return of heat can raise temperatures to a level that will allow normal operations if personnel are warmly clothed.

5.3.1.1. **Central Heating Systems Repair.** For those installations that have a large central heating system, damage following an attack or disaster can be widespread. It may well involve the production plant along with the distribution system. The feasibility of conducting expedient repairs to the heating system will depend to a great degree upon the amount of damage incurred. For example, if an earthquake or bomb explosion causes a large rupture of the central boiler, it is unlikely that expedient repair techniques will suffice. On the other hand, a break in one of the pipes leading from the boiler could probably be expediently repaired. Fortunately, the inherent strength of materials used to contain the pressure within the system also serves to protect the system from external damage. Expedient repairs to central heating systems may consist of the following:

5.3.1.1.1. **Production Plant Repairs.** Expedient repair of heat production plants may be delayed pending structural and/or electrical support. Damaged walls may have to be shored to prevent structural collapse or electrical utility service may have to be restored to power control and monitoring devices. From a mechanical perspective, broken pipes may need to be repaired or replaced, damaged automatic controls may have to be bypassed with manual ones, and internal cannibalization may be required in order to get some boilers back in operation. As stated earlier, however, if a plant's boilers have sustained significant damage, the production plant is probably beyond immediate repair.

5.3.1.1.2. **Distribution System Repairs.** The high heat and pressure associated with most heating systems are characteristics that preclude the use of many expedient repair methods and materials used to otherwise correct water distribution system damage. For example, temporary connectors, such as fire hoses, which are effective in bridging damage to a water distribution system, will likely not tolerate the high temperatures and pressures of a heat distribution line. Similarly, a standard sealer or joint compound which could patch a water leak will break down when applied to a steam line. If repairs are attempted, only materials which have been specifically designed to withstand the stresses imposed by heating systems should be used. Pipe replacement and welding are the most common repair techniques used to correct distribution system problems. Caution must be exercised, however, since welding of high-pressure vessels is a specialized technique and requires substantial experience. You cannot slap together a steam line, even in a contingency mode, and expect it to work. In overseas areas, expect to encounter older systems which may contain components that are no longer in production. Repair parts for these facilities may have to be custom fabricated or cannibalized from other systems. Most locations, however, should have an emergency stock of heating system materials. Tap this source as much as possible.

5.3.1.2. **Individual Systems Repair.** Installations without a central heating system generally feature individual building systems. The great advantages of these independent units are that damage is limited to the system which supports a single building and general repair concepts are, for the most part, universally applicable. The basic question then becomes whether or not to repair.

5.3.1.2.1. The easiest way to deal with a damaged individual heating system is to ignore it. If the weather permits, or the facility is not critical to the base mission, delay repairs until emergency conditions are essentially over. Another quick alternative when extensive repairs are required is to move personnel into a nearby building with a working heating system.

5.3.1.2.2. Expedient repairs to an individual heating unit are generally less complex than repairs on a large central system. Damage is confined and easy to determine since the independent system does not involve a dispersed network. Components are smaller, making it easier for repair crew members to install replacements. Also, spare parts may be more readily available from base supply and local vendors. Furthermore, since there often are many facilities containing similar individual heating systems, there are more opportunities for cannibalization of parts from low- priority buildings. If the damage is limited to the system's ducting, temporary flexible ducts can be rapidly put in place to correct the problem. **Figure 5.1.** shows examples of flexible ducting.

Figure 5.1. Typical Flexible HVAC Ducting.

5.3.2. Alternative Heating Sources. If attempts to repair existing installation heating systems fail, temporary heating sources can be provided for mission-essential facilities. Remember, however, alternate heat sources can be dangerous and require frequent checks and servicing. As time permits, systems should be repaired by using existing stocks or cannibalized materials, thereby freeing the portable heaters for use elsewhere.

5.3.2.1. **Space Heaters.** Various types of space heaters provide an alternative to central or individual heating systems. Fuel-fired heaters (**Figure 5.2.**) can be used in large open buildings if the odor is not objectionable and explosive vapors are not present. The propane heater on the right of the figure delivers 8,000 to 24,000 BTUs of portable, infrared heat from a common 20-lb propane cylinder. A number of variations are readily available on the open market, including larger units designed to meet higher heating demands. **Table 5.1.** provides approximate propane fuel consumption information for various temperatures. In general, open flame heaters are dangerous, especially the unvented type. If they are used the catalytic types are the safest. Electric heaters (**Figure 5.3.**) provide a safe alternative to open flame units provided temporary wiring and power sources can handle the extra load. Space heaters can be obtained from various sources. BEAR assets contain units (**Figure 5.4.**) that can be used in permanent structures or tents. Commercial space heaters may be available from local vendors. Some installation units may also have portable shop heaters which can be reassigned to more critical facilities.

Figure 5.2. Typical Portable Fuel-Fired and Propane Heaters.

Table 5.1. Propane Vaporization Rate Information.

Vaporization Rate 100-LB Propane Cylinders (approximate)			
Maximum continuous draw in BTU Per Hour at various temperatures			
Lbs. of Propane in Cylinder	**0 Degree F 1 Tank**	**20 Degrees F 1 Tank**	**40 Degrees F 1 Tank**
100	113,000	167,000	214,000
90	104,000	152,000	200,000
80	94,000	137,000	180,000
70	83,000	122,000	160,000
60	75,000	109,000	140,000
50	64,000	94,000	125,000
40	55,000	79,000	105,000
30	45,000	66,000	85,000
20	36,000	51,000	68,000
10	28,000	38,000	49,000
LP Conversion: 8.547 cu. ft. per pound; 4.24 lbs. per gal.; & 36.45 cu. ft. per gal.			

Figure 5.3. Typical Industrial Portable Electric Heater.

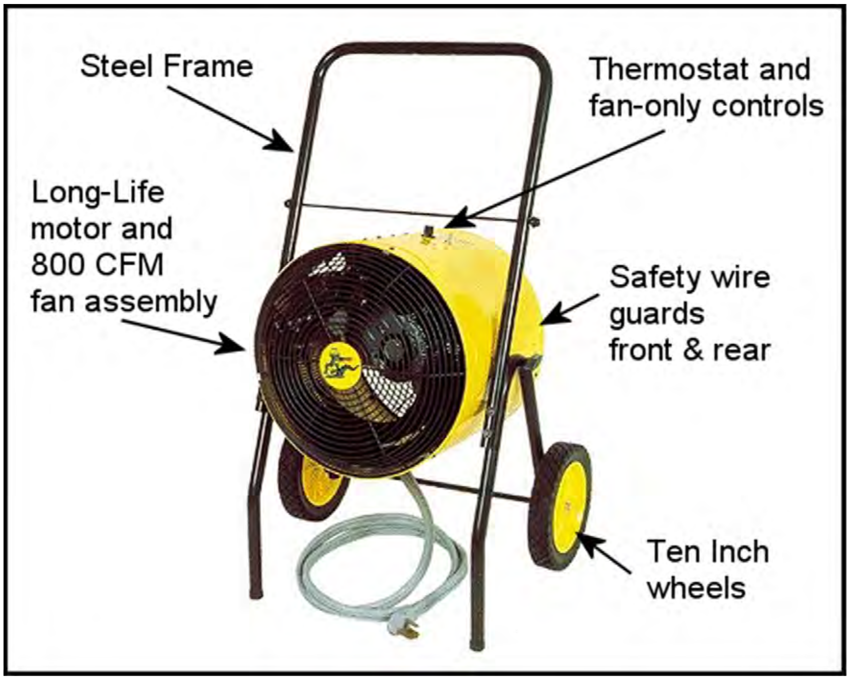


Figure 5.4. BEAR Heater Asset.

5.3.2.2. **Cart-Type Ducted Heaters.** Cart-type ducted heaters provide an excellent alternate heat source because combustion stays outside the structure being heated. The units may be available from organizations on base, such as aerospace ground equipment (AGE) or communications squadrons, after requirements for aircraft sorties and other vital operations have been met.

5.3.2.3. **Improvised Heaters.** The use of improvised heaters should be avoided except in cases of extreme cold and where no other alternative exists. The primary dangers inherent with improvised heating systems are the possibility for asphyxiation and fire hazard potential. Caution must be taken to ensure that dangerous fumes are vented during combustion and any open flame is properly contained. One of the most common types of improvised heaters consists of a 55-gallon drum converted for use as a burner coupled with makeshift sheet metal ducting to vent fumes to the outside. Remember, improvised heaters do not completely contain combustion vapors. Therefore, even with vents to the outside, makeshift heaters should never be used in totally enclosed areas.

5.4. Air Conditioning Systems. Most, if not all, installations have some facilities that cannot function properly without air conditioning and/or climate control support. Today's Air Force relies on sophisticated electronics that support the operation and maintenance of such things as aircraft navigation and attack systems, computer systems, communications, and air traffic control equipment. These systems are highly susceptible to heat build-up and fail rapidly if subjected to overheating conditions. This situation makes air conditioning support critical to these mission-essential facilities. As a general rule, air conditioning systems are more vulnerable than their heating counterparts. Most critical climate control system components are located externally to the facility they serve and therefore are more susceptible to damage. Two air conditioning or refrigeration systems are used by the Air Force: the vapor compression system and the absorption system. The vapor compression system is the most common.

5.4.1. Repair of Air Conditioning Systems. Typical air conditioning repairs tend to be manpower intensive and usually take a considerable amount of time. Like heating systems, air conditioning support is highly dependent on a reliable electric supply. In addition to being time intensive, it is common to have a very large number of unit and system variations present on the average base. These factors make developing an expedient repair strategy and standardized repair kit to satisfy all potential needs both cost prohibitive and virtually impossible. Expedient repairs may typically involve replacing parts and locating and repairing leaks within the system.

5.4.1.1. Replacing Parts. If system rejuvenation is plausible and parts are not available in a standardized repair kit, consider obtaining needed parts from similar units that support less critical functions.

5.4.1.2. Leak Testing and Repair. If a mission-essential refrigeration unit is operable except for minor leaks after a natural disaster or damage from attack, the usual first course of action would be to charge the unit as a temporary measure and move on to the next issue. However, if the situation allows for a more concerted effort, permanent repairs should always be considered to avoid duplication of effort. When a leak is found and repaired, the complete unit should be rechecked not only to confirm the repair, but also to ensure that there are no additional leaks.

5.4.1.2.1. The method for leak testing varies with the refrigerant used. However, most methods involve applying pressure to the system with an inert gas, such as nitrogen or carbon dioxide. With proper care, nitrogen or carbon dioxide may be used safely when pressure-testing for leaks. However, be aware that the pressure in a nitrogen cylinder is usually about 2,000-psi and the pressure in a carbon dioxide cylinder is normally about 800-psi. Consequently, a pressure-reducing device that has both a pressure regulator and relief valve must always be used when testing with either of these gases. Check the system's nameplate before conducting this type of test. In most cases, it will provide recommended testing pressures. If this information is not provided, UUneverUU test all or part of a hermetic system at pressures exceeding 170-psi.

5.4.1.2.2. Many companies recommend using the refrigerant in the system to test for leaks. In such situations, sensitive electronic leak detectors like those addressed below should be employed.

5.4.1.3. Leak Detection Devices. As a general rule, refrigeration system leaks are usually very tiny and require sensitive detecting devices. Commonly used detection devices include bubble solutions, fluorescent dye, and electronic detection devices such as the corona discharge (**Figure 5.5.**), heated diode (**Figure 5.6.**), and UV lamps. The newer electronic detectors can be used with R-134a, R-123, and other new alternative refrigerants.

Figure 5.5. Corona Tester.

Figure 5.6. Heated Diode Tester.

5.4.2. Alternative Air Conditioning Sources. If air conditioning systems cannot be expediently repaired after an attack or natural disaster, portable units are the ideal way to go until time and resources allow permanent repairs. A number of BTU variations are available that support air conditioning requirements, ranging from small area units to large package configurations used for cooling entire buildings. Two examples of large portable units are shown in **Figure 5.7.**

Figure 5.7. Typical Large Portable Air Conditioning Units.

5.5. Electrical System. After an attack or disaster, power for airfield lighting, navigational aids (NAVAIDS), communications centers, C2 nodes, medical facilities, and other important activities must be restored before the installation can resume its operational mission. If the attack or disaster resulted in downed or damaged electrical lines, the repair or isolation of life-threatening electrical hazards must also receive high priority.

5.5.1. **Basic Safety Rules.** Detailed safety procedures for electrical repair operations are contained in Air Force criteria and must be strictly followed. Electrical safety requirements in AFI 32-1064, *Electrical Safe Practices, and UFC 3-560-01, Electrical Safety O&M,* are mandatory and outline the type of arc thermal performance value (ATVP) rated PPE to wear when working on or near energized circuits, when work on or near energized circuits is authorized, and who is the energized work authority. Table 4-2 in UFC 3-560-0 defines hazard./risk category classifications for work tasks. As outlined in AFI 32-1064 and UFC 3-560-01, work on or near energized lines and equipment is prohibited except in rare circumstances and then only when approved in advance by the BCE or equivalent. When authorized, the energized work will only be performed after the energized work permit completion is accomplished IAW AFI 32-1064.

5.5.2. **Primary and Secondary Circuits.** The electrical system can be divided into two major subsystems: primary circuits and secondary circuits. Circuits above 600 volts are generally referred to as primary or feeder circuits. Circuits carrying less than 600 volts are usually referred to as low voltage or secondary circuits. Even in a contingency situation, work on the high-voltage primary systems will be performed only by craftsmen with specialized qualifications and equipment.

5.5.3. **Components of Electrical System.** The electrical system supporting a typical installation consists of three components: production, distribution, and interior wiring. Each component of the system should be viewed in terms of its anticipated damage during a contingency and the expedient repair techniques needed to adequately remedy the damage.

5.5.3.1. **Production Systems.** At overseas installations, electrical power is either supplied by base power plants or commercial sources. In the CONUS, primary power is most likely provided by a commercial grid. If the commercial source is interrupted, usually the only alternative is to disconnect the impaired power source from the distribution system and substitute generators to power vital facilities. Most mission-essential facilities already have dedicated standby generators with an automatic transfer capability to maintain operations in the event the prime power is lost.

5.5.3.2. **Distribution Systems.** The power distribution system may consist of substations, switchgear, and utility lines that are either overhead or underground. Overhead power lines and the associated utility poles are likely to suffer extensive damage during a hurricane, tornado, or enemy attack. An underground system, although better protected from the high winds common to hurricanes and tornadoes, is still vulnerable to the effects of an earthquake, flooding, or enemy munitions. There are three basic types of distribution systems: radial, loop, and network. Any combination of these three systems can be found at most installations.

5.5.3.2.1. Radial System. The radial layout is one in which a mainline is established through the approximate center of an installation and branch lines are run from the main to power various facilities. A very basic radial layout is shown in **Figure 5.8.** The primary disadvantage of the radial layout is that a break of wires at point "B" results in a complete loss of power to all facilities on the installation. Thus, the radial system is less effective since it is very susceptible to extreme weather conditions, war damage, and sabotage. However, since the radial system requires considerably less material, manpower, and time to construct, radial systems are often used during contingency beddowns.

5.5.3.2.2. Loop System. A loop or ring layout supplies power to a facility from more than one direction as shown in **Figure 5.9.** Note that a break in the circuit at point "A" will not cause complete power failure since power may still be distributed through the lower section of the loop. Thus, a loop system has an inherent capability to prevent complete power loss of all facilities. Faults in the circuit can be isolated and repaired without large disruption of service. In addition, the loop layout normally distributes power with less voltage drop. The primary disadvantage of the loop system is that it requires more material and time to construct than the radial system.

Figure 5.8. Basic Radial Layout.

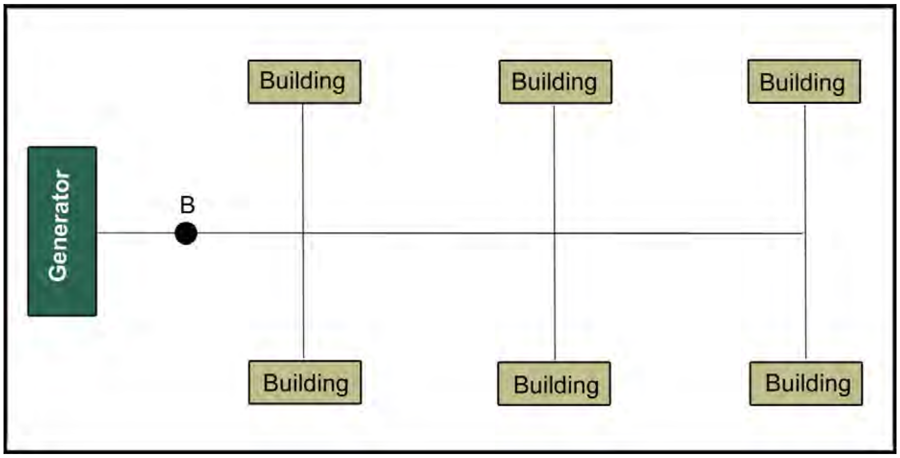
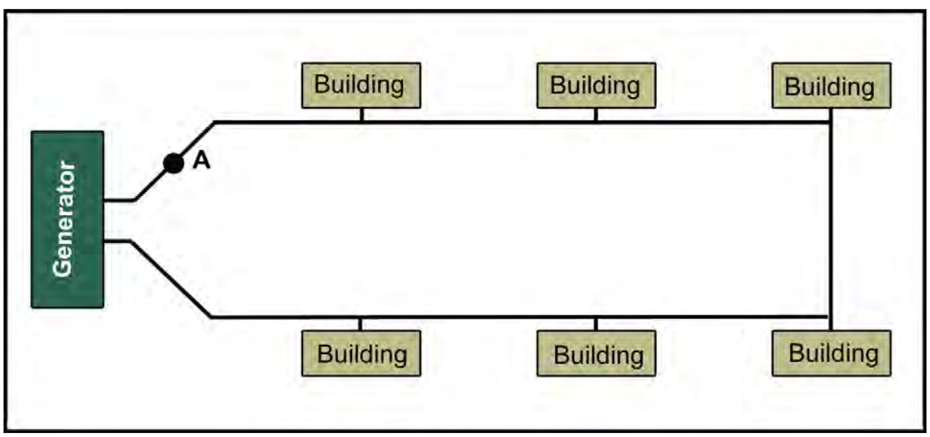


Figure 5.9. Basic Loop Layout.



5.5.3.2.3. Network System. A network system is simply a merger of both the radial and loop systems. In particular, it uses the independent feeder system of the radial system to supply power to distribution transformers while also paralleling the secondary lines that are used in the loop concept. This configuration capitalizes on the strong individual points of both the radial and loop systems, thereby allowing optimum flexibility and efficiency.

5.5.3.3. **Interior Wiring.** After transmission and distribution systems, the "third leg" of the electrical system is the interior wiring. It generally consists of the electrical wiring, switches, outlets, circuit breakers, and other electrical accessories located within a building after the service entrance interface.

5.5.4. **Repairing Electrical Systems.** After assessing the initial damage to an electrical system after an attack or disaster, the first action should be the isolation of those damaged areas presenting life-threatening hazards to personnel or posing the potential for additional property damage. Once initial isolation is accomplished, damage control center (DCC) personnel, using installation utility plans and maps, determine how to best restore electrical power to vital installation facilities. Typically, this is accomplished by rerouting power lines to bypass damaged areas. After damage assessment data have been posted to the installation utility maps, the DCC should be able to quickly direct electrical system rerouting using the existing, undamaged circuits. When rerouting around damaged areas, remember that non-standard materials can be used provided they do not jeopardize safety. If capable of carrying the required loads, wires and cables of different sizes or those normally designed for other uses may be substituted as expedient power lines. Strictly adhere to electrical safety requirements outlined in previous paragraphs and ensure proper "phasing" of conductors is accomplished. Additionally, conductors, wire, and other components may be salvaged from unimportant or abandoned facilities.

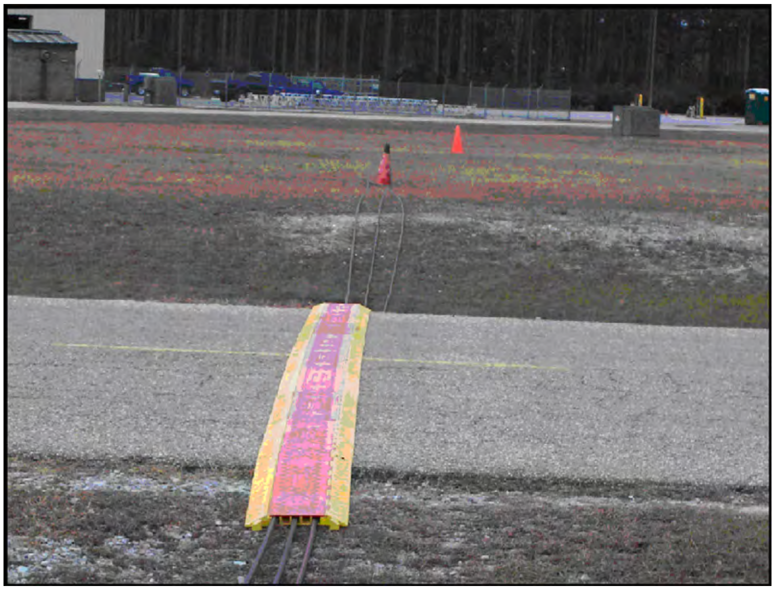
5.5.4.1. Repairing Power Production System. The extent of damage to an independent power production plant on the installation will vary with the type of emergency that has occurred. Natural disasters, such as hurricanes and tornadoes, are likely to cause structural damage to the plant as well as disrupt the plant's connections to the distribution system. An enemy attack will probably cause structural damage and disruption of connections to the distribution system, and it may produce damage to other components of the power system; e.g., demolished control equipment, broken turbine blades, and shattered insulators and bushings. In repairing such damage, take full advantage of bench stocks maintained by each power plant or draw on base supply sources. As a last resort, try cannibalization. Generators, as an alternate power source, will probably be in short supply, making it imperative that these vital assets be properly positioned and maintained. Generators should be limited to providing power to only those facilities that are absolutely crucial to base operations. AFI 32-1063, *Electric Power Systems*, shall be used to determine those facilities that are authorized emergency or standby generators. Consider damaged or inoperative generators as a source of spare parts. Components and parts from several damaged generators may be reassembled to produce one usable machine. Equipment other than disabled generators may serve as a source of repair parts; e.g., injectors from a diesel engine in a destroyed vehicle can be salvaged and adapted to a generator engine.

5.5.4.2. Repairing Power Distribution System. Expedient repairs to power distribution systems are limited by the extent of damage involved and availability of spare parts. A large part of most electrical distribution systems is composed of non-repairable items such as poles, insulators, cross arms, switch gear, and in most cases, transformers. Only a few items within the electrical distribution system lend themselves to repair. Items such as conductors, grounding wires, guy wires, anchors, service entrances, and occasionally transformers fall into this category.

