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EXPEDIENT ROADS, DRAINAGE, AND PROTECTIVE STRUCTURES

DEPARTMENT OF THE AIR FORCE

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Tactical Doctrine

EXPEDIENT ROADS, DRAINAGE, AND PROTECTIVE STRUCTURES

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PURPOSE: The Air Force Tactics, Techniques and Procedures (AFTTP) presented in this publication provide ideas and guidance to Air Force (AF) civil engineer (CE) craftsmen for accomplishing expedient construction and repair of roads, drainages, and protective structures when standard equipment and materials are not available or when necessary for minimum-essential restoration. This publication supports Air Force Instruction (AFI) 10-209, *RED HORSE Program*, AFI 10-210, *Prime Base Engineer Emergency Force (BEEF) Program*, and Air Force Doctrine Annex 3-34, *Engineer Operations*. Refer recommended changes and questions about this publication to the Office of Primary Responsibility (OPR) using the AF Form 847, *Recommendation for Change of Publication*; route AF Forms 847 from the field through the appropriate functional chain of command and 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 (IAW) Air Force Manual (AFMAN) 33-363, *Management of Records*, and disposed of IAW the Air Force Records Disposition Schedule (RDS) in the Air Force Records Information Management System (AFRIMS). 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 AF.

APPLICATION: This AFTTP is nondirective. It applies to AF, Air National Guard, and AF Reserve Command CE units. The expedient methods provided here are primarily applicable during wartime and overseas contingency operations, and force beddown at initial contingency locations outside the United States (US) with shortages of standard construction materials. Some expedient methods may be applicable during disaster recovery operations when immediate action is necessary and resources are limited.

SCOPE: The information in this publication does not supersede any legal requirements (domestic US law for operations in the US and for operations outside the US: US law with extraterritorial application, applicable international agreement requirement, or combatant command directive) that specify how things must be done. For the purpose of this document, "expedient" is defined as "a means devised or employed in a time and place where prompt action is essential." Expedient engineering does not preclude using normal engineer practices where time and materials are available. For information about Airfield Damage Repair (ADR) procedures, refer to Unified Facilities Criteria (UFC) 3-270-07, *O&M*: *Airfield Damage Repair* and other publications in the AFTTP 3-32-series and Air Force Pamphlet (AFPAM) 10-219-series.

Chapter 1

INTRODUCTION

1.1. Overview. This AFTTP addresses field expedient construction and repair methods for roads, drainages, and protective structures when time and materials are limited or when conventional methods are impractical to employ. Most of the highlighted construction methods involve expedient materials readily available at deployed locations (see **paragraph 1.4** for a review of expedient construction materials). While using expedient construction methods during wartime and overseas contingency operations is common, some procedures may be applicable during disaster recovery operations when immediate action is necessary or resources are limited. The illustrations of basic material applications and proven field construction methods was compiled from multiple sources, including data from Department of Defense (DOD), Joint, and Service publications as well as Best Practices and Lessons Learned from AF Civil Engineers and US Army Corps of Engineers (USACE). Any data and procedures presented are general in nature and personnel should not consider it as mandatory guidance. **Note:** The information in this publication does not supersede any legal requirements (domestic US law for operations in the US and for operations outside the US: US law with extraterritorial application, applicable international agreement requirement, or combatant command directive) that specify how things must be done, including any procedures, requirements, and applications related to contingency construction. See **Attachment 1** for a glossary of references and supporting information.

1.2. Environmental Considerations. The United States Air Force (USAF) is committed to maintaining environmental quality to ensure long-term access to the air, land, and water needed to protect US interests abroad. Although a high level of environmental quality can be difficult to achieve during contingency operations, the health and safety of personnel is critical in military operations. Safe food and water, and a means of properly disposing of waste is essential. The intention of environmental goals during contingencies is to minimize risks to human health and safety, and prevent unnecessary damage to the environment while maximizing the natural resources available to support readiness and operational effectiveness. In US jurisdictions, permits might be required even for emergency operations. Further information on how to integrate environmentally responsible practices during contingency operations can be found in Air Force Handbook (AFH) 10-222V4, *Environmental Considerations for Overseas Contingency Operations*.

1.3. General Safety Practices. The first rules for any situation requiring CE expedient applications are to be flexible and remain safe. Always keep safety in mind when using nonstandard construction methods and materials. Unsafe field operations could cause injuries, disable equipment, and negatively affect the mission. Never compromise safety when employing expedient methods described in this publication. Fire precautions should be considered as necessary.

1.3.1. Construction and repair work involves activities that can injure workers in many different ways. Working from high elevations or with flammable fuels, high voltages, dangerous chemicals, and rotating, cutting, and crushing equipment associated with CE operations are significant hazards. Be vigilant; adhere to technical data warnings and cautions, and wear protective clothing and equipment IAW safety information and standards.

1.3.2. Crew leaders should know assigned personnel's capabilities and limitations and monitor work efforts accordingly. Ensure activities are coordinated with stakeholders. For example, debris removal from inside and around facilities can be a dangerous task and vibrations from heavy equipment can cause a building to collapse on recovery workers. Worksite personnel should not only be cognizant of this hazard, they should also be aware of and able to recognize other potential safety hazards associated with the job.

1.3.3. A key responsibility of supervisors is to ensure personnel have and wear the necessary personal protective equipment (PPE) and individual protective equipment (IPE) for the working environment. Typical items such as lumber, masonry materials, and sheet metal can cause cuts and injuries. Even a small cut can develop into a serious injury if the wound becomes infected. When working in a contaminated environment, be sure to wear the appropriate IPE for the hazard present. In addition, wash contaminated clothing and take a shower as soon as possible after working in a contaminated environment. Additionally, it is important to protect workers from hazards such as high-pressure subsystems and components, harmful solvents and adhesives, and infectious black and gray water products from wastewater systems. **Note:** Black water refers to latrine wastewater containing human waste. Gray water refers to wastewater from non-latrine sources such as showers, laundries, kitchen operations, and handwashing devices.

1.3.3.1. AFI 91-203, *Air Force Consolidated Occupational Safety Instruction*, lists PPE for selected CE activities. Although technical orders (T.O.) and other job-related publications address proper wear and use of PPE and IPE (for chemical, biological, radiological, and nuclear defense), workers have the ultimate responsibility to properly use, inspect, and care for protective equipment assigned to them.

1.3.3.2. Workers should adhere to AFI 32-1064, *Electrical Safe Practices*, when lethal voltages are involved. PPE that provides appropriate arc flash protection is required for all personnel working on or near exposed energized electrical equipment operating at 50 volts or more. See UFC 3-560-01, *Operation and Maintenance: Electrical Safety*, and National Fire Protection Association (NFPA) 70, *National Electric Code*, to identify tasks that require Arc Flash PPE.

1.3.4. Every job or operation has its own particular safety hazards and everyone involved must follow proper safety procedures to prevent injury or illness. This is especially critical during force beddown at contingency locations and base recovery activities. Exposure to construction and heavy equipment, power production equipment, fuel and mechanical systems, and water or wastewater systems makes for an assortment of job related hazards—remain vigilant to stay safe.

1.4. Expedient Construction Materials. Both natural and manufactured materials are options for expedient construction during base development at contingency locations, including soil, wood, rock, metal, cement, and soil-filled containers made of cloth, wire, and synthetic materials. Obviously, some of these materials are not expedient if not readily available; however, this chapter addresses each to some degree—focusing primarily on expedient approaches.

1.4.1. **Soil.** As might be expected, soil is the most commonly available material. It is the primary fill material for revetments and soil berms. It can afford effective protection against direct fire, indirect fire fragmentation, and blast effects when properly amassed. For these reasons, protective structures at contingency locations often use sandbags or contemporary soil-filled wire and fabric containers as an expedient method. Three considerations form the basis of projectile and fragment penetration in soil: for materials of the same density, the finer the grain the greater the penetration; penetration decreases with increase in density; and penetration increases with increasing water content. As such, soil used for protective purposes, regardless of type, should always be protected against water intrusion. For soils of the same density, course-grained material provides better penetration protection than fine-grained types. In addition, sandy soils are normally far superior to clay, or loam varieties.

1.4.2. **Wood.** Several wood sources may be available at your location, including lumber, plywood, wood sheathing, cut logs, scrap wood material, etc. Due to availability, wood is a routine choice for structural support in a survivability position. However, because of its low density and relatively low compressive strength, wood generally has limited value as a direct means of protection from projectiles or fragmentation. It also provides poor protection from ionizing and thermal radiation. Because of its low ignition point, fire easily destroys wood. In some areas of the world, wood construction materials are not readily available. Wood can also be subject to damage from pests.

1.4.3. **Metal.** In the past, steel kits were the most frequently used material for protection against the effects of both direct fire and indirect fragmentation. When configured in the proper gauge, they provide a high degree of defense against projectile penetration. Often steel shielding defeated rounds by absorbing their impacts or by deflecting them away from the intended target. Even though many contemporary expedient barriers are soil-filled structures made of less durable material, effective expedient metal structures made from corrugated metal, steel mats, or commercial metal revetment kits are good options.

1.4.4. **Reinforced Concrete.** Steel reinforced concrete can provide excellent protection against both direct fire and indirect fire fragmentation. However, it does have one noticeable drawback. By nature, its rigidity makes it susceptible to cracking and structural failure when an explosive shell detonates nearby. This shortcoming can also result in large pieces of concrete displacing and instantaneously transforming into dangerous projectiles. Using reinforced concrete is an expedient protection option if preformed portable sections are readily available for positioning on short notice.

1.4.5. **Rock.** Rock shielding can be effective against direct fire and indirect fragmentation. However, due to the joints that are present in a rock formation, multiple hits can cause structural weakness when this material is not in an encasement of some sort. Another downside associated with the use of rock as a shielding substance is that it can fragment and easily become projectiles when exposed to frequent impacts or blasts. On the positive side, large, hard igneous rocks can deform, stop, deflect, or prematurely detonate fused projectiles. In addition, if amassed and adequately encased, small rock such as gravel is an option and is much less susceptible to moisture retention than soil.

1.4.6. **Masonry.** Brick and masonry have the general characteristics of rock for protection against both direct fire and indirect fire fragmentation. Although, not commonly considered as an expedient protection option, brick and masonry often involved indigenous materials and as such can be an acceptable option when other desirable materials are limited. In addition, masonry protective structures require little maintenance as compared to sandbag and wooden structures.

1.4.7. **Snow, Ice, and Ice Concrete.** Initially, during a hasty beddown, snow and ice may be the only material available at some northern tier locations. Although not often apparent, when used in mass or in combination with frozen soil or ice chunks, it can be effective against small caliber weapons and smaller proximity blasts. Ice concrete is a dense, frozen mixture of sand and water or sand with gravel, crushed rock, and water. At least 10 percent of the mixture should be sand. Add only enough water to make the mixture slightly liquid. A sheet of ice concrete that is 4 inches thick will freeze solid in four to six hours at minus 13 degrees Fahrenheit. It may be an option for overhead cover, parapets, breastworks, or as sandbag filler.

1.4.8. **Other Expedient Resources.** Other locally available materials may be options for expedient shielding purposes. However, most of these materials usually become a consideration due to the lack of availability of normal hardening resources. A few examples include old rubber tires, landing mats, concrete culverts, aircraft cargo pallets, steel shipping boxes, and empty metal drums. All of these have limited value as a direct means of protection from projectiles or fragmentation, but can be effective when used in combination with soil, gravel, or even concrete.

Chapter 2

EXPEDIENT ROADS AND DRAINAGE SYSTEMS

2.1. Overview. Establishing useable roadways during beddown at contingency locations and after an attack or disaster could be critical to sustain the mission or recover the base. Procedures might be as simple as clearing or patching existing pavements or as arduous as creating expedient road surfaces and drainage systems with limited materials and equipment. Difficult terrain and poor soil conditions—especially muddy conditions (i.e., wet sand, saturated clay, wet silt), make road construction and repair more problematic. Oftentimes, engineer work crews will need to use ingenuity, available resources, and a lot of strenuous labor to provide temporary, workable traffic surfaces in a timely fashion. This chapter addresses soil conditions and their effect on roadway construction, soil classification and field-expedient identification, expedient roadway construction and repair, drainage methods, and drainage erosion control and maintenance. Consider applying these concepts, methods, and examples singularly, in combination, or modified to suit field conditions for expedient construction. An engineer contingent faced with resource shortfalls may find these methods useful to satisfy minimum requirements for mission accomplishment until additional resources become available. More information on road construction and soils engineering is available in the references in **paragraph 2.8**. For airfield pavement repair, consult UFC 3-270-07, *O&M: Airfield Damage Repair*, UFC 3-260-01, *Airfield and Heliport Planning and Design*, and relevant publications in the AFTTP 3-32-series.

2.2. General Soil Conditions. Existing soil conditions could have a major effect on roadway construction and repairs; consequently, understanding soil characteristics and properties is essential when undertaking expedient roadway projects. The physical characteristics of soil help determine their usefulness for roadway construction and repair. While characteristics such as color, odor, texture, particle size and shape aid in soil description, additional properties such as compactness, moisture, plasticity, and strength provide significant insight into the engineering behavior of various soils. Soil characteristics and testing procedures highlighted in this chapter are sourced from AFH 32-1034, *Materials Testing*, and AF Engineer Technical Letter (ETL) 02-19, *Airfield Pavement Evaluation Standards and Procedures*, Appendix A, and relevant UFC 3-200-series publications. Consult these sources for detailed information on soil properties, testing, classifications, and standard road construction and repair practices.

2.2.1. **Grain-Size Groups.** The size of the particle grains in the soil mass determines its size group. Engineers use sieves, which are screens attached to metal frames (**Figure 2.1**), to help define the size of particle grains. **Table 2.1** lists various Ubified Soil Classification System (USCS) size groups. Coarse-grained soil particles that fall into the gravel or sand groups are individually discernible to the naked eye—fine-grained soil particles are not. In the fine particle group, particles passing the No. 200 sieve, but larger than 0.002 to 0.005 millimeter are called silt; those finer are called clay.

Figure 2.1. Dry Sieve Analysis.

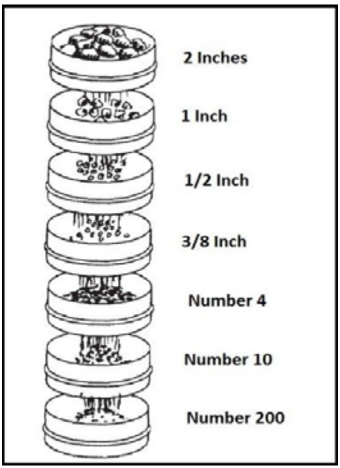


Table 2.1. Soil Grain Size Groups.

Size Group	Sieve Passing	Size Retained On	Example
Boulders	No maximum Size*	10 Inch	
Cobbles	10 Inch	3 Inch	
Gravels	3 Inch	No. 4	Lemon to pea
(Coarse)	3 Inch	0.75 Inch	Lemon to walnut
(Fine)	0.75 Inch	No. 4	Walnut to pea
Sands	No. 4	No. 200	Pea to powdered sugar
(Coarse)	No. 4	No. 10	Pea to rock salt
(Medium)	No. 10	No. 40	Rock salt to table salt
(Fine)	No. 40	No. 200	Table salt to powdered sugar
Fines	No. 200	No minimum Size	
*In military engineering, the maximum size of boulders is accepted as 40 inches (based on the maximum jaw opening of a rock-crushing unit).			

2.2.2. **Soil Gradation.** Gradation describes the distribution of the different size groups within a soil sample. The soil may be well graded or poorly graded. Well-graded soil has a good representation of all particle sizes from the largest to the smallest (**Figure 2.2**), and no one size is either overabundant or missing. Poorly graded soils are either those containing a narrow range of particle sizes (uniformly graded) or those lacking some intermediate sizes (gap-graded). A uniformly graded soil consists primarily of particles of nearly the same size. A gap-graded soil contains both large and small particles, but the absence of some particle sizes breaks the gradation continuity (**Figure 2.3**).

Figure 2.2. Well-Graded Soil.

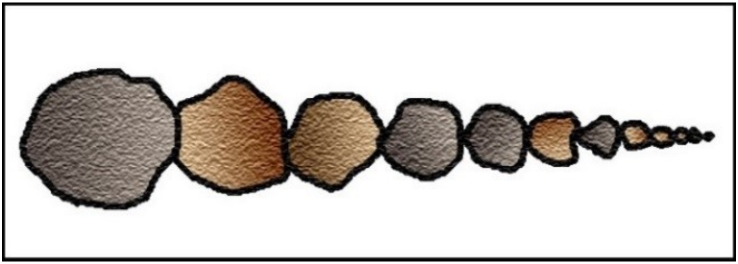
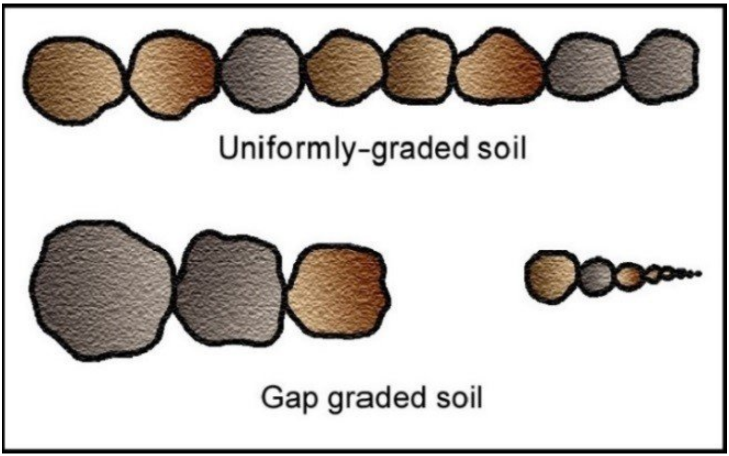


Figure 2.3. Poorly Graded Soils.



2.2.3. **Soil Plasticity.** Plasticity is a property of the fine-grained portion of a soil that allows it to be deformed beyond the point of recovery without cracking or appreciable volume change. This property permits rolling of clay into thin threads at some moisture contents without crumbling. Only clay minerals possess this property; thus, the degree of plasticity is a general index to the clay content of a soil. Engineers sometimes use the terms “fat” and “lean” to distinguish between highly plastic and moderately plastic soils. Soil plasticity is determined by observing the different physical states that a plastic soil passes through as the moisture content changes. The boundaries between the different states as described by the moisture content at the time of changes is the “consistency” or “Atterberg limits.”

2.2.3.1. The liquid limit (LL) is the percent moisture content at an arbitrary limit between the liquid and plastic states of a soil. Above this value, consider the soil a liquid that flows freely under its own weight. Below this value, it will deform under pressure without crumbling, provided the soil exhibits a plastic state.

2.2.3.2. The plastic limit (PL) is the percent moisture content at an arbitrary limit between the plastic and brittle states. As the sample is dried, it reaches the semisolid state when the soil is no longer pliable and crumbles under pressure. In practical terms, the PL is the lowest moisture content at which a soil can be rolled into a thread 1/8 inch in diameter without crushing or breaking. If a cohesive soil has a moisture content above the PL, a thread may be rolled to less than 1/8 inch in diameter without breaking. If the moisture content is below the PL, the soil will crumble when personnel attempt to roll it into 1/8-inch threads. When the moisture content is equal to the PL, personnel can roll out a thread by hand to 1/8 inch in diameter; then it will crumble or break into pieces 1/8 to 3/8 inch long with further attempts to roll the sample. Some soils (for example, clean sands and gravels) are non-plastic and the PL cannot be determined. Silts also are essentially non-plastic materials, since they are usually composed predominantly of bulky grains, if platy grains are present, they may be slightly plastic.

2.2.3.3. Between the liquid and plastic limits is the plastic range. The numerical difference in moisture contents between the two limits is the plasticity index (PI). The PI defines the range of moisture content of the soil in a plastic state (PI = LL - PL).

2.2.4. **Soil Strength.** A soil's strength or its ability to withstand a load relates to its shearing resistance. Shearing resistance is especially important to the bearing capacity of soils used as a base or subgrade. The California Bearing Ratio (CBR) is a measure of the shear strength (or shearing resistance) of a soil under carefully controlled conditions of density and moisture. Since testing for CBR values in a laboratory is time-consuming and impractical for expedient or contingency evaluations, several alternative methods are available for use in the field—shown here are two common methods. One alternative involves using existing USCS empirical testing data to estimate CBR values. Another alternative is to use penetration shear test instruments for on-site soil testing. The penetration shear tests results translate to CBR values to quantify soil strength. In addition to the information below, personnel should review AFH 32-1034 and AF ETL 02-19 for specific soil testing and data recording procedures.

2.2.4.1. **USCS Soil Characteristics Table.** The quickest and least accurate method to determine soil CBR values is to use the range of values in the USCS Soil Characteristics addressed in **paragraph 2.3**. The CBR values range from as low as 3 to as high as 80, depending on the type of soils. The fine-grained soils vary from 3 for organic clays to 15 for micaceous or diatomaceous silts and sands. The sand-silt-clay coarse-grained combinations range from 10 for the clayey mixtures to 40 for the gravelly and silty sands. Gravelly soils range from 20 for the clayey group to 80 for the well-graded gravels and gravel-sand mixtures. While these approximate values provide some useful information, personnel should use actual test values to determine the bearing capacity of soils.

2.2.4.2. **Soil Penetration Shear Test.** On-site soil testing is an accurate method to determine soil CBR values. These tests are routinely accomplished using man-portable or truck-mounted penetration shear test instruments. Below are two of the man-portable instruments used in the field:

2.2.4.2.1. Airfield Cone Penetrometer (ACP). The ACP is a probe-type instrument that when pushed down through the soil gives an airfield index (AI) of soil strength; these AIs correlate to CBR values. Its range is limited to 0 to 18 CBR and it will not penetrate many crusts, thin base course, or gravel materials that may overlie soft soil layers. Shown in **Figure 2.4** is the AI-CBR correlation. Consistency of test results is also difficult due to variability of soil strengths that affect the rate of penetration. The ACP is a 0.375-inch-diameter rod with a cone attached to one end and a handle/load indicator on the other (**Figure 2.5**). The angle of the cone is 30 degrees and the diameter of the base of the cone is 0.5 inch. The ACP works best in weak, fine-grained soils, such as silt and clay. It is not suitable for coarse-grained soils, such as gravels. Since it will not penetrate through stronger soil layers, do not assume that the soil strength underneath the impenetrable layer is adequate.

Figure 2.4. Correlation of AI and CBR.