5.5.4.2.1. Conductors. Overhead power lines may need to be hung from trees, existing structures or new poles. In some instances, cutting the damaged line on both sides of the destruction and bridging the area with new cable may be necessary. If it does not pose a danger, run the new power cable directly on the ground. It can always be properly buried or elevated when time and resources are more available. Low-voltage distribution cables can be placed or run along the ground. Conductors that cross roads or pathways must be buried or protected by some means at the crossing. **Figure 5.10.** and **Figure 5.11.** show two different techniques for such crossings. The former displays a commercial cable protector being used, and the latter shows how to protect cables using PVC and sandbags. The latter figure also has the cables on both sides of the road protected from foot traffic by sandbags. Schedule 40 Polyvinyl Chloride

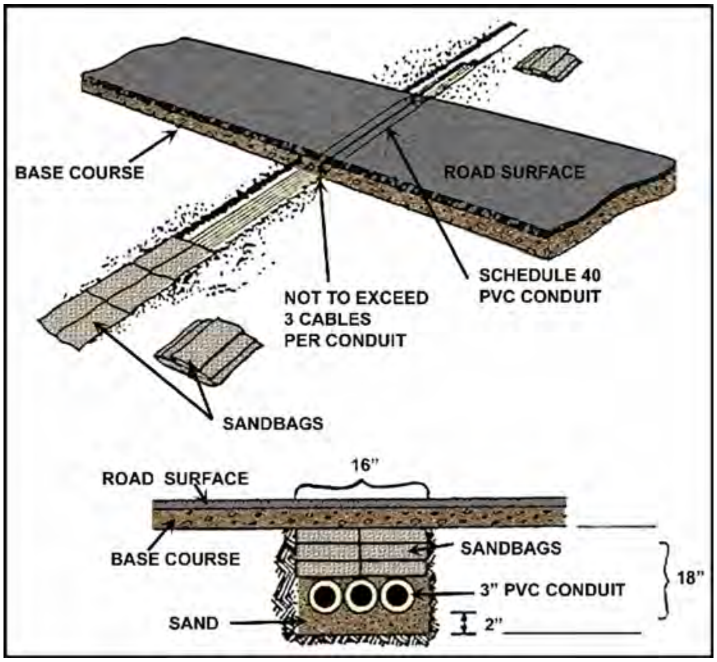
(PVC) conduit with a diameter of 3 to 4 inches is suitable for expedient raceways under crossings. In applications for which excessively high roadway temperatures are expected, Schedule 80 PVC should be used if available. For average temperatures over 90°F, the number of cables per raceway should be limited to three to prevent insulation overheating. In addition, the raceway in this application must also have at least 60 percent air space in its section to reduce the possibility of overheating.

Figure 5.10. Commercial Cable Protector Across Roadway.



5.5.4.2.1.1. Cable Burial Requirements. As manpower becomes available, the cables that were placed on the ground should be direct-buried to protect them from threat, equipment, and personnel damage; to prevent deterioration by the elements; and to improve their current- carrying ability. In moderate temperature locations, a burial depth of 8 inches for secondary cable and 18 inches for primary cable is normally adequate. However , in sites where high temperature is anticipated, ensure that the secondary cable has at least 12 to 16 inches of cover.

Figure 5.11. Underground Roadway Crossing.



5.5.4.2.1.2. Buried Cable Grounding. To save time and labor, distribution cables can be placed in trenches along with water and sanitary lines. To reduce personnel exposure to electrical hazard, it is highly advisable to place a bare copper conductor in the trench alongside the cables if the cable does not have concentric neutral wires inside the cable jacket. This conductor must be bare and solidly attached to the generator ground terminal and to the frames of all connected electrical equipment. The size of the bare conductor should be close to the size of the largest insulated conductor in the trench.

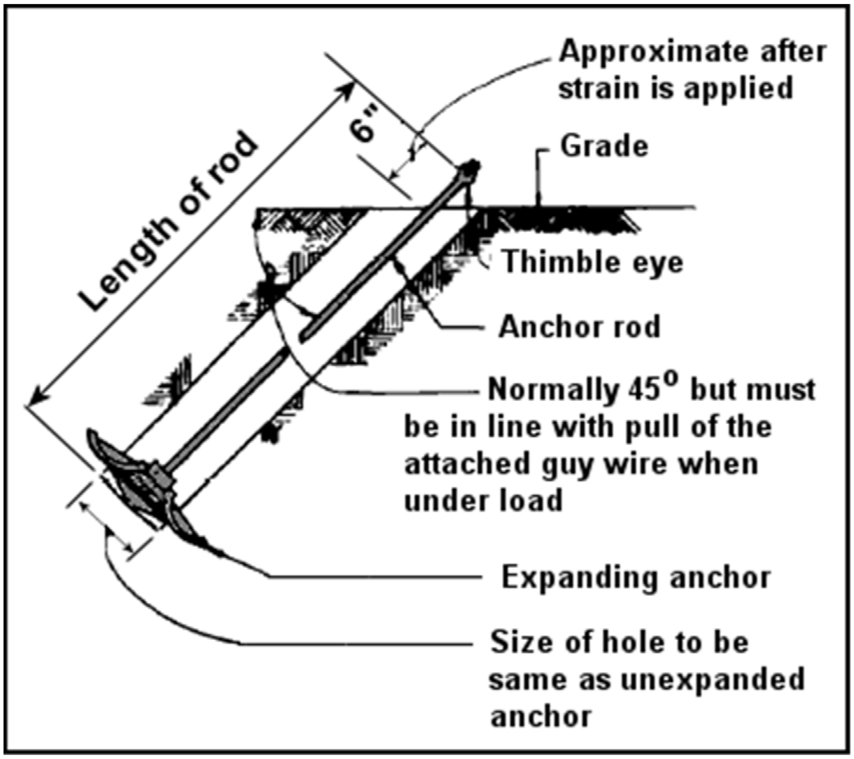
5.5.4.2.2. Grounding Wires and Rods. Proper grounding of electrical systems is essential to the safe operation of the system. Grounding is most often accomplished by driving ground rods into the ground with a minimum 1/0 American Wire Gage (AWG) bare copper wire from the ground rod to either the device or system to be grounded. The spacing and depth of ground rods depends upon the resistance to ground to the earth at the site. In the absence of the capability to measure the resistance to ground and determine actual grounding requirements for the site, use a 3/4-inch diameter metal water pipe with at least 10 feet in contact with the earth, or a ground rod driven at least 8 feet into the earth or into the permanent ground water level, if known. Electrical continuity is essential in a grounding system; therefore, all connections must be clean and properly bonded. The design and application of grounding to an electrical system should normally be inherent in the system installation and not something that is added at a later date.

5.5.4.2.3. **Guys (Wires and Anchors).** Expedient repairs to guys usually involve replacing or resetting guy wires and anchors while raising new poles or bracing existing poles. In new work, guys should generally be installed before power line wires are strung. In reconstruction work, guys should be installed before making any changes in the line wires while at the same time being careful not to place excessive pull on the pole and wires already in position. Improperly or inadequately guyed power lines will soon begin to sag, degrading the reliability of the line. When replacing guy wires, determine the condition of the pole before removing the old guy wire. If the pole is weak, it should be securely braced before any changes in pole strains are made. Make sure the guy wire is installed so there is minimal interference with the climbing space on the pole, and guys should clear all energized wires. In some cases, it may be necessary to install a guy hook to prevent the guy from slipping down the pole. Position these hooks so they do not interfere with climbing and cannot be used as steps. Where guys are liable to cut into the surface of a pole, protect the pole by installing a guy plate at the attachment point. The plate should be well secured to the pole to prevent the possibility of injury to a worker climbing up or down the pole. When guys are installed near roadways, position them so they do not interfere with street or roadway traffic. Guys located near streets should be equipped with yellow traffic guards (sometimes called "anchor shields"). Any guy wires containing snarls or kinks should not be used for line work, and it is preferable to use guy wires of the correct length to avoid unnecessary splices. The type of anchor used in these repairs must provide suitable resistance to uplift and is therefore dependent on the condition of the soil. **Table 5.2.** indicates suitable anchor types based on a range of soils from hard to soft. While the soil descriptions are not an industry standard, manufacturers are familiar with this or similar classifications. For the majority of cases, the most suitable anchor is an expanding type (**Figure 5.12.**), because most lines are installed in ordinary soils.

Table 5.2. Anchors Suitable for Various Soils.

Type of Anchor	General Soil Type	No.	Classification Description
Rock	Hard	1	Solid bedrock
		2	Dense clay; compact gravel; dense fine sand; laminated rock; slate; schist; sandstone
		3	Shale; broken bedrock; hardpan; compact clay-gravel mixtures
Expanding	Ordinary	4	Gravel; compact gravel and sand; claypan
		5	Medium-firm clay; loose sand gravel; compact coarse sand
Swamp or as Suitable	Soft	6	Soft-plastic clay; loose coarse sand; clay silt; compact fine sand
		7	Fill; loose fine sand; wet clays; silt
		8	Swamp; marsh; saturated silt; humus

Figure 5.12. Expanding Anchor Details.



5.5.4.2.4. Service Entrances. During the aftermath of an attack or disaster, it may become necessary to repair or build new service entrances with expedient methods and materials. New installations would be intended as temporary measures only and would be upgraded as the situation stabilizes or used where the location is intended only as a one-time, short-term development. An electrical service entrance is the point at which electrical service enters a facility, and it normally consists of a main junction box, circuit breakers or fuses, and any other equipment located between the main junction and service drop, including meters. An expedient service entrance can be constructed as follows:

5.5.4.2.4.1. If service entrance cable is available, a weather head can be formed with plastic electrician's tape that will effectively seal moisture out of the cable insulation for a service entrance purpose (**Figure 5.13.**). Individually insulated wires can be bundled, tied with marline, and wrapped with tape to form a service entrance cable. Should plastic tape not be available, friction tape can be used to wrap the cable; however, if friction tape is used, it should be coated with varnish to render it waterproof before installation.

5.5.4.2.4.2. Normally, split bolt connectors or compression splices will be used to connect the service entrance conductors to the service drop conductors. In an emergency where both conductors are solid, terminal loops can be turned in the conductors and a bolt with two washers can be used to make the connection (**Figure 5.14.**). This type of connection should be taped on all hot conductors, but tape is not required for the neutral conductor.

Figure 5.13. Taped Weather Head.

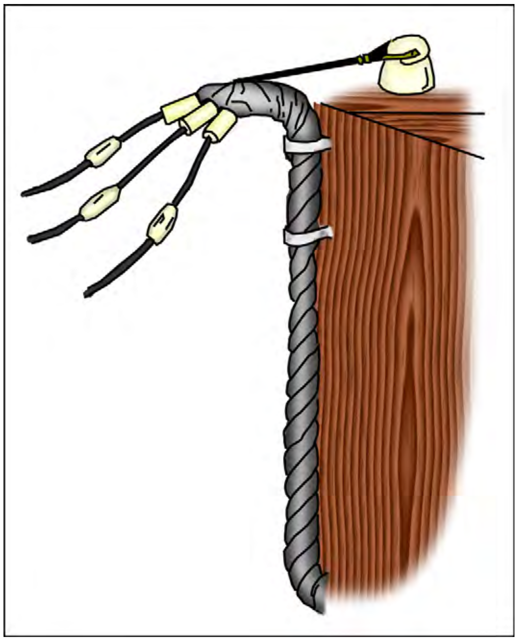
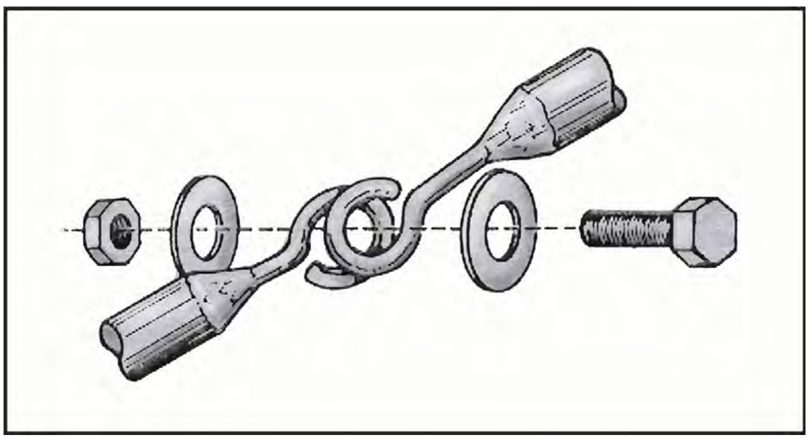
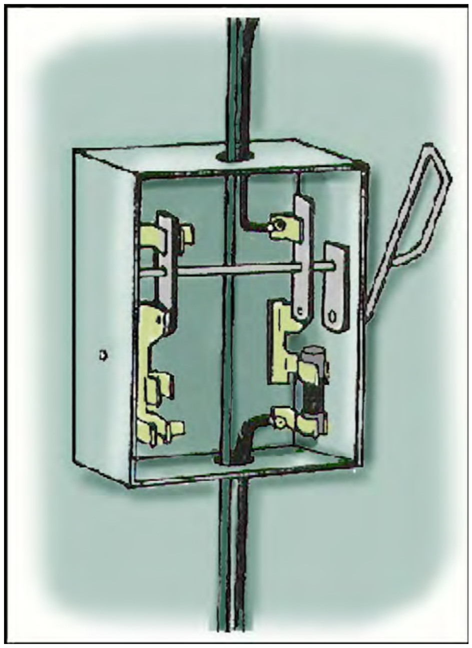


Figure 5.14. Emergency Service Entrance Connection.



5.5.4.2.4.3. If circuit breaker panels or mains are not available, using safety switches for service equipment can protect light loads. It may be necessary to bridge one set of contacts inside the switch so that the neutral will be a solid, unbroken circuit. The hot circuits can then be fused to the proper ampacity through the operating contacts (**Figure 5.15.**). Keep in mind that this is an emergency situation and that the fuses should be well below the ampacity of the branch circuits installed to protect the insulation of these branch circuits. Regardless of circumstances, some method must be provided to open all circuits within the structure with a maximum of five hand motions.

Figure 5.15. Safety Switch Used as Service Equipment.



5.5.4.2.5. **Transformer Repair.** Expedient repair of transformers can be accomplished if the damage is not too extensive. Cracks or holes in the tank can be patched by welding, provided testing indicates that internal windings have not been compromised. Transformers can be returned to service after being thoroughly dried and replacing lost or contaminated oil. Keep in mind that oil from damaged transformers must be filtered before being reused and that motor oil is not a satisfactory substitute for transformer use (a transformer requires a highly refined mineral oil free from moisture or other impurities). In most cases, there will not be sufficient spare transformers available to provide a one-for-one replacement for damaged units. For example, you may not have a single-phase transformer with the capacity for the required load. In such a case, it may be necessary to parallel two smaller transformers in order to supply the load (**Figure 5.16.**). This expedient solution will solve an immediate problem, but it is not cost effective and should be replaced when the correct equipment becomes available. In a situation where three-phase power is needed and one transformer out of the three is damaged, three-phase power can still be provided by making what are commonly called open-delta connections. **Figure 5.17.** shows the open-delta connection when a four-wire, three-phase wye primary is involved. **Figure 5.18.** illustrates the connections that must be made to achieve the open-delta connection when a three-wire, three-phase delta primary is involved. Regardless of the type of primary involved, these connections are used only for emergency situations and should not be constructed as permanent installations. The two transformers used in the open-delta connection will only supply 86.6 percent of their rated capacity. The total capacity of the bank will be only 57.7 percent of the original bank capacity.

Figure 5.16. Paralleling Single Phase Transformers.

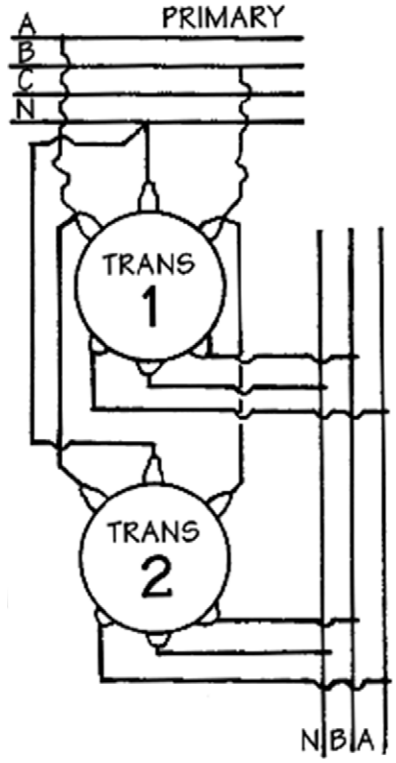


Figure 5.17. Open–Delta With Wye Primary.

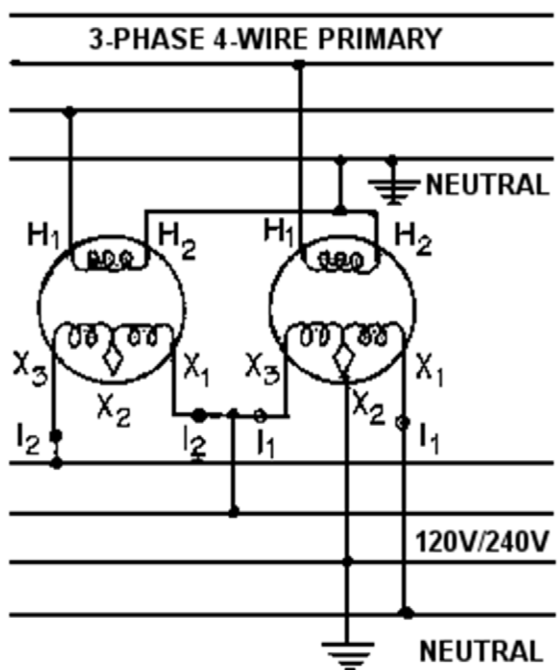
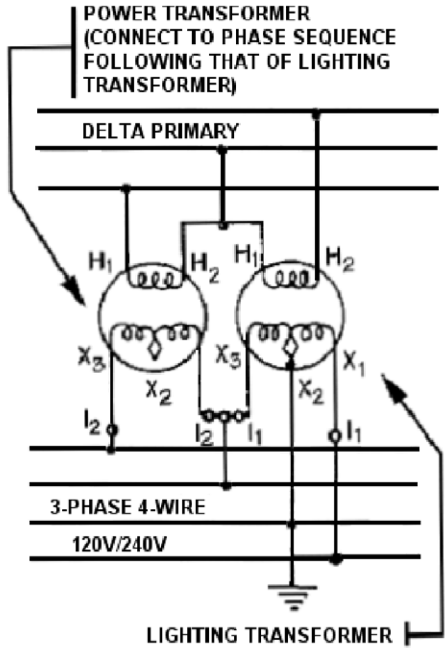


Figure 5.18. Open-Delta With Delta Primary.

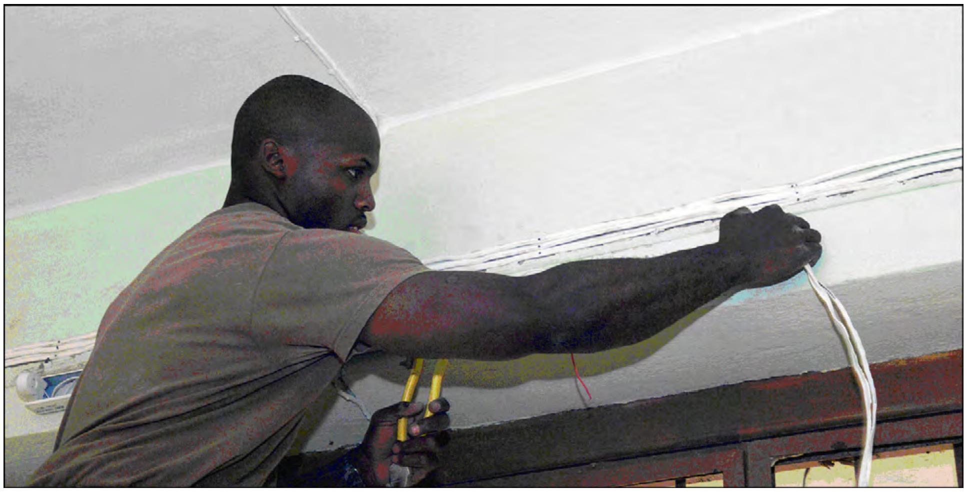


5.5.4.3. Repairing Interior Wiring. Expedient repairs to the interior wiring of a structure depend on the extent of damage and the criticality of the facility. If the facility is not critical to current base recovery operations, delay repairs until additional resources are available. For facilities considered essential to base operations, determine the minimum level of required electrical service. Does an entire structure need power or only a small portion of it? What type of equipment will the electrical system of the building be required to support? Will it only need minimum electrical voltage to provide lighting, or are there requirements for specialized voltages to power large air conditioning units, refrigeration units, or X-ray machines? For example, there is no need to devote excessive manpower and materials to complete restoration of the base hospital's electrical system if the hospital staff needs only one section of the building and one X-ray machine. In this case, electrical wiring in this section of the building could be restored and a special high-voltage cable could be run to operate the X-ray machine.

5.5.4.3.1. When making expedient repairs to the interior wiring, use undamaged wiring to the maximum extent possible. This will cut repair time and result in fewer exposed live circuits when the facility is returned to operation. As with distribution systems, damaged areas can be bypassed with new wiring to complete a vital circuit.

5.5.4.3.2. When bypassing damaged areas or running temporary lines into a structure, wiring can be run across floors and other building surfaces to expedite repairs. However, if the facility will have a high volume of personnel traffic, tack the wiring to the wall or ceiling to prevent further damage or hazards. The temporary wiring does not have to be concealed to present a finished appearance; it only needs to be functional and out of the way of heavy traffic (**Figure 5.19.**).

Figure 5.19. Installation of Temporary Interior Wiring.



5.5.4.3.3. Another important consideration in the expedient repair of interior electrical systems is the supply of wiring, switches, and associated hardware needed to make repairs. Depending on the extent of damage, base supply sources may not have adequate levels to provide for all repair needs. In these cases, cannibalization and substitution become very important. At theater locations, many components will be of foreign manufacture and not readily available through US supply channels, making it imperative that repair crews salvage as much as possible. Structures declared irreparable may contain switches, wiring, and other hardware that can be used to restore electrical services to other structures. A note of caution: do not inflict additional or unnecessary damage during salvage attempts. Structures being salvaged may have to be rehabilitated in the future.

5.5.5. Foreign Wiring Systems. Another type of contingency situation involves reactivating an established installation in a foreign country. In this case, the facilities on the installation would be intact but possibly requiring renovation or modifications.

5.5.5.1. Foreign Systems Interface. The primary difference between US and foreign wiring systems is that most foreign systems have not been installed according to the standards outlined by the US National Electric Code (NEC). This fact may be attributed largely to the material shortages in many foreign countries, particularly economically depressed nations, which have dictated the use of materials at hand. Additional details regarding material variances and electrical system comparisons are described in the following paragraphs.

5.5.5.1.1. Voltage. The U.S. uses nominal voltages that range from 120 to 240 volts for single-phase alternating current (AC) and 208 to 600 volts for three-phase AC in low-voltage distribution systems. A considerable number of foreign countries use other voltages, requiring our electrical equipment to be converted, modified, or operated inefficiently when powered by these foreign electrical systems.

5.5.5.1.2. Frequency. The standard frequency of AC distribution in the US is 60 Hertz (Hz). In many foreign lands, 50-cycle frequency generation is common; but the electrician may also encounter frequencies such as 25, 40, 42, and 100 cycles. General guidelines for using 60 Hz electrical equipment on 50 Hz power sources is provided in paragraph **5.5.5.4.**

5.5.5.1.3. Materials. The wiring materials commonly used in foreign countries are normally peculiar to the country's manufacture. The US employs the American Wire Gage (AWG) system, which is peculiar to US installations. Most foreign wire will differ in size and use. Also, receptacles, switches, and plugs used in foreign wiring systems are different and normally cannot be mated or used with similar American-manufactured components. Be aware that problems may be created when dissimilar materials are used interchangeably in a power-distribution system. The close association of dissimilar metals may cause galvanic corrosion at the joints that eventually destroys the usefulness of the equipment. This is a particular concern when aluminum and copper are joined. New materials are especially made for connection to copper or aluminum with no adverse effects and will be appropriately marked. Except in emergency expedient installation, dissimilar metals must never be used together. If aluminum is exclusively used in a system, a special joint compound must be applied to all connections or joints to protect against excess surface oxidation. The oxide of an aluminum conductor differs from copper oxide in that it adds a high contact resistance to the wire.

5.5.5.2. Expedient Procedures Involving Foreign Systems. During contingency operations in a foreign country, the Air Force may use all or part of an electrical system on a foreign installation. Though the decision of employment is largely determined by the immediate circumstances, the Air Force electrician or unit commander will follow one of two general procedures as outlined below.

5.5.5.2.1. Since the electrical components of a foreign and domestic electrical system cannot be interchanged, the decision may be made to use all foreign equipment. The obvious problem in this decision is one of supply. The parts needed may not be readily available.

5.5.5.2.2. If time is a consequential factor, consideration should be given to the use of standard electrical items made in the US and the modification of plugs or connections so that they may be used in the foreign system. Although this method usually results in decreased operating efficiency, the ease of adaptability and abundance of supplies usually outweigh the reduction in performance.

5.5.5.3. Different Voltage Effects. Whenever possible, all equipment should be operated at its rated voltage. To expedite foreign system use, items built to operate at standard American voltages may have to function at different voltages. Though such items may not be operated efficiently, their availability for use may be an important military need. Some effects of voltage differences on common electrical devices are explained below.

5.5.5.3.1. Lighting Fixtures. When fluorescent lamps are operated at voltages higher than standard, both the lamp and ballast life are shortened. Line voltages below the minimum of the operating ranges of 110-125, 199-216, or 220-250 volts will cause uncertain starting, short lamp life, and reduced lighting efficiency. When incandescent lamps are used and operated at voltages higher than their ratings of 114, 120, and 125 volts, they also have a shortened lamp life below that expected; but their light output is increased. Conversely, if the line voltage of operation is below standard, the life of the lamp is increased; but the lighting efficiency is reduced approximately 3 percent for each 1 percent drop in rated voltage.

5.5.5.3.2. Motors. Rotating equipment, such as motors and fans, is usually manufactured to operate with a permissible voltage variation of 10 percent within their prescribed rating. The combined voltage and frequency variation is also limited to 10 percent. Higher voltages give increased torque, increased efficiency, and increased starting temperature. Operating at voltages differing from rated voltages by more than 10 percent may be permitted only in an extreme emergency since the equipment may be damaged or even destroyed by such operations.

5.5.5.4. Different Frequency Effects. Electrical operating items based on resistance characteristics (such as heaters, hot plates, and electric stoves) operate efficiently over all ranges of distribution frequencies used throughout the US and foreign territories. Rotating equipment and items such as lights and transmission or receiving equipment are adversely affected by variations in frequency. Some of the effects of frequency changes on this type of equipment are described below.

5.5.5.4.1. Resistive Loads. Fluorescent lights rated to operate at a nominal 60-cycle current can be used at 50 cycles, but with a shorter ballast life. At lower than 60-cycle frequencies, a noticeable flicker in the light output can be detected. This is undesirable where painstaking and meticulous work is being performed. Operation at lower frequency is not satisfactory and should be avoided. Incandescent lights, because of their resistance design, will operate satisfactorily at all of the frequencies encountered overseas. However, lamps designed to function at 60 Hz will not burn as brightly at 50 Hz and ovens will not be as hot.

5.5.5.4.2. Static Induction Devices. Distribution transformers, electric discharge lighting ballasts, series lighting current regulators, and other static inductive equipment induce magnetic energy fields in iron as part of their normal operation. The magnetic flux density is directly proportional to the volts/hertz ratio of the power source. Consequently, the voltage must be reduced proportionally to maintain the volts/hertz ratio at the design point.

5.5.5.4.3. Transmitting Equipment. All receiving and transmitting equipment, or other items which have transformers included in their wiring, will not operate satisfactorily either below or above their rated line frequency and should be used only in an emergency. In some cases, there may be frequency converters available, particularly in flight line operations, which can be obtained and used when the equipment operation is mission essential.

5.5.5.4.4. Induction Motors. Induction motors rated for 60 Hz operation will run at about 5/6 of rated speed when connected to a 50 Hz source. Consequently, if a motor is nominally rated to run at 1800 rpm at 60 cycles and is operated at 50 cycles, its output speed will be reduced to approximately 1500 rpm. Motor current varies inversely with both source frequency and voltage. As the 50 Hz source voltage is reduced, motor current heating the winding increases while iron loss heating is decreasing. No amount of voltage reduction can compensate for both heating effects simultaneously. However, induction motors rated at 120V, 60 Hz will operate successfully at about 110V, 50 Hz if the speed reduction can be tolerated. Keep in mind that some motors are built to function at either 50 or 60 cycles.

5.5.5.5. Electric Motor Voltage/Hertz Variation Remedies. Corrective measures for two of the more common major electric motor problems related to voltage and hertz incompatibilities are provided below.

5.5.5.5.1. Motor Heating Due to Iron Saturation. Motor geometry establishes a design volts/hertz ratio. As addressed earlier, if the motor will be operated at less than designed frequency, then the voltage must be reduced proportionately (5/6) to maintain the volts/hertz ratio at or below the design limit.

5.5.5.5.2. Reduced Motor Shaft Speed. Shaft speed is a function of source frequency and motor configuration. The coupling to the drive load often involves belts, pulleys, chains, or gears. A change in drive ratios could correct the speed. However, many loads operate adequately at 5/6 of design speed.

5.5.6. Miscellaneous Reference Material. The next few pages list reference information regarding load-carrying capacity of wire, load current and circuit breaker sizes for AC motors, a description of common AWG wire sizes, types, and general uses along with pole sizing and setting specifications.

5.5.6.1. Wire Size and Voltage Drop Determination. The size of wire for a given section of a system is selected based on the amount of electrical load that it must carry and on the allowable voltage drop. Note the larger the wire size, the greater its capacity and the less resistance it will have, hence, less voltage drop. Economy, however, should be considered in size determination. **Table 5.3.** shows the KVA (kilovolts-amperes) and current-carrying capacities for wires ranging from No. 8 to a 4/0. In addition, **Table 5.4.** lists current and circuit breaker sizes for AC motors.

Table 5.3. KVA Load-Carrying Capacity of Wire.

Wire Size[1] (AWG)[2]	Maximum Amperes	Type of Circuit				
		1Ø 2W 120V (KVA)	1Ø 3W 120/240V (KVA)	3Ø 4W 127/220V (KVA)	1Ø 2W 2,400V (KVA)	3Ø 4W 2,400/4,160V (KVA)
8	75	9	18	29	180	540
6	100	12	24	38	240	720
4	150	18	36	57	360	1,080
2	180	22	44	69	432	1,296
1/0	250	30	60	95	600	1,800
4/0	435	52	104	166	1,044	3,130

[1]Overhead wires with weatherproof insulation or bare wires.
[2] American Wire Gage

Table 5.4. Full-Load Current and Circuit-Breaker Sizes for AC Motors.

MOTOR HORSE-POWER	SINGLE PHASE				THREE PHASE			
	118-VOLT		220-VOLT		220-VOLT		440-VOLT	
	Current (AMPS)	Circuit Breaker Size (AMPS)	Current (AMPS)	Circuit Breaker Size (AMPS)	Current (AMPS)	Circuit Breaker Size (AMPS)	Current (AMPS)	Circuit Breaker Size (AMPS)
1/6	3.34	15	1.67	15	--	--	--	--
1/4	4.0	15	2.4	15	--	--	--	--
1/2	7	15	3.5	15	2.5	15	1.3	15
3/4	9.4	25	4.7	15	2.8	15	1.4	15
1	11	25	5.5	15	3.3	15	1.7	15
1 1/2	15.2	25	7.6	25	4.7	15	2.4	15
2	20	50	10	25	6	15	3	15
3	28	50	14	35	9	25	4.5	15
5	46	70	23	50	15	25	7.5	15
7 1/2	68	125	34	70	22	50	11	25
10	86	200	43	70	27	50	14	35
15	--	--	--	--	38	70	19	50
20	--	--	--	--	52	125	26	70
25	--	--	--	--	64	125	32	70
30	--	--	--	--	77	125	39	70
40	--	--	--	--	101	200	51	125
50	--	--	--	--	125	200	63	125
60	--	--	--	--	149	225	75	125
75	--	--	--	--	180	400	90	200
100	--	--	--	--	244	400	123	200

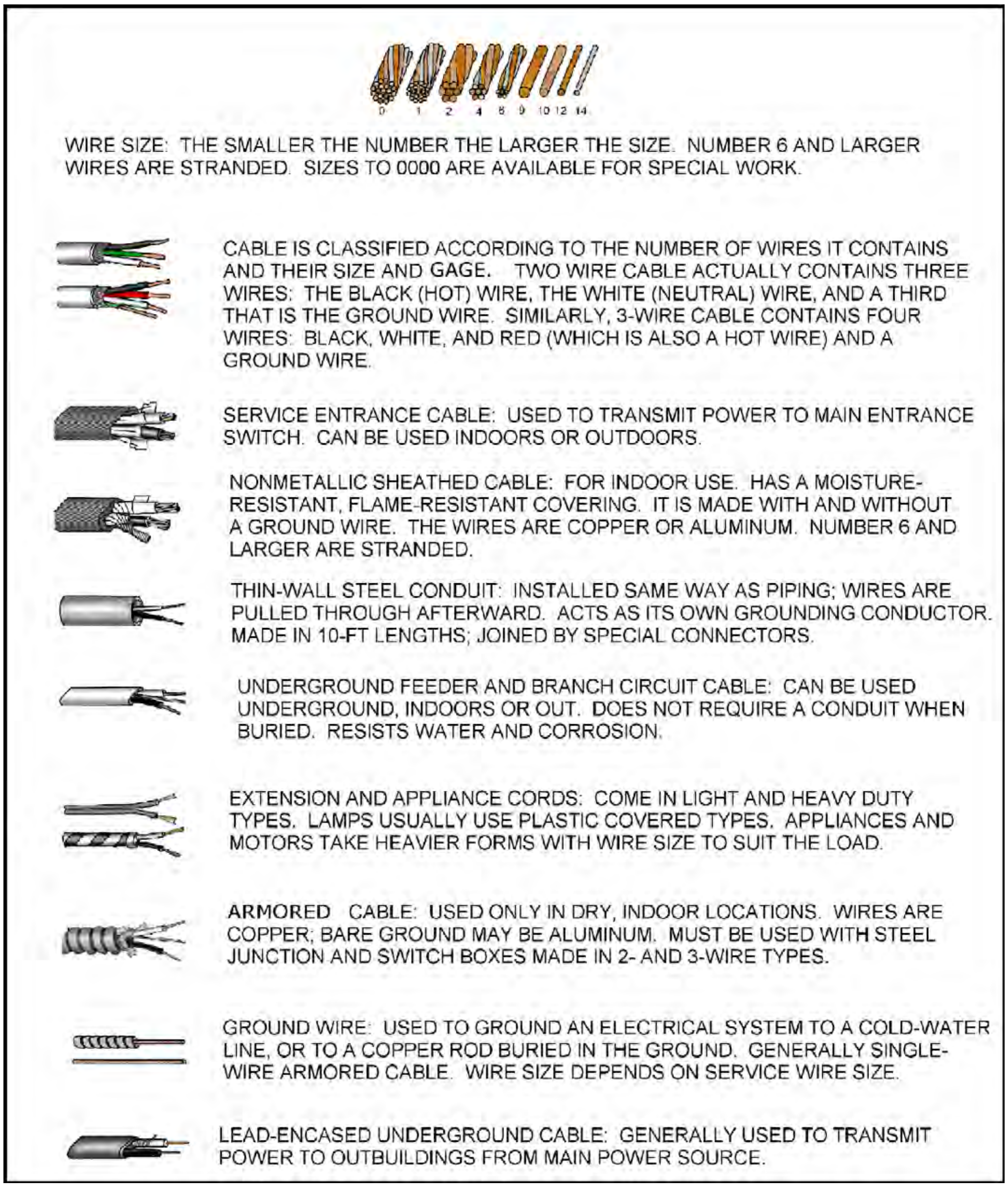
5.5.6.2. Conductor Types. Conductors used in installation overhead distribution systems are usually copper, although they may be steel, aluminum, or combinations of these metals. **Figure 5.20.** provides information regarding common AWG wire sizes, types, and applications. In addition, **Table 5.5.**, **Table 5.6.**, and **Table 5.7.** list the wire sizes for 120-volt, single-phase circuits, number of wires allowable in various conduits, and the wire sizes for 240-volt, single-phase circuits, respectively. Lastly, **Figure 5.21.** shows four of the more common wire splice techniques in use today.

5.5.6.2.1. Copper Conductors. Copper has high conductivity and is easily spliced. Hard-drawn or medium-hard-drawn copper is desirable for distribution conductors because of its strength. Since heating and cooling reduces the wire's tensile strength from 50,000-psi to 35,000-psi, soldered splices should not be used on hard-drawn copper wire because the hot solder weakens the joints. Splicing sleeves are normally used when making joints.

5.5.6.2.2. Steel Conductors. Steel wire used as a conductor permits long spans because of its high tensile strength. Steel has about 10 to 15 percent as much conductivity size-for-size as copper, but the short life and low conductivity of steel wire are overcome, to some extent, by the use of copper-clad steel made by welding a copper coating to the steel wire.

5.5.6.2.3. Weatherproofing. Triple-braid weatherproofing is preferred to double braid. Improved types of weatherproofing include plastic covering and layers of impregnated unspun cotton or impregnated rubber filler. Before these newer type coverings are used, approval should be obtained from the higher command having jurisdiction.

Figure 5.20. Wire Sizes, Types, and Uses.



5.5.6.2.4. Primary Distribution. For primary distribution below 5,000 volts, either bare or weatherproof conductors may be used. The ordinary weatherproof covering is not to be considered as insulation, although it does prevent breakdowns on the lower primary voltages caused by conductors swinging together. For all primary distribution over 5,000 volts, bare conductors are ordinarily used.

5.5.6.2.5. Secondary Distribution. Weatherproof wires are used for secondary distribution. The weatherproof covering is an effective insulation for secondary voltages, permitting rack-type distribution and closely spaced secondary conductors. No wire smaller than a No. 8 should be used for secondary distribution or for any external transmission of power.

Table 5.5. Wire Sizes for 120-Volt, Single-Phase Circuits.

Load (AMPS)	Minimum Wire Size (AWG)	Service Wire Size (AWG)	WIRE SIZE (AWG) DISTANCE ONE-WAY FROM SUPPLY TO LOAD (FT)												
			50	75	100	125	150	175	200	250	300	350	400	450	500
15	14	10	14	12	10	8	6	6	6	6	4	4	4	2	2
20	14	10	12	10	8	8	6	6	6	4	4	2	2	2	2
25	12	8	10	8	8	6	6	4	4	4	2	2	2	1	1
30	12	8	10	8	6	6	4	4	4	2	2	1	1	0	0
35	12	6	8	6	6	4	4	4	2	2	1	1	0	0	2/0
40	10	6	8	6	6	4	4	2	2	2	1	0	0	2/0	2/0
45	10	6	8	6	4	4	2	2	2	1	0	0	2/0	2/0	3/0
50	10	6	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0
55	8	4	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	4/0
60	8	4	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0
65	8	4	6	4	2	2	2	1	0	2/0	2/0	3/0	4/0	4/0	
70	8	4	6	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	
75	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
80	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
85	6	4	4	4	2	1	1	0	2/0	3/0	3/0	4/0			
90	6	2	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
95	6	2	4	2	2	1	0	2/0	2/0	3/0	4/0				
100	4	2	4	2	2	1	0	2/0	2/0	3/0	4/0				

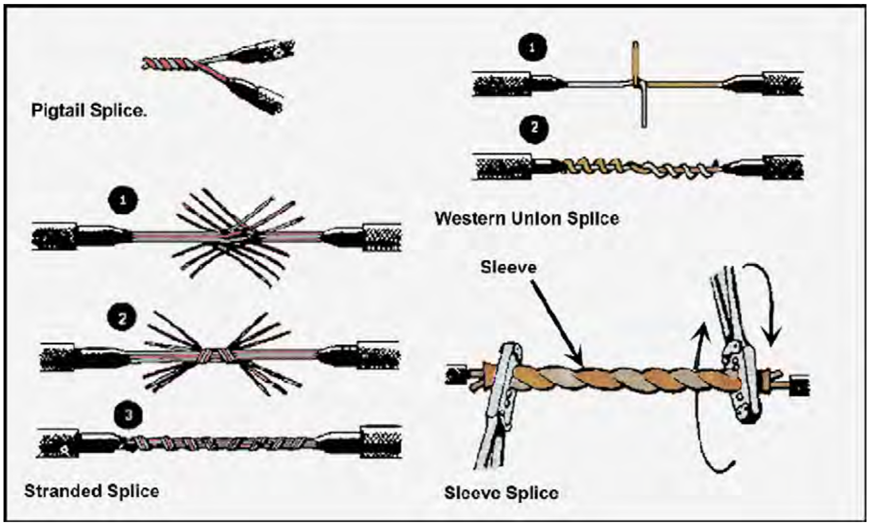
Table 5.6. Number of Wires Allowable in Various Sized Conduits.

Wire Size	NUMBER OF WIRES IN ONE COUNT								
	1	2	3	4	5	6	7	8	9
18	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4
16	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4
14	1/2	1/2	1/2	1/2	3/4	3/4	3/4	1	1
12	1/2	1/2	1/2	3/4	3/4	1	1	1	1 1/4
10	1/2	3/4	3/4	3/4	1	1	1 1/4	1 1/4	1 1/4
8	1/2	3/4	1	1	1 1/4	1 1/4	1 3/4	1 3/4	1 3/4
6	1/2	1	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2
4	3/4	1 1/4	1 1/4	1 1/2	2	2	2	2	2 1/2
2	3/4	1 1/4	1 1/2	1 1/2	2	2	2 1/2	2 1/2	2 1/2
1	3/4	1 1/2	1 1/2	2	2	2 1/2	2 1/2	3	3
1/0	1	1 1/2	2	2	2 1/2	2 1/2	3	3	3
2/0	1	2	2	2 1/2	2 1/2	3	3	3	3 1/2
3/0	1	2	2	2 1/2	3	3	3	3 1/2	3 1/2
4/0	1 1/4	2	2 1/2	2 1/2	3	3	3 1/2	3 1/2	4
Rubber-Covered or Weatherproof Wire									

Table 5.7. Wire Sizes for 240-Volt, Single-Phase Circuits.

Load (AMPS)	Minimum Wire Size (AWG)	Service Wire Size (AWG)	WIRE SIZE (AWG) DISTANCE ONE-WAY FROM SUPPLY TO LOAD (FT)												
			100	150	200	250	300	350	400	500	600	700	800	900	1,000
15	14	10	14	12	10	8	6	6	6	4	4	4	4	2	2
20	14	10	12	10	8	8	6	6	6	4	4	2	2	2	2
25	12	8	10	8	8	6	6	4	4	4	2	2	2	1	1
30	12	8	10	8	6	6	4	4	4	2	2	1	1	0	0
35	12	6	8	6	6	4	4	4	2	2	1	1	0	0	2/0
40	10	6	8	6	6	4	4	2	2	2	1	0	0	2/0	2/0
45	10	6	8	6	4	4	2	2	2	1	0	0	2/0	2/0	3/0
50	10	6	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0
55	8	4	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	4/0
60	8	4	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0
65	8	4	6	4	2	2	2	1	0	2/0	2/0	3/0	4/0	4/0	
70	8	4	6	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	
75	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
80	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
85	6	4	4	4	2	1	1	0	2/0	3/0	3/0	4/0			
90	6	2	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
95	6	2	4	2	2	1	0	2/0	2/0	3/0	4/0				
100	4	2	4	2	2	1	0	2/0	3/0	3/0	4/0				
125	4	2	4	2	1	0	2/0	3/0	3/0	4/0					
150	2	1	2	1	0	2/0	3/0	4/0	4/0						
175	2	0	2	0	2/0	3/0	4/0	4/0							
200	1	0	1	0	2/0	3/0	4/0								
225	1/0	1/0	1/0	2/0	3/0	4/0									
250	2/0	2/0	2/0	2/0	3/0	4/0									
275	3/0	3/0	3/0	3/0	4/0										
300	3/0	3/0	3/0	3/0	4/0										
325	4/0	4/0	4/0	4/0											
Table is based upon an approximate 3% voltage drop.															

Figure 5.21. Common Wire Splices.



5.5.6.3. Overhead Distribution Pole Requirements. At established installations, electrical distribution lines are often overhead, supported by poles or strung from building to building. As a general rule, lines carrying over 240 volts are supported on poles while those carrying 120 to 240 volts may be supported on masts or insulators attached to buildings. Service wires should be kept at least 3 feet from windows and 8 inches above flat roofs. Since theater of operations electrical distribution systems are exclusively overhead systems, wooden poles similar to those used in civilian construction are used to carry the conductors. Unlike civilian construction, cross arms are not often used at overseas installations. Instead, conductors are hung directly on the pole, one above the other.

5.5.6.3.1. **Pole Selection.** The poles used in a distribution system should consist of a good grade of timber that will last. Good pressure-treated Texas southern pine, for example, can be expected to last 35 to 50 years. Conversely, untreated local timber such as soft pine may last only a couple of years and have a useful life of only one season under unfavorable conditions. However, the fact that a pole is in good condition is not proof that it can satisfactorily support the line. Poles must withstand column loadings as well as transverse loads from wind and turns in the line.

5.5.6.3.2. **Pole Height and Class.** **Table 5.8.** shows the required heights and classes of poles for various types of loadings in military installations. The smaller a class number the sturdier the pole. The class of a given pole depends on its length, diameter, and the material from which it is made. The height is governed by restrictions both above and below the proposed conductors. Near airfields, poles must be kept low, yet high enough to provide adequate clearance over streets and roads. Corner poles, transformer poles, and the like are usually one or more classes heavier and sometimes 5 feet higher than line poles. **Table 5.9.** gives the required classes for transformer poles.

Table 5.8. Height and Class of Power Poles.

Pole	Minimum Height (feet)*	Minimum Class	Normal Class
Line Pole	30	7	5
Corner Pole (guyed)	30	6	4
Corner Pole (unguyed)	30	2	2
Dead End Pole (guyed)	30	5	4
Dead End Pole (unguyed)	30	2	2
Transformer Poles	35	**	
* Increase heights by 5 feet if telephone or signal wires are carried or likely to be installed. ** Refer to **Table 5.9.**			

Table 5.9. Power Pole Size for Transformers.

New Pole for Transformer	Existing Pole	Maximum Transformer Size (KVA)	
Minimum Class	Minimum Class	One-Phase	Three-Phase
6	7	5	
5	6	15	5
4	5	50	37 ½
2	3	75	75
2	2	100	100

5.5.6.3.3. **Vertical Wire Spacing.** Vertical wire spacing is the clear distance between wires. Six-inch minimum spacing is required for spans up to and including 200 feet while 12-inch minimum spacing is required for spans over 200 feet. A clear space is always left at the top of an electrical pole. This distance is equal to the wire spacing, that is, 6 inches for 200-foot spans and less and 12 inches for spans greater than 200 feet.

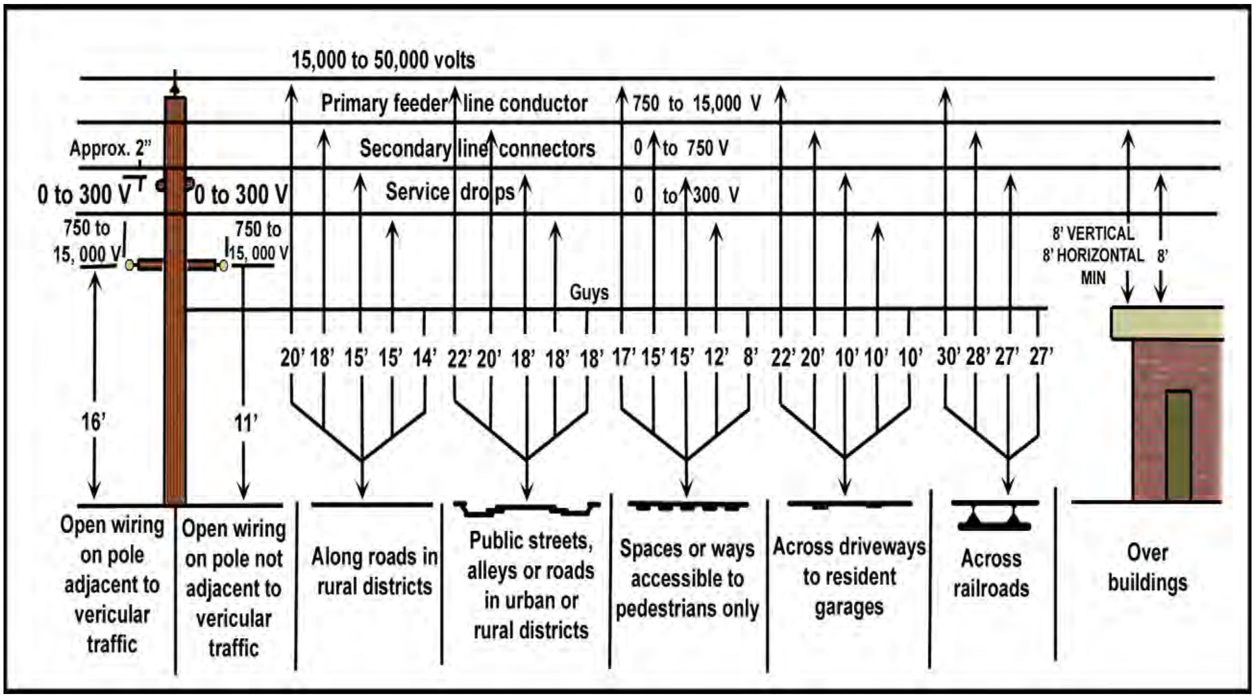
5.5.6.3.4. Setting Poles. Poles should be set deep enough to develop their full bending strength at the ground line. **Table 5.10.** gives the recommended setting depths in soil and in rock. The actual setting or installation of the poles is done by one of three methods: by hand, with a crane, or by using a nearby pole as a gin pole.