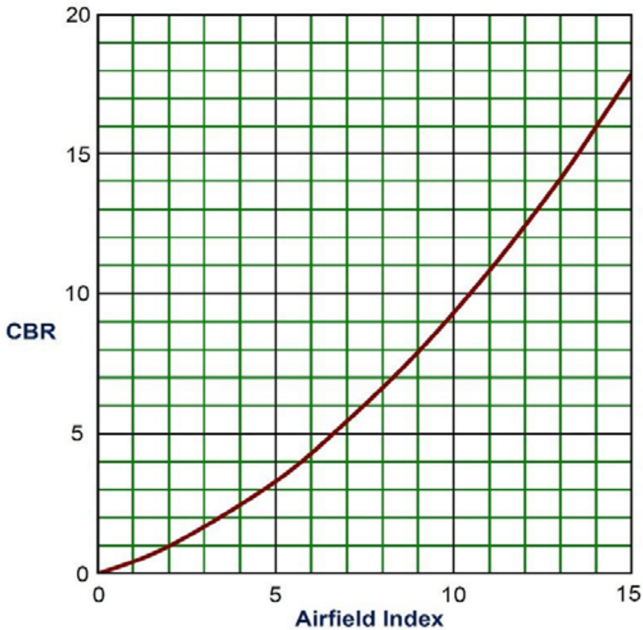
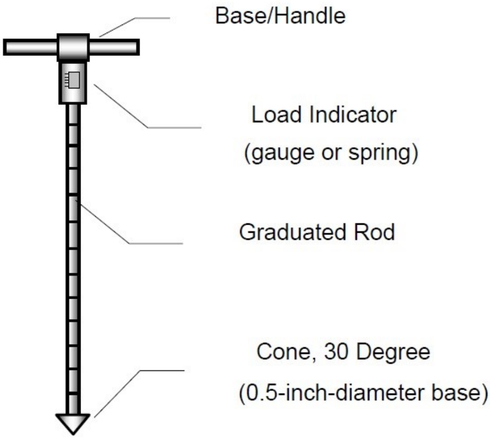


Figure 2.5. ACP.



2.2.4.2.2. Dynamic Cone Penetrometer (DCP). The DCP is the preferred method of obtaining CBR field data. It will measure soil strengths ranging from 1 to 100 CBR. A powerful, relatively compact, sturdy device that produces consistent results, the DCP consists of a stainless steel rod, 16 millimeters in diameter, with a cone attached to one end (**Figure 2.6**). The operator drives the cone into the soil by an 8-kilogram (17.6-pound) sliding hammer dropped from a height of 575 millimeters. The angle of the cone is 60 degrees and the diameter of the base of the cone is 20 millimeters. The rod may be either a scored version or smooth, requiring the use of an adjacent measuring scale. Operators use disposable cones that mount on an adapter in situations where the cone is difficult to remove from the soil. This disposable cone remains in the soil. Use of disposable cones can increase the number of tests accomplished per day. Two people are required to operate the DCP. One person, the operator, holds the device by its handle in a vertical position and taps the device using the slide hammer until the base of the cone is flush with the surface of the soil. The second person, or recorder, then measures the distance between the cone and the surface, ensures the device remains in a vertical position, measures the cone penetration, counts the number of hammer drops between measurements, and records the data. Both the operator and recorder should be alert to any sudden increases in cone penetration rates, which indicate weaker soil layers. Consult AFH 32-1034 and AF ETL 02-19 for detailed soil testing procedures using the DCP. The DCP kit includes:

- 1-case assembly
- 1-top rod threaded and welded to the handle
- 1-bottom rod threaded and welded to the anvil
- 1-dual-mass hammer
- 1-vertical scale in centimeters and inches
- 1-go/no go gauge
- 6-hardened, 60-degree, fixed cones
- 3-hardened cone adapters and 200 disposable cones
- 2-channel lock pliers
- 1-can of light, lubricating oil
- 1-thread-locking compound
- 1-hexagonal wrench set (5/64 to 1/4 inch)

Figure 2.6. DCP.

2.3. Soil Classification. Generally, the USCS classify soils into three major divisions; coarse-grained, fine-grained, and highly organic (**Table 2.2**). Soil groups include sand (S), gravel (G), silt (M), clay (C), organic (O), and highly organic (Pt). Basic soil classifications utilize a dual symbol, e.g., a soil meeting the criteria for a sandy clay would be designated (SC). When unable to classify borderline soils with a single dual symbol, such as SC, it may require four letters to describe them fully. For example, (SM-SC) describes a sand that contains appreciable amounts of silt and clay. In essence, each soil component contributes its characteristics to the soil mixture. Soil characteristics such as well-graded, poorly-graded, and low and high LL further define the condition of the soil and its potential usability. **Table 2.3** through **Table 2.5** catalogue various soil characteristics from the USCS. The following paragraphs briefly examine these classifications. **Note: Paragraph 2.4** addresses field expedient soil identification.

Table 2.2. USCS Soil Divisions, Groups, and Characteristics.

Major Soil Divisions			
Coarse-grained	Fine-grained		Highly organic
Soil Group Symbols			
G	Gravel	M	Silt
S	Sand	C	Clay
O	Organic (silts and clays)	Pt	Highly Organic (peat)
Soil Characteristics			
W	Well-graded	L	Low LL (less than 50)
P	Poorly-graded	H	High LL (50 or greater)

Table 2.3. Soil Characteristics (Part 1).

Soil Divisions		Group Symbol		Value as Subbase or Subgrade	Value as Base Course
Coarse Grained Soils	Gravel and Gravelly Soils	GW		Excellent	Good
		GP		Good to Excellent	Poor to Fair
		GM	d	Good to Excellent	Fair to Poor
			u	Good	Poor
		GC		Fair to Good	Poor
	Sands and Sandy Soils	SW		Good	Poor
		SP		Fair to Good	Poor to Not Suitable
		SM	d	Good	Poor
			u	Fair to Good	Not Suitable
		SC		Fair to Good	Not Suitable
Fine Grained Soils	Silts and Clays LL<50	ML		Fair to Poor	Not Suitable
		CL		Fair to Poor	Not Suitable
		OL		Poor	Not Suitable
	Silts and Clays LL>50	MH		Poor	Not Suitable
		CH		Poor to Very Poor	Not Suitable
		OH		Poor to Very Poor	Not Suitable
Highly Organic Soils		Pt		Not Suitable	Not Suitable

Note: Division of GM and SM groups into subdivisions of d and u are for roads and airfields. Suffix d is used when the LL is 28 or less and the PI is 6 or more. Suffix u is used when the LL is greater than 28.

Table 2.4. Soil Characteristics (Part 2).

Soil Divisions		Group Symbol		Potential Frost Action	Compressibility and Expansion
Coarse Grained Soils	Gravel and Gravelly Soils	GW		None to Very Slight	Almost None
		GP		None to Very Slight	Almost None
		GM	d	Slight to Medium	Very Slight
			u	Slight to Medium	Slight
		GC		Slight to Medium	Slight
	Sands and Sandy Soils	SW		None to Very Slight	Almost None
		SP		None to Very Slight	Almost None
		SM	d	Slight to High	Very Slight
			u	Slight to High	Slight to Medium
		SC		Slight to High	Slight to Medium
Fine Grained Soils	Silts and Clays LL<50	ML		Medium to Very High	Slight to Medium
		CL		Medium to Very High	Medium
		OL		Medium to Very High	Medium to High
	Silts and Clays LL>50	MH		Medium to Very High	High
		CH		Medium	High
		OH		Medium	High
Highly Organic Soils		Pt		Slight	Very High

Note: Division of GM and SM groups into subdivisions of d and u are for roads and airfields. Suffix d is used when the LL is 28 or less and the PI is 6 or more. Suffix u is used when the LL is greater than 28.

Table 2.5. Soil Characteristics (Part 3).

Soil Divisions		Group Symbol		Drainage Characteristics	Unit Dry Weight	Field CBR
Coarse Grained Soils	Gravel and Gravelly Soils	GW		Excellent	125 – 140	60 – 80
		GP		Excellent	110 – 130	25 – 60
		GM	d	Fair to Poor	130 – 145	40 – 80
			u	Poor to Impervious	120 – 140	20 – 40
		GC		Poor to Impervious	120 – 140	20 – 40
	Sands and Sandy Soils	SW		Excellent	110 – 130	20 – 40
		SP		Excellent	100 – 120	20 – 25
		SM	d	Fair to Poor	120 – 135	20 – 40
			u	Poor to Impervious	105 – 130	10 – 20
		SC		Poor to Impervious	105 – 130	10 – 20
Fine Grained Soils	Silts and Clays LL<50	ML		Fair to Poor	100 – 125	5 – 15
		CL		Impervious	100 – 125	5 – 15
		OL		Poor	90 – 105	4 – 8
	Silts and Clays LL>50	MH		Fair to Poor	80 – 100	4 – 8
		CH		Impervious	90 – 110	3 – 5
		OH		Impervious	80 – 105	3 – 5
Highly Organic Soils		Pt		Fair to Poor	--	--

Note: Division of GM and SM groups into subdivisions of d and u are for roads and airfields. Suffix d is used when the LL is 28 or less and the PI is 6 or more. Suffix u is used when the LL is greater than 28. CBR is estimated.

2.3.1. **Coarse-Grained Soils.** Coarse-grained soils are those in which at least half the material is retained on a Number 200 sieve. These soils have two major divisions, gravels and sands. A coarse-grained soil is considered gravel if more than half the coarse fraction by weight is retained on a Number 4 sieve. With gravelly and sandy soils, there is no clear-cut boundary or exact point of division between them, relative to soil behavior. Where a mixture occurs, the primary name is the predominant fraction and an adjective is the minor fraction. For example, a sandy gravel would be a mixture containing more gravel than sand by weight.

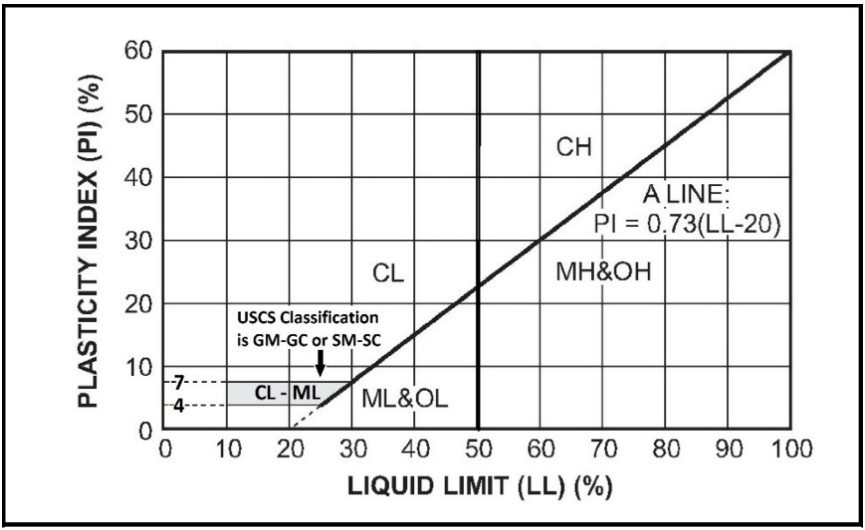
2.3.1.1. Divide coarse-grained soils further into groups based on the amount of fines they contain. **Table 2.6** lists these amounts as less than 5 percent, more than 12 percent, and between 5 and 12 percent. This cataloguing method allows for a more precise classification. For example, coarse-grained soils with between 5 and 12 percent of material passing the Number 200 sieve, and which meet the criteria for well-graded soil, require a dual symbol, as shown in the table.

Table 2.6. Coarse-Grained Soil Groups.

Less than 5 percent passing Number 200 sieve		**More than 12 % passing Number 200 sieve**	
GW	Well-graded gravels and gravel-sand mixtures	GM	Silty gravel and poorly graded gravel/sand-silt mixtures
SW	Well-graded sands and gravelly sands	SM	Silty sands and poorly graded sand-silt mixtures
GP	Poorly-graded gravels and sandy gravel mixtures	GC	Clayey gravels and poorly graded gravel-sand-clay mixtures
SP	Poorly-graded sands and gravelly sands	SC	Clayey sands and poorly graded sand-clay mixtures
Between 5 and 12 % passing Number 200 sieve			
GW-GM	GP-GM	SW-SC	SW-SM
GW-GC	GP-GC	SP-SC	SP-SM

2.3.1.2. The use of USCS soil groups M (silt) and C (clay) address the plasticity characteristics of the material passing a Number 40 sieve. The symbol M indicates the material passing the Number 40 sieve is silty in character. M usually designates a fine-grained soil of little or no plasticity. The symbol C indicates that the binder soil is clayey in character. One method to determine if fines are clayey or silty is to plot the known LL and PI on a plasticity chart (**Figure 2.7**).

Figure 2.7. Plasticity Chart.



2.3.1.3. Similarly, coarse-grained soils containing more than 12 percent of material passing the Number 200 sieve, and for which the limits plot in the shaded area (PI between 4 and 7) of the plasticity chart, are borderline between silt and clay and are classified as (SM-SC) or (GM-GC). In rare instances, a soil may fall into more than one borderline zone. If using appropriate symbols for each possible classification, the result should be a multiple designation using three or more symbols. This approach is unnecessarily complicated. It is best to use only a double symbol in these cases, selecting the two believed most representative of probable soil behavior. If there is doubt, use the symbols representing the poorer of the possible groupings.

2.3.2. **Fine-Grained Soils.** Fine-grained soils are those in which more than half the material passes a Number 200 sieve. Do not classify fine-grained soils by grain size, but according to plasticity and compressibility. Plasticity is the ability of a soil to deform without cracking or breaking. Compressibility is the property of a soil that permits it to deform under the action of an external compressive load. While all soils are compressible to a certain extent, the principal concern here is the effect of reduction in soil thickness (volume) under a load like that applied by the weight of roadways or pavement structures. The compressibility of the underlying soil could lead to the settlement of such structures.

2.3.2.1. As listed in **Table 2.7**, fine-grained soils include silts and lean clays (ML and CL); organic silts, lean organic clays, and micaceous or diatomaceous soils (OL and MH), and fat clays and fat organic clays (CH and OH). The USCS further classify these soils into two major groups, the H group (high compressibility) and the L group (low compressibility). Indicated on the plasticity chart, the H group are soils with a LL of ≥ 50; L group soils have a LL of < 50.

2.3.2.2. Typical soils of the (ML) and (MH) groups are inorganic silts. Those of low plasticity are in the (ML) group; others are in the (MH) group. The (ML) group includes:

- Very fine sands
- Rock flours
- Silty or clayey fine sands with slight plasticity

2.3.2.3. Micaceous and diatomaceous soils generally fall into the (MH) group but may extend into the (ML) group with LLs < 50. The same statement is true of certain types of kaolin clays, which have low plasticity. Plastic silts fall into the (MH) group.

2.3.2.4. Just as for borderline coarse-grained soils, fine-grained soils that fall into borderline areas or zones also have dual symbols (for example, CL-ML, silty clayey sand or gravel).

Table 2.7. Fine-Grained Soils.

Silts and Clays		
L-Group LL < 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
	CL	Gravelly clays, sandy clays, inorganic clays of low to medium plasticity, lean clays, silty clays
	OL	Organic silts and organic silty clays of low plasticity
H-Group LL > 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils; elastic silts
	CH	Inorganic clays of high plasticity (Heavy clays)
	OH	Organic clays of medium to high plasticity, organic silts

2.3.3. **Highly Organic Soils.** The USCS symbol (Pt) is a special classification reserved for the highly organic soils, such as peat, which have many undesirable engineering characteristics (**Table 2.8**). Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

Table 2.8. Highly Organic Soils.

Highly Organic		
Highly organic soils	Pt	Peat and other highly organic soils; readily identified by color, odor, spongy feel, and frequently by fibrous texture

2.4. Field Expedient Identification. Although soil testing in a laboratory is usually the preferred method, during the initial stages of a contingency operation a lack of time or facilities may make laboratory testing difficult. If necessary, use field-testing to assess soil properties and classify soil material. The calculations can distinguish between different soil types and properties and estimate potential engineering behavior of the soil during and after construction. While necessary for some contingency construction, these expedient classifications are approximations. Do not use them for designing permanent or semi-permanent road construction projects.

2.4.1. **Equipment.** Practically, all field-expedient soil testing is possible with no equipment or accessories other than a small amount of water. However, improved accuracy and uniformity of results increase by using certain equipment. The following equipment is easily transportable and should be available in most engineer units. If necessary, simply improvise items using available resources.

2.4.1.1. Sieves. A Number 40 US standard sieve. Any screen with about 40 openings per lineal inch is usable, or an approximate separation by sorting the materials by hand is an option. Use a Number 4 sieve to define the limit between gravels and sands, and use the Number 200 sieve for separating sands and fines.

2.4.1.2. Excavation hand tools. A pick and shovel or a set of entrenching tools for obtaining soil samples. A hand auger is useful if the desire is to obtain samples from depths more than a few feet below the surface.

2.4.1.3. Pan and heating element (oven, stove, etc.), for drying soil samples.

2.4.1.4. Mixing bowl and pestle (rubber/wooden) for pulverizing the fine-grained portion of the soil; may be improvised using a canteen cup and wooden dowel.

2.4.1.5. Scales or balance for weighing soil samples.

2.4.1.6. Knife or small spatula for obtaining and trimming soil samples to the desired size.

2.4.2. **Data Collected.** Soil data collected should provide a basic description of the soil and its properties. Soil properties forming the basis for the USCS are percentage of gravels, sands, or fines; shape of the grain-size distribution curve; and plasticity of the soil. **Table 2.9** lists soil properties and example data usually included in a soil description. Complete descriptions with classification symbol(s) are much more useful than a symbol or other isolated portion of a description alone. See **paragraph 2.4.3** for expedient soil test methods.

Table 2.9. Soil Properties and Examples.

Soil Property	Example Description
Color	Dark brown to white
Grain size (including estimated maximum grain size and estimated percent by weight of fines (material passing No. 200 sieve))	Coarse-grained soil, maximum particle size 2-3/4 inches, estimating 60 percent gravel, 36 percent sand, and 4 percent passing the No. 200 sieve
Gradation	Poorly graded (insufficient fine gravel, gap-graded)
Grain shape	Gravel particles sub-rounded to rounded
Water content (i.e., dry, moist, wet)	Dry
Plasticity	Non-plastic
Predominant type	Predominately gravel
Secondary components	Considerable sand and a small amount of non-plastic fines (silt)
Classification symbol	(GP)
Remarks (i.e., content; compactness; cohesiveness near PL; dry strength; and geologic name/source	Slightly calcareous, no dry strength, dense in the undisturbed state

2.4.3. **Test Methods.** Soil testing methods that aid in the field identification of soils include visual examinations, sedimentation tests, and plasticity tests. Each of these tests provide insight into the potential engineering behavior of the soil tested, both during and after construction. For additional instructions, review AFH 32-1034 and ETL 02-19, Appendix A.

2.4.3.1. **Visual examination.** This test should establish the color, grain sizes, grain shapes of the coarse-grained portion, approximate gradation, and some properties of the undisturbed soil.

2.4.3.1.1. Color. Color helps to identify and distinguish between various soil types. It may also indicate the presence of certain chemicals, minerals, or impurities. Describe the color of the sample when initially taken in the field at the as-sampled water content, because the color may change with changes in water content. Include the apparent moisture content at the time of identification (**Table 2.10**). Colors generally become darker as the moisture content increases and lighter as the soil dries. Some fine-grained soil (OH, OL) with dark, drab shades of brown or gray, including almost black, contain organic material. In contrast, clean, bright shades of gray, olive green, brown, red, yellow, and white are associated with inorganic soils. Gray-blue or gray-and yellow mottled colors frequently result from poor drainage. Red, yellow, and yellowish-brown result from the presence of iron oxides. White to pink may indicate considerable silica, calcium carbonate, or aluminum compounds.

Table 2.10. Water Content of Soil.

Description	Conditions
Dry	No sign of water and soil is dry to touch
Moist	Signs of water and soil is relatively dry to touch
Wet	Signs of water and soil is definitely wet to touch; granular soil exhibits some free water when densified

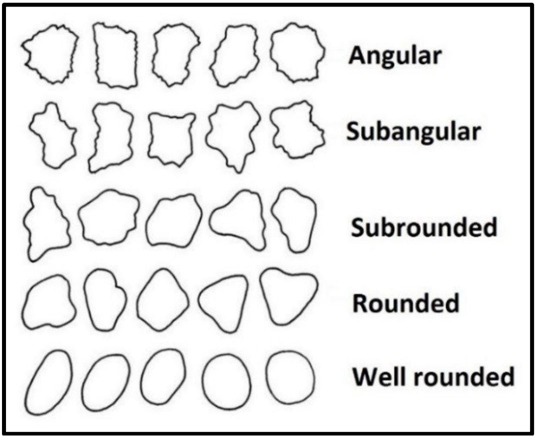
2.4.3.1.2. Grain size. Establish the maximum particle size of each soil sample to determine the upper limit of the gradation curve. Gravels range down to the size of peas; sands start just below this size and decrease until the individual grains are just distinguishable by the naked eye. Silt and clay particles are indistinguishable as individual particles. See **paragraph 2.2** for more information on grain size groups.

2.4.3.1.3. Grain shape. The shape of individual grains in a soil mass plays an important role in the engineering characteristics (strength and stability) of the soil. Two general shapes are normally recognized, bulky and platy. Platy shaped grains (clay and silt) are virtually indistinguishable to the naked eye. Visible bulky-shaped grains have five subdivisions. Listed below and illustrated in **Figure 2.8** are the five subdivisions in descending order of desirability for construction.

- *Angular* particles are those that have been recently broken up and are characterized by jagged projections, sharp ridges, and flat surfaces. Angular gravels and sands are generally the best materials for construction because of their interlocking characteristics. Such particles are seldom found in nature, however, because physical and chemical weathering processes usually wear off the sharp ridges in a relatively short period time. Angular material is usually produced artificially, by crushing.
- *Sub-angular* particles are those that have been weathered to the extent that the sharper points and ridges have been worn off.
- *Sub-rounded* particles are those that have been weathered to a further degree than sub-angular particles. They are still somewhat irregular in shape but have no sharp corners and few flat areas. Materials with this shape are frequently found in streambeds. If composed of hard, durable particles, sub-rounded material is adequate for most construction needs.
- *Rounded* particles are those on which all projections have been removed, with few irregularities in shape remaining. The particles resemble spheres and are of varying sizes. Rounded particles are usually found in or near streambeds or beaches.

- *Well-rounded* particles are rounded particles in which the few remaining irregularities have been removed. Like rounded particles, well-rounded particles are also usually found in or near streambeds or beaches.

Figure 2.8. Bulky Grain-Shaped Particles.