Table 5.10. Power Pole Setting Depths.

Pole Height (feet)	Depth of Setting (feet)	
	In Soil	In Rock
20	5.0	3.0
25	5.5	3.5
30	5.5	4.0
35	6.0	4.0
40	6.0	4.0
45	6.5	4.5
50	7.0	4.5
55	7.5	5.0
60	8.0	5.0

5.5.6.3.5. Clearances. Minimum clearances of conductors over ground, rails, and other objects are given in **Figure 5.22.** Special consideration must be given to railroad yards and material handling areas. Allow a minimum horizontal clearance of 11 inches from the outside face of a curb or roadbed to the face of the pole to prevent damage by vehicles. The clearances shown may be decreased in theater of operations construction where safety factors are reduced. The engineer officer must use sound judgment in establishing minimum clearances for a given project, taking into account materials available, military necessity, urgency of the project, and other factors.

Figure 5.22. National Electric Safety Code (NESC) Minimum Clearances.



5.5.6.4. Frequency and Voltage Data. Different power frequencies and voltages are used in different parts of the world. In the US, 60 Hz is the most common frequency and secondary distribution voltages of 120/208, 120/240, and 277/480 are common. **Table 5.11.** provides an extensive list of frequencies and secondary voltages for commercial power systems in many foreign lands and US territories. This data is subject to change so always verify before beginning work.

Table 5.11. List of Frequencies and Voltages.

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Afghanistan	**50 Hz**	**wye**	**220**	**380**
Algeria	**50 Hz**	**wye**	**127**	**220**
	50 Hz	**wye**	**220**	**380**
American Samoa	**60 Hz**	**delta**	**120/240**	**240**
	60 Hz	**delta**	**240/480**	**480**
Angola	**50 Hz**	**wye**	**220**	**380**
Antigua	**60 Hz**	**wye**	**230/400**	**400**
Argentina	**50 Hz**	**wye**	**220**	**380**
Australia	**50 Hz**	**wye**	**240/415**	**415**
Bahamas	**60 Hz**	**wye**	**120/208**	**208**
	60 Hz	**delta**	**120/240**	**240**

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Bahrain	50 Hz	wye	230/400	400
	60 Hz	wye	230/400	400
Bangladesh	50 Hz	wye	220/380	380
Barbados	50 Hz	wye	115/200	200
	50 Hz	delta	115/230	230
Belgium	50 Hz	wye	127/220	220
	50 Hz	wye	220/380	380
Belize	60 Hz	delta	110/220	220
	60 Hz	delta	220/440	440
Benin	50 Hz	wye	220	380
Bermuda (UK Dependency)	60 Hz	wye	120/208	208
	60 Hz	delta	120/240	240
Bolivia	50 Hz	delta	110/220	220
	50 Hz	delta	115/230	230
	50 Hz	wye	220	380
	50 Hz	wye	230/400	400
Botswana	50 Hz	wye	220	380
Brazil	60 Hz	delta	110/220	220
	60 Hz	wye	115/220	220
	60 Hz	delta	115/230	230
	60 Hz	wye	125/216	216
	60 Hz	wye	127/220	220
	60 Hz	wye	220/380	380
	50 Hz	delta	220/440	440
	60 Hz	wye	230/400	400
Bulgaria	50 Hz	wye	220	380
Burma	50 Hz	wye	230/400	400
Burundi	50 Hz	wye	220	380
Cambodia	50 Hz	wye	120	208
	50 Hz	wye	220/380	380
Cameroon	50 Hz	wye	127	220
	50 Hz	wye	220/380	380

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
	50 Hz	wye	230/400	400
Canada	60 Hz	delta	120/240	240
	60 Hz	wye		575
Canary Island (Spain)	50 Hz	wye	127/220	220
	50 Hz	wye	220/380	380
Cape Verde	50 Hz	wye	220/380	380
Cayman Islands (UK Dependency)	60 Hz	delta	120/240	240
Central African Rep.	50 Hz	wye	220	380
Chad	50 Hz	wye	220	380
Channel Islands (UK Dependency)	50 Hz	wye	230	400
	50 Hz	wye	240	415
Chile	50 Hz	wye	220/380	380
China	50 Hz	wye	220	380
Colombia	60 Hz	delta	110/220	220
	60 Hz	wye	120/208	208
	60 Hz	wye	150/240	240
Congo	50 Hz	wye	220	380
Costa Rica	50 Hz	delta	120/240	240
Cyprus	50 Hz	wye	240	415
Czech Republic	50 Hz	wye	220/380	380
Denmark	50 Hz	wye	220/380	380
Djibouti	50 Hz	wye	220	380
Dominica	50 Hz	wye	230	400
Dominican Republic	60 Hz	delta	110/220	220
Ecuador	60 Hz	wye	120/208	208
	60 Hz	delta	120/240	240
	60 Hz	wye	127/220	220
Egypt	50 Hz	wye	220/380	380
El Salvador	60 Hz	delta	115/230	230
Equatorial Guinea	50 Hz	wye	220	380

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Ethiopia	**50 Hz**	**wye**	**220**	**380**
Faeroe Islands (Denmark)	**50 Hz**	**wye**	**220/380**	**380**
Fiji	**50 Hz**	**wye**	**240/415**	**415**
Finland	**50 Hz**	**wye**	**220**	**380**
France	**50 Hz**	**wye**	**110**	**190**
	50 Hz	**delta**	**110**	**220**
	50 Hz	**wye**	**115**	**200**
	50 Hz	**delta**	**115**	**230**
	50 Hz	**wye**	**127**	**220**
	50 Hz	**wye**	**220**	**380**
French Guiana (Dependency of France)	**50 Hz**	**wye**	**220/380**	**380**
Gabon	**50 Hz**	**wye**	**220**	**380**
Gambia	**50 Hz**	**wye**	**220**	**380**
Germany	**50 Hz**	**wye**	**220**	**380**
Ghana	**50 Hz**	**wye**	**220/400**	**400**
Gibraltar (UK Territory)	**50 Hz**	**wye**	**240**	**415**
Greece	**50 Hz**	**wye**	**220**	**380**
Greenland (Denmark)	**50 Hz**	**wye**	**220/380**	**380**
Grenada	**50 Hz**	**wye**	**230**	**400**
Guadeloupe (France)	**50 Hz**	**wye**	**220/380**	**380**
Guam (US Territory)	**60 Hz**	**delta**	**110/220**	**220**
	60 Hz	**wye**	**120/208**	**208**
Guatemala	**60 Hz**	**delta**	**120/240**	**240**
Guinea	**50 Hz**	**wye**	**220/380**	**380**
Guinea-Bissau	**50 Hz**	**wye**	**220/380**	**380**
Guyana	**50 Hz**	**delta**	**110/220**	**220**
	60 Hz	**delta**	**110/220**	**220**

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Haiti	60 Hz	delta	110/220	220
	60 Hz	wye	120/208	208
Honduras	60 Hz	delta	110/220	220
Hong Kong (China)	50 Hz	wye	200/346	346
Hungary	50 Hz	wye	220/380	380
Iceland	50 Hz	wye	220/380	380
India	50 Hz	wye	220	380
	50 Hz	wye	230	400
Indonesia	50 Hz	wye	127	220
	50 Hz	wye	220	380
Iran	50 Hz	wye	220/380	380
Iraq	50 Hz	wye	220	380
Ireland	50 Hz	wye	220	380
Isle of Man (UK Dependency)	50 Hz	wye	240	415
Israel	50 Hz	wye	230	400
Italy	50 Hz	wye	127	220
	50 Hz	wye	220	380
Ivory Coast	50 Hz	wye	220	380
Jamaica	50 Hz	wye	110/220	220
Japan	50 Hz	delta	100/200	200
	60 Hz	delta	100/200	200
Jerusalem (Israel)	50 Hz	wye	220/380	380
Jordan	50 Hz	wye	220/380	380
Kenya	50 Hz	wye	240	415
Korea	60 Hz	delta	100/200	200
	60 Hz	delta	105/210	
	60 Hz	wye	220	380
Kuwait	50 Hz	wye	240	415
Laos	50 Hz	wye	220	380
Lebanon	50 Hz	wye	110	190

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
	50 Hz	wye	220	380
Lesotho	50 Hz	wye	220	380
Liberia	60 Hz	wye	120/208	208
	60 Hz	delta	120/240	240
Libya	50 Hz	wye	127	220
	50 Hz	wye	230	400
Luxembourg	50 Hz	wye	120/208	208
	50 Hz	wye	220/380	380
Macao (China)	50 Hz	wye	220/380	380
Madagascar	50 Hz	wye	127/220	220
	50 Hz	wye	220/380	380
Madeira Islands (Portugal)	50 Hz	wye	220/380	380
Majorca Island (Spain)	50 Hz	wye	127/220	220
	50 Hz	wye	220/380	380
Malawi	50 Hz	wye	230/400	400
Malaysia	50 Hz	wye	240	415
Maldives	50 Hz	wye	230	400
Mali	50 Hz	wye	220	380
Malta	50 Hz	wye	240	415
Martinique (France)	50 Hz	wye	220/380	380
Mauritius	50 Hz	wye	230	400
Mexico	60 Hz	wye	127/220	220
Monaco	50 Hz	wye	127	220
	50 Hz	wye	220	380
Montserrat (UK Territory)	60 Hz	wye	230	400
Morocco	50 Hz	wye	127	220
	50 Hz	wye	220	380
Mozambique	50 Hz	wye	220/380	380

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Nepal	**50 Hz**	**delta**	**220**	**440**
Netherlands	**50 Hz**	**wye**	**220**	**380**
Netherlands Antilles	**60 Hz**	**delta**	**115/230**	
	60 Hz	**wye**	**120/208**	**208**
	50 Hz	**wye**	**127/220**	**220**
	50 Hz	**wye**	**220/380**	**380**
New Caledonia (France)	**50 Hz**	**wye**	**220/380**	**380**
New Zealand	**50 Hz**	**wye**	**230/400**	**400**
Nicaragua	**60 Hz**	**delta**	**120/240**	**240**
Niger	**50 Hz**	**wye**	**220/380**	**380**
Nigeria	**50 Hz**	**wye**	**230**	**415**
Northern Ireland	**50 Hz**	**wye**	**220**	**380**
	50 Hz	**wye**	**230**	**400**
Norway	**50 Hz**	**wye**	**230**	**230**
Okinawa (Japan)	**60 Hz**	**delta**	**100/200**	
	60 Hz	**delta**	**120/240**	
Oman	**50 Hz**	**wye**	**240**	**415**
Pakistan	**50 Hz**	**wye**	**220/380**	**380**
	50 Hz	**wye**	**230/400**	**400**
Panama	**60 Hz**	**delta**	**110/220**	**220**
	60 Hz	**delta**	**115/230**	**230**
	60 Hz	**wye**	**120/208**	**208**
Papua New Guinea	**50 Hz**	**wye**	**240**	**415**
Paraguay	**50 Hz**	**wye**	**220**	**380**
Peru	**60 Hz**	**delta**	**110/220**	**220**
	50 Hz	**wye**	**220**	**220**
Philippines	**60 Hz**	**delta**	**110/220**	**220**
	60 Hz	**delta**	**115/230**	**230**
Poland	**50 Hz**	**wye**	**220/380**	**380**
Portugal	**50 Hz**	**wye**	**220/380**	**380**

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Puerto Rico (US Possession)	**60 Hz**	**delta**	**120/240**	**240**
Qatar	**50 Hz**	**wye**	**240**	**415**
Romania	**50 Hz**	**wye**	**220**	**380**
Russia	**50 Hz**	**wye**	**220/380**	**380**
Rwanda	**50 Hz**	**wye**	**220**	**380**
Samoa	**50 Hz**	**wye**	**230/400**	**400**
Saudi Arabia	**60 Hz**	**wye**	**127**	**220**
	50 Hz	**wye**	**220**	**380**
Scotland (UK)	**50 Hz**	**wye**	**240**	**415**
Senegal	**50 Hz**	**wye**	**127/220**	**220**
Seychelles	**50 Hz**	**wye**	**240**	**240**
Sierra Leone	**50 Hz**	**wye**	**230**	**400**
Singapore	**50 Hz**	**wye**	**230**	**400**
Slovakia	**50 Hz**	**wye**	**220/380**	**380**
Somalia	**50 Hz**	**delta**	**110**	**220**
	50 Hz	**wye**	**220**	**380**
	50 Hz	**delta**	**220**	**440**
South Africa	**50 Hz**	**wye**	**220/380**	**380**
	50 Hz	**wye**	**230/400**	**400**
	50 Hz	**wye**	**250/433**	**433**
Spain	**50 Hz**	**wye**	**127/220**	**220**
	50 Hz	**wye**	**220/380**	**380**
Sri Lanka	**50 Hz**	**wye**	**230**	**400**
St. Kitts and Nevis	**60 Hz**	**wye**	**230**	**400**
St. Lucia	**50 Hz**	**wye**	**240**	**416**
St. Vincent	**50 Hz**	**wye**	**230**	**400**
Sudan	**50 Hz**	**wye**	**240**	**415**
Suriname	**60 Hz**	**delta**	**115/230**	**230**
	50 Hz	**wye**	**127/220**	**220**
Swaziland	**50 Hz**	**wye**	**230**	**400**
Sweden	**50 Hz**	**wye**	**220/380**	**380**

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Switzerland	**50 Hz**	**wye**	**220/380**	**380**
Syria	**50 Hz**	**wye**	**220/380**	**380**
Tahiti (France)	**60 Hz**	**wye**	**127/220**	**220**
Taiwan	**60 Hz**	**delta**	**110/220**	**220**
Tanzania	**50 Hz**	**wye**	**230/400**	**400**
Thailand	**50 Hz**	**wye**	**220/380**	**380**
Togo	**50 Hz**	**wye**	**127**	**220**
	50 Hz	**wye**	**220**	**380**
Tonga	**50 Hz**	**wye**	**240/415**	**415**
Trinidad and Tobago	**60 Hz**	**delta**	**115/230**	**230**
	60 Hz	**wye**	**230/400**	**400**
Tunisia	**50 Hz**	**wye**	**127**	**220**
	50 Hz	**wye**	**220**	**380**
Turkey	**50 Hz**	**wye**	**220/380**	**380**
Uganda	**50 Hz**	**wye**	**240/415**	**415**
United Arab Emirates	**50 Hz**	**wye**	**220/380**	**380**
	50 Hz	**wye**	**230/400**	**400**
	50 Hz	**wye**	**240/415**	**415**
U. K. (England)	**50 Hz**	**wye**	**240/415**	
	50 Hz	**delta**	**240/480**	
United States	**60 Hz**	**wye**	**120/208**	**208**
	60 Hz	**delta**	**120/240**	**240**
	60 Hz	**wye**		**460**
Uruguay	**50 Hz**	**wye**	**220**	**220**
Venezuela	**60 Hz**	**delta**	**120/240**	**240**
Vietnam	**50 Hz**	**wye**	**120**	**208**
	50 Hz	**wye**	**127**	**220**
	50 Hz	**wye**	**220**	**380**
Virgin Islands (US)	**60 Hz**	**delta**	**120/240**	**240**
Wales (UK)	**50 Hz**	**wye**	**240/415**	**415**
Yemen	**50 Hz**	**wye**	**230**	**400**

COUNTRY	FREQUENCY (HERTZ)	SYSTEM	SINGLE PHASE	THREE PHASE
Yemen Arab Republic	**50 Hz**	**wye**	**220**	**380**
Zaire	**50 Hz**	**wye**	**220/380**	**380**
Zambia	**50 Hz**	**wye**	**220**	**380**
Zimbabwe	**50 Hz**	**wye**	**220/380**	**380**
	50 Hz	**wye**	**230/400**	**400**

Chapter 6

CONSTRUCTING EXPEDIENT SANITATION FACILITIES

6.1. Introduction. Sanitation during beddown operations or contingencies includes providing facilities for disposal of human waste and basic personal hygiene. Prepackaged deployable facilities like those in **Figure 6.1.** are part of BEAR packages that support deployed forces when there are inadequate or no sanitary systems available. However, expedient methods must be available to provide crude, temporary amenities until these deployable prepackaged facilities arrive.

6.2. Overview. This chapter presents basic data and concepts to help personnel provide rudimentary sanitation facilities for initially deployed forces and during contingencies. These concepts can be expanded by duplication to support additional people but are not considered long-term solutions. Facilities addressed in this chapter consist of expedient field latrines, urinals, and hand-washing stations. These concepts should help personnel accomplish the minimum requirements for sanitation needs until additional, more permanent resources are obtained.

Figure 6.1. Typical Deployment Package Sanitary Asset.

6.3. Human Waste Disposition Policy. Air Force policy directs that human waste be disposed of with good sanitary practices; and the Air Force must comply with federal, state, and local environmental laws for human waste. Few laws specifically address human waste disposal in the field; nevertheless, proper human waste disposal is essential to maintaining good health and requires command emphasis at all levels. For more information on managing waste disposal, see AFH 10-222, Volume 4, *Environmental Guide for Contingency Operations Overseas,* and FM 3-100.4, *Environmental Considerations in Military Operations.*

6.3.1. **Responsibilities.** At installation level, base engineers are responsible for constructing, maintaining, and operating fixed sewage systems. Commanders are responsible for providing human waste disposal facilities in the field. During contingencies when deployable kits are not available, engineer support will be required to construct various types of field disposal devices.

6.3.2. **Field Facility Considerations.** The type of field latrine selected for a given situation depends on a number of factors–the number of personnel, the duration of the stay at the site, and geological and climatic conditions. Preventive-medicine personnel can assist in determining the right type, location, number, and size of latrines. The locations of base camp latrines are usually a compromise between the requirement for separation from dining facilities and water sources and convenience for personnel. Multiple latrine sites are clearly necessary for larger base camps. Sanitation and maintenance are critical to prevent disease transmission to and from personnel.

6.4. Latrine Facilities. Expedient latrines are basic versions of either pit or aboveground drum- type latrines. They are intended for temporary use until more suitable facilities are erected or while an existing sanitary sewer system is being rehabilitated.

6.4.1. **Basic Field Requirements.** The following general rules apply to constructing all types of pit latrines, except cat holes. To ensure that food and water are protected from contamination, latrines should be at least 100 yards from the dining facility and 100 feet from the nearest water source. Latrines should not be dug below the groundwater table or where they may drain into a water source. (The groundwater table can be determined from information given by local inhabitants or excavating to the groundwater table.) Latrines are usually built at least 30 yards from the end of the unit area but within a reasonable distance for easy access. They should be lighted at night if the military situation permits. If lights cannot be used, tie pieces of cord or tape to trees or stakes as guides to the latrines. **Note:** Latrines must be policed daily. Specific unit personnel are to be assigned the responsibility of ensuring that the latrines are always properly maintained.

6.4.1.1. **Drainage and Fly Control.** Place a canvas or brush screen around each latrine or enclose it in a tent. If possible, heat the shelter in cold climates. Dig a drainage ditch around the screen or tent to prevent water from flowing over the ground into the latrine. For fly control, spray the shelter with an insecticide twice a week. If fly problems persist, spray the pit contents and box interior twice a week with a residual insecticide.

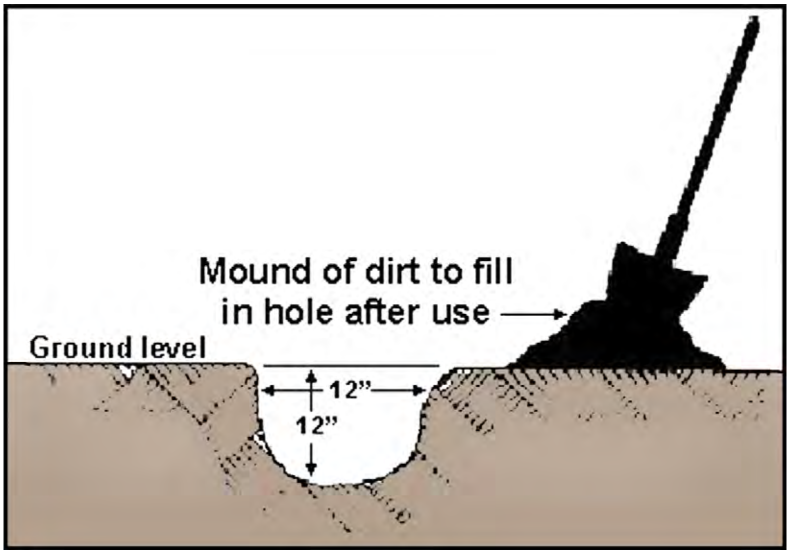
6.4.1.2. **Latrine Closing Procedures.** Close a latrine pit when it is filled to within 1 foot of the surface or when it is being abandoned. Remove the latrine box and close as follows: (1) fill the pit to the surface with successive, 3-inch layers of earth and pack each layer down, (2) place a l-foot mound of dirt over the length of the pit to prevent fly pupa from getting out of the closed latrine, and (3) install a rectangular sign on top of the mound. The sign should indicate the type of pit and the date closed; include the unit designation in non-operational areas.

6.4.2. **Types of Field Latrines.**

6.4.2.1. **Pit Latrines.** There are several versions of the pit latrine and as the name suggests, it involves digging a pit in the ground. This type of latrine is normally used where the groundwater table is deep enough to prevent groundwater contamination or water standing in the latrine pit. It is also limited to areas that are free of impervious rock formations near the surface. The pit latrines addressed in this chapter include the cat hole, cross tree, straddle tree, deep pit, and bore hole latrines. Alternatives to pit latrines are available for locations where a high groundwater table or a rock formation near the surface prevents digging a pit of adequate depth. They will be addressed later in this chapter.

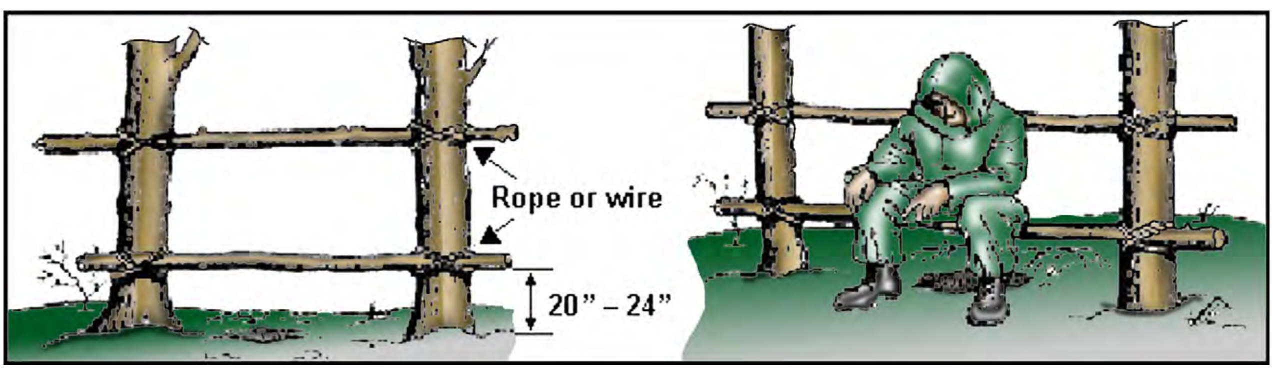
6.4.2.1.1. **Cat Hole Latrine.** The simplest of all pit latrines and field human waste disposal devices is the cat hole latrine (see **Figure 6.2.**). This latrine is used by individuals on the move or when on patrol (if individual waste collection bags are not available) and is covered immediately after use. It is also used in situations where latrine facilities are not available. As indicated in the drawing, a cat hole latrine should be dug at least 1 foot wide and 1 foot deep. After use, replace and repack the removed soil.