2.4.3.1.4. Grain size distribution. Examining a dry sample spread on a flat surface can make an approximate identification. Pulverize all lumps until individual grains are exposed, but not broken. Recommend using a rubber-faced or wooden pestle and a mixing bowl, but mashing the sample underfoot on a smooth surface will suffice for an approximate identification. Separate the larger grains (gravels and some sands) by picking them out individually. Examine the remainder of the soil and estimate the proportions of visible individual particles and fines (**Figure 2.9**). Convert these estimates into percentages by weight of the total sample. If the fines exceed 50 percent, consider the soil fine-grained (M, C, or O). If the coarse material exceeds 50 percent, the soil is coarse-grained (G or S). Examine coarse-grained soil for gradation of the particle sizes from the largest to the smallest. A good distribution of all sizes means the soil is well graded (W). Overabundance or lack of any size means the material is poorly graded (P). Estimate the percentage of the fine-grained portion of the coarse-grained soil for further classification. Fine-grained soils and fine-grained portions of coarse-grained soils require other tests for identification.

Figure 2.9. Grain Size Distribution.

2.4.3.1.5. Undisturbed soil properties. Characteristics of the soil in the undisturbed state may be helpful in identification. The compactness of gravels or sands may be loose, medium, or dense. Clays may be hard, stiff, or soft. Record the ease or difficulty of sample removal. The moisture content of the soil influences the in-place characteristics. It is helpful to know the weather just prior to and during the field evaluation to determine how the soil has reacted or will react to weather changes. The presence of decayed roots, leaves, grasses, and other vegetable matter in organic soils produces soil which is usually dark when moist, having a soft spongy feel and a distinctive odor of rotting organic matter. The odor may be musky and slightly offensive. The odor is especially apparent in undisturbed conditions or in fresh samples. The odor becomes less obvious as the sample is exposed to air. Make the odor stronger by heating a wet sample.

2.4.3.2. **Plasticity tests.** Fine-grained soil particles are generally not classified using gradation criteria but primarily by characteristics related to plasticity. Expedient field tests can help determine the cohesive and plastic characteristics of fine-grained soil. Except where noted, these tests are performed on material passing the No. 40 sieve, and include the breaking or dry strength test, roll or thread test, ribbon test, wet shaking test, cast test, wash test, bite or grit test, shine test, feel test, and sedimentation test.

2.4.3.2.1. Breaking or dry strength test. Prepare a pat of soil about 2 inches in diameter and 0.5 inch thick by molding it in a wet, plastic state. Allow the pat to dry completely (in the sun, in an oven, or inside the engine compartment), then grasp the pat between the thumbs and forefingers of both hands and attempt to break it. If the pat breaks, try to powder it by rubbing it between the thumb and forefinger of one hand. **Note:** Dry pats of highly plastic clays often display shrinkage cracks. Breaking the pat along such a crack may not give a true indication of the strength. It is important to distinguish between a break along such a crack and a clean, fresh break that indicates the true dry strength of the soil. If the:

- Pat cannot be broken nor powdered by finger pressure, it is a very highly plastic soil (CH)
- Pat can be broken with great effort, but cannot be powdered, it is a highly plastic soil (CL)
- Pat can be broken and powdered, but with some effort, it is a medium plastic soil (CL)
- Pat breaks easily and powders readily, it is a slightly plastic soil (ML, MH, or CL)
- Pat has little or no dry strength and crumbles or powders when picked up, it is a non-plastic soil (ML or MH) or (OL or OH)

2.4.3.2.2. Roll or thread test. Mix a representative portion of the sample with water until you can mold or shape it without it sticking to your fingers. Describe this moisture content as being just below the sticky limit. Prepare a nonabsorbent rolling surface by placing a sheet of glass or heavy wax paper on a flat or level support, then shape the sample into an elongated cylinder and rapidly roll the prepared soil cylinder on the surface into a thread approximately 0.125 inch in diameter. If the moist soil rolls into a thread, it has some plasticity. The number of times you can roll it into a thread without crumbling is a measure of the degree of plasticity. The higher the soil is on the plasticity chart, the stiffer the threads are as they dry out and the tougher the lumps are if the soil is remolded after rolling. Soils that cannot be rolled are non-plastic. **Note:** Micaceous silts and sands can be rolled due to the flaky nature of the mica. The wet shaking test is the only way to distinguish this property. If the:

- Soil can be molded into a ball or cylinder and deformed under very firm finger pressure without crumbling or cracking, it is high plasticity (CH)
- Soil can be molded, but it cracks or crumbles under finger pressure, it is medium plasticity (CL)
- Soil cannot be lumped into a ball or cylinder without breaking up, it is low plasticity (CL, ML, or MH)
- Soil forms a soft, spongy ball or thread when molded, it is an organic material (OL or OH)
- Soil cannot be rolled into a thread at any moisture content, it is a non-plastic soil (ML or MH)

2.4.3.2.3. Ribbon test. Prepare a soil sample as in the roll or thread test. Form a roll of soil about 0.5 to 0.75 inch in diameter and 3 to 5 inches long. Lay the roll across the palm of one hand (palm up) and starting at one end, squeeze the roll between the thumb and forefinger over the edge of the hand to form a flat unbroken ribbon about 0.125 to 0.25 inch thick. Allow the ribbon as formed to hang free and unsupported. Continue squeezing and handling the roll carefully to form the maximum length of ribbon that can be supported only by the cohesive properties of the soil. If the:

- Sample holds together for a length of 8 to 10 inches without breaking; it is highly plastic and highly compressive (CH)
- Soil can be ribboned only with difficulty to 3- to 8-inch lengths; it is low plasticity (CL)

2.4.3.2.4. Wet shaking test. Form a ball of soil about 0.75 inch in diameter, moistened with water to just below the sticky limit. Smooth the soil pat in the palm of the hand with a knife blade or small spatula, shake it horizontally, and strike the back of the hand vigorously against the other hand. When shaking, water comes to the surface of the sample producing a smooth, shiny, or livery appearance. Squeeze the sample between the thumb and forefinger of the other hand. The surface water will disappear. The surface will become dull and the sample will become firm, resisting deformation. Cracks will occur as pressure is continued and the sample will crumble. If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together. This process can only occur when the soil grains are bulky and non-cohesive. It is easy to identify very fine sands and silts by this test. Even small amounts of clay will tend to retard the reaction to this test. A rapid reaction is typical of non-plastic, fine sands and silts. A sluggish reaction indicates slight plasticity, indicating the silt has small amounts of clay or organic silts. **Note:** No reaction at all does not indicate a complete absence of silt or fine sand.

2.4.3.2.5. Cast test. Compress a handful of damp (not sticky) soil into a cylinder and observe its ability to be formed and handled. If the:

- Soil crumbles when touched - GP, SP, SW, GW
- Soil cast withstands careful handling - SM, SC
- Soil cast can be handled freely - ML, MH
- Soil cast withstands rough handling - CL, CH

2.4.3.2.6. Wash test. Place a small dry sample of soil into the palm of the hand and cover with water. Note how quickly the water discolors and how long the fines are suspended. One variation is to look for mud puddles or create them, disturb the soil surface and note how the water discolors and how long the fines are suspended. If the water becomes completely discolored and hides the sand particles there is evidence of greater than 5 percent silt content.

2.4.3.2.7. Bite or grit test. Grind a small pinch of soil lightly between the teeth. For sandy soils, the sharp hard particles of even fine sands will grate very harshly between the teeth and will be highly objectionable. For silty soils, silt grains are not particularly gritty, but their presence is still quite unpleasant and easily detected. With clayey soils, the clay grains feel smooth and powdery like flour, and dry lumps will stick when lightly touched with the tongue. **Note:** Ideally, perform this test on material passing the No. 200 sieve to avoid biting into sand and providing separation between silty and clayey fines.

2.4.3.2.8. Shine test. Rub a clay sample with a fingernail or smooth metal surface such as a knife blade. Highly plastic clay will produce a definite shine; lean clays will remain dull.

2.4.3.2.9. Feel test. For consistency, squeeze a piece of undisturbed soil between the thumb and forefinger; it may be hard, stiff, brittle, friable, sticky, plastic, or soft. Remold the soil by working it between the hands. This can indicate the natural water content. Clays that become fluid on remolding are probably near their liquid limit; if they remain stiff and crumble, they are probably below their liquid limit. Check the texture by rubbing a portion of fine-grained soil between the fingers or on a more sensitive area such as the inside of the wrist. Results are similar to the bite or grit test. **Note:** Ideally, perform this test on material passing the No. 200 sieve to avoid sand particles giving an erroneous reaction.

2.4.3.2.10. Sedimentation test. From visual examination, it is relatively easy to approximate the proportions of gravels and sands in a soil sample. Determining the proportion of fine-grained particles is more difficult but just as important. Although you can separate the fines from the sample using a No. 200 sieve, the sedimentation test is an alternate field method to separate fines from the sand particles in a soil sample. Placing a small amount of the fine fraction of a soil (such as a heaping teaspoon) in a transparent cup or jar, covering it with about 5 inches of water, and agitating it by stirring or shaking will completely suspend the soil in water. With cohesive soils, it will be necessary to break up all lumps of soil before adding the water. After soil particles have been dispersed in the water and then left, they will start to settle to the bottom, beginning with the larger sized particles, in time-periods indicated in **Table 2.11**. Smaller particles will settle through water at a slower rate than large particles. Since all of the particles of soil larger than the No. 200 sieve will have settled to the bottom of the cup or jar 30 seconds after the mixture has been agitated, it follows that the particles remaining in suspension are fines. Carefully pour the water containing the suspended fines into another container 30 seconds after agitation, add more water to the cup or jar containing the coarse fraction, and repeat the procedure until the water-soil mixture becomes clear 30 seconds after mixing. The cup or jar will contain the coarse fraction of the soil and the other container will hold the fines. After absorbing or evaporating the water off, the relative amounts of fines and sands can be accurately determined. In clay soils, the clay particles will often form small lumps (flocculate) that will not break up in water. If after several repetitions of the test substantial amounts of clay are still present in the coarse material, the sand will feel slippery. Further mixing and grinding with a stick will be necessary to help break up these lumps.

Table 2.11. Sedimentation Test.

Approximate Time of Settlement in 5 Inches of Water	Grain Diameter	Differentiates
2 seconds	0.4 mm	Coarse sand – fine sand
30 seconds	0.072 mm (No. 200 sieve)	Sand – fines
10 minutes	0.03 mm	Coarse silt – fine silt
1 hour	0.01 mm	Silt – clay

2.4.3.2.11. **Table 2.12** is a convenient way to track various field identification tests. As tests are completed, mark the results on the chart. The results from the different tests may vary, but by plotting the test results, you will have a general indication of the soil type. Essentially, soil types and their characteristics can affect how the soil will behave as a construction material. Once soil testing and surveys are completed, consider the preparations and actions needed to accomplish the specific expedient roadway construction or repair project.

Table 2.12. Summary of Field Identification Test Results.

<table>
<tr><th colspan="7">Field Identification of Soils</th></tr>
<tr><th rowspan="2">Test</th><th rowspan="2">Material</th><th colspan="5">Soil Types</th></tr>
<tr><th>ML</th><th>MH</th><th>CL</th><th>CH</th><th>OL/OH</th></tr>
<tr><td>Dry strength</td><td>< 40 sieve (wet)</td><td>No to low</td><td>Low to medium</td><td>Medium to high</td><td>Very high</td><td>Low</td></tr>
<tr><td>Roll/thread</td><td>< 40 sieve (sticky)</td><td>Low</td><td>Low to medium</td><td>Medium</td><td>High</td><td>Spongy</td></tr>
<tr><td>Ribbon</td><td>< 40 sieve (sticky)</td><td>No cohesion</td><td>Little cohesion</td><td>3 to 8 inches</td><td>8 to 10 inches</td><td></td></tr>
<tr><td>Wet shake</td><td>< 40 sieve (sticky)</td><td>Slow to rapid</td><td>No to slow</td><td>No to slow</td><td>No</td><td></td></tr>
<tr><td>Cast</td><td>Damp</td><td colspan="2">Handle freely</td><td colspan="2">Handle roughly</td><td></td></tr>
<tr><td>Bite/feel</td><td>< 40 (< 200) sieve</td><td colspan="2">Unpleasant</td><td colspan="2">Smooth</td><td></td></tr>
<tr><td>Shine</td><td rowspan="4"></td><td colspan="3">Dull</td><td>Shine</td><td></td></tr>
<tr><td>Wash</td><td colspan="5">Discolors quickly, > 5% silt</td></tr>
<tr><td>Dust</td><td colspan="2">> 10% silt</td><td colspan="3"></td></tr>
<tr><td>Sedimentation</td><td colspan="2">30 seconds</td><td colspan="2">1 hour</td><td></td></tr>
</table>

2.5. Expedient Road Construction and Repair. Generally, expedient road construction and repair is in response to an immediate need, and usually done quickly and with whatever suitable materials are available. Road surfaces at initial contingency locations may be near nonexistent or consist primarily of graded dirt surfaces. As time becomes available, these earthen roads can be improved for increased traffic loads by covering them with material from a borrow pit or with processed material. The focus of this section is on road construction preparations, soil stabilization methods, and road surfacing options over unstable soils using expedient materials. **Note:** Construction or repair of concrete pavement surfaces with cement-based materials are not expedient methods and will not be addresses here. For detailed information related to flexible and rigid pavement designs, refer to UFC 3-250-01, *Pavement Design for Roads and Parking Areas*, UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*, and UFC 3-250-04, *Standard Practice for Concrete Pavements*.

2.5.1. **Preparations.** Key preparations to expedient roadwork include determining on-site soil conditions and available construction options. When the in-place soil is not strong enough for the road design, it can be chemically or mechanically stabilized, covered with a bituminous surface treatment, covered with expedient surface materials, or have the unstable soil replaced. If the soil is stable, the most practical and probably most used type of expedient road surface and subgrade consist of compacted gravel surfaces—a process very familiar to engineer personnel. Generally, expedient roads are short-lived and intended as temporary measures, so ensure preparations address future needs to construct surfaces that are more durable should the area matures or move towards an enduring location.

2.5.1.1. **Design Considerations.** Expedient roads usually consists of unsurfaced or aggregate-surfaced roads. Unsurfaced roads have in-place natural soil or borrow soil as its surface. Surface preparations usually include clearing and grubbing followed by scarifying grading, and compacting. Ideally, the design (compacted) CBR value of in-place soil should exceed the CBR value required. If the in-place design CBR value is less than the CBR required, the engineer should be prepared to decrease the design life or improve the in-place soil to meet the CBR required by using soil stabilization/treatment, or placing aggregate. Aggregate-surfaced roads are similar in design to unsurfaced roads. However, in aggregate-surfaced roads, layers of high-quality material cover the natural subgrade to improve its strength. Materials used in aggregate roads should have greater strength than the subgrade and be placed so that the higher-quality material is on top of the lower quality material. Final road design should depend on the traffic type, intensity, and duration. For detail information on aggregate road design and construction, refer to UFC 3-250-09FA, *Aggregate Surfaced Roads* *and Airfield Areas*. Before beginning construction on expedient roads, verify the planned route, then determine if land clearing or subgrade improvement is necessary.

2.5.1.2. **Land-Clearing Preparations.** Oftentimes, land clearing precedes road construction or repair activities. Land clearing may involve removal and disposal of vegetation, rubbish, and surface boulders embedded in the ground along the planned route. During hostilities, it may include the removal and disposal of mines, booby traps, and unexploded explosive ordnance (UXO). Engineers use heavy equipment, power tools, hand tools, explosives, or even fire to clear and prepare the required acreage. **Note:** Avoid using fire to clear land if suitable equipment and sufficient personnel are available for other methods.

2.5.1.2.1. Safety. Before starting land clearing operations, carefully consider the safety of all personnel and equipment during clearing operations. Proper supervision and planning will help to prevent accidents caused by falling trees, uprooted stumps, stump holes, and rough or broken terrain.

2.5.1.2.2. Climate and Geology. Clearing, grubbing, and stripping operations differ in every climatic zone because each zone has different forest and vegetative types. Soils, altitudes, water tables, and other factors vary widely within each zone. Verify and consider local factors before beginning any clearing operation.

2.5.1.2.3. Camouflage. If cover and concealment of the clearing operation is a concern, you should not remove standing trees and brush outside the designated cleared area unless necessary. When uprooting trees with bulldozers, take care to control their fall and avoid breaking surrounding trees.

2.5.1.2.4. Timber Salvage. For optimal use of resources, consider trimming all useful timber for logs, piles, and lumber; stockpile it for future use in bridge, culvert, and other expedient construction applications. Push or skid this timber into a salvage area where it can relocated to a sawmill or other processing location with little difficulty.

2.5.1.2.5. Temporary Drainage. Phased development of the drainage system in the early stages of clearing, grubbing, and stripping is essential to ensure uninterrupted construction. Delays caused by flooding, subgrade failures, and heavy mud conditions, and the subsequent immobilization of construction equipment can be eliminated by careful development of the drainage system before, or concurrent with, other construction. Use the original drainage features as much as possible without disturbing natural grades. Grade drainage ditches downhill. Fill holes left by uprooted trees and stumps with acceptable soil, and compact the ground to prevent the accumulation of surface water. Use dozers and graders for this work. Slope the ground toward drainage ditches to prevent ponding on the surface. Backfill existing ditches at the latest possible time to permit the best use of the original drainage.

2.5.1.2.6. Disposal of Cleared Material. The choice of waste disposal method depends on the type of construction, environmental concerns, the location, the threat, and the time available. Generally, to speed disposal and keep the area clear for equipment operation, push cleared material off the construction site and into the surrounding timber. To dispose of material as rapidly as possible, assign personnel and equipment to accomplish this concurrently with the clearing and grubbing. The disposal method should be consistent with the methods of camouflage, salvage, and drainage used for clearing.

2.5.1.3. **Subgrade Preparations.** Whether constructing permanent or temporary roadways, or performing expedient repairs to existing roads, the condition of the subgrade and other underlying layers are important considerations. Specifically, any distortions or displacements occurring in the subgrade will be reflected in the base course and continue upward into non-rigid roadway surfaces. Subgrades and base course should be adequate to support the anticipated traffic loads for the time required. In some instances, in-placed soils may need to be compacted and improved, or stabilized (by treatment with additives) to achieve the desired effect. Subgrades can be stabilized mechanically (by adding granular materials), chemically (by adding chemical admixtures), or with a stabilization expedient (sand-grid, matting, or geosynthetics). Stabilization with chemical admixtures (lime, Portland cement, and fly ash) is generally costly but may prove to be economically feasible, depending on the availability of the chemical stabilization agent in comparison with the availability of granular material. Consider the following factors when determining the suitability of a subgrade:

- General characteristics of the subgrade soils
- Depth to bedrock
- Depth to the water table
- Compaction that can be attained in the subgrade
- CBR values of un-compacted and compacted subgrades
- Weak or soft layers or organics in the subsoil
- Detrimental frost action or excessive swell susceptibility

2.5.2. **Soil Stabilization.** Soil stabilization is the alteration of one or more soil properties, using mechanical means or additives to create an improved soil material possessing the desired engineering properties. Stabilizing soils can increase strength and durability or to prevent erosion and dust generation. Regardless of the purpose for stabilization, the desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of the project. There are numerous methods to stabilize soils; however, all stabilization methods fall into the two broad categories of mechanical and additive stabilization. Some stabilization techniques use a combination of these two methods. For additional information on soil stabilization, consult AFH 32-1034 and UFC 3-350-11, *Soil Stabilization for Pavements*.

2.5.3. **Mechanical Stabilization.** Mechanical stabilization relies on physical processes to stabilize the soil, altering the physical composition of the soil (soil blending) or placing a barrier in or on the soil to obtain the desired effect. Mechanical stabilization through soil blending is the most economical and expedient method of altering the existing material. When soil blending is not feasible or does not produce a satisfactory soil material, consider geosynthetics (sometimes referred to as geofabrics or geotextiles) or additive stabilization methods as an option.

2.5.3.1. **Soil Blending and Compaction.** Involves mechanically mixing or blending two or more gradations of soil material to obtain a mixture that meets the required specifications. For example, the natural soil at a selected location has low load-bearing strength because of excess clay, silt, or fine sand. However, within a reasonable distance, suitable granular materials may occur, and if blended with the existing soils can markedly improve the soil at a much lower cost in labor and materials than involved with importing surfacing.

2.5.3.1.1. One type of mechanically stabilized soil surface is a sand-clay road. It consists of a natural or artificial mixture of sand and clay that is graded and drained to form a road surface. Although difficult to obtain, the PI should be less than 5 and LL less than 25 in case this layer becomes a subbase after placing additional layers above the sand clay. The gradation requirements for a typical sand-clay surface are in **Table 2.13**, under the column for 1 -inch sand-clay. The addition of fine gravel (slightly larger than the No. 4 sieve) usually adds stability. Sand-clay roads will carry light traffic reasonably well and heavy traffic except under bad weather conditions. The amount of moisture these roads absorb determines their stability under traffic loads. They require dust control, blading, and dragging. Sand-clay roads withstand traffic better than ordinary earthen roads, but their use is limited to areas where a suitable mixture of sand and clay occurs naturally or where a deficiency of either soil is readily corrected. As a base course for future surfacing, sand-clay roads produce poor results, unless engineers reduce the plasticity by additive stabilization with an agent such as lime.

Table 2.13. Suggested Grading Requirements for Sand-Clay Surfaces.

Sieve Designation	Percent Passing by Weight
1 inch	100
No. 10	65-90
No. 40	33-70
No. 200	8-25

2.5.3.1.2. Gravel roads consist of a compacted layer of gravelly soil that meets the plasticity requirements for mechanically stabilized soil mixtures. The gravel is graded from coarse to fine, with a maximum allowable size of 1 inch. Listed in **Table 2.14** are suggested gradation requirements for a gravel surface. A natural pit- or bank-run gravel may meet these requirements without further processing other than screening. Some pit- or bank-run gravels may require both screening and washing to meet the requirements. River-run gravels normally require the addition of binder to the soil, as do mechanically stabilized soil mixtures. River-run gravels may also require crushing to provide a rough, angular surface rather than the natural, smooth surface characteristic of river-run materials. The ability to carry heavy, sustained traffic depends on the strength and hardness of the gravel, the cohesiveness of the clay binder, the thickness of the layer, and the stability of the subgrade. Personnel can build these roads rapidly, even in cold weather. Like other untreated surfaces, gravel roads require considerable maintenance such as blading and dust control in dry weather. During wet weather, proper maintenance is difficult, especially under heavy traffic. Gravel road surfaces with low plasticity make excellent base courses for later-stage pavements.

Table 2.14. Suggested Grading Requirements for Gravel Surfaces.

Sieve Designation	Percent Passing by Weight
3/4 inch	100
No. 4	70-100
No. 10	35-80
No. 40	25-50
No. 200	8-25

2.5.3.1.3. Mechanical mixing of soil-aggregate materials can be accomplished at the construction site, a central plant, or a borrow area, and then spread and compacted to the required densities by conventional means. If the mixture does not meet the specifications after blending, other stabilization methods may be an option. See **Table 2.15** for the steps involved in on-site blending.

Table 2.15. On-Site Soil Blending Steps.

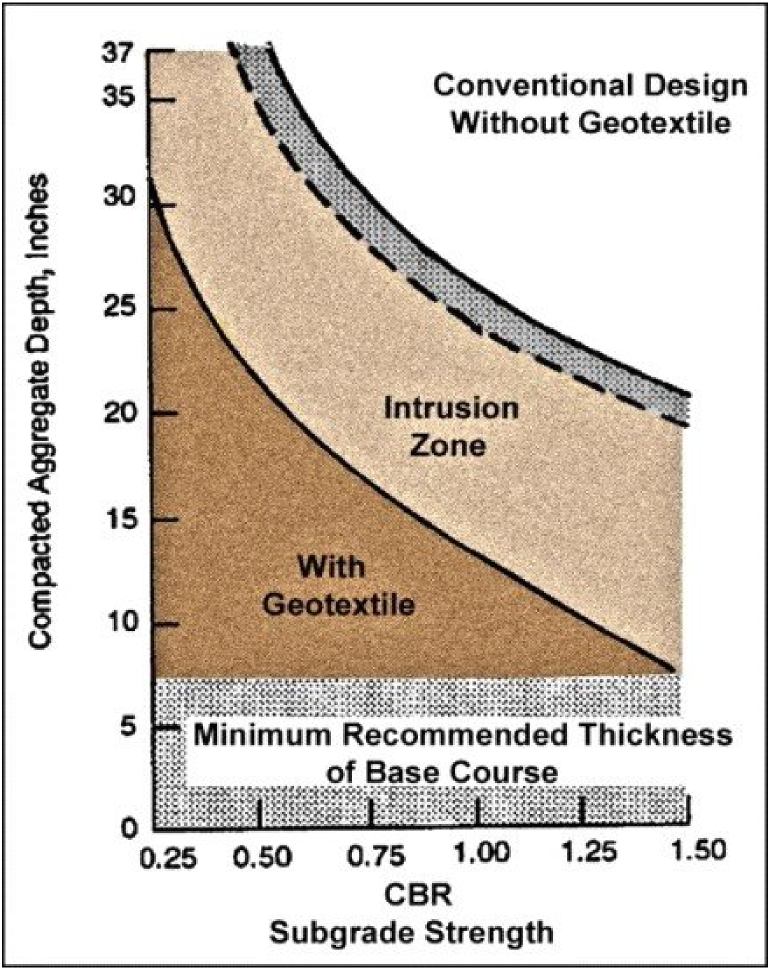
Soil Blending (On-Site)
Preparation: – Shape the area to crown and grade – Scarify, pulverize, and adjust the moisture content of the soil, if needed – Reshape the area to crown and grade
Add imported soil materials using one of the following methods: – Distribute evenly by means of an improved stone spreader – Use spreader boxes behind dump trucks – Tailgate each measured truck, loading to cover a certain length – Dump in equally spaced piles; form into windrows with a motor grader before spreading
Mixing: – Add water to obtain moisture content of about 2 percent above optimum and mix with a rotary mixer, pulvimixer, blade, scarifier, or disk – Continue mixing until the soil and aggregate particles are in a uniform, well-graded mass – Blade to crown and grade, if needed
Compaction: – Compact to specifications determined by the results of compaction tests performed on the blended soil material – Select the appropriate types(s) of compaction equipment, based on the gradation characteristics of the blended soil

2.5.3.2. **Geosynthetics Liners and Barriers.** In broad terms, geosynthetics products are made of permeable fabrics (woven and non-woven) and used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a human-made project, structure, or system. In relation to expedient road construction and repair, geosynthetics liners and barriers can reinforce weak subgrades and separate soil layers (**Figure 2.10**).

Figure 2.10. Using Geosynthetics in Road Construction.

2.5.3.2.1. A main concern during horizontal construction at expeditionary contingency locations is often with separating and reinforcing low load-bearing soils to reduce construction time. In many situations, using geofabrics can reduce soil requirements, which saves time, materials, and equipment costs. Tests show that for low load-bearing soils (generally anything less than a CBR value of 5), the use of geosynthetics fabric 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 2.11** illustrates this concept.

Figure 2.11. Comparison of Aggregate Depth Requirements.



2.5.3.2.2. Engineers also use geosynthetics fabrics for rapid stabilization of swamps, peat bogs, and beach sands. 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 difficult and time-consuming. Furthermore, when using mucking, the area should have a sound, stable soil underneath the soft soil and suitable fill material nearby. Consequently, during contingencies, engineer teams usually place a bridge of base course construction material directly over the weak soil, separated by a layer of geosynthetics material, as shown in **Figure 2.12**.

2.5.3.2.3. Illustrated in **Figure 2.13** is the basic construction sequence for the direct fill process. A wide range of geosynthetics fabric (geofabric) is available to meet various soil conditions. Selection of the proper geosynthetics will depend on the actual soil and hydraulic conditions. **Note:** For additional information on road design and the types and application of geosynthetics review UFC 3-250-01, UFC 3-250-09FA, and UFC 3-220-08FA, *Engineering Use of Geotextiles*,

Figure 2.12. Geofabrics Separate and Confine Weak Subgrades.

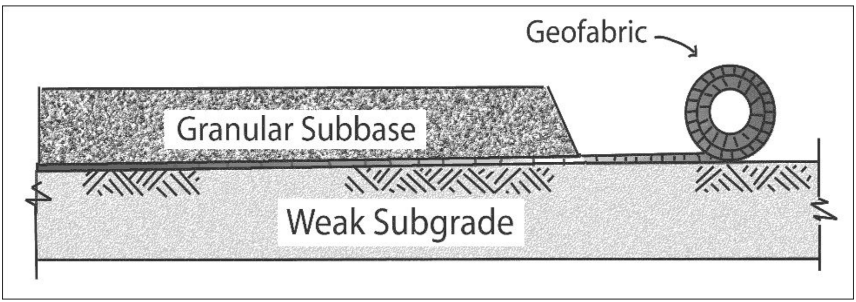
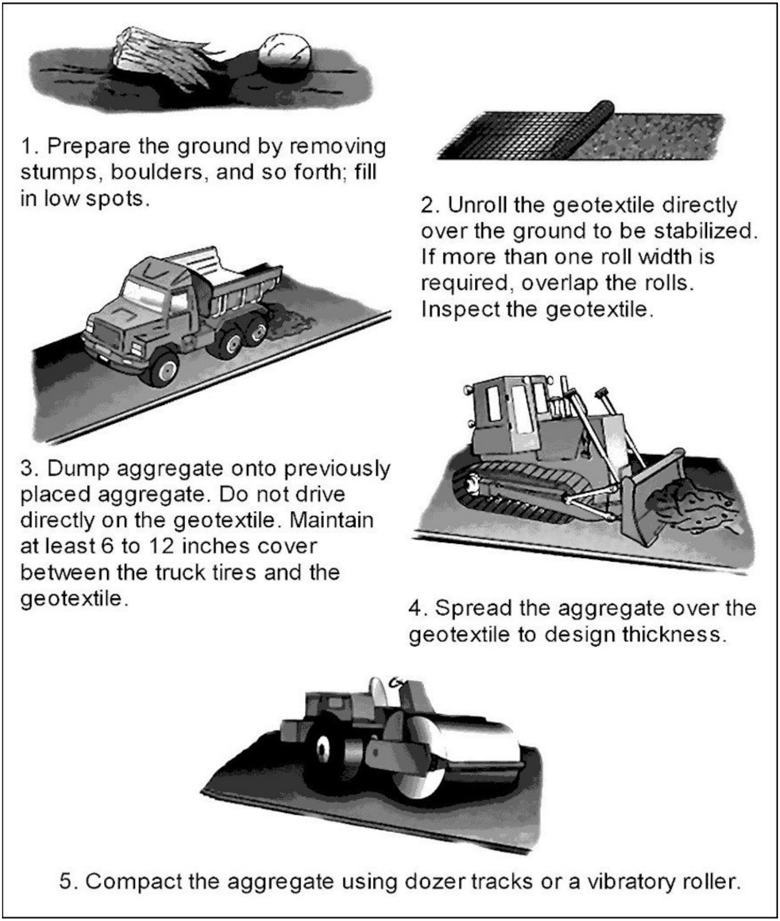


Figure 2.13. Basic Geotextile Construction Sequence.



2.5.3.3. **Geosynthetics Cells.** Use of geosynthetics cells (often referred to as Geocells or sand grids) as an expedient method to stabilize loose sands and produce a load-distributing base layer for expedient road construction may be an option. Sand-grid road construction greatly improves wheeled vehicle trafficability over sand and sandy soils. The sand grid stabilizes the soil by confining the sand or sandy materials in interconnected cellular elements improving load-bearing capability. It has application in areas where sandy materials are abundant and quality construction aggregates are not available. The plastic honeycomb grid (National Stock Number [NSN] 5680-01-198-7955) is manufactured and shipped in unexpanded sections (11 feet by 5 inches by 8 inches), which are easily expanded for field use (**Figure 2.14**). Each section weighs 110 pounds and expands to form a honeycomb arrangement that covers an area 8 by 20 feet and 8 inches thick. Other applications of sand-grid technology include field expedient walls and revetments covered in **Chapter 3** of this publication. The following paragraphs address procedures for building expedient sand-grid roads.

Figure 2.14. Expanding Sand-Grid Material.

2.5.3.3.1. Below is the recommended equipment for building sand-grid roads. Work crews can quickly construct a sand-grid road using bucket loaders, graders, and vibratory compaction rollers for site preparation. The use of rough-terrain forklifts, water distributors, asphalt distributors, shovels, and plywood sheets can increase the effectiveness and speed of construction. Once the equipment is on hand, accomplish site preparations; i.e., perform normal cut and fill operations to reach the desired grade; back blade the surface for smoothness; compact the sand subgrade at a moisture content approaching saturation using the vibratory roller. Afterwards, layout the sand-grid pattern and begin installation. Installation rate is approximately 65 square feet per man-hour.

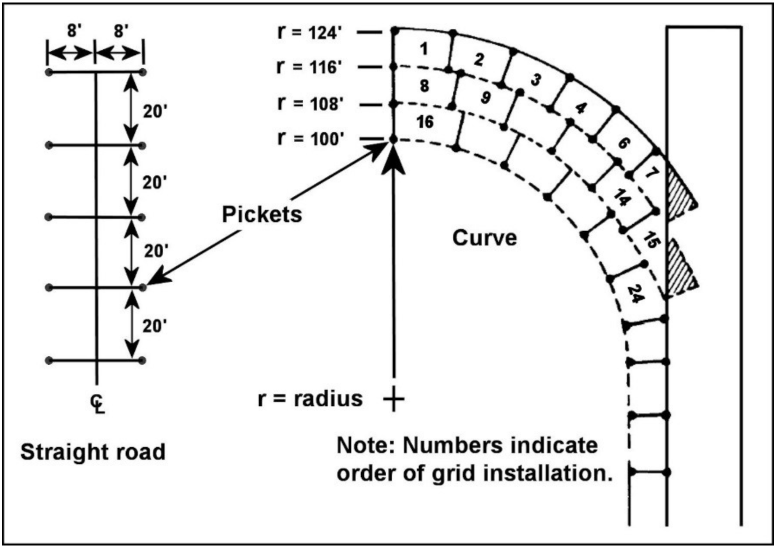
- Graders
- Bucket loaders (smooth-bucket, no teeth)
- Rough-terrain forklifts
- Vibratory rollers
- Water distributors
- Bituminous distributors
- Long-handled round-pointed shovels
- Plywood sheets (3/8-inch by 8-foot by 4-foot)

2.5.3.3.2. Sand-grid road designs are simple, require minimum skilled labor, and use local materials whenever possible. Install the grid by setting the stakes and string lines in 8-foot by 20-foot boxes in the desired pattern. See **Figure 2.15** for layout patterns.

2.5.3.3.3. Expand each grid section by pulling the ends outward to slightly over 20 feet, then shaking the section in the air to obtain uniform cell openings. Place the section according to your layout pattern. Use pickets or place sand in the corner cells and approximately every fifth cell on the sides to anchor the grid in place.

2.5.3.3.4. To construct joints between grids, use small, 3/8-inch plywood sheets to allow workers to stand on top of the unfilled grid to have access to the joints. For end joints, the rounded end cells from different sections should touch each other. For longitudinal (side-by-side) joints, interlock the “welded” cell portions of each section, as if fitting a puzzle. Fill the jointed cells with sand. If necessary, level the joints by placing plywood over the joints and having crews walk on top of the plywood.

Figure 2.15. Example Sand-Grid Layout Pattern.



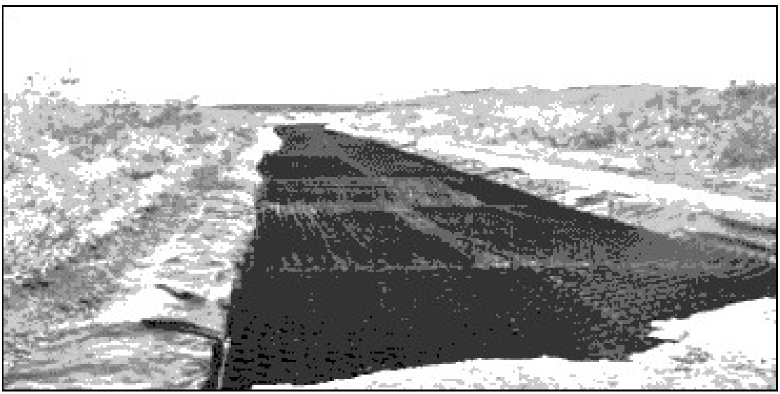
2.5.3.3.5. Fill each grid section using a bucket loader. Drop the sand vertically into the cells from a height of at least 2 feet. Do not push the sand forward or cells will displaced. Overfill the grids by 2 to 4 inches so bucket loaders can operate on the sand-filled grid layer without damaging any cells. Use shovels and rakes to spread overfill across the cells to form a uniform layer. Have bucket loaders vary wheel paths to achieve uniform compaction.

2.5.3.3.6. If water is readily available, wet the sand using a water distributor. This will significantly aid in the compaction process. Compact the road surface with one or two passes of the vibratory roller. Remove excess sand from the grid surface with a grader or by back-blading with a bucket loader. Do not use a bucket loader with teeth because cell damage can result. Compact the road surface again with one pass of the vibratory roller. **Note:** Do not over compact the surface because it could damage the sand grid and result in premature failure.

2.5.3.3.7. To stabilize and seal the road surface, a sand-asphalt surfacing is formed by spraying a suitable liquid-asphalt cement, emulsion, or cutback (rapid curing (RC) 250 at 165+^{0} F is preferred) on the surface of the sand-grid layer. Spray the asphalt product on the road surface and allow enough time for the asphalt product to soak into the grid structure (usually about 10 hours). The asphalt should penetrate into the top 1/2 to 1 inch of sand in the cells. Apply a very light coat (1/4 inch) of blotter sand using shovels. Compact the road using one pass of a non-vibrating roller. Vibrating the road at this point will break the asphalt bonds.

2.5.3.3.8. To further increase road life, apply and compact a 3-inch surface coat of 1-inch (maximum) gravel, if available. This layer will add a protective cover over the sand-grid road, significantly increasing the road life. Over a sand subgrade, this sand-grid road is capable of supporting over 10,000 passes of heavy truck traffic including tandem axle loads of up to 53,000 pounds. However, avoid tracked vehicles traveling over this road, as their tracks will easily damage the grid cells. **Figure 2.16** is shows a sand-grid road under construction over unstable sandy terrain.

Figure 2.16. Using Sand-Grid in Road Construction.



2.5.4. **Additive Soil Stabilization.** Additive soil stabilization involves adding a manufactured commercial product to the soil in the proper quantities to improve the quality of the soil layer. Additives may stabilize the soil chemically, physically or by a combination of the two. Examples of pure chemical stabilizers are lime, acids, and enzymes that cause a chemical change in the soil. Examples of pure physical stabilizers are bitumens that bind the soil by adhesion and fibers that bind by mechanical friction and interpenetration. Other stabilizers such as lime-cement-fly ash (LCF) may bind soil particles together, but also induce chemical changes in the soil. Most additive stabilization projects involve the use of cement, lime, or fly ash. Listed in **Table 2.16** are soil stabilization applications and methods. While some of the methods appear to be labor intensive, they are quite the opposite when compared against standard road construction methods. This section reviews techniques for additive soil stabilization. Readers should consider consulting AFH 32-1034, UFC 3-250-11, *Soil Stabilization for Pavements*, and UFC 3-250-01 for additional information on soil testing and the selection and use of additive soil stabilizers. When there is not enough time to perform thorough mix design tests, the suggested stabilizer amounts in **Table 2.17** may be acceptable for listed soil types and classes. Avoid adding excessive amounts of cement because it will likely lead to an increase in shrinkage cracking, which will lead to deterioration of the pavement surface. **Note:** The use of cement, lime, or fly ash to stabilize a soil with a high content of sulfates (as present in many Southwest Asia countries) can lead to heave from ettringite formation. Engineers may need to have soil tested for sulfate content before selecting a stabilization agent. Selecting the type and quantity of additives depend on the soil classification and the degree of improvement in the soil quality desired. Although effective, there are hazards associated with soil stabilizers. While the hazard of airborne particles is reduced significantly in the open air on the construction site, when working with these materials, refer to detailed information listed in the Material Safety Data Sheet prepared by the product manufacturer.

Table 2.16. Suitable Stabilization Methods for Specific Applications.

Application	Soil Type	Treatment Method
Subgrade Stabilization Improves load-carrying and stress-distribution characteristics	Fine-grained	SA, SC, MB, C
	Coarse-grained	SA, SC, MB, C
	Clays of low PI	C, SC, CMS, LMS, SL
	Clays of low PI	SL, LMS
Reduces frost susceptibility	Fine-grained	CMS, SA, SC, LF
	Clays of low PI	CMS, SC, SL, LMS
Improves waterproofing and runoff	Clays of low PI	CMS, SA, LMS, SL
Controls shrinkage and swell	Clays of low PI	CMS, SC, C, LMS, SL
	Clays of low PI	SL
Reduces resiliency	Clays of low PI	SL, LMS
	Elastic silts or clays	SC, CMS
Base Course Stabilization Improves substandard materials	Fine-grained Clays of low PI	SC, SA, LF, MB,SC, SL
Improves load-carrying and stress-distribution characteristics	Coarse-grained	SA, SC, MB, LF
	Fine-grained	SC, SA, LF, MB
Reduces pumping	Fine-grained	SC, SA, LF, MB, membranes
Dust Palliative	Fine-grained	CMS, SA, oil or bitumi-nous surface spray, PSB
	Plastic soils	CMS, SL, LMS, APSB, DCA 70

Legend: APSB = Asphalt penetration surface binder; LMS=Lime-modified soil; C=Compaction; MB=Mechanical blending; CMS=Cement-modified soil; DCA 70=Polyvinyl acetate emulsion; LF=Lime-fly ash; SA=Soil-asphalt SC=Soil-cement; SL=Soil-lime; PI=Plasticity Index

Table 2.17. Soil Stabilizers for Different Soil Types.

Soil Type	Class	Fine Content	Plasticity Index	Stabilizer Type (a)	Percent Additives
Sand (1A)	SW or SP	Low	All	Portland Cement	3-5
Sand (1B)	SW-SM, SP-SW, SW-SC, or SP-SC			Emulsion Polymer	3-5
				Fiber (b)	0.2-0.5
Sand (1C)	SM, SC, or SM-SC	High	High	Lime and Portland Cement	3-5 and 3-5
			Low	Portland Cement	5
			Intermediate	Fiber (b)	As above 0.2-0.5
Gravel (2A)	GW or GP	Low	All	Portland Cement	3-5
				Emulsion Polymer	3-5
				Fiber (b)	0.2-0.5
Gravel (2B)	GW-GM, GP-GM, GW-GC, or GP-GC				
Gravel (2C)	GM, GC, or GM-GC	High	High	Lime and Portland Cement	3-5 and 3-5
			Low	Portland cement	5
			Intermediate	Fiber (b)	As above 0.2-0.5
Clays, Silts (3)	CH, CL, MH, ML,	High High High	High (>20)	Lime and Portland Cement	5-7 and 5-7 c)
			Low (<12)	Portland Cement	7 (c)

<table>
<tr><td></td><td>OH, OL, or ML-CL</td><td></td><td>Intermediate (12-20)</td><td>Lime or Portland Cement Fiber (b)</td><td>As above 0.2-0.5</td></tr>
<tr><td colspan="6">(a) All of these stabilizers require a polymer emulsion surface coating of 0.25–1 gallon/square yard (1:2 dilution with water) for weatherproofing. Reapplication of surface coating may be necessary depending on traffic and conditions.

(b) Monofilament polypropylene fiber used in combination with stated stabilizers—length and denier will vary depending on soil type. In general, the finer the soil, the more fiber surface area (length and shape) is needed to interact with the soil-stabilizer matrix.

(c) In some cases, intermediate and high plasticity clays may require stabilizer amounts significantly higher than suggested.</td></tr>
</table>

2.5.4.1. **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 dry weight 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. Just as cement, soil-cement strengthens better when temperatures are reasonably warm; keep the mixture above freezing during curing. The rate of strength gain is substantially lower at 50 degrees Fahrenheit than at 70 or 80 degrees Fahrenheit. In frost areas, it is not always sufficient to protect the mixture from freezing during a 7-day curing period. Completing construction before the onset of freezing conditions may be essential.

2.5.4.1.1. For expedient soil stabilization, cement is often the stabilizer of choice by engineers. Cement is available worldwide and used with a wide variety of soils. 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. It is capable of bridging over weak subgrade areas and is resistant to deterioration caused by seasonal moisture changes and freeze/thaw cycles. However, soil-cement wearing surfaces may become difficult to maintain over the life of the road because the material can turn into a low quality concrete, making it hard to grade and correct potholes or surface deterioration. Therefore, it may be beneficial to place a gravel surface over the stabilized material or treat it with an emulsion, chip seal, or other surface treatment.

2.5.4.1.2. Although detailed laboratory testing is usually not an option for expedient operations, determine the suitable cement content, compaction, and water requirements for the soil material used. Mixing options for soil-cement include mixed in 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, mix cement with either clay or granular soils, and follow the four basic soil-cement paving steps: spreading, mixing, compacting, and curing. See **Table 2.18** for the steps involved in on-site soil-cement modification steps.

Table 2.18. On-Site Cement Stabilization Steps.