Figure 6.2. Cat Hole Latrine.



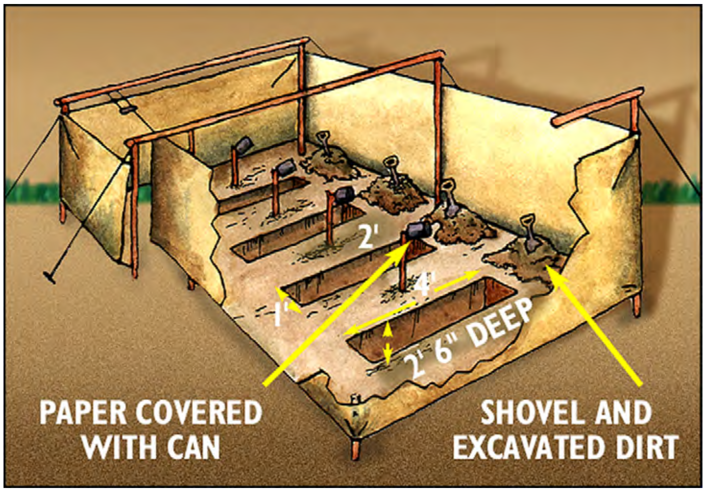
6.4.2.1.2. **Cross Tree Latrine.** Another very basic latrine is the cross tree type (see **Figure 6.3.**). One latrine will usually serve the needs of 6 to 8 personnel. As might be expected, the latrine is situated downwind from the beddown area, but not so far from the shelters as to encourage individuals to break sanitary discipline. In areas where it is difficult to dig a pit, ration boxes or similar material should be used to collect waste. A urinal, designated for each shelter, should also be located within 4 to 5 meters (4 to 5 yards) of the shelter. Urinal variations are provided elsewhere in this chapter. A windbreak of boughs, tarpaulins, ponchos, or snow wall can be constructed to provide both privacy and protect the latrine from the wind.

Figure 6.3. Cross Tree Latrine.



6.4.2.1.3. **Straddle Trench Latrine.** The most common type of latrine for temporary (one to three days) beddowns is the straddle trench or straddle pit latrine (see **Figure 6.4.**). A straddle trench latrine is usually dug 1 foot wide, 2 1/2 feet deep, and 4 feet long. In this configuration, it will accommodate two people at the same time. Provide straddle trenches to serve at least 4 percent of the unit's male strength and 6 percent of the female strength. Thus, for a unit of 100 men and 100 women, at least four latrines are needed for the men and six for the women. Place the trenches at least 2 feet apart. As shown in the drawing, there are no seats with this type of latrine. Instead, boards may be placed along both sides of the trench to provide better footing. Place toilet paper on a suitable holder and protect it from bad weather with a tin can or other covering. Remove the earth and pile it at the end of the trench so that each individual can properly cover his excreta and toilet paper.

Figure 6.4. Typical Straddle Trench Latrine.

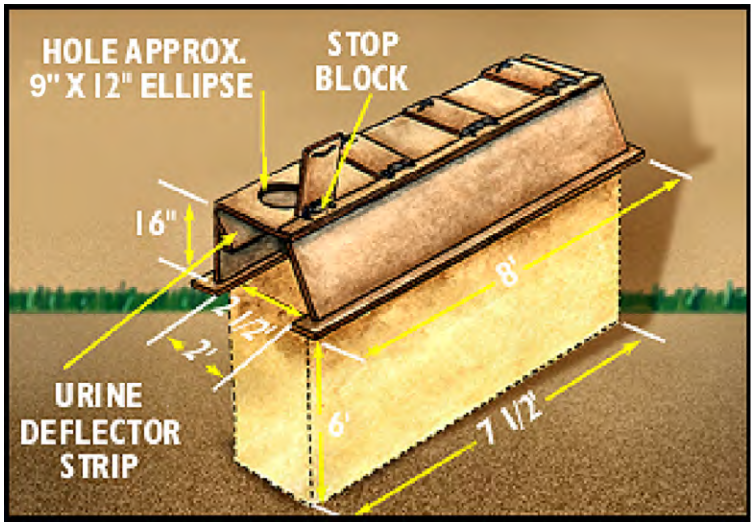


6.4.2.1.4. **Deep Pit Latrine.** The deep pit latrine is used for longer periods of time and in built-up areas. As shown in **Figure 6.5.**, it is used with a latrine box. The standard latrine box has four seats and is 8 feet long and 2 1/2 feet wide at the base. A unit of 100 men requires two four-seat latrine boxes. Cover the holes with fly-proof, self-closing lids. Fly proof the cracks with strips of wood or tin. Place a metal deflector (can be made with a flattened can) inside the front of the box to prevent urine from soaking into the wood.

6.4.2.1.4.1. Dig the pit about 2 feet wide and 7 1/2 feet long. This will give the latrine box 3 inches of support on all sides. The depth of the pit depends on the estimated length of time the latrine is to be used. As a rough guide, allow a depth of 1 foot for each week of estimated use, plus 1 foot for the dirt cover when closed. Rock or high groundwater levels often limit the depth of the pit, but it should be no deeper than 6 feet. Support may be needed in some types of soil to prevent the sides from collapsing. If so, use planking or a similar material. Pack the earth tightly around the bottom edges of the box to seal any openings through which flies might enter. **Note:** If the ground is too hard for digging or if the water table is too high, use a pail latrine or a burnout latrine instead. Both are described elsewhere in this chapter.

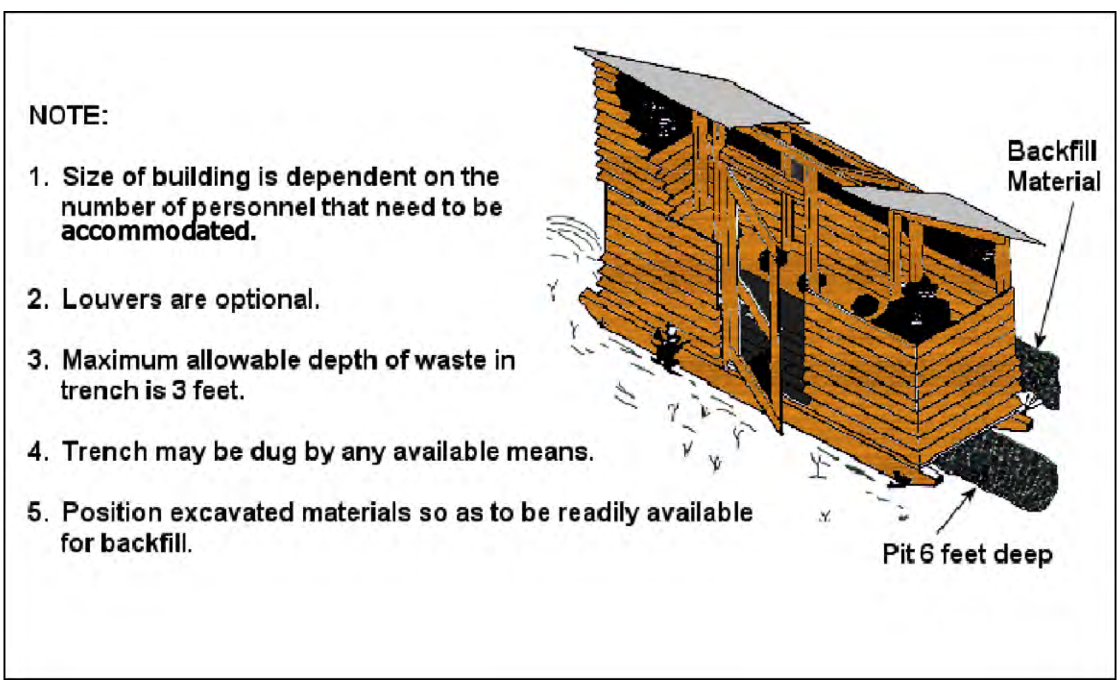
6.4.2.1.4.2. To prevent flies from breeding and to reduce odors, keep the latrine box clean, the seat lids closed, and the cracks sealed. Maintain a good fly control program in the area. Applying lime to the pit contents or burning it does not effectively control flies or odor. The box and latrine seats should be scrubbed with soap and water daily.

Figure 6.5. Deep Pit Latrine.



6.4.2.1.5. **Portable Latrines.** The portable latrine uses a latrine box similar to the deep pit latrine except the latrine box is built inside a portable structure that offers limited privacy and protection from the elements. If prepackaged deployable sanitation assets are delayed during a sizeable deployment or beddown activity; this more substantial portable latrine may serve large groups better than some of the other expedient options discussed in this chapter. Portable latrines vary; however, all are built on the same basic precepts of mobility, adequate ventilation, proper sanitation, and reasonable privacy. Once the supporting pit is filled, the latrine is simply relocated to another spot, usually in the same vicinity, and the old pit is then filled and closed as discussed previously. Figure 6.6. shows an example of this type of facility.

Figure 6.6. Portable Latrines.



6.4.2.1.6. **Bored Hole Latrine.** A bored hole latrine consists of a hole that is about 18 inches in diameter and 15 to 20 feet deep. As indicated in **Figure 6.7.**, a one-hole latrine box covers it. The actual diameter is not critical, so make it as large as available augers permit. Remove both ends of a metal drum and sink it into the ground to serve as a box. Make a fly-proof seat cover with a self-closing lid to fit the top of the drum. If a drum is not available, construct a fly-proof, wooden box that is 18 inches high. A bored hole latrine is satisfactory for small units.

6.4.2.2. **Expedient Latrines in High Groundwater Areas.** Latrines should not be dug below the groundwater table or where they may drain into a water source. The groundwater table can be determined from information given by local inhabitants or excavating to the groundwater table. The latrines described below are normally used where the groundwater table is high and groundwater contamination or water standing in the latrine pit is probable. They are also ideal when an impervious rock formation is close to the surface, preventing adequate dispersal of liquids.

6.4.2.2.1. **Mound Latrine.** A dirt mound makes it possible to build a deep-pit latrine without the pit extending into water or rock. Construct a mound of earth that is at least 6 feet wide and 12 feet long. It must be able to support a four-hole latrine box. The mound should be high enough to meet the pit's depth requirement. Allow 1-foot from the base of the pit to the water or rock level. Break up or plow the area where it is to be placed to aid in seepage of liquids from the pit. If timber is available, build a crib of desired height to enclose the pit and support the latrine box. Build the mound and compact it in successive l-foot layers to the top of the crib as shown in **Figure 6.8.** Roughen the surface of each layer before adding the next. If timber for a crib is unavailable, construct the mound to the desired height in l-foot layers, as described and dig the pit into the mound. If necessary, brace the walls with wood, sandbags, or other material to prevent them from collapsing. Fly proof and enclose a mound latrine as described in paragraph **6.4.1.1. Note:** The size of the mound base depends on the type of soil in the area. Make the mound larger if the slope is steep. Also, it may be necessary to build steps up a steep slope.

Figure 6.7. Bored Hole Latrine.

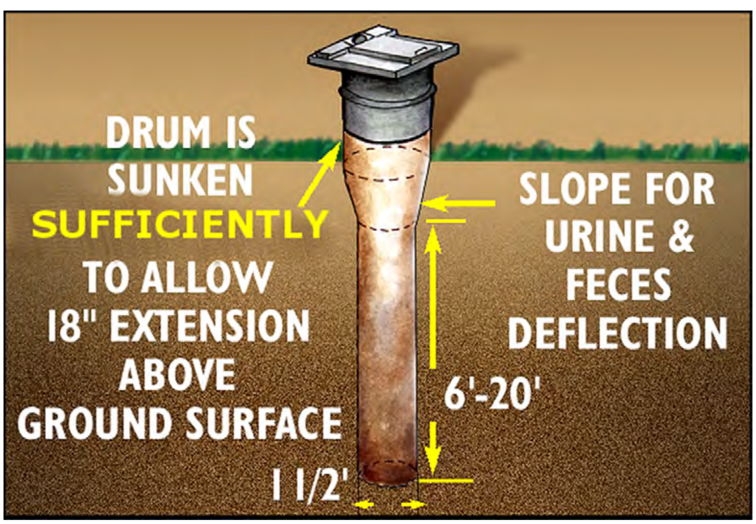
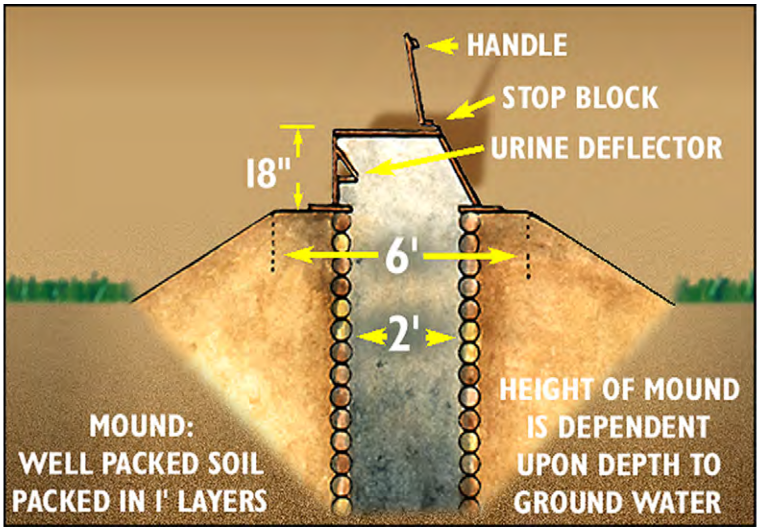


Figure 6.8. Mound Latrine.



6.4.2.2.2. **Burn Out Latrine.** A burn out latrine (**Figure 6.9.**) is particularly suitable for jungle areas with high groundwater tables. It has also been extremely useful in the past in desert regions where an impervious rock layer lay a short distance under the sand. When using this technique, ensure the burning location is downwind of the base camp. For a unit of 100 men and 100 women, at least eight men's latrines and eight women's latrines are needed. As shown in **Figure 6.10.**, construct a burn out latrine by first placing a 55-gallon drum in the ground. Leave enough of the drum above the ground for a comfortable sitting height. The drum may be cut in half, making two latrines of less capacity. Place a wooden seat with a fly-proof, self-closing lid on top of the drum. Weld handles to the sides of the drum, allowing two men to carry it with ease, because drums must be moved before the contents are burned. Have two sets of drums, if possible, so one set can be used while the other set is being burned out. Encourage male personnel to urinate in a urine disposal facility rather than a burn out latrine because more fuel is required to clean a latrine with a liquid content. Burn the contents of each drum daily by adding sufficient fuel to incinerate the fecal matter (**Figure 6.11.**). Do not use highly volatile fuel because of its explosive nature. A mixture of 1 quart of gasoline to 5 quarts of diesel oil is effective; nevertheless, use it with caution. Burn the contents again if they are not rendered dry and odorless in one effort. Bury the residual ash once the burning process is complete.

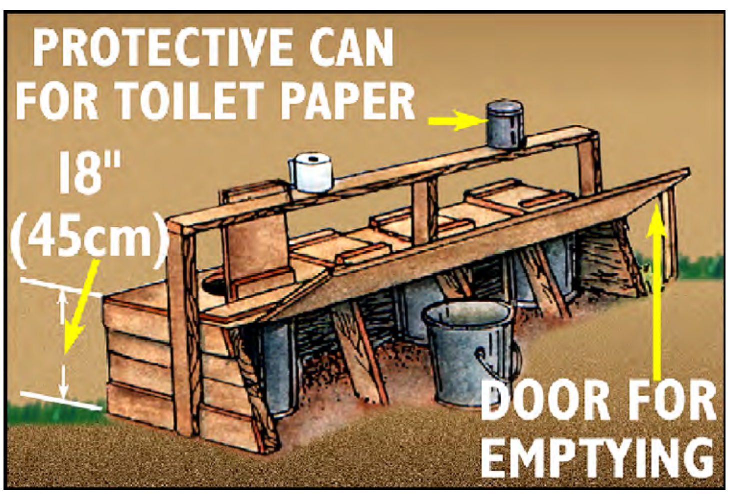
Figure 6.9. Multiple-Station Burn Out Latrines.

Figure 6.10. Burn Out Latrine Details.

Figure 6.11. Performing Daily Burn Out Latrine Functions.

6.4.2.2.3. Pail Latrine. Build a pail latrine when conditions (populated areas, rocky soil, marshes) are such that a latrine cannot be dug. Construct a standard latrine box according to paragraph **6.4.2.1.4.** Also add a floor and place a pail under each seat. Place hinged doors on the rear of the box (see **Figure 6.12.**) to facilitate removal of pails when emptying. Position the box to form a part of the outer wall (if the box is located in a building) while ensuring that the rear of the box opens directly to the outside of the building. The box should be fly proof, and the seats and rear doors should be self-closing. Construct the floor of the box with an impervious material (concrete if possible) and allow enough slope toward the rear to facilitate rapid drainage of washing water. Clean pails at least once daily and bury, burn, or dispose of the contents by another sanitary method. Plastic liners for the pails reduce the risk of accidental spillage. Tie the filled bags at the top before disposal.

Figure 6.12. Typical Pail Latrines.

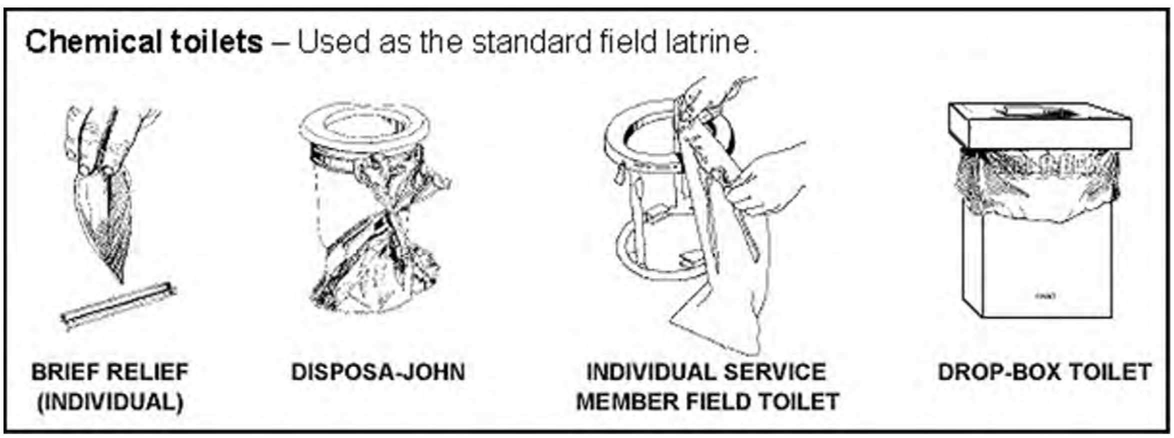


6.4.2.3. **Alternate Latrine Options.** During certain contingencies, a lack of resources may make it difficult to build one of the aforementioned latrines. In such situations, the makeshift toilet described below may serve as a temporary solution. In contrast, where time and resources are plentiful, it may be worthwhile to construct mobile latrines ahead of an anticipated population increase. These options address both ends of the spectrum—from rudimentary to a cut above simple functionality. Both have their place during the right situation.

6.4.2.3.1. **Makeshift Toilet.** During an emergency or during field activities where digging a cat hole latrine is not an option, an expedient toilet can be made using a common water bucket. Simply line a bucket with a garbage bag and make a toilet seat out of two boards placed parallel to each other across the bucket. After each use, pour a disinfectant such as bleach (1 part liquid chlorine bleach to 10 parts water) into the garbage bag to help avoid infection and stop the spread of disease. Cover the bucket tightly when it is not in use. Bury garbage and human waste to avoid the spread of disease by rats, insects, and other vectors. Dig a pit two to three feet deep and at least 50 feet downhill or away from any well, spring, or water supply.

6.4.2.3.2. Personal Toilets. During very short deployments or during special operations, individuals may be provided personal chemical toilets (**Figure 6.13.**). Also, when on a march, personal disposal bags should be used first, if available. If not available, personal cat holes are another option. Always dispose of waste immediately to prevent flies from spreading germs from waste to food or water supplies. Disposing of waste also helps keep unwanted animals out of the beddown area.

Figure 6.13. Typical Personal Chemical Toilets.



6.5. Urinals. In permanent and semi-permanent camps, urine disposal facilities are usually connected to the sewer system. However, in the field, separate devices for urine disposal are often necessary. At least one urine disposal facility is required for each male latrine or per 100 personnel. Following are examples of some of the more common expedient field devices used for the disposition of urine and their applicable maintenance procedures. As a general rule, urinals should always be situated either in or very near male latrines. This avoids undesirable soiling of the latrine seats and immediate area.

6.5.1. Urine Soakage Pit. One of the best devices for urine disposal in the field is a urine soakage pit (see **Figure 6.14.**). Begin construction of this item by digging a pit 4 feet square and 4 feet deep. Next, fill it with an aggregate material and lay a border along each edge so that each side of the soakage pit's surface is 5 feet long. Ideally the border should be 6 inches wide, 4 inches deep, and composed of small stones. Depending on available materials, use either pipe urinals or trough urinals with this pit. An optional feature is the ventilating shafts with screened openings that extend from about 8 inches above the pit to within 6 inches of the bottom of the pit. As shown in **Figure 6.14.**, pipe urinals should be at least 1 inch in diameter and installed at an angle near each corner of the pit or, if needed, on the sides halfway between the corners. The pipes should extend at least 8 inches below the surface of the pit. Place a funnel made of tarpaper, sheet metal, or similar material in the top of each pipe. The upper rim of the funnel should extend about 30 inches above the ground surface. For fly control and as a sound sanitation practice, if tarpaper funnels are used, fill the funnels with straw and replace them on a daily basis. Note: A soakage trench (see paragraph **6.5.4.**) may be used when the groundwater table or a rock formation precludes digging a standard urine soakage pit.

6.5.2. **Trough Urinal.** If materials are available and more permanent facilities are desired, build a trough urinal as shown in **Figure 6.15.**. The trough is U- or V-shaped and made of sheet metal or wood. If it is constructed of wood, line it with heavy tarpaper. The four troughs forming the sides should be no more than 4 1/2 feet long when they are used with a soakage pit and an apron. Each trough should slope slightly toward one corner where a pipe carries the urine to the soakage pit. Another expedient urinal variation is shown in **Figure 6.16.**

Figure 6.14. Typical Urine Soakage Pit.

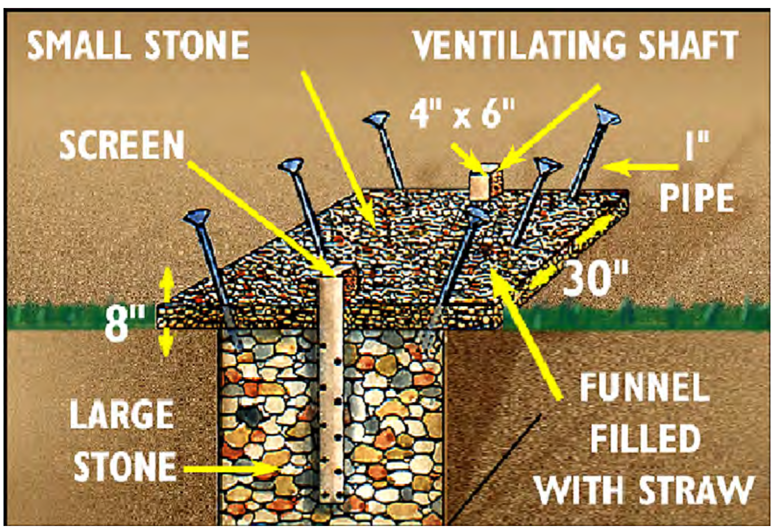


Figure 6.15. Common Trough Urinal.