Soil-Cement Modification (On-Site)
Preparation: – Shape the area to crown and grade – Scarify, pulverize, and pre-wet the soil, if needed – Reshape the area to crown and grade

Spreading: (Use one of the following methods) – Spot the bags of cement on the road, empty the bags, and level the cement by raking or dragging – Apply bulk cement from self-unloading trucks (bulk trucks) or dump trucks with spreader
Mixing: – Add water and mix in place with a rotary mixer – Perform by processing in 6- to 8-foot-wide passes (the width of the mixer) or by mixing in a windrow with either a rotary mixer or motor grader
Compaction: – Begin compaction immediately after the final mixing (no more than 1 hour should pass between mixing and compaction), otherwise cement may hydrate before compaction is completed – Use pneumatic-tired and sheepsfoot rollers; finish the surface with steel-wheeled rollers
Curing: (Use one of the following methods) – Prevent excessive moisture loss by applying a bituminous material at a rate of approximately 0.15 to 0.30 gallon per square yard – Cover the soil-cement with 2 inches of soil or thoroughly wetted straw

2.5.4.2. **Lime.** Experience has shown that lime reacts with clay to produce decreased plasticity, increased workability and strength, and reduced swell. Lime can potentially stabilize many soil classifications within the USCS. Consider lime stabilization with all soils having a PI greater than 10 if more than 25 percent of the soil passes the No. 200 sieve.

2.5.4.2.1. 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. Schedule lime-soil mixtures so that gains in durability is sufficient to resist any freeze/thaw cycles expected. Be aware, pavement damage is likely if you allow heavy vehicles on the lime-stabilized soil before a 10- to 14-day curing period. 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; recommend a bituminous surface treatment to prevent surface deterioration.

2.5.4.2.2. Use lime 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 you are modifying or stabilizing the soil. 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.

2.5.4.2.3. When you add lime to soil, a combination of reactions begins to take place immediately. These reactions are nearly complete within one hour, although substantial strength gain is not apparent 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 mixes with a soil generally causes a significant change in the plasticity of the soil.

2.5.4.3. **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. The two broad classes of fly ash are Class C and Class F, based on their calcium oxide (CaO) content.

2.5.4.3.1. 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 class of fly ash is usable as a stand-alone stabilizing agent. The strength characteristics of Class C fly ash with CaO less than 25 percent improves by adding lime.

2.5.4.3.2. 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.

2.5.4.3.3. Lime Fly Ash (LF) Mixtures. LF mixtures can contain either Class C or Class F fly ash. The LF 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. Base the moisture density relation on the 16 percent mixture. Construct LF in layers not less than four compacted inches. The engineer sets final thickness and actual proportions. After constructing LF, keep the surface moist until a bituminous curing cover is applied.

2.5.4.3.4. Lime-Cement-Fly Ash (LCF) Mixtures: The design methodology for determining the LCF ratio for deliberate construction is the same as for LF except add cement at the ratio of 1 to 2 percent of the design fines content. Optionally, use cement in place of or in addition to lime; however, maintain the design fines content. 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. Add cement in 1/2 percent increments until strength is adequate. Listed in **Table 2.19** are common on-site construction methods using fly ash and fly ash mixtures. Refer to UFC 3-250-11 and UFC 3-250-01 for more information on fly ash stabilization.

Table 2.19. On-Site Fly Ash and Fly Ash Mixtures Stabilization Steps.

Fly Ash/Lime-Fly Ash/Lime-Cement-Fly Ash Stabilization (On-Site)
Preparation: – Shape the area to crown and grade – Scarify and pulverize the soil, if needed – Reshape the surface to crown and grade
Spreading: (Use one of the following methods) – Spot the bags of fly ash on the road, empty the bags into individual piles, and distribute the fly ash evenly across the surface with a rake or harrow – Apply fly ash or fly ash mixture in bulk from self-unloading trucks (bulk trucks) or dump trucks with spreader
Mixing: – Begin mixing operations within 30 minutes of spreading fly ash – Mix the soil and fly ash thoroughly by using a rotary mixer, by windrowing with a motor grader, or by using a disk harrow – Continue to mix until the mixture appears uniform in color
Compaction: – Add water to bring the soil moisture content to 2 percent above the optimum moisture content (OMC) – Begin compaction immediately following final mixing; compaction must be completed within 2 hours of mixing – Minimum compaction effort for soils treated with fly ash is 95 percent of the maximum dry density of the mixed material – Reshape to crown and grade; then finish compaction with steel-wheeled rollers
Curing: Protect the surface from drying to allow the soil material to cure for not less than 3 days; this may be accomplished by: – Applying water regularly throughout the curing period

– Covering the amended soil with a 2-inch layer of soil or thoroughly wetted straw
– Applying a bituminous material at the rate of approximately 0.15 to 0.30 gallon per square yard

2.5.4.4. **Geosynthetics Fibers.** Sometimes referred to as geofibers or sand fibers, these products may be an option in rapid-road-construction to overcome sandy and soft soil deficiencies. Although many types of synthetic fibers are available, polypropylene fibers are low cost, has different lengths and diameters, and have an extensively test history. Primarily, they are available as monofilament, fibrillated, and tape fibers. Testing has shown that monofilament and tape fibers are more efficient for rapid stabilization. Fibrillated fibers can require extensive mixing for maximum efficiency. Polypropylene fibers mixed into soil without adhesives (cement) rely exclusive on mechanical interlock, friction, and fiber entanglement between soil particles to anchor the fiber in place. Thus, a high surface area fiber (such as a tape fiber) may be more efficient in a fine-grained clay soil than in a coarse-grained soil (such as gravel) where fewer soil grains are in contact with the fiber.

2.5.4.4.1. The most important fiber property for soil stabilization is fiber length. Longer fibers generally result in improved performance but hamper construction. The longer fibers are more difficult to mix and considerable balling may occur, diminishing efficiency. Testing of different fiber lengths indicate fiber lengths from 3/4 inch to 1-1/2 inch results in good soil improvements with minimal balling. Furthermore, adding too many fibers can cause poor performance by increases fiber-to-fiber contact resulting in a more porous mix with lower density. Tests indicate 1 percent fiber is the optimum amount for wheeled traffic loads.

2.5.4.4.2. Sandy soil stabilization using this method involves mixing small amounts of hair-like, polypropylene fibers into moist sand with a field or rotary mixer (**Figure 2.17**). The sand-fiber mix is then compacted with a smooth-drum vibratory roller. Next, add a wearing surface by spraying a resin-modified emulsion or emulsified asphalt onto the surface to bond the sand grains with the fiber filaments and protect the sand-fiber surface. Using this soil stabilization and road construction method, engineer work crews can quickly provide expedient roadway surfaces at remote sites, over beaches, or across desert sands with fewer resources than required for other road-building methods. Testing indicates that roads constructed with this technology can carry over 10,000 passes of heavy wheeled vehicle traffic with little or no maintenance required. Sand-fiber stabilization uses existing military construction equipment and requires no special construction skills. In addition, sand-fiber soil stabilization is an option on a wide variety of sands and silty soils found around the world.

Figure 2.17. Blending Fibers into Soil for Stabilization.

2.5.4.5. **Emulsion Polymers.** Emulsion polymers (sometimes referred to as latex) used for soil stabilization are generally vinyl acetate or acrylic-based polymers suspended in water by surfactants. They typically consist of 45 to 50 percent polymer content by weight. Analogous to latex paint, the emulsion polymers cures by water loss. The polymers used for soil stabilization typically have excellent tensile and flexural strength, adhesion to soil particles, and resistance to water. However, limits to these materials often include a short shelf life (less than 2 years) due to bacterial growth and settling. Do not mix emulsion polymers with gray water or salt water for dilution.

2.5.5. **Expedient Surfacing Options.** While it can be a rare occurrence, civil engineers may need to improvise an expedient roadway surface for vehicles to traverse relatively short sections of sandy or muddy soil when traditional construction resources are unavailable. The following methods address expedient surfacing options over sandy or muddy soil when other options are limited. The types of expedient surfacing addressed here include logs and saplings, wooden planks, and wire mesh placed on the natural soil to improve the roadway.

2.5.5.1. **Logs (Corduroy).** Road surfaces constructed of logs (split or round) laid side-by-side and transversely (crosswise) to the centerline are referred to as corduroys. These surfaces may be ideal expedient roadways over soft ground at initial contingency locations where timber is readily available. Generally, the three types of corduroy roads are standard corduroy, corduroy with log stringers, and heavy corduroy.

2.5.5.1.1. Standard corduroy. A standard corduroy road consists of crossed logs laid directly on the ground (**Figure 2.18**). This type corduroy road is the most frequently used and consists of one layer. Construct a standard corduroy road using the procedures listed in **Table 2.20**.

Figure 2.18. Standard Corduroy Road Section.

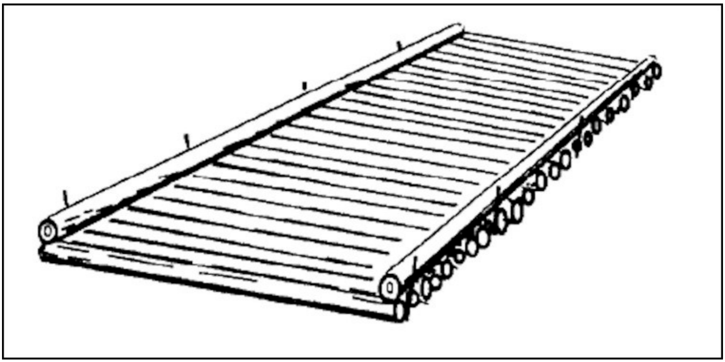
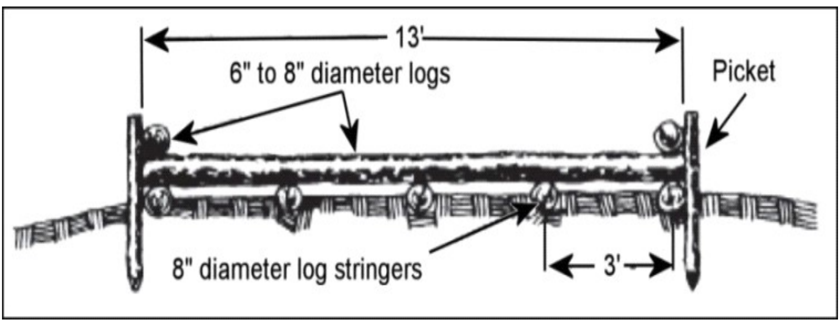


Table 2.20. Standard Corduroy Construction.

Standard Corduroy
– Place 6-8 inch-diameter, 12-foot logs next to each other (butt to tip)
– Place 6-inch-diameter logs along the edges of the roadway, and wire or drift-pin them in place
– Drive 4-foot-long pickets into the ground at regular intervals along the outside edges of the road to hold it in place
– Fill the chinks between logs with brush, rubble, or twigs; cover the surface with a layer of gravel or dirt to make the surface smoother
– Construct side ditches and culverts the same as for normal roads

2.5.5.1.2. Corduroy with log stringers. A standard corduroy road that is more substantial and has two layers. Construct it by placing log stringers parallel to the centerline on 3-foot centers, and lay the corduroy over the stringers as described above for standard corduroy. Securely pin the corduroy decking to the stringers, and prepare the surface as shown in **Figure 2.19**.

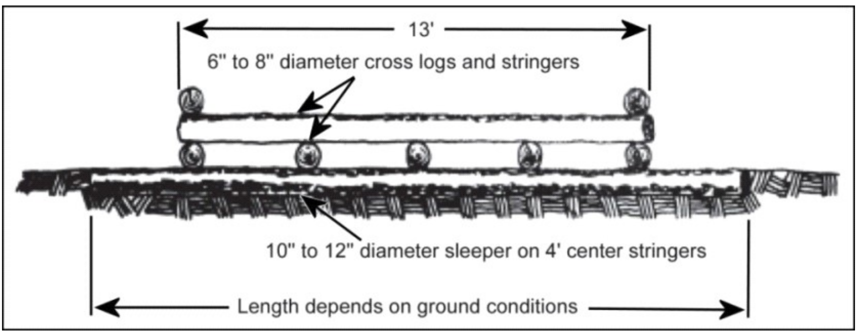
Figure 2.19. Corduroy Road with Log Stringers.



2.5.5.1.3. Heavy corduroy. A heavy corduroy road has three layers. It consists of crossed logs and stringers laid on sleepers. Place sleepers (heavy logs 10 to 12 inches in diameter and long enough to carry the entire road) at right angles to the centerline on 4-foot centers. Build a heavy corduroy road with log stringers on top of the sleepers as shown in **Figure 2.20**.

2.5.5.1.4. The softer the ground, the heavier the type of corduroy required. This is the basic rule for determining the type of corduroy road needed. Stringers and sleepers do not increase the bearing capacity of the decking. They serve as a crib to keep the road surface above the level of the soft ground. Stringers and sleepers sink into the ground until they reach a stratum that is capable of supporting the load. In other words, they provide depth for a stable structure. On firm ground, standard corduroy is adequate; on soft ground, stringers are necessary; and on extremely soft ground, sleepers are required. Portable corduroy mats (made by wiring together 4-inch-diameter logs) is a hasty expedient option that personnel can prefabricate and put down quickly when needed. Corduroy mats are very similar to Chespaling mats addressed in **paragraph 2.5.5.2**, but corduroy mats are heavier.

Figure 2.20. Heavy Corduroy Road.



2.5.5.1.5. The greatest objection to corduroy roads is the roughness of the surface. Gravel, earth, straw, tall weeds, or fine brush can be covered with earth to make the surface smoother. If the foundation is stable and suitable materials are available to construct a thin covering over the corduroy, a corduroy road is a good temporary road. Provide a blanket of earth or gravel to protect the surface if tracked vehicles use the road.

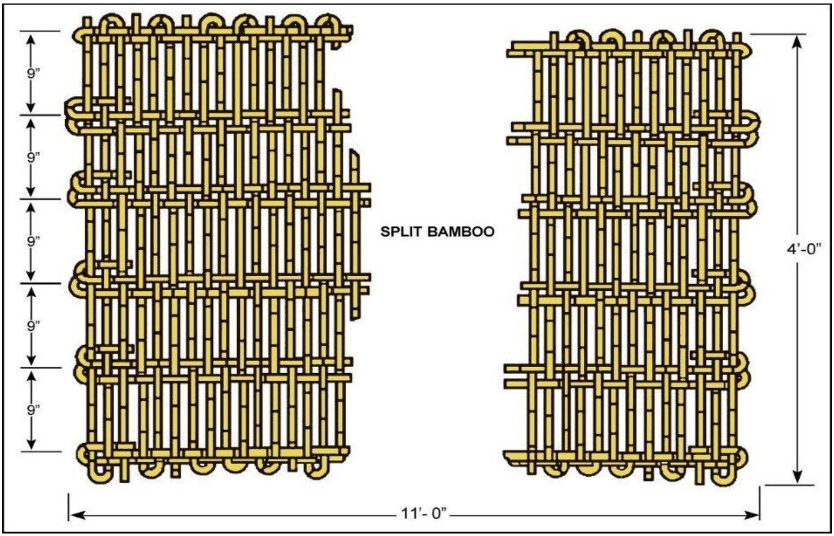
2.5.5.2. **Saplings (Chespaling).** Chespaling is a hasty expedient surface for either mud or sand. Create chespaling mats using green saplings, preferably about 1.5 inches in diameter and 6.5 feet long. Wire the saplings together to form a 12-foot-long mat as shown in **Figure 2.21**. To reuse the mats, personnel often roll them into bundles and carry them on wheeled vehicles to the next location. Use the mats to cross sandy terrain or to get out of mud. Some mats are constructed from dimensioned timbers wired together to resemble a picket fence. Construct a variation slightly more effective for crossing sand by attaching chicken-wire netting to the bottom of the mats.

Figure 2.21. Assembling Saplings for Chespaling Mats.

2.5.5.2.1. To build a chespaling road, lay a double row of mats, each mat having its long axis parallel to the centerline with a 1-foot overlay at the centerline. Wire the mats together. Keep the road wet to prevent the saplings from becoming brittle and breaking.

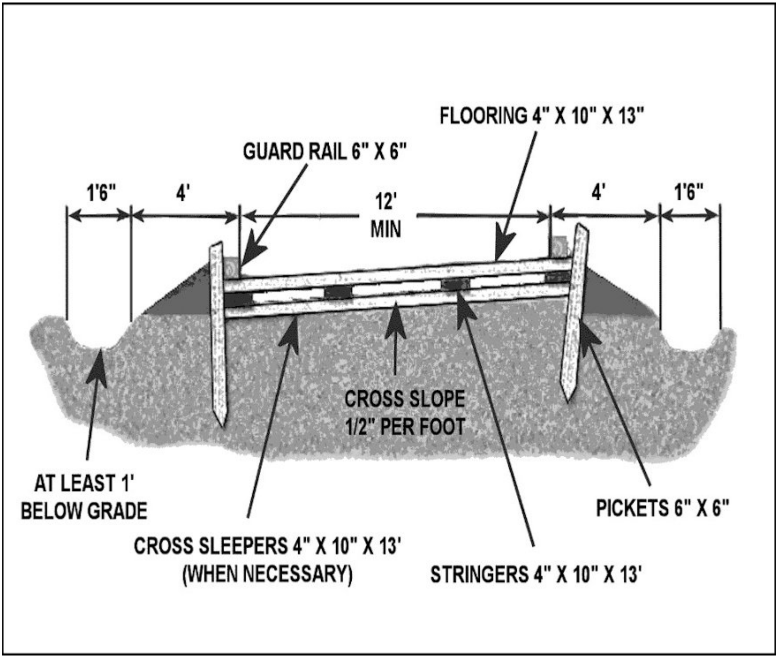
2.5.5.2.2. Bamboo mats are an excellent chespaling type expedient for beach roadways. These mats are light and comparatively strong. Create these mats by splitting 2-inch bamboo rods and weaving them into a mat in a manner similar to rug weaving (**Figure 2.22**). Soak the rods before weaving, and keep the mats moist while they are in use. An 11- by 4-foot mat takes about 15 man-hours to construct. Place the mats with the long dimension parallel to the centerline. The mats remain serviceable for three or four months on firm ground or sand. Bamboo mats are also usable over mud.

Figure 2.22. Bamboo Mat Construction Diagram.



2.5.5.3. **Plank Road.** For centuries, plank roads have been a solution to traverse sandy, rocky, and soggy bottom terrain. Engineers have constructed plank roads using planks laid across timber stringers running lengthwise. Today, these wooden plank roads are sometimes used as an expedient measure to cross short sections of loose sand or wet, soft ground. This type of road may last several months if built well and has an adequate base. Planks used for flooring, stringers, or sleepers should be 3 to 4 inches thick, 8 to 12 inches wide, and at least 13 feet long. When desired, rough, unfinished 3- by 10-inch planks can replace the 4- by 10-inch timbers shown in **Figure 2.23**.

Figure 2.23. Plank Road Construction Diagram.



2.5.5.3.1. Lay stringers in regular rows parallel to the centerline on 3-foot centers. Stagger the joints, and lay floor planks across the stringers. When seasoned lumber is used, leave 1-inch gaps between the stringers to allow for swelling when the lumber absorbs moisture. Spike the planks to every stringer. Place 6-inch-deep guardrails on each side, leaving a 12-inch gap between successive lengths of the guardrail for drainage of surface water. Place pickets along each side at approximately 15-foot intervals to hold the roadway in line. If necessary, place corduroy, fascine, or other expedient cross sleepers on 3- to 5-foot centers to hold stringers in the correct position or to gain depth for the structure.

2.5.5.3.2. To allow for drainage, construct the base with a transverse slope versus a center crown. Place treads over the floor planks parallel to the line of traffic to produce a smoother riding surface.

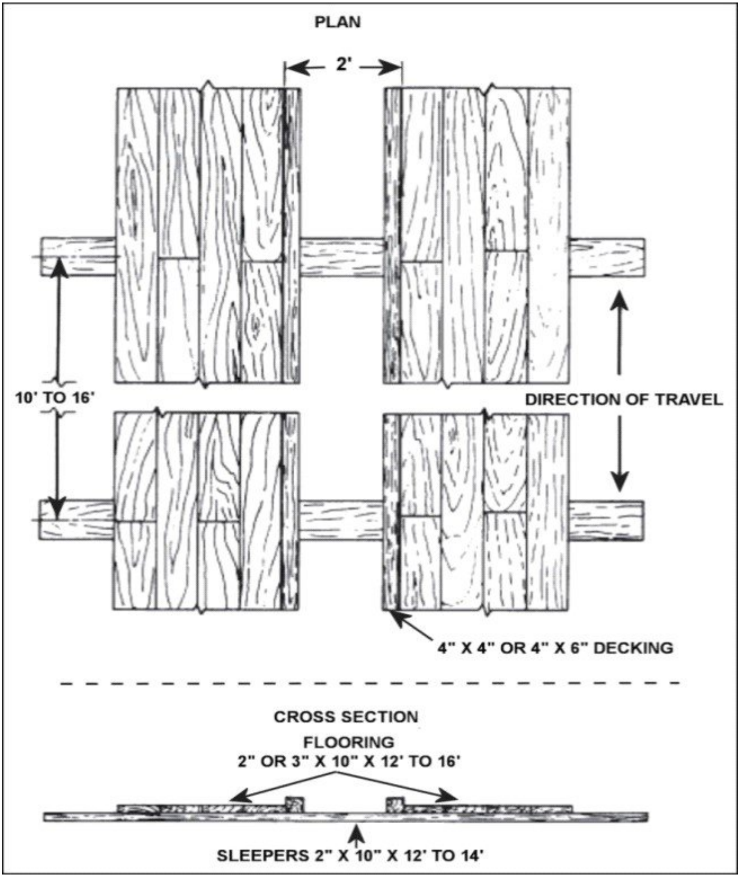
2.5.5.4. **Plank-Tread Road.** Work crews can usually build plank-tread roads easily and rapidly, and with less material than ordinary plank roads. **Figure 2.24** illustrates the construction details for the plank tread road.

2.5.5.4.1. Lay the sleepers, which are made of 2- by 10-inch material that is 12 to 16 feet long, across the centerline of the road. Embed the sleepers in the ground on 10- to 16-foot centers. The spacing of the sleepers depends on the length of plank available for tread. If the sleepers are more than 2 feet thick or hold the flooring too high off the ground, reduce the amount of spacing so that the flooring can carry the load without bending excessively.

2.5.5.4.2. Lay flooring planks, 2 to 3 inches thick by 10 to 12 inches wide, on top of the crossties. A 2-inch plank will suffice as road surfacing in most cases; however, use a 3-inch plank for extremely severe conditions. Tread sections can be fabricated and laid directly from a truck bed to facilitate placement. Optionally, place curbs on the inside of each tread to ease passage of the narrowest vehicle using the road.

2.5.5.4.3. In lieu of lumber, use logs to construct log-plank or log-tread roads. To prevent the logs from rolling sideways under traffic, securely spike them to the crossties. The spacing of the crossties depends on subgrade condition, but it is normally about 3 feet. For log tread roads, use curbs as described above.

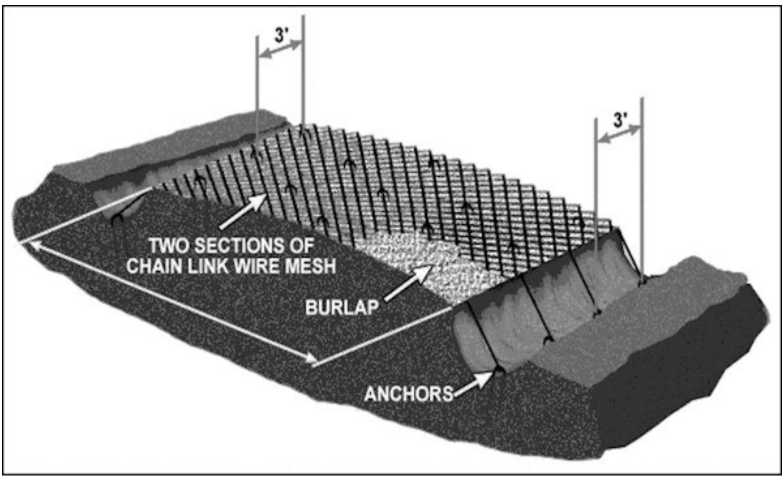
Figure 2.24. Plank-Tread Road Plan.



2.5.5.5. **Wire Mesh.** Use wire mesh such as chicken wire and chain-link fencing material for developing expedient surfaces over sandy portions of roadways or during bottom preparation of shallow-water crossings. For sand surfaces, add a layer of burlap or similar material underneath the wire mesh to help 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.

2.5.5.5.1. As illustrated in **Figure 2.25**, diagonal wires that cross the centerline at 45-degree angles and are securely attached to buried pickets fortify the lighter meshes. As might be expected, the more layers used the more durable the pad will become. Other roads should never cross wire mesh road sections unless planking or some such material is placed over the mesh to protect it. In addition, do not use mesh surfaces on muddy (unstable, saturated soil) roads because they prevent grading and reshaping of the surface when ruts appear.

Figure 2.25. Wire-Mesh Road Construction Details.



2.5.5.5.2. Commercial wire/fabric barriers, laid flat, provide similar confinement and separation, and may be more available in the local area than wire mesh and burlap. When roadways traverse shallow-water crossings, it may be necessary to use bottom fill materials such as gravel and rock to fill short, deep gaps and to raise the bottom of the crossing. If so, use wire mesh to keep the bottom fill material in place when exposed to traffic.

2.6. Expedient Drainage Construction and Repair. Quickly removing surface water and water runoff away from roads and critical infrastructure is vital for vehicle and facility operations anywhere. This is especially true at contingency locations vulnerable to heavy rains and flooding. CE tasks related to this endeavor may include developing expedient culverts, ditches, and other drainage methods for conveying storm water runoff and floodwaters away from critical roadways, work facilities, temporary housing, and flightline areas.

2.6.1. **Expedient Culverts.** Construct field-expedient culverts to convey water from one area to another, typically when building a roadway across a stream, diverting water to a reservoir, or managing storm water runoff. Be prepared to improvise culverts from available material. Below are common examples of expedient culvert materials and designs, including oil and gas drums, logs and timber, sand-filled bags and containers, and metal planks and mats. **Note:** If available, recommend 24” (600mm) storm drainpipe (or equivalent cubic diameter if pipe is not used) minimum with an emphasis on the proper support and backfill in loose sandy soil.

2.6.1.1. **Oil Drum Culverts.** When empty oil drums are used (**Figure 2.26**), the capacity of the culverts is equivalent to the same diameter of corrugated metal pipe (CMP) set at a comparable slope. **Note:** If using drums as culverts, take extreme care when using a cutting torch to remove the lids. Ensure the drum does not contain any flammable liquids, vapors, and materials or toxic gases before using the cutting torch. Joints between drums should be welded solid; however if that is not possible, tack welds may be used if provisions are made to seal the joints to prevent the culvert water from saturating the surrounding fill material.

2.6.1.2. **Log or Timber Box Culverts.** Culverts constructed of logs or timber are usable in the field as temporary measures until structures that are more permanent can be employed **Figure 2.27** and **Figure 2.28**). In both of these instances, an area equal to the end area of an appropriately sized CMP or concrete pipe outlet, on the same slope, can be used for hydraulic capacity.

Figure 2.26. Expedient Oil Drum Culvert.

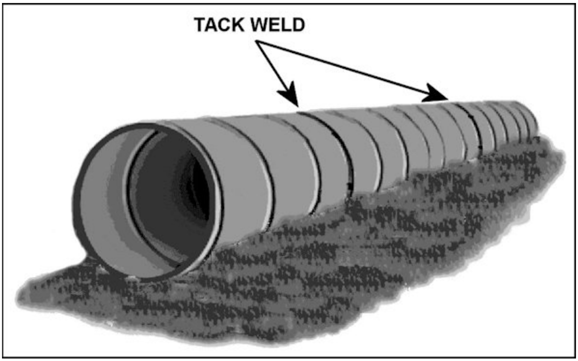


Figure 2.27. Log Box Culvert Example.

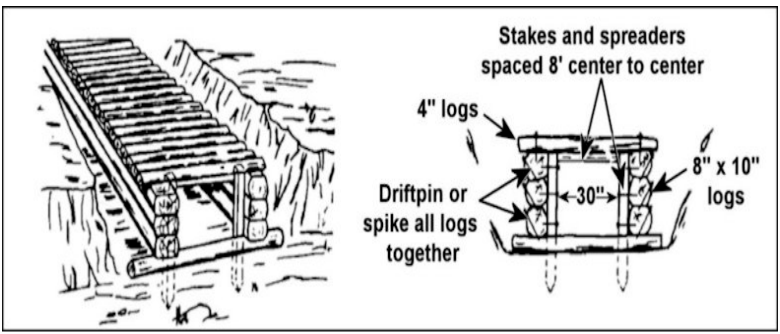
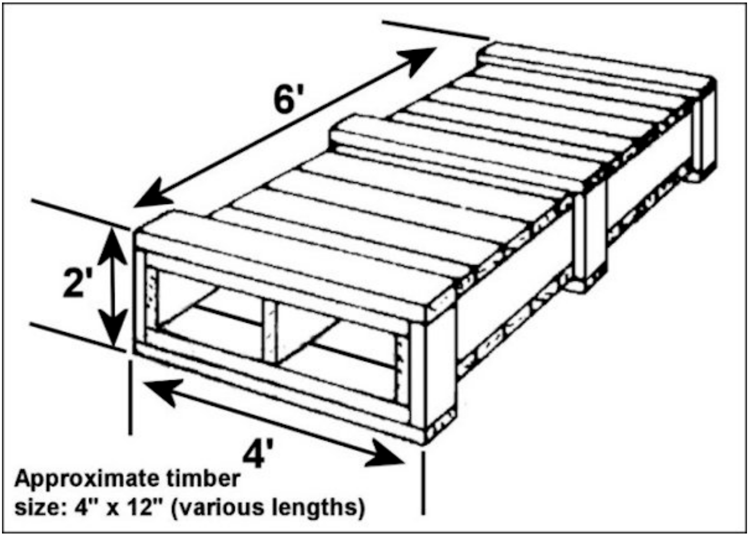


Figure 2.28. Timber Box Culvert Example.



2.6.1.2.1. When constructing a log or a timber culvert, the 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.

2.6.1.2.2. If using logs to obtain maximum structural strength, trim the logs where required to ensure proper seating and then securely fastened with spikes or drift pins (**Figure 2.29**). 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 steel planks (**Figure 2.30**), if a paved surface is not used. **Note:** A minimum cover of three feet over a culvert of this type is required.

Figure 2.29. Drift Pins and Spikes in Log Culverts.

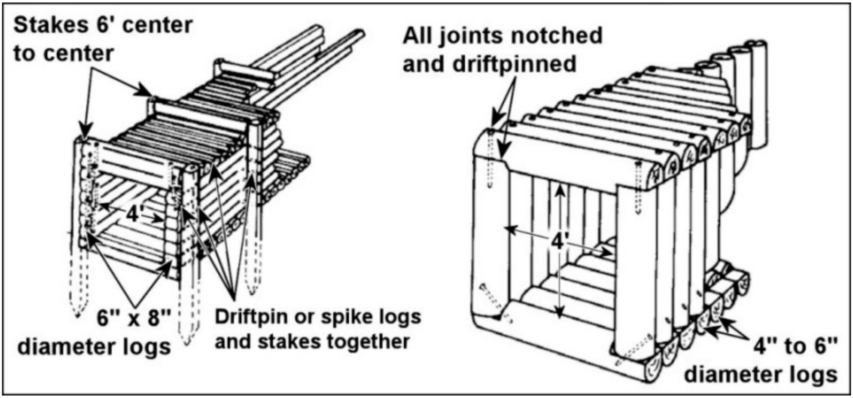
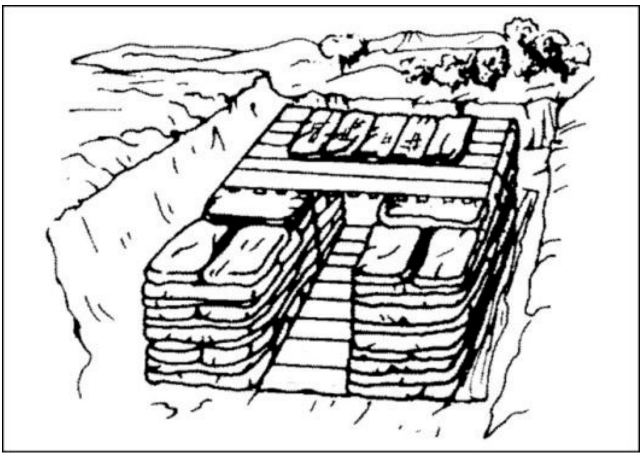


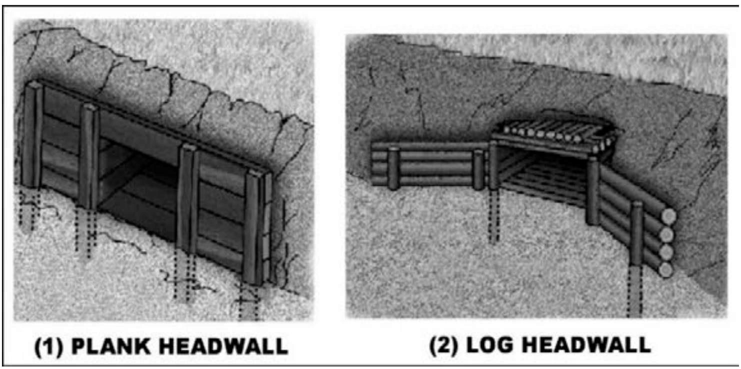
Figure 2.30. Expedient Sandbag and Metal Planks Culvert.



2.6.1.3. **Culvert Headwalls and Wingwalls.** Construct headwalls and wingwalls to prevent and control erosion, guide water into a culvert, reduce seepage, and to hold the end of a culvert in place.

2.6.1.3.1. Headwalls. Always use headwalls (also known as retaining walls) at the upstream end of a culvert. As an option, use headwalls 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. Construct headwalls using materials as durable as the culvert. If necessary, use sandbags or rubble as expedient measures. Extend the inlet end of the headwall pipe 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. **Figure 2.31** illustrates expedient headwalls made of wooden planks and logs.

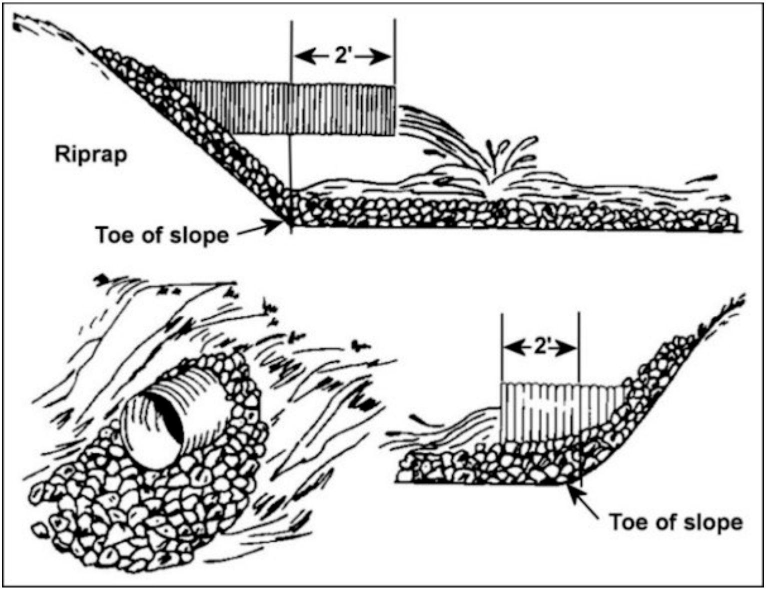
Figure 2.31. Expedient Headwall Examples.



2.6.1.3.2. Wingwalls. Wingwalls channelizes water and prevents 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 (2), includes wings.

2.6.1.3.3. Alternatives. Headwalls and wingwalls can be 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 (**Figure 2.32**). In addition, protect the area directly beneath the projecting culvert using 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.

Figure 2.32. Use of Riprap and Rubble with No Headwall.



2.6.2. **Expedient Open Top Culverts.** The open top culvert is another way to remove surface water away from the surface of roads. It is easy to construct and install using common hand tools. However, debris can easily fill the culvert or mechanized road maintenance equipment could cause damage. Typically, the open top culvert method consists of a "U" shaped wooden trough made of treated lumber (**Figure 2.33**). Install the trough flush with the roadway surface and angled 30 to 45 degrees downgrade. Extend the outlet end of this type of culvert beyond the edge of the road, and place riprap at the outlet end to prevent erosion. This type of culvert generally requires regular maintenance; consequently, use it only 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 2.34** where logs are used.

Figure 2.33. Open Top Culvert Design.

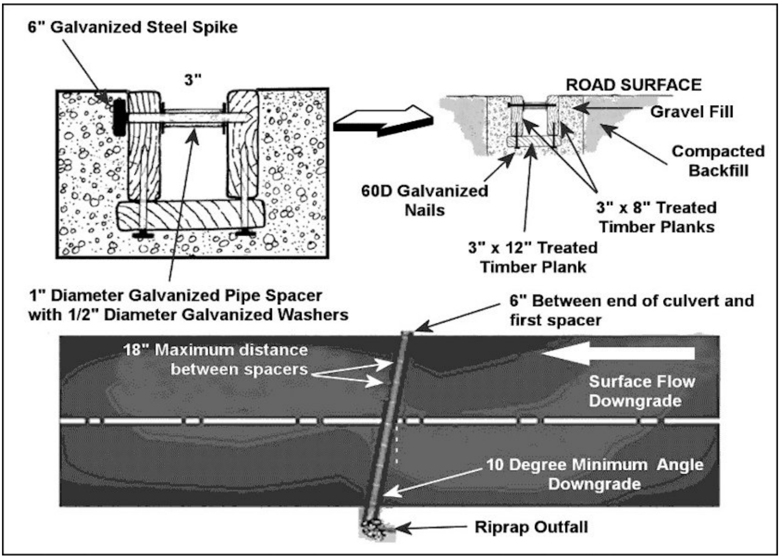
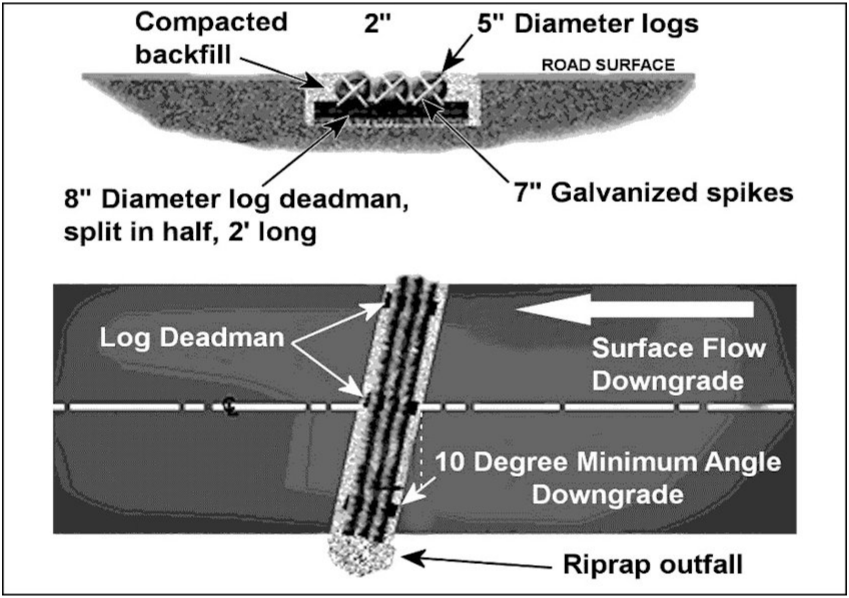
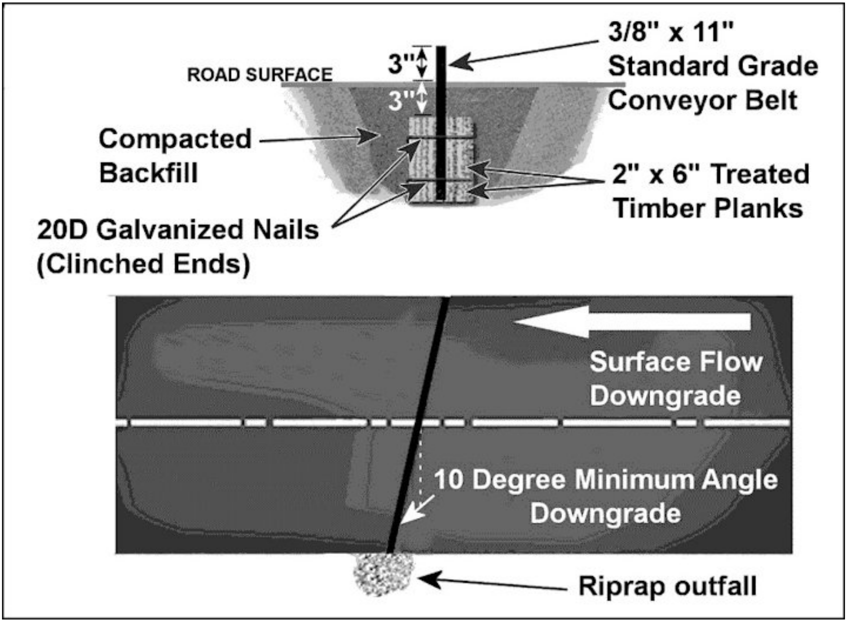


Figure 2.34. Open Top Culvert Built Using Logs.



2.6.3. **Deflectors.** Install a deflector to remove water off the surface of an expedient road. Deflectors are particularly effective on sloping roads and help to stop channeling and rutting of the road surface. A deflector is simply rubber belt material (3/8-inch to 1/2-inch thick) fastened between treated timbers. If flat rubber belt material is not available, use unserviceable arresting barrier tape. As illustrated in **Figure 2.35**, bury the timbers at a slight angle across the roadway with only about 3 inches of the belt exposed. As water runs down the surface of the roadway, the belt intercepts the water and disperses it 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 2.35. Deflector Construction Details.

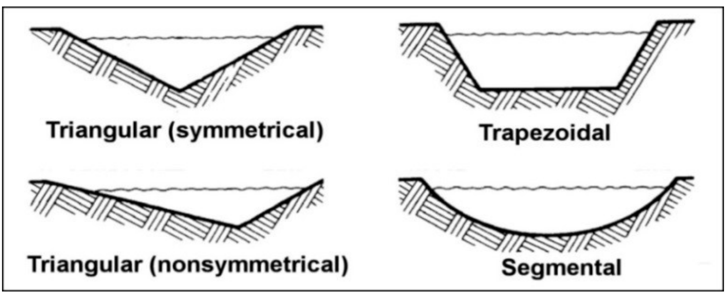


2.6.4. **Open-Channel or Ditch.** The ditch is the most common open-channel cut into the soil used to convey water. Often critical after a flood, ditches and channels handle unwanted surface water and controls or enhances water runoff. The purpose, topography, and available engineer equipment will usually determine ditch size, shape, location, and construction method. Establishing adequate surface water drainage around roadways, buildings and other structures in flat terrain can sometimes be difficult and may require extensive grading and ditching to achieve sufficient water runoff from these areas. Consider the erosion potential when designing open channels or ditches for storm water conveyance.

2.6.4.1. The main types of ditches used in road and airfield construction are interceptor, side ditch, and diversion. An interceptor ditch is generally located on a hillside above a roadway or other feature requiring protection. Its function is to intercept runoff and direct the flow to a more desirable location. It is usually located above side hill cuts to prevent erosion of the cut. A side ditch is located along the side of a road. It collects runoff from the road and adjacent areas and transports it to a culvert or diversion ditch. When the topography allows, build a diversion ditch to transport water away from roadways or airfields. Use it in conjunction with interceptor and side ditches to transport water between culverts or to divert an existing stream channel around a project.

2.6.4.2. From an expedient construction perspective, the available engineer equipment usually governs the shape of the ditch. However, the most common shapes of ditch cross sections are the triangular (symmetrical and nonsymmetrical), trapezoidal, and segmental (**Figure 2.36**). Triangular ditches are appropriate for most situations. If large quantities of runoff are probable, a trapezoidal ditch may be the better option. Guard against being too conservative when it comes to sizing drainage ditches; an oversized ditch causes less problems than one too small. When constructing ditches in the airfield clear zone, consult UFC 3-260-01 for added details regarding ditch design, location and any other specific requirements.

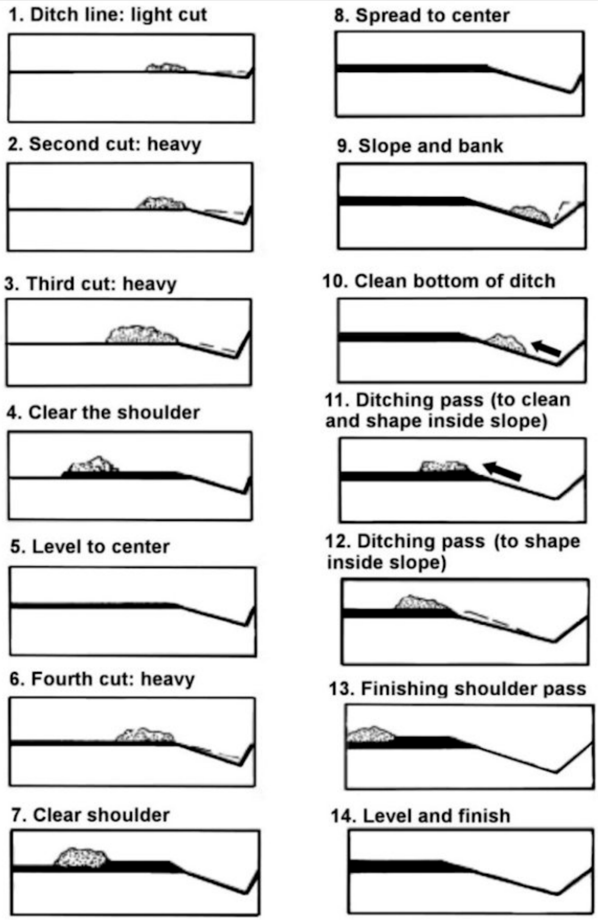
Figure 2.36. Common Ditch Cross-Section Shapes.