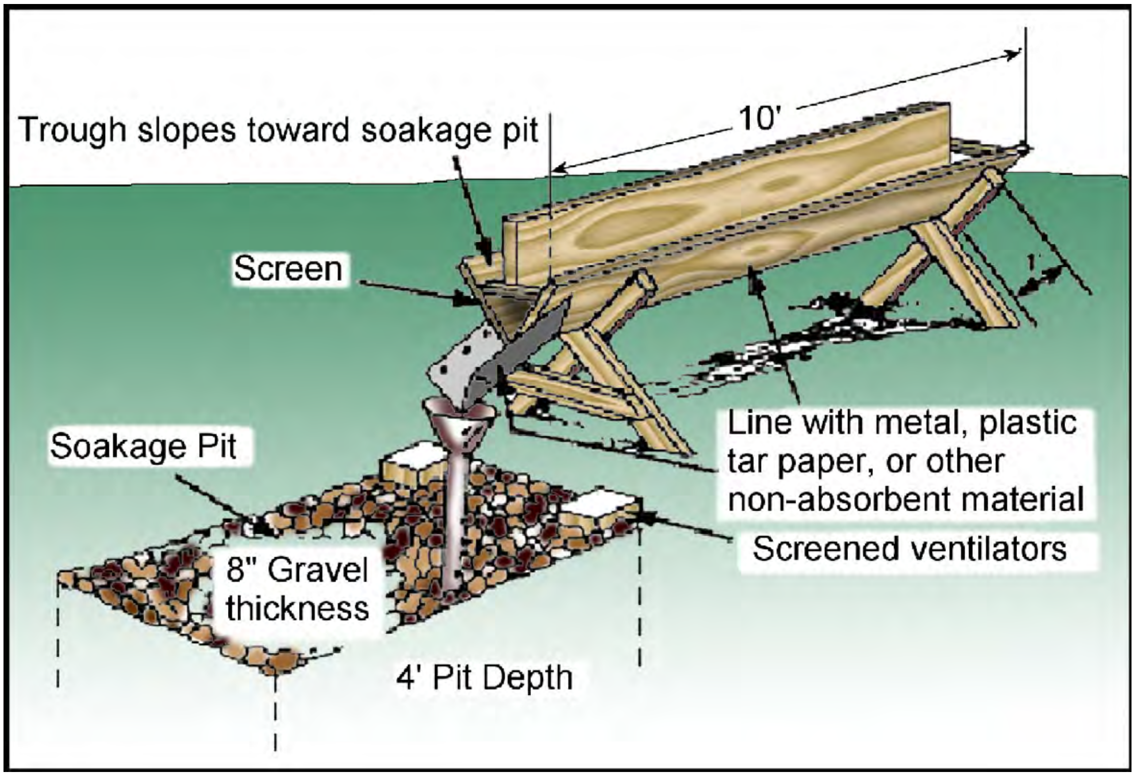
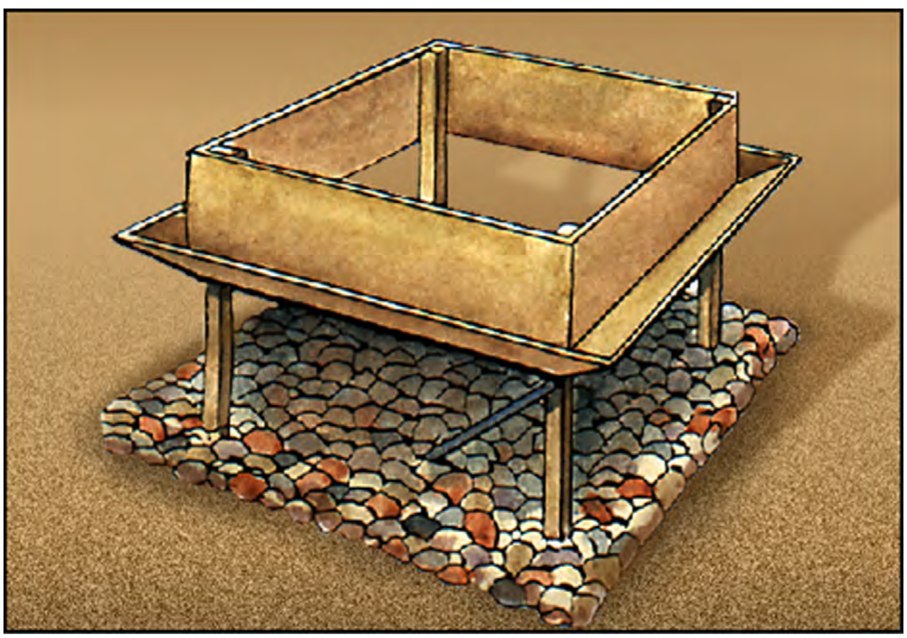


Figure 6.16. Trough Urinal Variation.



6.5.3. **Urinoil.** The urinoil represents a further modification for more permanent installation (**Figure 6.17.**). In its simplest form, an urinoil is a 55-gallon drum containing oil that is placed over a recessed soakage pit, thus the name, urin oil. Waste POL can be used; but vegetable oil is preferred. Urine voided through the screen immediately sinks through the oil to the bottom of the drum. The action of the urinal is somewhat like that of a barometer. As more urine is added, the oil level rises in the 3-inch pipe. This continues until it reaches the 1 1/2-inch notch on the overflow pipe in the center of the drum. Atmospheric pressure and the weight of the oil cause the urine to overflow until equilibrium is reestablished in the drum. The oil also acts as an effective seal against odors and flies. The screen is easily lifted with attached hooks for removal of debris. To initiate the operation of the urinoil, place the prepared drum in position on the soakage pit and tamp the ground around the drum to the level shown in the drawing. Next, pour at least one foot of water into the drum. Lastly, add waste oil (about 32 gallons) until the oil reaches the point indicated in the graphic. The urinoil is now ready for use and will remain functional as long as the soakage pit will accept urine.

6.5.4. **Soakage Trench.** Use a soakage trench (**Figure 6.18.**) when the groundwater level or a rock formation precludes digging a soakage pit. The trench consists of a pit, 4 feet square and 1 foot deep. The pit has a trench radiating outward from each side for a distance of 6 or more feet. Dig the trenches 1 foot wide, varying the depth from 1 foot at the center to 1 1/2 feet at the outer ends. Fill the pit and trenches with material similar to that used in the soakage pit.

6.5.5. **Maintenance of Urine Disposal Facilities.** Proper maintenance of urinal facilities consists of the steps in **Table 6.1.**

Figure 6.17. Basic Urinoil Details.

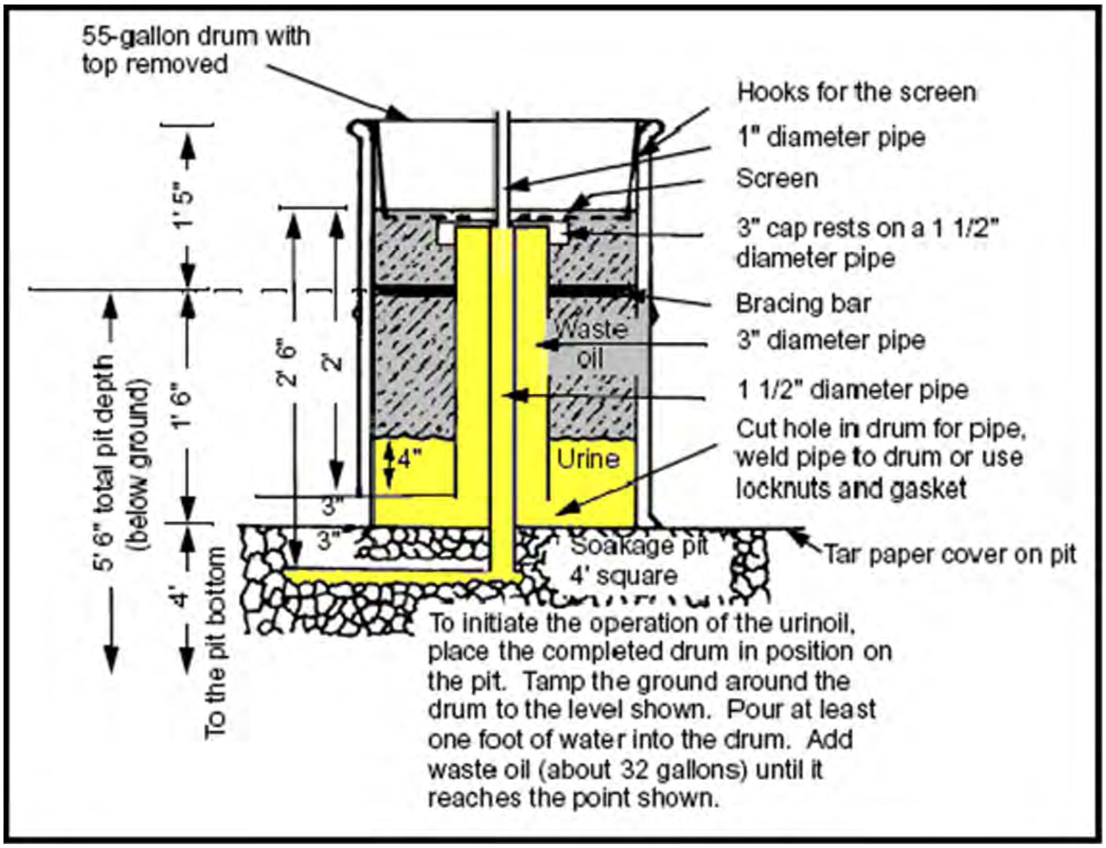


Figure 6.18. Soakage Trench.

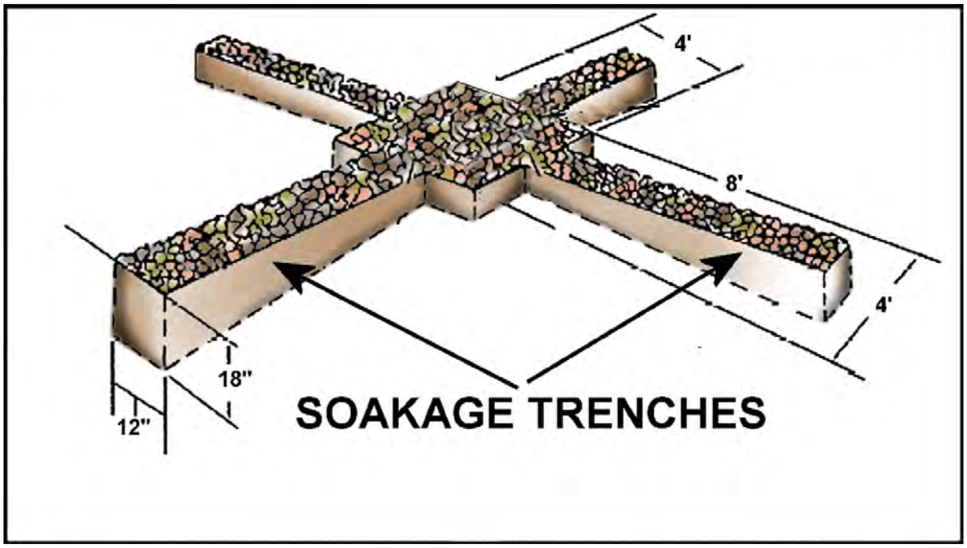
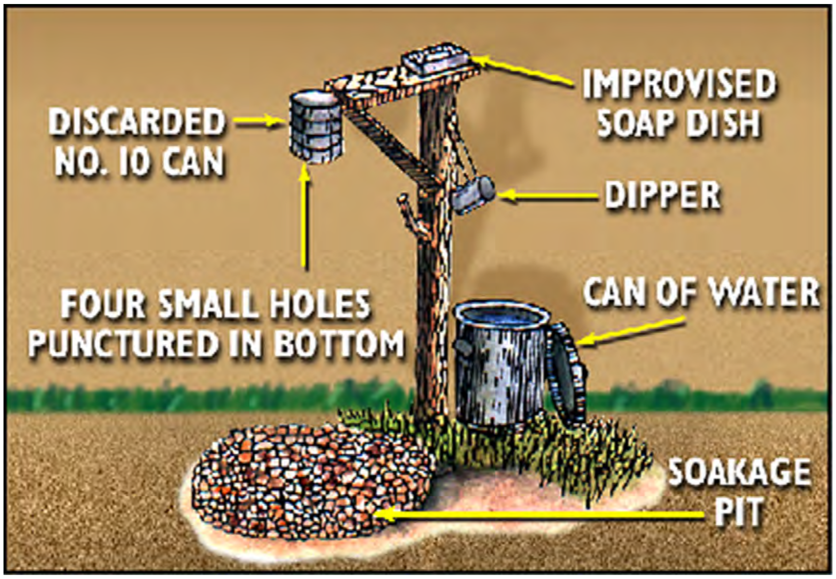


Table 6.1. Urinal Maintenance.

Urinal Maintenance	
Step 1	For proper operation and sanitary purposes, individuals must urinate in the trough or the pipe, not directly on the pit's surface.
Step 2	Wash funnels and troughs with soap and water daily.
Step 3	Replace funnels when necessary.
Step 4	Prevent oil or grease from getting into the pit to prevent clogging. Oil leeching through the pit may also contaminate the groundwater.
Step 5	If the latrine is located some distance from sleeping areas, place a large can or pail at a convenient location for use as a urinal at night. Empty the can into the trough, pipe, or soakage trench every morning, and wash the pail with soap and water before reusing it.
Step 6	When a urine soakage pit is abandoned or becomes clogged, spray it with insecticide. Mound it over with a 1-foot covering of compacted earth and place a rectangular sign on the mound indicating the type of pit and date of closure.

6.6. Expedient Hand-Washing Devices. Simple hand-washing devices must be available at field latrine locations. These devices should be easy to operate and have a constant supply of water. As previously mentioned, the importance of hand-washing devices must be given aggressive emphasis, because hands contaminated with fecal material are a common means of disease transmission. An expedient hand-washing device is shown in **Figure 6.19.**

Figure 6.19. Expedient Hand Washing Device.



Chapter 7

CONSTRUCTING EXPEDIENT SOIL BERMS AND DIKES

7.1. Introduction. In today's high-tech engineering environment, low-tech engineering solutions are sometimes the best way to satisfy certain expedient field construction requirements. A prime example is the building of berms and dikes. In addition to force protection requirements, engineers are frequently tasked to build earthen berms for landfills, hazardous materials, burn pits, aircraft engine blast and noise abatement, and other expeditionary activities. Dikes are often constructed for spill control, flood control, and basic water management operations. Both berms and dikes have been around for centuries and like today, ancient engineers also used these methods for fortification and water management. The simplicity of design, ease of construction, and effectiveness ensure berms and dikes will continue to be a valuable engineering solution in the future.

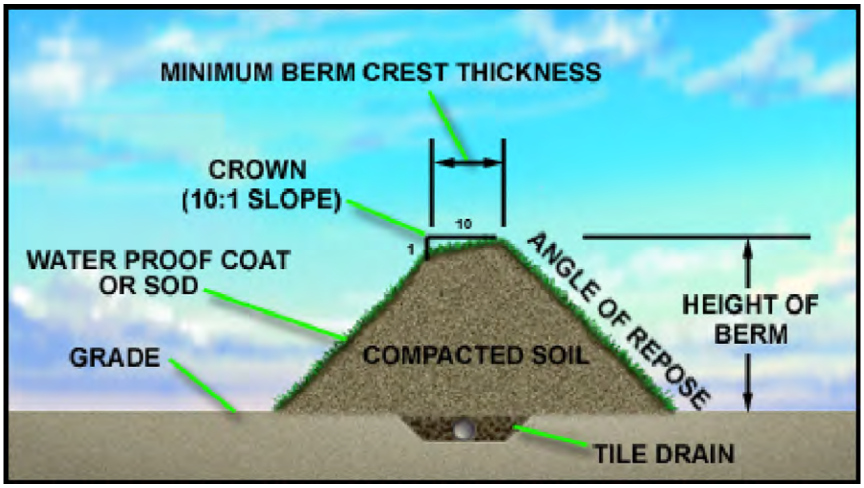
7.2. Overview. This chapter reviews expedient field construction procedures for soil berms and dikes and highlights how these applications are used to satisfy specific engineering challenges. There are several definitions for berms. Many are described as a raised barrier or bank of earth that separates two areas (see **Figure 7.1.**). Conversely, dikes are often depicted as a ditch or channel or as a raised barrier that encloses an area. Each of these berm and dike applications will be addressed in this chapter.

Figure 7.1. Berm Construction During Desert Operations.

7.3. Soil Berms. In an expeditionary field environment, soil berms are constructed around different sites and facilities for a variety of reasons. They can be employed as either freestanding structures or built against building exterior walls and retaining walls. Freestanding berms typically require more soil and room to construct than other berms; however, they are very effective when employed in applications such as burn pits, landfills, and hazardous material storage.

7.3.1. **General Construction Requirements.** Due to their size, most berm construction usually involves the use of heavy construction equipment. Typically, the berms are built of compacted soil and must be designed to contend with the ever-present effects of gravity. If the sides of a berm are too steeply sloped, the soil will shift. Because of this, the base of berms is often at least three times the width at the top. **Figure 7.2.** shows some general berm construction requirements. The top of a berm should have a 10-to-1 slope to minimize water ponding on the crest and subsequently soaking into the structure's interior. Also, once built, the sides of earthen berms should be faced to control erosion. A variety of face-sealing methods are available to meet this purpose. Sod and polyethylene are two common methods. Other construction guidelines and factors are explained in the following paragraphs. **Table 7.1.** provides labor comparisons for construction of soil berms and other types of revetments. As can be seen, berms are generally less labor intensive and quicker to build than some of the more common revetment materials—particularly sandbag protective structures.

Figure 7.2. General Berm Construction Factors.



7.3.2. **Berm Base Dimensions and Slope Angle.** For general planning purposes, expect to make the base of a freestanding berm three times its height. However, if time is available, a more detailed analysis may be in order. Simply put, the allowable side slope of the berm face coupled with the width of the berm crest determines the width of the berm base. In practice, for expedient situations, the maximum realistic slope is the natural angle of repose of the soil. The lesser the slope, the greater berm stability during inclement weather. For cohesionless soils (those composed primarily of sand), the slope angle can be taken as the angle of internal friction. **Table 7.2.** gives friction angles for a range of soil types. However, if the soil type is unknown or time is not available to conduct proper compaction, it is generally conservative to use a 1-to-2 slope for preliminary design and planning purposes. For cohesive soils, greater slopes can typically be sustained. If time permits perform a slope failure analysis as described in standard soil mechanics texts or handbooks. A specific reference source is the multiservices product, Unified Facilities Criteria 3-220-03FA, *Soils and Geology Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures).*

Table 7.1. Construction Man-Hour Comparisons.

Revetment Type	Size	Construction Man-Hours Per 100ft^2 of Vertical Protection
Freestanding Berm	10 feet high by 3-foot crest	2.7
Bermed Wall	10 feet high by 3-foot crest	1.6
Sandbag Wall	10 feet high by 2.67 feet wide	90.0
A-1 Steel Bin Revetment	12 feet high by 5.25 feet wide	20.1
B-1 Steel Bin Revetment	16 feet high by 6.9 feet wide	22.6
Sandgrid	8 feet high by 3.17 feet wide	16.0
4-Meter Aircraft Revetment	13.7 feet high by 0.8 foot thick	0.9
Bitburg Revetment	6.58 feet high by 1 foot thick	0.9

Assumptions:

- Berms will be built using a front-end loader
- 4-Meter Aircraft and Bitburg Revetments are pre-positioned
- Ten sandbags could be filled and stacked per man-hour

Table 7.2. Cohesionless Soils Angles of Internal Friction.

ANGLE OF INTERNAL FRICTION OF COHESIONLESS SOILS	
Type of Soil	**Angle of Internal Friction**
Very loose sand	<29
Loose sand	29-35
Medium sand	30-40
Dense sand	36-45

For cohesionless soils (those compos ed primarily of sand), the slope angle can be taken as the angle of internal friction.

7.3.3. **Other Consequential Factors.** Other factors that must be taken into account when planning to construct any type of berm are soil composition, moisture content retention, proper drainage, and compaction requirements (see **Table 7.3.**).

Table 7.3. Other Construction Factors.

Soil Composition Factors:
A number of soil composition factors directly impact the performance of any earthen structure. In fact, the soil consistency of a berm has a direct relation to its stability and performance. In general, soil is primarily composed of sand or clay. There are also sandy loams and clay loams, but those are normally restricted to the relatively thin top layer of earth known as topsoil.
Moisture Content:
As addressed earlier in the chapter, it is very important that adequate measures be taken to seal the exterior of the structure at beddown locations where the annual precipitation level is high.
Proper Drainage:
Drainage should always be a prime consideration when constructing any earth berm. Poor drainage can rapidly undo all the hard work involved in building the structure. If the berm is to be built in a region of high rainfall, consider installing an interior drainage tile to remove moisture that may seep into the structure's encasement.
Compaction Requirements:
Proper compaction is an essential part of berm construction, regardless of the type of berm or soil involved. Basically, berm material is compacted to increase its density—greater density increases stability and performance. Berm compaction is done in layers, and the extent is dictated by both the soil type and its moisture content. Usually, compactions will occur after every 6-to-12-inch layer of material has been placed. Compaction can be accomplished using a hand tamp, portable vibratory tamper, or pneumatic plate. Heavy equipment (dozers/loaders) can compact in layers if tampers and rollers are not readily available. The hand tamp approach (**Figure 7.3.**) is a slow, labor-intensive process, but its simplicity means that it should always be available. The portable vibratory tamper (**Figure 7.4.**) is a motorized hand-controlled tool about the size of a common household lawn mower. The pneumatic plate is an excavator attachment and is one of the fastest methods available. A vibratory roller (**Figure 7.5.**) may also be used where construction of very large berms is involved.

Figure 7.3. Airman Using Portable Hand Tamp.

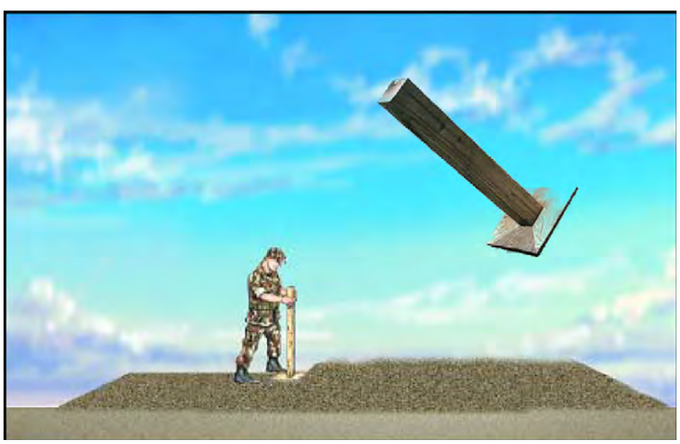


Figure 7.4. Portable Vibratory Compactors.

Figure 7.5. Vibratory Roller.

7.3.4. **Negative Aspects of Soil Berms.** Soil berms offer simple and effective engineering solutions to several field construction requirements. Soil berms also have negative aspects, especially from an expediency approach. The principle disadvantage associated with using berms is their large space requirements. Soil berms may not be a practical solution in very rocky terrain or where grading equipment is not available. Heavy equipment availability is an absolute necessity. Berms sited near taxiways and runways may increase problems related to blowing dust and debris. Arid locations, such as desert beddown sites, are particularly susceptible to this predicament. At such sites, erosion control measures are of particular importance. In areas where there is a large amount of rainfall, berms will require frequent maintenance, particularly if the sides and crest are not waterproofed, covered with sod, or otherwise adequately stabilized. If berms use sod as protective cover, slope angles steeper than 1 foot vertical to 3 foot horizontal (1V:3H) could make mowing grass difficult.