2.6.4.3. For expedient ditching, graders, dozers, or wheeled scrapers are usual choices for excavation; however, the backhoe, front-end loader, and crane are also options. The road grader is probably the most common heavy equipment item used for expedient ditch construction. An operator can quickly excavate the necessary cross section of triangular or V ditches handling flows up to 60 cubic feet per second. Grader efficiency drops significantly when cross sections of larger dimensions are required. Trapezoidal ditches are the common option specified for flows larger than 60 cubic feet per second. Use a wheeled scraper to excavate the flat bottom and midsection of this ditch rapidly, and dress back the side slopes with subsequent passes of a road grader. Excavate smaller bottom widths using the road grader (with its blade turned to a high angle) or other engineer equipment. Production rates will be much lower for the grader than those of the wheeled scraper. The 60 cubic feet per second guideline is flexible. If a scraper is not available to excavate a ditch carrying 100 cubic feet per second, use a grader to construct an oversized V ditch rather than using equipment with a lower production rate to construct a trapezoidal ditch. The segmental-ditch shape results when using explosives to create the ditch. Work crews often use this technique when the terrain is too soft to support excavating machinery. Ditches cut by hand will often bear this shape as well.

2.6.4.4. When using the road grader to excavate triangular ditches, make a 3- to 4-inch marking cut on the first pass at the outer edge of the bank slope. This can enhance grader control and produce straighter ditches. Make each subsequent ditch cut as deep as possible without stalling or losing control of the grader. Normally, make ditching cuts in second gear at full throttle. Start with the blade positioned so that the toe is in line with the center of the lead wheel. Bring each succeeding cut in from the edge of the bank slope so that the toe of the blade will be in line with the ditch bottom on the final cut. **Figure 2.37** illustrates the steps of the V-ditching method. The steps shown are for a single roadside ditch. Repeat the steps on the opposite side of the road.

Figure 2.37. Road Grader V-ditching Method.



Source: Modified from TM 3-34.62, Earthmoving Operations

2.7. 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 deposits in undesired locations. The primary cause for erosion is the velocity of the water in the channel. Controlling erosion helps to maintain an effective and clear drainage system with a minimum of maintenance. Most methods of control rely on dissipating the energy of the water, providing an erosion-resistant surface, or some combination of these techniques. This section addresses ways to reduce or eliminate the soil erosion in drainage systems.

2.7.1. **Controlling Velocity.** Water velocity in a channel is dependent on the slope, shape, and depth of the channel. Control erosion in the channel by lowering the velocity below the soil-erosion flow. Achieve lower water velocity by reducing the ditch side slope; making the ditch wider and shallower; lining the ditch with erosion-resistant material; or by constructing check dams. Building the ditch wider and shallower or with a reduced slope increases the surface area. Larger surface areas cause greater friction and lowers the water velocity. Since constructing new ditches at a different slope, width, and depth is usually impractical during field operations, expedient alternatives may include lining existing channels with erosion-resistant riprap and rubble or constructing check dams. Other methods such as terracing, using geosynthetics liners or natural liners (growing grass, turf), or paving the channel sides with asphalt or concrete may be used when time, materials, and other resources are available.

2.7.2. **Riprap.** Increasing the effective roughness of a ditch decreases ditch soil erosion. One easy way of doing this is with riprap (**Figure 2.38**). This method involves placing rocks or stones in the ditch bottom and sides to provide a protective cover over the soil to prevent soil erosion. Normally, rocks should be larger than 6 inches to assure stabilization. To prevent riprap failure due to velocity and turbulence, resulting in movement of rock and bed material, ensure appropriate rock size is used. Additionally, rocks 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 2.38. Riprap-Lined Drainage Ditches.

2.7.3. **Check Dams.** 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 deposits on the ditch bottom, decreasing the ditch slope itself. Consider using check dams when the slope ranges between 2 and 8 percent. Channels with slopes less than 2 percent generally do not require extensive erosion controls. With slopes in excess of 8 percent, it is usually more economical to pave the ditch with asphalt or concrete than to build check dams.

2.7.2.1. Expedient check dams may be constructed using lumber, logs, sandbags, rock, or other suitable and locally available materials. As illustrated in **Figure 2.39**, each dam should extend at least 2 feet into the sides of the ditch, and the ditch top should be at least 12 inches above the top of the dam. Correct spacing between check dams can be determined using the procedure in **Table 2.21**.

Figure 2.39. Typical Check Dam Design.

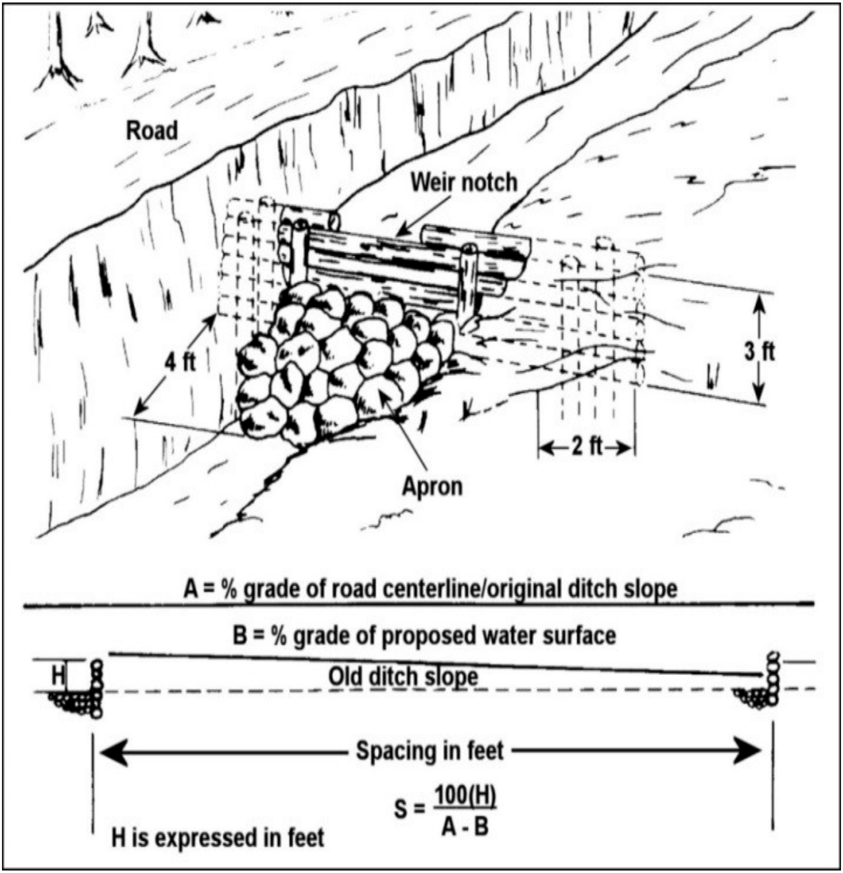


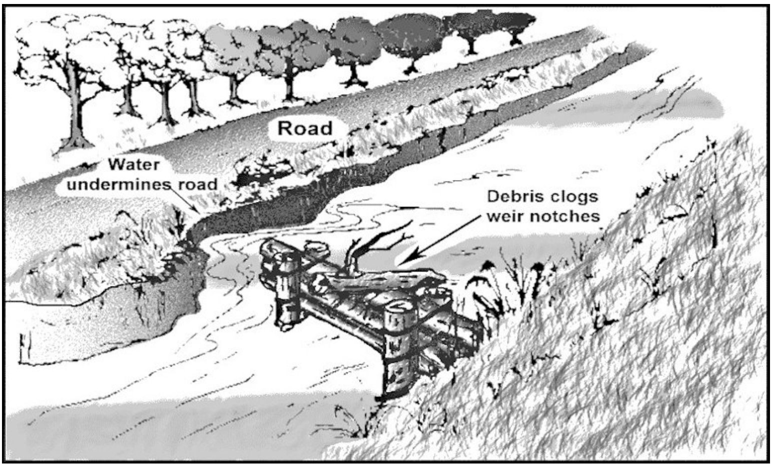
Table 2.21. Check-Dam Spacing Formula.

Check-Dam Spacing	
Formula: $S = \frac{100(H)}{A\text{-}B}$	
Where: S =	Spacing between check dams (This value should not be less than 50 feet).
H =	Height from the channel bottom to the lower edge of the weir notch
A =	Slope of the original ditch in percent.
B =	Desired slope in percent (Value should be set at two percent; the maximum slope that will not require additional erosion control).
Example Calculation:	
Original slope =	5 percent
Desired slope =	2 percent
H =	3 feet
S =	$\frac{100(H)}{A\text{-}B} = \frac{100(3)}{5\text{-}2} = \frac{300}{3} = 100$

2.7.2.2. The height between the bottom of the channel to the lower edge of the weir notch should not be greater than 3 feet (unless structurally designed) nor less than the practical limit of 1 foot. 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. Cut a weir notch 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.

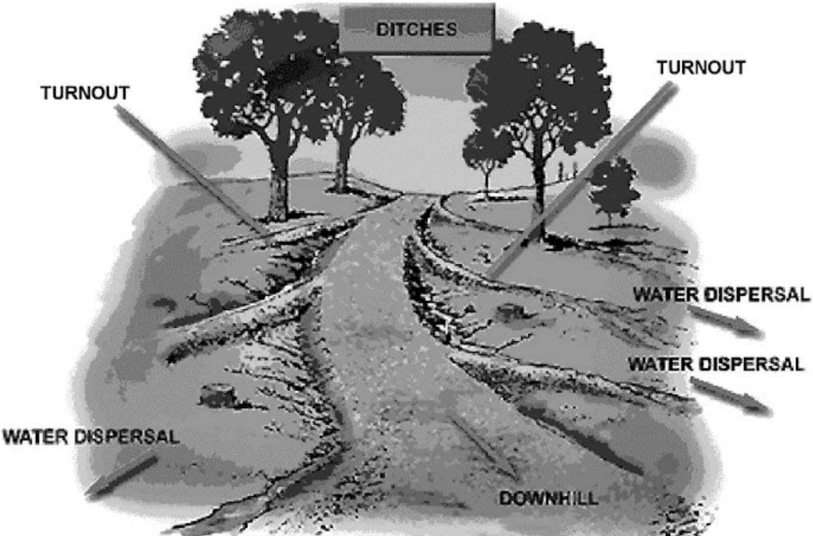
2.7.2.3. Erosion around the dam is the most common problem associated with check dams. The primary cause for this situation is that the weir notch is too small or clogged with debris causing water flow over the top of the dam. This situation results in erosion where the dam is anchored into the ground (see **Figure 2.40**), and if left uncorrected over time, will often result in more damage to adjacent structures than if the dam was never installed.

Figure 2.40. Dam Erosion Caused by Weir Notch Debris.



2.7.3. **Roadside Turnouts/Diversion Ditch.** If encountering hilly terrain during the construction of expedient roads, erosion in the supporting drainage ditches may be a problem. One method of fighting such erosion involves using riprap, but the use of turnouts might be more effective. Turnouts and diversion ditches 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 2.41** shows a typical turnout arrangement and a chart that indicates the spacing of turnouts in respect to the grading of the road.

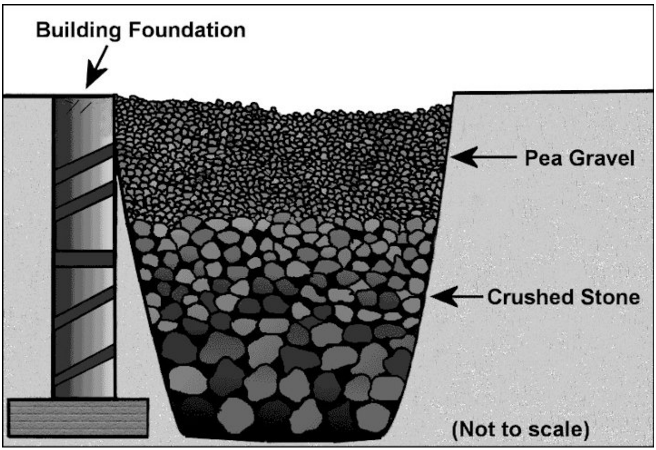
Figure 2.41. Turnout Layout and Spacing Requirements.



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

2.7.4. **French Drains.** When using French (or blind) drains near buildings and other structures, install them at the lowest point where standing water is found (see **Figure 2.42**). The drain may terminate at any point where the water will not drain back toward the structure. Normally, French drains are shallow systems and 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. A basic French drains is constructed by simply filling a ditch or trench with broken or crushed rock. Consider leaving the top surface of the rock exposed so the trench will act as a combination drain (surface and subsurface drainage) or cover the rock with a relatively impervious soil so that no surface water can penetrate. The latter is the general practice. However, consider using other methods for permanent construction because French drains have a tendency to silt up with prolonged use.

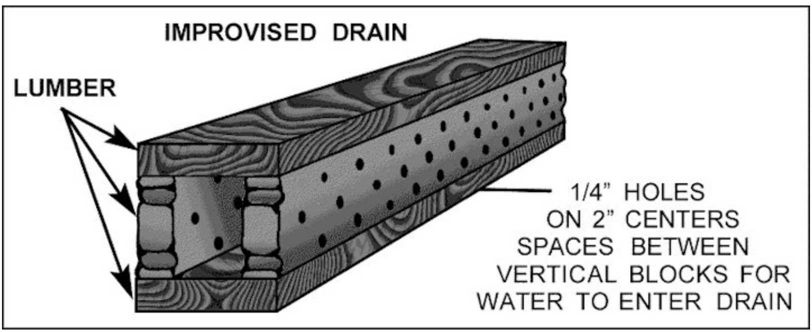
Figure 2.42. Open French Drain without Pipe.



2.7.4.1. In field construction, consider using French drains 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 when wrapped in a layer of geotextile fabric, ensures longer life by stopping any fines from clogging the system. In areas with severe drainage problems, run multiple perforated pipes together to act as water collectors or interceptor drains. This way, the water carries away more quickly when the surrounding earth is saturated.

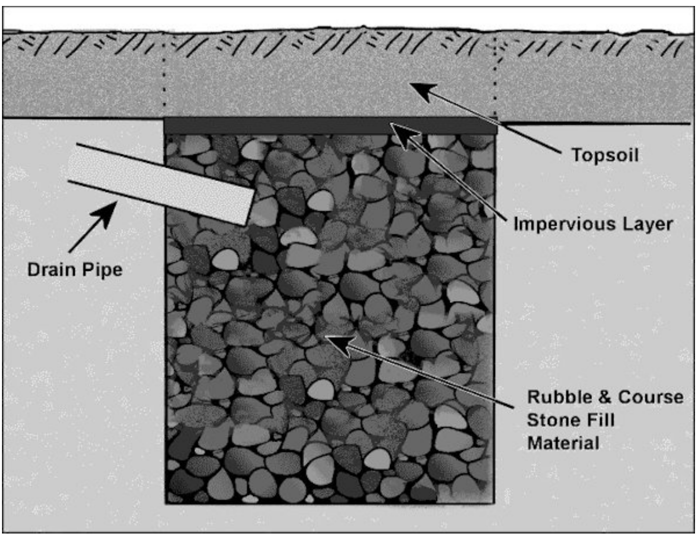
2.7.4.2. Installing a French drain with a perforated pipe is usually simple, but obstacles such as tree roots, boulders, and underground utilities, can make the project difficult and time-consuming. The basic procedure for installing a French drain that includes perforated pipe is as follows. Keep in mind, installing a system without piping and geotextile fabric is an option, but greatly reduced longevity due to silt transfer is likely. 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 2.43**. After pipe installation, 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 that, in most cases is a soak-away or watercourse. However, never discharge storm water runoff into a cesspool or septic tank, and never discharge wastewater into a French drain or soakaway.

Figure 2.43. Improvised Drain Line.



2.7.5. **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. Construct the soakaway in granular soil with good drainage properties. Do not use a soakaway 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. Lay the pipe to a fall of 1 in 40. The size of the soakaway should be a minimum of 3 feet by 3 feet by 3 feet 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 2.44**, place an impervious layer on the stone. Recommend using materials such as thick polyethylene, tarpaulin, or even a bed of concrete. Afterward, place topsoil on top of this layer to restore the garden level.

Figure 2.44. Typical Soakaway.



2.7.6. **Vertical Wells.** Consider constructing vertical wells to permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer of soil. Additionally, drive a vertical well when there is drainage obstruction or pockets drain with an easily maintained lateral sub-drain system. Often used in northern latitudes, vertical wells permit fast runoff from melting snow to get through the frozen soil and reach a pervious stratum. Under such conditions, treat the bottoms of these wells with calcium chloride or a layer of hay to prevent freezing.

2.8. Summary. The expedient construction and repair methods presented in this chapter do not replace traditional CE roadway and drainage construction or repair procedures. They provide potential options during emergencies or bare base development when time and resources are limited. Some of the methods may help to establish or restore critical roadways and drainage infrastructure at contingency locations. For additional information on soil conditions and testing, and development of road surfaces and drainages, consult the references listed in **Table 2.22**.

Table 2.22. Chapter 2 Quick References.

Road Construction and Repair	
AFH 32-1034	*Materials Testing*
UFC 3-220-08FA	*Engineering Use of Geotextiles*
UFC 3-250-09FA	*Aggregate Surfaced Roads and Airfields Areas*
UFC 3-250-11	*Soil Stabilization for Pavements*
UFC 3-250-01	*Pavement Design for Roads and Parking Areas*
UFC 3-250-03	*Standard Practice Manual for Flexible Pavements*
UFC 3-250-04	*Standard Practice for Concrete Pavements*
UFC 3-260-01	*Airfield and Heliport Planning and Design*

UFC 3-270-07	*O&M: Airfield Damage Repair*
ETL 02-19	*Airfield Pavement Evaluation Standards and Procedures*

Chapter 3

FIELD EXPEDIENT PROTECTIVE STRUCTURES

3.1. Overview. Protecting base personnel and unit operations is always an important force protection (FP) concern. In fact, during the initial stages of a force beddown at a contingency location, developing base defense infrastructure can be an urgent requirement. If tasked, our initial CE beddown forces may have to build various field-expedient protective structures until other FP measures become available. Expedient structures such as soil berms, anti-vehicular ditches, revetments, walls, bunkers, fighting positions, and guard towers play a vital role in initial base defense. While usually not complicated to build, these structures may provide needed protection during a critical phase of the base establishment mission.

3.1.1. Soil berms, walls, screens, and revetments provide protection along base perimeters, near buildings, power plants, and other valuable resources. Excavated ditches may serve as anti-vehicular barriers. Bunkers protect people and other important assets from the effects of conventional weapons. Fighting positions provide protective cover and allow base defense forces to more effectively engage attackers.

3.1.2. This chapter addresses techniques and procedures for creating the expedient protective structures below using materials and equipment readily available at most beddown locations. For additional information on these and other protective structures, review Graphic Training Aid (GTA) 90-01-011, *Joint Forward Operating Base (JFOB) Handbook*, and the references addressed in **paragraph 3.9**. In addition, the Whole Building Design Guide (WBDG) at **http://www.wbdg.org/ccb/browse_doc.php?d=9262** has drawings and design data for a number of barricades and protective structures. **Attachment 2** lists other websites and engineer reachback resources.

- Soil Berms
- Dikes

- Anti-Vehicular Ditches
- Walls and Revetments(including soil-filled containers and sand grids)
- Predetonation Screens
- Bunkers
- Defensive Fighting Positions
- Observations Posts

3.2. Soil Berms. Soil berms are among the oldest and simplest methods of providing improved and expedient protection to existing structures, personnel, and other assets. They have been around for centuries and like today, ancient engineers used berms for fortification. The simplicity of design, ease of construction, and effectiveness ensure berms will continue to be a valuable engineering solution well into the future. Berms are one of the best expedient means of protecting assets from blast effects as well as direct and indirect fire weapons. Furthermore, berms may deny the enemy a direct line of sight to protected assets or a vulnerable area such as a door opening. While berms provide good protection against attacks, they also are effective as vehicle barriers and containments structures. At contingency bases, engineers often build soil berms for landfills, hazardous materials, burn pits, aircraft engine blast and noise abatement, and other expeditionary activities. This section reviews field-expedient construction procedures for soil berms and highlights how they satisfy specific engineering challenges.

3.2.1. **General Berm Construction Guidelines.** Most descriptions identify a berm as a raised barrier or bank of earth that separates two areas. Soil berms may be less labor intensive and quicker to build than other common barriers—particularly sandbag walls or revetments requiring extensive time or materials to construct. Use berms as freestanding structures (i.e., earth mound barricades) or built against the exterior of retaining walls or other structures. Earth mound barriers typically require more soil and room to construct than berms placed against structures. Due to their large size, berm construction usually involves the use of heavy construction equipment. Built primarily of compacted soil, berm design should contend with ever-present gravity. If the sides of a berm are too steeply sloped, a shifting of the soil will occur. Because of this, you will generally find the base of a berm is often at least three times the width at the top. To minimize water ponding on the crest and subsequent soaking into the structure's interior, use a ten-to-one slope on the top of the berm (**Figure 3.1**). After building the berm, consider sealing the berm sides to control erosion. A variety of face sealing methods is available to meet this purpose; sod is a common method. While there are no height or length limitations on berm construction, the berm's dimensions are key factors relating its overall effectiveness. **Figure 3.2** illustrates the relationship between berm height, length, and crest dimensions.

3.2.1.1. **Berm Height.** The berm height (h_B) must be sufficient to protect the structure from the fragment spray or incoming projectile. Recommend setting the berm height at least equal to the height of the structure (h_S) or as high as practicable. If time permits, perform a more detailed analysis.

Figure 3.1. General Berm Construction Factors.