7.3.5. **Slope Protection for Soil Berms.** Many different types of slope protection have been employed to counter the effects of soil berm erosion. Techniques such as grass or vegetation, gravel, sand-asphalt paving, concrete paving, articulated concrete mats, riprap or rock blankets, and several different types of geotextile material have been used depending on the level of protection needed. However, in an expeditionary environment where time and resources are generally limited, techniques such as riprap, articulated mats, or paving may be avoided if high-class slope protection is not needed. Grass, geocells, or other geotextile protection methods may provide lower-class slope protection options, if necessary. Table 7.4. addresses the function or suitability of grass and geocells as slope protection. Slope protection for soil berms utilized as containment dikes and levees requires special consideration. Review paragraph 7.4.2. for information on dike and levee construction.

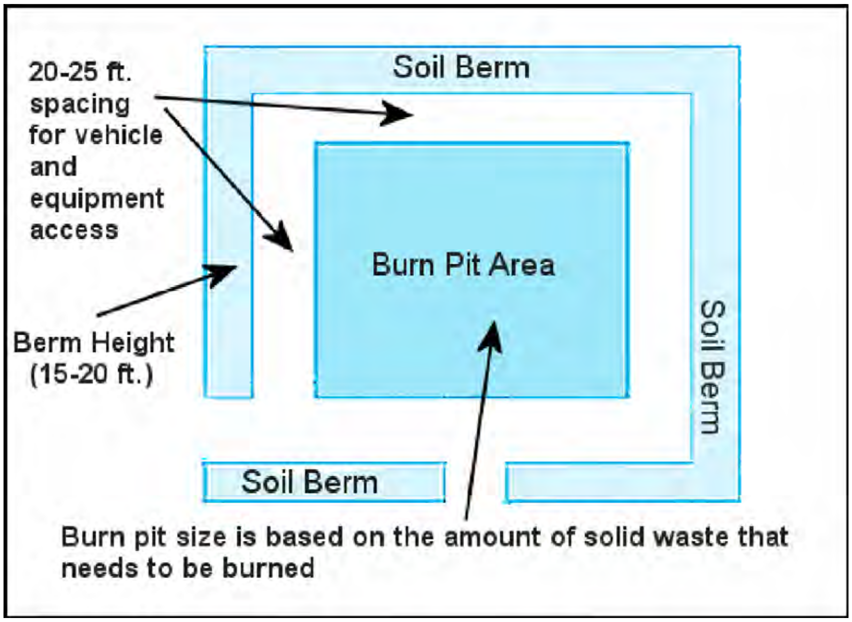
Table 7.4. Berm Slope Protection.

BERM SLOPE PROTECTION COVERS	
Type	Function or Suitability
Grass or Vegetation	• Counteracts soil movement down the slope and erosion from rainfall • Reinforces soil by providing network of roots that resist soil shearing • Permits excess water to drain from the slope
Geocells	• Limits soil movement down the slope • Soil confinement system that stabilizes soil berm fill material through use of cells or grids

7.3.6. **Berm Applications.**

7.3.6.1. **Burn Pits.** Burn pits are normally constructed to dispose of solid waste and hazardous waste materials. Burn pits at beddown locations will often be collocated with the base controlled waste disposal area. Burn pits are normally located far away from the main part of the installation to minimized personnel exposure to smoke and alleviate any impact on airfield operations caused by burning waste. As an added safety measure, a soil or earthen berm (usually 15'-20' high) is placed around the burn pit. Although berms for burn pits are constructed like other expedient berms, sometimes other features are incorporated into the design and construction of the pit. For example, dirt ramps may be added to allow access by dozers and compactors to perform routine maintenance on the pit. The size of the pit (and berm) is dictated by the amount of solid waste that needs to be burned in the pit. The height of the berm is also determined by factors at the beddown location. Factors such as groundwater table, pit design (above or below ground, loading ramps), maintenance equipment, personnel safety, etc., may affect how high the berm is built. Figure 7.6. is one example of a burn pit that utilizes a soil berm.

Figure 7.6. Typical Burn Pit Surrounded by a Soil Berm.



7.3.6.2. **Landfills, Hazardous Material Storage Areas, Airfields, and Firing Ranges.** Other than for force protection, freestanding soil berms are normally employed around these types of facilities to limit access, provide noise abatement, or provide a safety barrier. Regardless of the purpose or location, the construction procedures for freestanding soil berms are basically the same as those discussed in paragraph **7.3.1.** However, engineers should review and comply with ETL 06-11: *Small Arms Range Design and Construction*, when constructing soil berms for firing ranges.

7.4. Dikes. Dikes are generally constructed to support spill control measures or in response to floodwater emergencies and disasters. They consist of two basic features: either a raised embankment/barrier or a drainage ditch. The raised embankment is often constructed around fuel storage and distribution areas to limit damage due to accidental spills. Raised embankments are used in conjunction with ditch construction to hold back or drain floodwaters, respectively.

7.4.1. **Fuel Dikes.** Fuel dikes are constructed around POL tanks and bladders (**Figure 7.7.**) as a force protection measure and to contain fuel spills if the tanks rupture or catch on fire. Although the primary focus of this section is to address expedient fuel dike construction, a brief description of site selection and criteria is appropriate. Engineers tasked to build fuel dikes should work closely with logistics (fuels) specialists responsible for the design and operation of the fuel distribution system.

Figure 7.7. Dikes Placed Around Fuel Bladders.

7.4.1.1. **Site Criteria.** Selected sites should be in non-congested areas where other facilities do not interfere with fuel operations. Avoid locating fuel dikes in drainage areas above critical installations. Locate them in areas where a potential fuel fire will not spread down to other installation areas. The best sites are on flat ground in sloping terrain to allow for gravity flow to the issue side or first pumping station. Beachhead sites may be located in sandy seashore areas up from the beachline (**Figure 7.8.**). Sites should also have adequate drainage. Preferably, the water table should be more than 6 feet below the surface. Avoid marshlands, riverbanks, or bottomland subject to flooding and other sites with poor or undependabl drainage.

Figure 7.8. Cutting a Sand Dike for a Fuel Bladder.

7.4.1.2. **Fuel Dike Construction.** When constructing a fuel dike, the size or height should be such that the volume of liquid in the fuel bladder can be contained within the dike should a rupture occur. **Figure 7.9.** and **Figure 7.10.** give examples of a typical fuel dike construction. When preparing the surface, clear the site and grade about a 1 percent slope towards the issue side or tank drain location. Inspect the ground and remove any rocks, sticks, or sharp objects that could puncture the bladder. Place a dike basin drain at the lowest end of the bladder pad. The drain is a pipe (2-inch diameter minimum) with a gate valve. Place this pipe under the dike construction. The dike should extend about 1 foot above the fuel tank and be at least 4 feet wide at the crown. The walkway area between the dike and the fuel bladder should be about 2 feet wide to allow for maintenance.

Figure 7.9. Typical Fuel Dike.

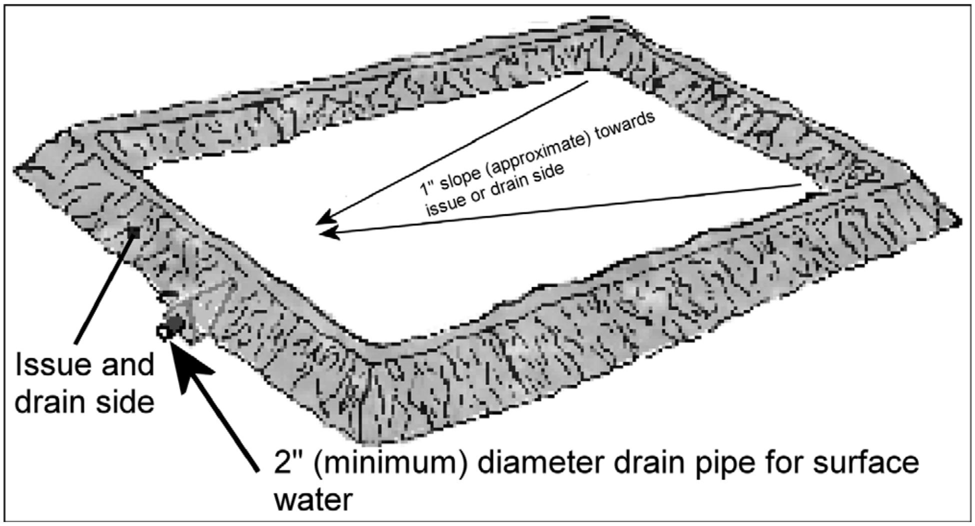
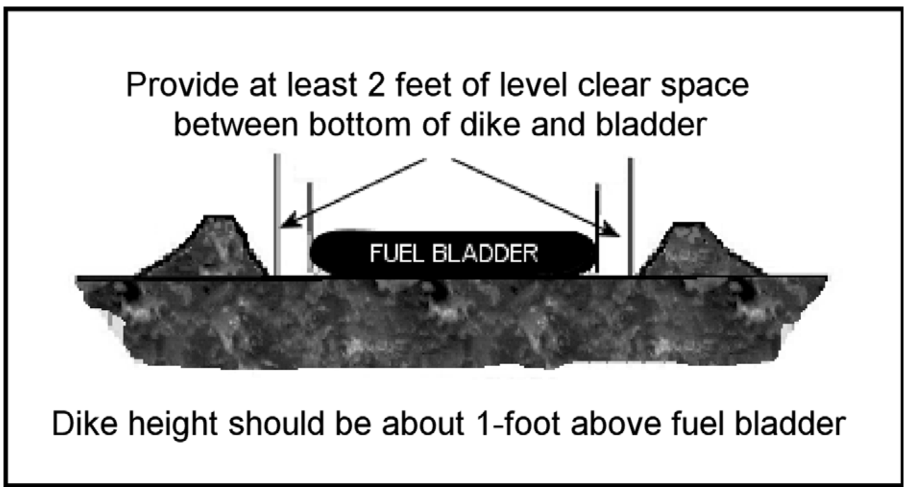


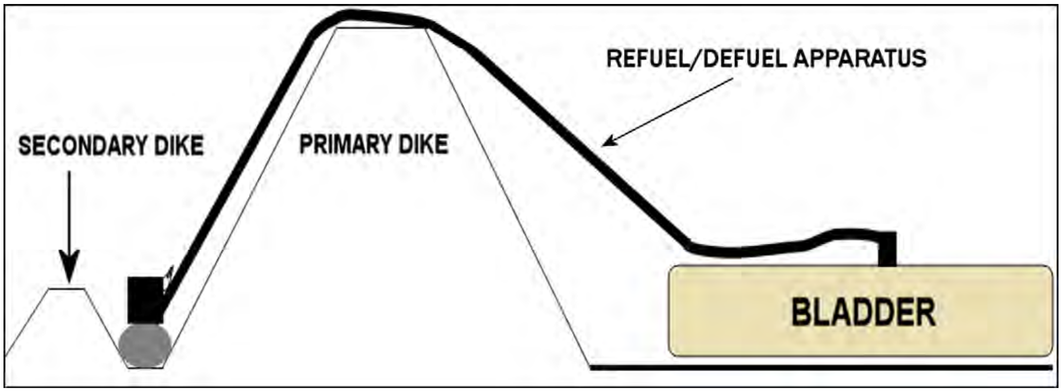
Figure 7.10. Fuel Dike Cross Section.



7.4.1.2.1. Dike construction for fuel bladders should be constructed to hold fuel amounts slightly larger than bladder capacity. When constructing the dike, ensure the fuel trucks, fueling and de-fueling, are able to travel over the ground adjacent to the dike. Keep in mind most of the trucks weigh more than 80,000 lbs. Stabilize the travel area around the dike by 50 to 100 feet to ease truck operations. If applicable, consider civilian delivery truck weights and turn radiuses when sizing the truck travel area.

7.4.1.2.2. Locations experiencing extreme heat for several months at a time will likely cause bladder leaks. Fuel bladder kits contain liners to hold spilled fuel if/when bladders burst or leak. Consider constructing secondary dikes outside of the primary dike to catch leakage and spillage of residual or accidental spills due to hose/coupling breaks (**Figure 7.11.**). The liners should be long enough to cover the secondary dike.

Figure 7.11. Illustration of Fuel Dike with Secondary Dike.



7.4.2. **Raised Flood Control Dikes.** Raised flood control dikes, embankments, or barriers (often referred to as levees) (**Figure 7.12.**) are typically constructed of soil and sandbags. However, sandbag levees are not considered an expedient method because significant time and personnel are needed to fill sandbags during an emergency (**Figure 7.13.**). In recent times, filled HESCO barriers have been used in the construction of expedient dike walls. Since expedient dikes are constructed in an emergency, their primary purpose is to provide flood protection for periods of only a few days or weeks. More permanent dikes or levees require more planning, analysis, time, and materials to construct and cannot be considered expedient. Although there is typically very little time to prepare for an unforeseen flood emergency, local emergency planners should address certain basics that engineers will need prior to dike construction. Issues such as the location of earth borrow sites; heavy equipment routes; proposed alignment for dike, equipment and supplies, and other matters should be determined before construction of the dike begins.

Figure 7.12. Earthen Dike Being Constructed to Control Flood Waters.

Figure 7.13. Personnel Constructing Sandbag Levee.

7.4.2.1. **General Construction Requirements.** The design of raised flood control dikes or barriers is very similar to that of freestanding soil berms discussed earlier; however, they serve two very different purposes. Flood control dikes are designed to hold back floodwaters, and their failure could potentially result in devastation over a wide area and adversely affect many people. Raised dikes constructed during an emergency should be built to hold throughout the entire flood event. Anytime there is water against the embankment, there is a potential danger that the dike could fail. Therefore, even under emergency situations, proven construction methods should be used when constructing raised flood control dikes—an emergency is not the time to experiment. The standard design of a raised dike is generally dictated by the foundation soils and the materials available for construction. Always attempt to make the dike or embankment compatible with the foundation. Information on foundation soils may be available from local officials or engineers, and it should be utilized. Use the information in paragraph **7.4.2.5.** as a guide when determining vertical and horizontal embankment design. Also keep in mind that a revised forecast may require additional fill to be placed.

7.4.2.2. **Alignment.** Before heavy equipment operators can begin moving earth to build a raised dike, engineer planners must establish an alignment for the proposed barrier. The alignment should be the shortest route possible, provide the maximum practical protection, and take advantage of any high ground where available. The flood barrier should be kept as far landward of the body of water as possible to prevent encroachment on the floodway. Sharp bends should also be avoided. Keep as many trees and as much brush between the dike and the water as possible to help deflect water current and debris. The earth borrow areas should have adequate material for construction of the dike and must be accessible at all times. Also, the borrow area should be located in an area that will not become isolated from the dike project by high water.

7.4.2.3. **Foundation Preparation.** Prior to constructing a raised embankment, the foundation area along the levee alignment should be prepared. Trees should be cut and the stumps removed. All obstructions above the ground surface should be removed, if possible. This includes brush, structures, snags, and similar debris. In snow-covered areas, push the snow riverward so as to decrease ponding when the snow melts. The foundation should then be stripped of topsoil and surface humus. Stripping may be impossible if the ground is frozen. In this case, the foundation should be ripped or scarified, if possible, to provide a rough surface for bonding with the embankment. Every effort should be made to remove all ice or soil containing ice. Frost or frozen ground can also give a false sense of security in the early stages of a flood fight. It can act as a rigid boundary and support the levee; but on thawing, soil strength may be reduced sufficiently to allow cracks or slides to develop. Frozen soil forms an impervious barrier to prevent seepage. This may result in a considerable buildup in pressure under the soils landward of the levee and, upon thawing, pressure may be sufficient to cause sudden blowouts. If this condition exists, it must be monitored and one must be prepared to act quickly if sliding or sand boils develop. If stripping is possible, the material should be pushed landward and riverward of the toe of the levee. **Note:** Clearing and grubbing, structure removal, and stripping should be performed only if time permits.

7.4.2.4. **Materials.** Earth fill materials for emergency levees will usually come from local borrow areas. As previously mentioned, an attempt should be made to utilize materials which are compatible with the foundation materials as explained below. However, due to time limitation, any local materials may be used if reasonable construction procedures are followed. The materials should not contain large frozen pieces of earth.

7.4.2.4.1. **Clay.** Clay is preferred because the section can be made smaller (steeper side slopes). Also, clay is relatively impervious and has a relatively high resistance to erosion when it is compacted. A disadvantage in using clay is that adequate compaction is difficult to obtain without proper equipment. Additionally, the water content in impervious fill can impact the compaction needs. Efforts are typically made at the borrow site to obtain material with the optimal moisture; otherwise, if that is not possible, more time may be required for compaction. Another disadvantage is that the clay may be wet, and sub-freezing temperatures may cause the material to freeze in the borrow pit and in the hauling equipment. Weather could cause delays and should definitely be considered in the overall construction effort.

7.4.2.4.2. **Sand.** If sand is used, the section should comply as closely as possible with recommendations in paragraph **7.4.2.5.1.** below. Flat slopes are important, as steep slopes without poly coverage will cause seepage through the levee to outcrop high on the landward slope and may cause the slope to slump.

7.4.2.4.3. **Silt.** Material that is primarily silt should be avoided, and if it is used, poly facing must be applied to the waterside slope. Silt, upon wetting, tends to collapse under its own weight and is very susceptible to erosion.

7.4.2.5. **Design Considerations.** As previously addressed, dike or levee designs are based on the soil foundation and available construction materials. The three foundation conditions cited below are classical and idealized, and usual field conditions depart from them to various degrees. However, they should be used as a guide so that possible serious flood fight problems might be lessened during high water. A top width adequate for construction equipment will usually facilitate raising the embankment. Also, the embankment height should be 2 feet higher than the forecast flood crest. Finally, actual embankment construction will, in most cases, depend on time, materials, and right-of-way available.

7.4.2.5.1. **Sand Foundation.** If the foundation material under the emergency dike is sand or some other pervious material, the following guidance is provided.

7.4.2.5.1.1. If the dike section is to be made of sand, use a minimum of 1V (Vertical) on 3H (Horizontal) river slopes. A 1V on 4H river slope is preferable and will be less susceptible to erosion, but a 1V on 3H slope is considered an adequate minimum for emergency purposes. Use 1V on 5H for the landward slope and a 10-foot top width.

7.4.2.5.1.2. If the dike section will be made of clay, use 1V on 2 1/2 H for both slopes. 1V on 3H slopes are preferable, but 1V on 1 1/2 H is an acceptable minimum for emergency purposes. The bottom width should comply with soil creep ratio criteria; i.e., L (across bottom) should be equal to C x H; where C is the foundation soil creep ratio (i.e., 9 for fine gravel and 15 for fine sand) and H is levee height. See **Table 7.5.** below for various soil creep ratios.

Table 7.5. Creep Ratios on Pervious Foundations. (Source: USACE EM 1110-2-1901)

SOIL CREEP RATIO	
Soil Type	**Critical Creep Ratio**
Very Fine Sand or Silt	18
Fine to Medium Sand	15
Coarse Sand	12
Fine Gravel or Sand and Gravel	9
Coarse Gravel including Cobbles	3.0
Very Hard Clay or Hardpan	1.6

7.4.2.5.2. **Clay Foundation.** If the foundation material under the emergency levee is clay, the following guidance is provided

7.4.2.5.2.1. If the dike section is to be made of sand, it should be constructed with 1V on 3H for the river slope. Again, a 1V on 4H is preferable, but the steeper slope is considered adequate for emergency purposes. Use 1V on 5H for the landward slope and a 10-foot top width, as described in the previous section.

7.4.2.5.2.2. If the dike section is to be made of clay, use 1V on 2 1/2 H for both slopes. Slopes of 1V on 3H are preferable for clay levees, but 1V on 1 1/2 H is an acceptable minimum for emergency purposes. With a clay foundation, there is no need to construct additional berms.

7.4.2.5.3. **Clay Layer Over a Sand Foundation.** If the foundation material is such that there is an impervious clay layer resting over a pervious sand layer, the following guidance is provided.

7.4.2.5.3.1. If the dike section is to be made of sand, use a minimum of 1V on 3H river slopes for emergency purposes. A 1V on 4H slope is preferable if this construction is possible. Use 1V on 5H landward slope and 10-foot top width. In addition, a landside berm of sufficient thickness may be necessary to prevent rupture of the clay layer. The berm may be constructed of sand, gravel, or clay, but since berms made of clay generally need to be wider and thicker than those made of pervious materials, it would probably reduce the construction effort to build the berm with sand or gravel if these materials are available. Standard design of berms requires considerable information and detailed analysis of soil conditions. Prior technical assistance may reduce berm construction requirements in any emergency situation.

7.4.2.5.3.2. If the dike section is to be made of clay, use 1V on 2 1/2 H for both slopes. Again, 1V on 3H slopes are preferable, but 1V on 1 1/2 H is an acceptable minimum for emergency purposes. Additionally, a berm may be necessary to prevent rupture of the impervious top stratum.

7.4.2.6. **Placement and Compaction.** Obtaining proper compaction equipment for a given soil type will be difficult. In most cases, the only compaction may be from hauling and spreading equipment; i.e., construction traffic routed over the fill.

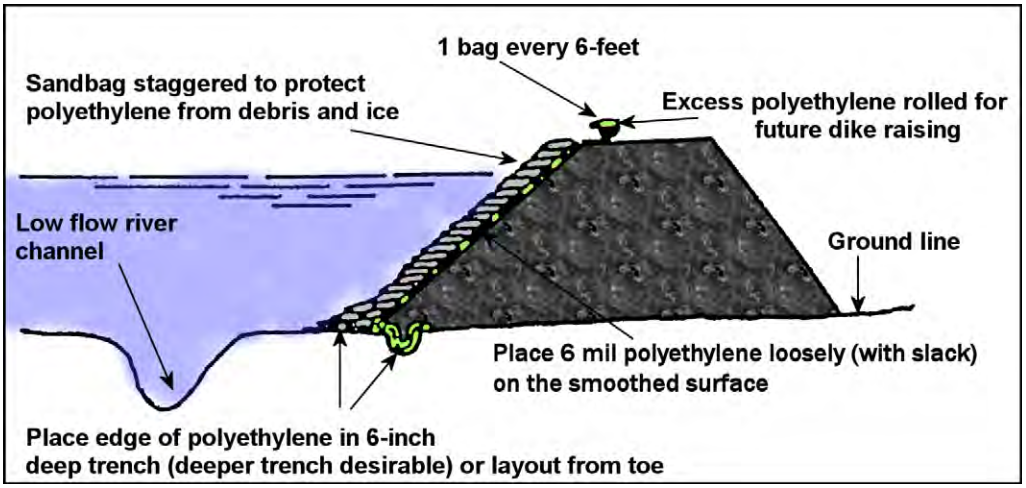
7.4.2.7. **Slope Protection.** Methods of protecting embankment slopes from current scour, wave wash, seepage, and debris damage are numerous and varied. During a flood emergency, time, availability of materials, cost, and construction capability preclude the use of all accepted methods of permanent slope protection. Field personnel must decide the type and extent of slope protection the emergency barrier will need. Several methods of protection exist which prove highly effective in an emergency. Again, resourcefulness on the part of the field personnel may be necessary for success.

7.4.2.7.1. **Polyethylene and Sandbags.** Experience has shown that a combination of polyethylene (poly) and sandbags is one of the most expedient, effective, and economical methods of combating slope attack in a flood situation (**Figure 7.14.**). Poly and sandbags can be used in a variety of combinations. Time becomes the factor that may determine which combination to use. Ideally, poly and sandbag protection should be placed in the dry. However, many cases of unexpected slope attack will occur during high water. A method for placement in the wet is covered below. See **Figure 7.15.** to **Figure 7.17.** for suggested methods of laying poly and sandbags. Since each flood fight project is unique (river, personnel available, materials, etc.), specific details of placement and materials handling will not be covered. Personnel must be aware of resources available when using poly and sandbags.

Figure 7.14. Poly Sheeting and Sandbags Reduce Water Absorption.

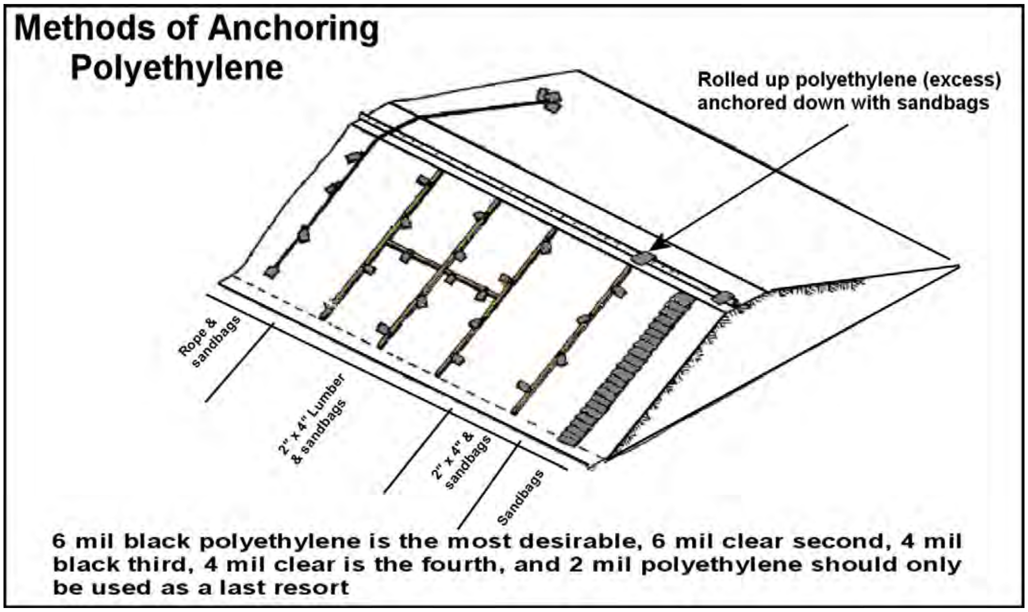
7.4.2.7.1.1. **Toe Anchorage and Poly Placement.** Anchoring the poly along the waterside toe is important for a successful job (see **Figure 7.15.**). This may be done three different ways: (1) After completion of the embankment, excavate a trench along the toe and place poly inside the trench and backfill the trench; (2) Place poly flat-out away from the toe and push earth over the flap; and (3) Place poly flat-out from the toe and place one or more rows of sandbags over the flap. After anchoring the poly, unroll the poly up the slope and over the top, leaving enough excess to anchor with sandbags. The poly should be placed from downstream to upstream along the slopes and overlapping at least 2 feet. The poly is now ready for the "hold down" sandbags.

Figure 7.15. Anchoring Polyethylene.



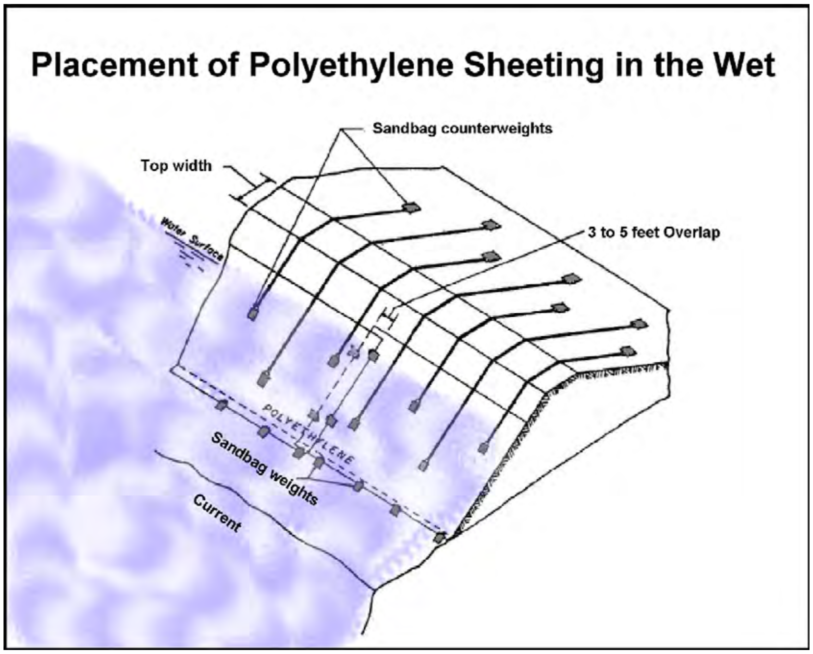
7.4.2.7.1.2. **Slope Anchorage.** Poly placed on raised embankments should be held down. An effective method of anchoring poly is a grid system of sandbags (**Figure 7.16.**), unless extremely high velocities of water, heavy debris, or a large amount of ice is anticipated. In that case, a solid blanket of sandbags over the poly should be used. A grid system can be constructed faster and requires fewer bags and much less labor than a total covering. Various grid systems include vertical rows of lapped bags, 2" x 4" lumber held down by attached bags, and rows of bags held by a continuous rope tied to each bag. Poly can also be held down by a system using two bags tied with rope and the rope saddled over the embankment crown with a bag on each slope.

Figure 7.16. Slope Protection.



7.4.2.7.1.3. **Placement in the Wet.** In many situations during high water, poly and sandbags placed in the wet must provide the emergency protection. Wet placement may also be required to replace or maintain damaged poly or poly displaced by current action. **Figure 7.17.** shows a typical section of embankment covered in the wet. Sandbag anchors are formed at the bottom edge of the poly by bunching the poly around a fistful of sand or rock and tying the sandbags to this fist-sized ball. Counterweights consisting of two or more sandbags connected by a length of 1/4-inch rope are used to hold the center portion of the poly down. The number of counterweights will depend on the uniformity of the levee slope and current velocity. Placement of the poly consists of first casting out the poly sheet with the bottom weights and then adding counterweights to slowly sink the poly sheet into place. The poly, in most cases, will continue to move down slope until the bottom edge reaches the toe of the slope. Sufficient counterweights should be added to ensure that no air voids exist between the poly and the levee face and to keep the poly from flapping or being carried away by the current. For this reason, it is important to have enough counterweights prepared prior to the placement of the sheet.

Figure 7.17. Placement of Polyethylene in the Wet.



7.4.2.7.1.4. **Overuse of Poly.** In past floods, there has been a tendency to overuse and, in some cases, misuse poly on slopes. For example, on well compacted clay embankments in areas of relatively low velo cities, use of poly would be unnecessary. Also, placement of poly on landward slopes to prevent seepage must not be done. It will only force seepage to another exit and may prove detrimental. Poly has been used on the landside slope of levees to prevent rainwater from entering a crack wh ere slope movement has occurred, particularly in fat clay soils. Keeping water out of the cracks resulting from slope movements is desirable to prevent lubrication and additional hydrostatic pressure on the slip surface.

7.4.2.7.2. **Riprap.** Riprap is a positive means of providing slope protection (**Figure 7.18.**) and has been used in a few cases where erosive forces were too large to effectively control by other means. Objections to using riprap when flood fighting are: (1) rather costly; (2) large amount necessary to protect a given area; (3) availability; and (4) little control over its placement, particularly in the wet. In situations when suitablerock is not available within economical hauling distance, soil cement slope protection may be a viable option.

7.4.2.7.3. **Miscellaneous Measures.** Several other methods of slope protection have been used. Small groins, extending 3.05 m (10 ft) or more into the channel were effective in deflecting current away from the levees. Log booms have been used to protect levee slopes from debris or ice attack. Logs can be cabled together and anchored with a deadman in the levee. The boom will float out in the current and, depending on log size, will deflect floating objects. Straw bales pegged into the slope may be successful against wave action as well as straw spread on the slope and overlain with snow fence.

Figure 7.18. Placement of Riprap.

7.4.2.8. **Using Wire/Fabric Earth Filled Barriers.** Earth filled barriers can be used for fast construction of a water dike wall. The walls need to be reinforced on the opposite side (landside) of the water with earthen material filled with organic/rock mixture for strength.

7.4.3. **Drainage Ditches and Channels.** As previously addressed, drainage ditches and channels are also defined as a type of dike. They are used to control or enhance water runoff (**Figure 7.19.**) and are often employed after a flood to handle unwanted surface water. Sometimes requests are made to locate irrigation and/or drainage ditches in close proximity to the landside levee toe. This could lead to serious seepage and/or slope stability problems. The location and depth of proposed ditches should be established by seepage and stability analyses. This requires information on foundation soil conditions, river stages, and geometry of the proposed ditch. Local engineers should be consulted before constructing drainage ditches, especially if raised levees are in the immediate area. See **Chapter 2** for more information on expedient drainage construction measures.

Figure 7.19. Creating a Drainage Ditch to Enhance Water Runoff.

7.5. Additional References. This chapter focused on the expedient construction of berms and dikes used for flood- and spill-control measures, landfill operations, and other uses not normally addressed in force protection publications. For information on constructing berms and dikes as a force protection measure, consult AFH 10-222, Volume 14, *Guide to Fighting Positions, Obstacles and Revetments*. Information can also be found in the interactive *Berms & Dikes* course located at the Air Force Civil Engineer Virtual Learning Center. Check with the Unit Training Manager for more information about this course.

Chapter 8

INFORMATION COLLECTION, RECORDS, AND FORMS.

8.1. Information Collections. No information collections are created by this publication.

8.2. Records. The program records created as a result of the processes prescribed in this publication are maintained in accordance with AFMAN 37-123 (will convert to AFMAN 33-363) and disposed of in accordance with the AFRIMS RDS located at **https://afrims.amc.af.mil/rds_series.cfm**.

8.3. Forms (Adopted and Prescribed).

8.3.1. **Adopted Forms.** AF IMT 847, *Recommendation for Change of Publication*.

8.3.2. **Prescribed Forms.** No prescribed forms are implemented in this publication.

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Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

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Abbreviations and Acronyms

AC—Alternating Current

AFB—Air Force Base

AFCESA—Air Force Civil Engineer Support Agency

AFH—Air Force Handbook

AFI—Air Force Instruction

AFMAN—Air Force Manual

AFPAM—Air Force Pamphlet

AFRIMS—Air Force Information Management System

AGE—Aerospace Ground Equipment

ANG—Air National Guard

AOR—Area of Responsibility

AWG—American Wire Gage

BCE—Base Civil Engineer

BEAR—Basic Expeditionary Airfield Resources

BTU—British Thermal Unit

C2—Command and Control

CaO—Calcium Oxide

CBR—California Bearing Ratio

CE—Civil Engineer

CFCs—Chlorinated Fluorocarbons

CFS—Cubic Feet per Second

CGI—Combustible Gas Indicator

CMP—Corrugated Metal Pipe

CONUS—Continental United States

DC—Direct Current

DCC—Damage Control Center

EOC—Emergency Operations Center

ERDC—Engineer Research and Development Center

ETL—Engineering Technical Letter

FI—Flame Ionization Detector

FM—Field Manual

GPH—Gallons per Hour

MIL-HDBK—Military Handbook

HQ—Headquarters

HVAC—Heating, Ventilation, and Air Conditioning

HZ—Hertz

IPE—Individual Protective Equipment

KW—Kilowatt

KVA—kilovolt-amperes

LCF—Lime-Cement Fly Ash

LFA—Lime Fly Ash

MAJCOM—Major Air Command

MSDS—Material Safety Data Sheet

NEC—National Electric Code

NESC—National Electrical Safety Code

O.C.—On Center

OFDA—Office of Foreign Disaster Assistance

OPR—Office of Primary Responsibility

OSB—Oriented Strand Board

POL—Petroleum, Oils and Lubricants

PSI—Pounds Per Square Inch

PSIG—Pounds Per Square Inch Gauge

PSP—Pierced Steel Planking

PVC—Polyvinyl Chloride

QTP—Qualification Training Package

RDS—Records Disposition Schedule

RED HORSE—Rapid Engineer Deployable Heavy Operational Repair Squadron Engineer

REMR—Repair, Evaluation, Maintenance, and Rehabilitation

ROWPU—Reverse Osmosis Water Purification Unit

RPM—Revolutions Per Minute

RURK—Rapid Utility Repair Kit

SWA—Southwest Asia

TEMPER—Tent, Extendable Modular Personnel

T.O.—Technical Order

UFC—Unified Facilities Criteria

US—United States

USACE—US Army Corps of Engineers

USAF—United States Air Force

USAID—United States Agency for International Development

USCS—Unified Soil Classification System

UV—Ultra Violet

WRM—War Reserve Materiel

Terms

Air Force Civil Engineer Support Agency (AFCESA)—A field operating agency (FOA) located at Tyndall Air Force Base, Florida. The Readiness Support Directorate (HQ AFCESA/CEX) acts as the Air Force program manager for base civil engineer (BCE) contingency response planning.

AM-2 Matting—Developed during the Vietnam conflict, the AM-2 mat was used as a surface for runways, taxiways, and aircraft parking aprons. The mat is created by laying the interlocking aluminum panels in an offset pattern, similar to that used inlaying bricks. In smaller numbers, the AM-2 panels were used to make an airfield damage repair patch.

B-1 Revetment—A galvanized metal revetment assembled using metal pins and filled with sand or similar material. B-1 revetments are often capped with concrete to prevent water from entering the fill material. They are primarily used to protect parked aircraft; however, they can also be used for facility hardening.

Bare Base—An installation having minimum essential facilities to house, sustain, and support operations to include, if required, a stabilized runway, taxiways, and aircraft parking areas. A bare base must have a source of water that can be made potable. Other requirements to operate under bare base conditions form a necessary part of the force package deployed to the bare base.

Beddown—The act of providing facilities, utilities, services, construction, operations, and maintenance support to a deployed force with the overall intent of establishing a basic mission capability.

Bitburg Revetment—A fork lift-moveable revetment made of reinforced concrete usually used for facility hardening.

Cannibalize—To remove serviceable parts from one item of equipment in order to install them on another item of equipment.

Command and Control (C2)—The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

Continental United States (CONUS)—United States territory, including the adjacent territorial waters, located within North America between Canada and Mexico.

Contingency—An emergency involving military forces caused by natural disasters, terrorists, subversives, or by required military operations. Due to the uncertainty of the situation, contingencies require plans, rapid response, and special procedures to ensure the safety and readiness of personnel, installations, and equipment.

Contingency Response Plan—A base civil engineer plan of action developed in anticipation of all types of contingencies, emergencies, and disasters.

Conventional Weapons—A weapon which is neither nuclear, biological, nor chemical.

Damage Control Center—A C2 node for engineer forces at unit-level which controls the pre; trans; and post-attack activities of the engineer work force.

Decontamination—The process of making any person, object, or area safe by absorbing, destroying, neutralizing, making harmless, or re moving chemical or biological ag ents or by removing radioactive material clinging to or around it.

Deployment—The movement of forces with in areas of operation; the positioning of forces into a formation for battle; the relocation of forces and material to desi red areas of operations. Deployment encompasses all activities from origin or home station through des tination, specifically including intra-continental United States, inter-theater, and intra-theater movement legs, staging, and holding areas.

Domestic Sewage—The waste from toilets, lavatories, urinals, bath tubs, showers, laundries, and kitchens.

Exercise—A military maneuver or simulated wartime op eration involving planning, preparation, and execution. It is carr ied out for the purpose of tr aining and evaluation. It ma y be a combined, joint, or single-Service exercise, depending on participating organizations.

Facility—A real property entity consisting of one or more of the follow ing: a building, a structure, a utility system, pavement, and underlying land.

Field Deployable Latrine—A field hygiene equipment ite m included in the BEAR sets consisting of three toilets and a urinal tro ugh mounted above a water tank and a waste holdi ng tank. The unit is normally placed inside a TEMPER tent.

Force Beddown—The provision of expedient facilities for troop support to provide a platform for the projection of force. These facilities may include modular or kit-type substitutes.

Hardening—The process of providing protection against the effects of conventional weapons. It can also apply to protection against the si de effects of a nu clear attack or against the effects of a chemical or biological attack.

Limiting Factor—A factor or condition that, either temporarily or pe rmanently, impedes mission accomplishment. Illustrative examples are transportation network deficiencies, lack of in-place facilities, malpositioned forces or materiel, extreme climatic conditions, distance, transit or overflight rights, political conditions, etc.

Mobility—A quality or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission.

Petroleum, Oils, and Lubricants (POL)—A broad term which includes all petroleum and associated products used by the Armed Forces.

pH—A numerical measure of the acidity or alkalinity of a solution, usually measured on a scale of 0 to 14.

Potable Water—Water that is safe for consumption.

Prime BEEF (Base Engineer Emergency Force)—A Headquarters US Air Force, major command (MAJCOM), and base-level program that organizes civil engineer forces for worldwide direct and indirect combat support roles. It assigns civilian employees and military personnel to both peacetime real property maintenance and wartime engineering functions.

Prime Power—Power that is continuously generated.

RED HORSE—Squadrons established to provide the Air Force with a highly mobile, self-sufficient, rapidly deployable civil engineer capability required in a potential theater of operations.

Reverse Osmosis Water Purification Unit (ROWPU)—A water purification device which uses a series of membranes to eliminate impurities. The ROWPU is capable of removing dissolved minerals.

Sanitary Sewer—A sewage system that carries only domestic sewage.

Service Entrance—All components between the termination point of the overhead service drop or the underground service lateral and the building main disconnecting device with the exception of the utility company's metering equipment.

Service Entrance Equipment—Equipment located at the service entrance that provides over- current protection for the feeder and service conductors and provides a means of disconnecting the feeders from energized service conductors.

Storm Sewage—The inflow of surface runoff during or immediately following a storm or heavy rain.

Survivability—Capability of a system to accomplish its mission in the face of an unnatural (man-made) hostile, scenario-dependent environment. Survivability may be achieved by avoidance, hardness, proliferation, or reconstitution (or a combination).

TEMPER Tent—A metal-framed, fabric-covered facility used primarily for billeting and administrative-type functions. It is the most common facility in the BEAR packages.

Voltage—Electrical potential or electromotive force; basic unit of voltage is the volt.

War Reserve Materiel (WRM)—Materiel required in addition to primary operating stocks and mobility equipment to attain the operational objectives in the scenarios authorized for sustainability planning in the defense planning guidance. Broad categories are: consumables associated with sortie generation (to include munitions, aircraft external fuel tanks, racks, adapters, and pylons); vehicles; 463L systems; materiel handling equipment; aircraft engines; bare base assets; individual clothing and equipment; munitions, and subsistence.

Watt—The basic unit of electrical power; power (in watts) equals voltage (volts) multiplied by current (amperes).

Attachment 2

CRACK REPAIR USING EPOXY INJECTION METHOD

A2.1. Purpose. To provide guidance on use ofepoxy injection to repair cracks in concrete. The following information was extracted from Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Technical Note CS-MR-3.9, Crack Repair Method: Epoxy Injection.

A2.2. Description. This method can be used to repair cracks as narrow as 0.002 inch. The method generally consists of drilling holes at close intervals along the cracks, in some cases installing entry ports, and injecting the epoxy under pressure. For massive structures, an alternative procedure consists of drilling a series of holes, usually 7/8 inch in diameter that intercepts the crack at a number of locations. Typically, holes are spaced at 5-foot intervals.

A2.3. Equipment, Tools, and Personnel Requirements. A concrete drill, an epoxy injection system, a means of cleaning holes and cracks, and normal hand tools are required. One man can repair cracks using this method, but a two- or three-man operation is more efficient. Epoxy injection requires personnel with a high degree of skill for satisfactory execution.

A2.4. Applications and Limitations. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures. However, unless the crack is dormant (or the cause of cracking is removed, thereby making the crack dormant), it will probably recur, possibly somewhere else in the structure. If the crack is activeand the desired is to seal it while allowing continued movement at that location, a sealant or other material that allows the crack to function as a joint must be used. The ambient temperature may also limit application of this method. In the case of delaminated bridge decks, epoxy injection can be an effective intermediate-term repair method. In this case, steps in paragraph **A2.5.1.**, **A2.5.2.**, and **A2.5.6.** outlined below are omitted. The process is terminated at a specific location when epoxy exits from the crack at some distance from the injection ports. This method does not arrest ongoing corrosion.

A2.5. Step-By-Step Procedure.

A2.5.1. Clean the cracks. The first step is to clean cracks that have been contaminated. Oil, grease, dirt, or fine particles of concrete prevent epoxy penetration and bonding. Preferably, contamination should be removed by flushing with water or some other especially effective solvent. The solvent is then blown out using compressed air, or adequate time is provided for air-drying.

A2.5.2. Seal the surface. Surface cracks should be sealed to keep the epoxy from leaking out before it has gelled. Where the crack face cannot be reached, but where there is backfill, or where a slab-ongrade is being repaired, the backfill material or subbase material is often an adequate seal. A surface can be sealed by brushing an epoxy along the surface of the crack and allowing it to harden. If extremely high injection pressures are needed, the crack should be cut out to a depth of 1/2 in. and width of about 3/4 in. in a V-shape, filled with an epoxy, and struck off flush with the surface. If a permanent glossy appearance along the crack is objectionable and if high injection pressure is not required, a strippable plastic may be applied along the crack. When the job is completed, the dry filler can be stripped away to expose the gloss-free surface.

A2.5.3. Install the entry ports. Three methods are in general use:

A2.5.3.1. Drilled holes—fittings inserted. Historically, this method was the first to be used and is often used in conjunction with V-grooving of the cracks. The method entails drilling a hole into the crack, approximately 3/4 inch in diameter and 1/2 to 1 inch below the apex of the V-grooved section, into which a fitting, such as a pipe nipple or tire valve stem, is bonded with an epoxy adhesive. A vacuum chuck and bit are useful in preventing the cracks from being plugged with drilling dust.

A2.5.3.2. Bonded flush fitting. When the cracks are not V-grooved, a method frequently used to provide an entry port is to bond a fitting flush with the concrete face over the crack. This flush fitting has a hat-like cross section with an opening at the top for the adhesive to enter.

A2.5.3.3. Interruption in seal. Another means of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

A2.5.4. Mix the epoxy. This is done either by batch or continuous methods. In batch mixing, the adhesive components are premixed according to the manufacturer's instructions, usually with the use of a mechanical stirrer, like a paint mixing paddle. Care must be taken to mix only the amount of adhesive that can be used prior to commencement of gelling of the material. When the adhesive material begins to gel, its flow characteristics begin to change, and pressure injection becomes more and more difficult. In the continuous mixing system, the two liquid adhesive components pass through metering and driving pumps prior to passing through an automatic mixing head. The continuous mixing system allows the use of fast-setting adhesives that have a short working life.

A2.5.5. Inject the epoxy.

A2.5.5.1. Hydraulic pumps, paint pressure pots, or air-actuated caulking guns can be used. The pressure used for injection must be carefully selected. Increased pressure often does little to accelerate the rate of injection. In fact, the use of excessive pressure can propagate the existing cracks, causing additional damage.

A2.5.5.2. If the crack is vertical, the injection process should begin with pumping epoxy into the entry port at the lowest elevation until the epoxy level reaches the entry port above. The lower injection port is then capped, and the process is repeated at successively higher ports until the crack has been completely filled and all ports have been capped.

A2.5.5.3. For horizontal cracks, injection should proceed from one end of the crack to the other in the same manner. The crack is full if the pressure can be maintained. If the pressure cannot be maintained, the epoxy is still flowing into unfilled portions or leaking out of the crack.

A2.5.6. Remove the surface seal. After the injected epoxy has cured, the surface seal should be removed by grinding or other means, as appropriate. Fittings and holes at entry ports should be painted with an epoxy-patching compound.

A2.6. Environmental Considerations. Reasonable caution should guide the preparation, repair, and cleanup phases of any crack repair activities involving potentially hazardous and toxic chemical substances. Manufacturer's recommendations to protect occupational health and environmental quality should be carefully followed. In instances where the effects of a chemical substance on occupational health or environmental quality are unknown, chemical substances should be treated as potentially hazardous and toxic materials.

A2.7. Reference. Additional information can be found in EM 1 110-2-2002, *Evaluation and Repair of Concrete Structures,* at **http://www.usace.army.mil/publications/eng-manuals/**.