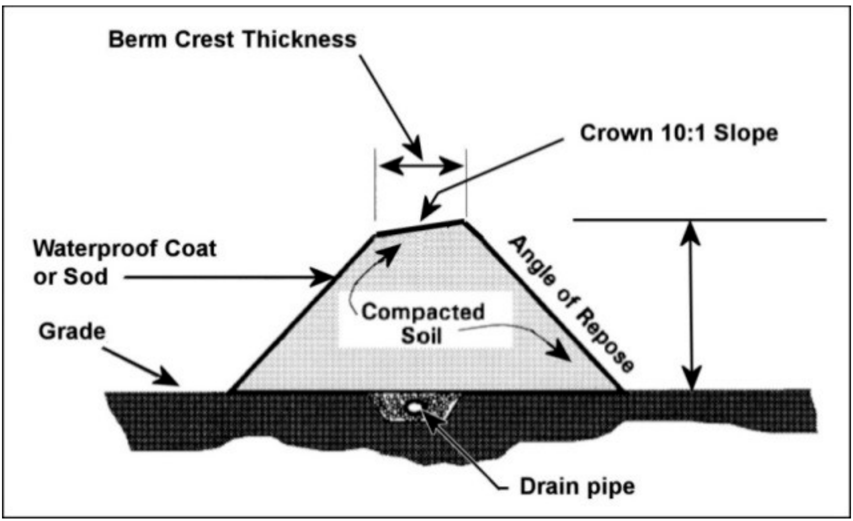
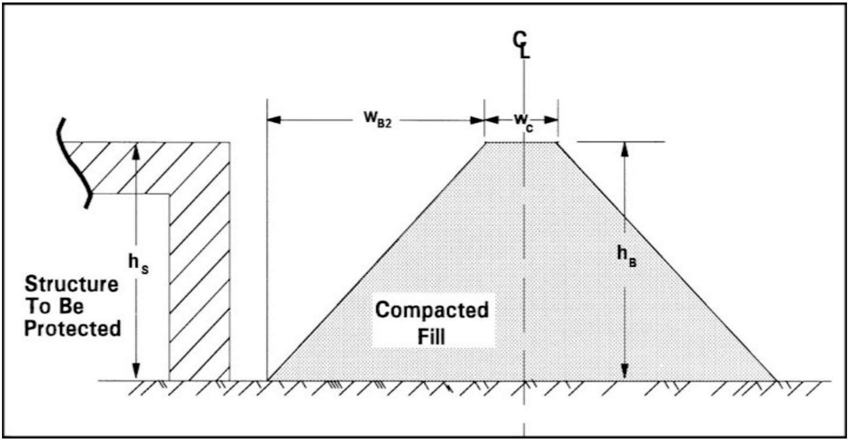


Figure 3.2. Common Freestanding Berm Configuration.



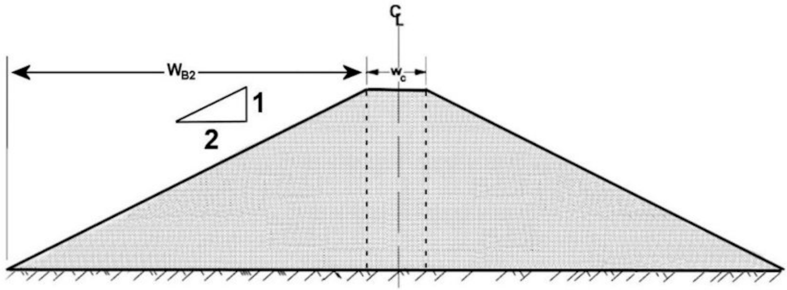
3.2.1.2. **Berm Crest.** The width of the berm's crest (W_c) is a key design variable. The relatively large space requirements of soil berms and potential need to move large volumes of earth make it desirable to minimize this width. As it relates to protection against weapons fire, design the width at the crest of the berm for the ballistic threat, that is, the design fragment or other projectile. The degree to which this thickness must defeat the ballistic threat depends on the protection requirements and the construction of the structure. For example, in the case of a thin-walled, non-hardened structure, it is desirable that the berm completely prevent the incoming projectile from reaching the wall. However, with a semi-hardened, reinforced concrete structure, it may only be necessary to slow the incoming projectile so that spall of the concrete wall does not occur.

3.2.1.3. **Berm Base.** 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 is in order. Determine the width of the base (W_{B2}) of the sloped portion of the berm by the allowable side slope of the berm face. In practice, for expedient situations, the maximum realistic slope is the natural angle of repose of the soil. The less the slope, the greater the protection provided and the greater the stability of the berm under repeated onslaught—particularly during inclement weather. For cohesionless soils (those composed primarily of sand), the slope angle can be taken as the angle of internal friction. **Table 3.1** gives friction angles for a range of soil types. However, if the soil type used is unknown or time is not available to accomplish proper compaction, it is generally conservative to use a 1 Vertical to 2 Horizontal (1V:2H) slope for preliminary design and planning purposes (**Figure 3.3**). As would be anticipated, cohesive soils sustain greater slopes. Nevertheless, consider the potential for moisture content variations. If time permits, engineers can perform a slope failure analysis, as described in standard soil mechanics texts or handbooks. Example sources include UFC 3-220-10N, *Soil Mechanics,* and UFC 3-220-01, *Geotechnical Engineering*.

Table 3.1. 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
Very dense sand	>45
For cohesionless soils, those composed primarily of sand, the slope angle can be taken as the angle of internal friction.	

Figure 3.3. Preliminary Design Slope of Freestanding Berm.



3.2.2. **Soil Berm Variations.** The two expedient soil berm variations highlighted here include freestanding berms and berms built against structures. Whether freestanding or positioned against a retaining wall or other structure, most soil berms constructed in a TO are considered an expedient protective measure. However, large soil berms requiring extensive time and earth moving equipment to construct seem difficult to classify as a field-expedient protective measure.

3.2.2.1. **Freestanding Berms.** A freestanding berm that is well positioned and composed of dry sand or soil will normally provide exceptional penetration protection. Listed in **Table 3.2** are essential factors associated with building a freestanding berm. However, on the negative side, freestanding berms require the most material and room to construct, of the various berms addressed in this chapter. In addition, it may provide limited protection against explosive blast overpressures in the near range (2 to 10 times berm height) because blast waves quickly reform after passage over the berm, and no blast overpressure protection in the far range. As a result, freestanding berm structures may not be appropriate for applications requiring significant blast overpressure reductions. However, berms built against a structural wall and those built with a supporting retaining wall can dramatically reduce the damage from both fragment impact as well as blast overpressures.

Table 3.2. Common Freestanding Berm Guidelines.

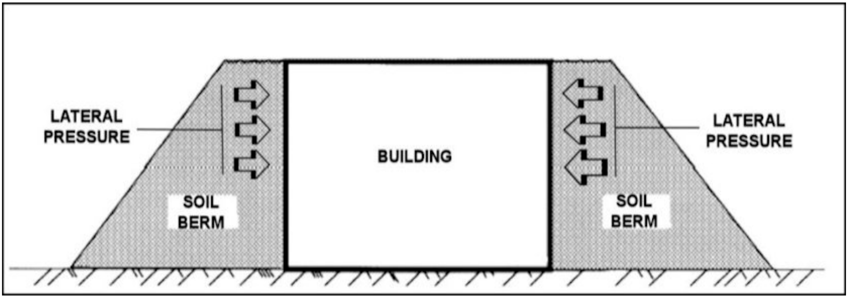
Berm Design Guidelines
– Berm height based on asset height
– Minimum crest width based on threat condition
– Side slope varies (commonly 1V:1H to 1V:2H)
– Crest slope 1V:10H
– Compacted soil
– Erosion control
– Drain tile
– Regular inspection and maintenance

3.2.2.2. **Berms Built Against Building Walls.** Berms built directly against the side of a building requiring protection can reduce the amount of soil required. However, be aware that even though this configuration does save time and material, there are also severe limitations associated with employing this procedure.

3.2.2.2.1. As illustrated in **Figure 3.4**, the berm exerts extreme lateral pressure against the walls of the involved structure. The amount of pressure applied depends upon factors such as the berm height and the type of soil and its water content.

3.2.2.2.2. Some conventional wall systems may not be capable of supporting the lateral pressures exerted by berms built directly against their walls. Engineers should analyze walls for stability, however, during contingencies, conservative approximations may be appropriate to assess lateral pressure.

Figure 3.4. Soil Berms Built Against Building Walls.



3.2.3. **Negative Soil Berm Aspects.** Soil berms offer simple and effective engineering solutions to several field construction requirements. They also have negatives aspects, especially from an expediency approach. The principle disadvantage associated with using berms is their large space requirements. Often the resource needing protection will not have sufficient clear area around it to allow construction of a berm of adequate dimensions. In addition, a berm may not be a practical hardening option for structures sited in very rocky terrain or in areas where grading equipment is not available. Heavy equipment availability is an absolute necessity. At airbase facilities, berms sited near taxiways and runways can exacerbate problems related to blowing dust and debris. Arid locations, such as desert beddown sites, are particularly susceptible to this condition. 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 do not have waterproofing, sod covering, or otherwise adequately stabilized. If berms use sod as cover, slope angles steeper than 1V:3H could make mowing grass difficult.

3.2.4. **Slope Protection for Soil Berms.** Many different types of slope protection can 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 are potential options depending on the level of protection needed. However, in an expeditionary environment where time and resources are generally limited, avoid techniques such as riprap, articulated mats, or paving if high-class slope protection is not necessary. Grass, geocells, or other geotextile protection methods may provide lower-class slope protection options, if necessary. **Table 3.3** addresses the function or suitability of grass and geocells as slope protection. Slope protection for soil berms utilized as containment dikes require special consideration. Review **paragraph 3.3** for information on dike construction.

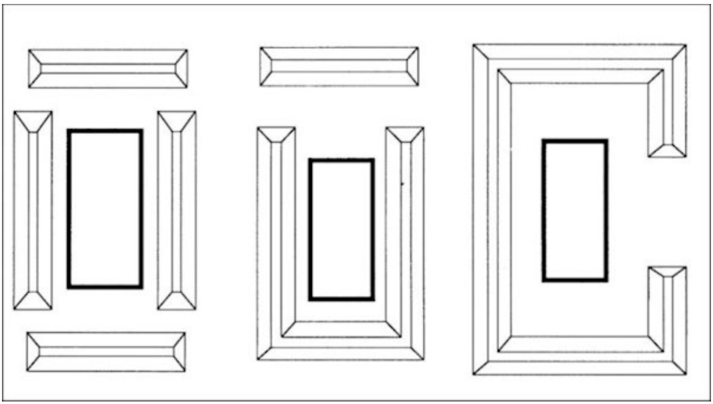
Table 3.3. Berm Slope Protection.

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

3.2.5. **Berm Applications.** In addition to force protection, using freestanding soil berms around airbase facilities such as landfills, burn pits, hazardous material storage areas, airfields, firing ranges and other areas may be an option 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 similar to those discussed in **paragraph 3.2.1**. However, when constructing soil berms for firing ranges, engineers should review and comply with ETL 11-18, *Small Arms Range Design and Construction*.

3.2.6. **Berm Arrangement.** Berm placement to protect assets is more of an art than science. The key is keeping bomb fragments and projectiles from having an unobstructed path to the protected resource. **Figure 3.5** depicts possible arrangements of berms around a building or resource for protection. It is not always necessary to construct berms in a straight line. If a curved arrangement is better, use it. Using other protective measures such as walls and revetments may be an option to shield access paths through berms.

Figure 3.5. Berm Arrangements.



3.2.7. **Other Consequential Factors.** Consider other factors such as soil composition, moisture content retention, proper drainage, and compaction requirements when planning to construct any type of protective berm.

3.2.7.1. **Soil Composition.** A number of soil composition factors directly affect the performance of any earthen protective structure. As it relates to protection against weapons fire, the soil consistency of a berm has a direct association to its effectiveness against the dynamics of shrapnel and ballistic impacts. In general, soil can fall into one of two categories; it is primarily composed of either 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. Sand and clay provide noticeably different degrees of protection for comparable structures. If the soil used is a mixture of clay and sand, always base your berm size on the material that provides the least penetration protection, in this case the clay.

3.2.7.2. **Moisture Content.** The depth of projectile and fragment penetration within a soil berm is a determinant of three factors: the finer the grain—the greater the penetration; penetration decreases with an increase in density; and penetration increases with increasing water content, regardless of soil type. Therefore, it is important to take adequate measures to seal the exterior of the structure when at beddown locations where the annual precipitation level is high. Consult UFC 3-340-01, *Design and Analysis of Hardened Structures to Conventional Weapons Effects* (FOUO), for calculating the specific protection afforded by various soil types against fragments and projectiles.

3.2.7.3. **Proper Drainage.** Drainage should also be a prime consideration when constructing any soil berm. Poor drainage can rapidly undo all the hard work involved in building the protection. In the same vain, if building the berm in a region of high rainfall, also consider installing an interior drainage pipe to remove moisture that may have seeped into the structure's encasement (see **Figure 3.1**). Always cut drainage channels to carry water away from the protected asset and berm.

3.2.7.4. **Compaction.** Proper compaction is an essential part of berm construction, regardless of the type of berm or soil involved. Berm material is compacted to increase its density—the greater the density the higher the level of projectile protection. Complete berm compaction in layers, the soil type and its moisture content dictate the extent of compaction. Usually, compactions will occur after placing every six- to twelve-inch layer of material. For small berms, compaction can be accomplished using a hand tamp, portable vibratory tamper, or pneumatic plate. The hand tamp approach is a slow, labor-intensive process, but its simplicity means that it should always be available. The portable vibratory tamper is a motorized hand-controlled tool about the size of a common household lawnmower. The pneumatic plate is an excavator attachment and is one of the fastest methods available. A vibratory roller may be used where construction of large berms are involved.

3.2.8. **Expedient Berm Retaining Wall.** Build expedient berm retaining walls using lumber, plywood, corrugated metal, precast concrete revetments, or other available materials. **Figure 3.6** through **Figure 3.8** illustrates berm and retaining wall applications to protect structures and other assets. By placing berm retaining walls close to the structure, a significant reduction in air blast loading on the structure is possible.

Figure 3.6. Concrete Modular Revetment Retaining Wall.

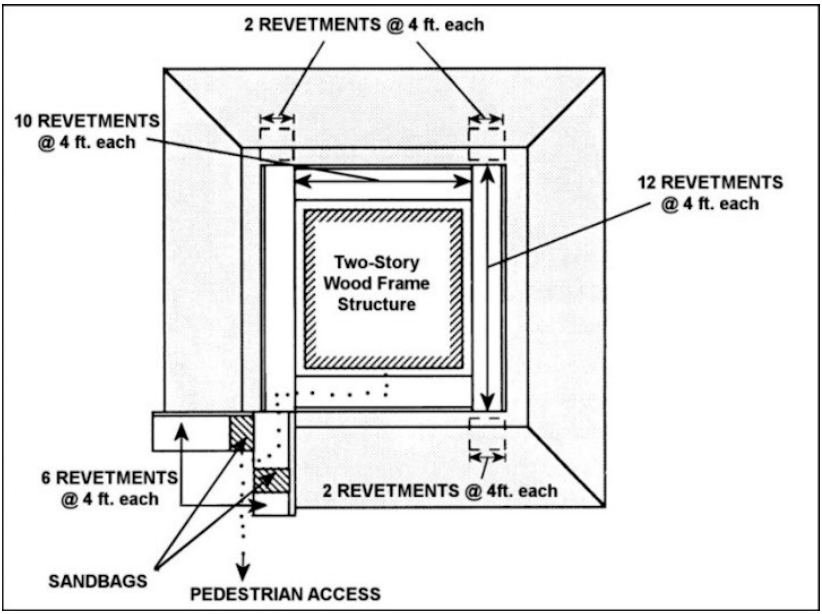


Figure 3.7. 4-Meter Concrete Revetment Retaining Wall (Profile).

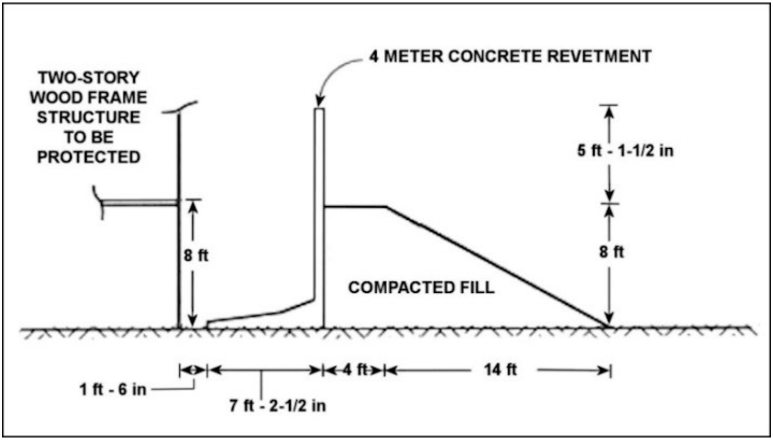
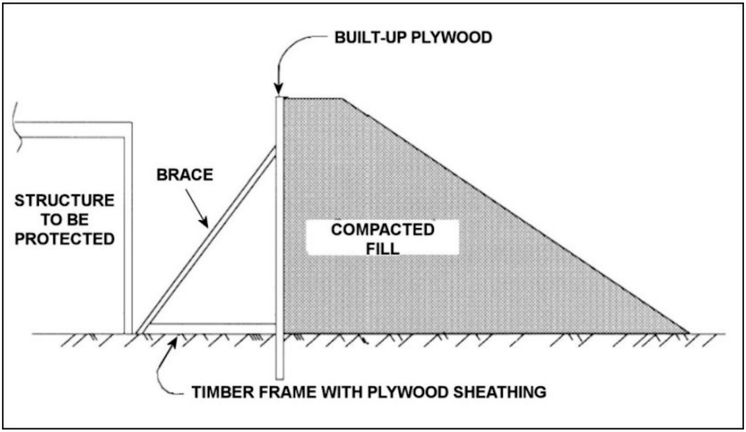


Figure 3.8. Plywood Retaining Wall Variation.



3.2.8.1. An 8-foot high, one-sided retaining wall may be built using 6 by 12-inch lumber posts, 4 by 4-inch horizontal runners, and a sheathing surface that consists of either 1-1/2 inches (min) of plywood, heavier gauge (16 gauge or better) corrugated metal, or metal mats. Place posts 4 feet into the ground and no more than 2 feet apart for each runner. Next, fill in between the 4 by 4-inch runners by nailing short sections of 4 by 4-inch lumber to the posts between runners, and then fasten the plywood or metal sheathing to the 4 by 4-inch runners.

3.2.8.2. There are two ways to anchor the retaining walls to supporting posts. The more protected way is to anchor each post at about 2/3 the height of the berm material (**Figure 3.9**). Use at least 3/8-inch guy cable run on a 3V:1H slope down to a deadman anchor. The alternative method is to anchor each post to three individual deadmen anchors placed along the face of the berm, as shown in **Figure 3.10**. While this can help stabilize the berm, it exposes the anchors to more damage from a blast.

Figure 3.9. Anchoring Soil Retaining Wall.

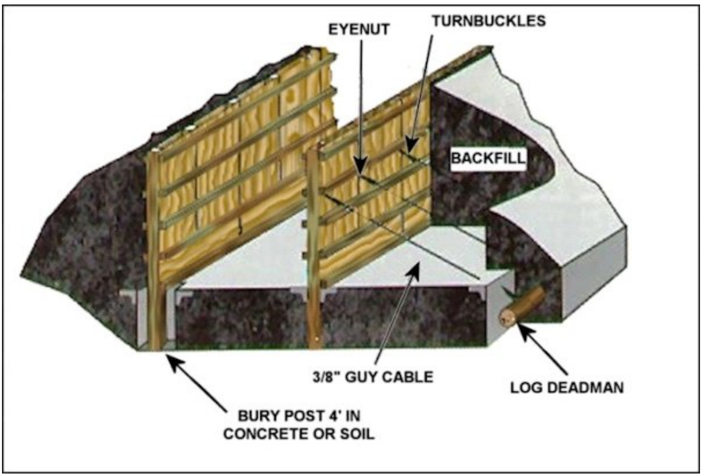
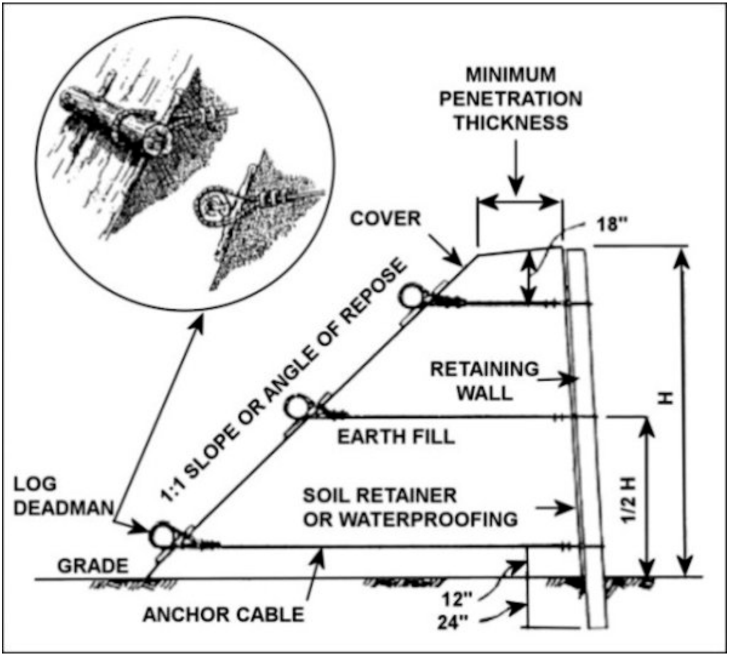


Figure 3.10. Alternate Retaining Wall Berm Anchoring System.



3.3. Dikes. Although not always considered as a FP measure, dikes can protect base personnel and important operations and resources via spill control, flood control, and basic water management. Dikes may resemble a ditch/channel or a raised embankment/barrier. **Chapter 2** addresses ditch and channel construction for water management therefore; this section only addresses raised barriers. Engineer work crews routinely build raised barriers around fuel storage and distribution areas to protect fuel systems and limit damage from spills. Engineers also use dikes to hold back or help control the flow of floodwaters.

3.3.1. **Fuel Dikes.** Using fuel dikes around petroleum, oil, and lubricants (POL) tanks and bladders (**Figure 3.11**) helps to contain fuel spills if the tanks rupture or catch fire. Although the primary focus here 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 3.11. Fuel Bladder Containment Dike.

3.3.1.1. **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. 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 undependable drainage.

3.3.1.2. **Fuel Dike Construction.** When constructing a fuel dike, the size or height of the dike should be such that the volume of liquid in the fuel bladder plus the average seasonal precipitation can be contained within the dike should the bladder ruptures. **Figure 3.12** illustrates construction layout for a single 10,000 gallon (10K) fuel dike. Illustrated in **Figure 3.13** is a typical fuel dike layout for 50K and 210K fuel bladder. 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 gate valve on the drainpipe should remain closed except when releasing non-impacted storm water from the diked area. 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. For proper containment, the wall of the fuel dike on the issue side should be of sufficient height to account for the downward slope (approximately 3-inch drop to the issue side).

3.3.1.2.1. 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. To ease truck operations, stabilize the travel area around the dike by 50 to 100 feet. If applicable, consider civilian delivery truck weights and turn radiuses when sizing the truck travel area.

3.3.1.2.2. 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 3.14**). The liners should be long enough to cover the secondary dike. Refer to AFPAM 23-221, *Fuels Logistics Planning*, and T.O. 37A12-15-1, *Collapsible Fuel Bladders*, for other fuel dike or berm construction details.

Figure 3.12. Single Fuel Dike (Typical).

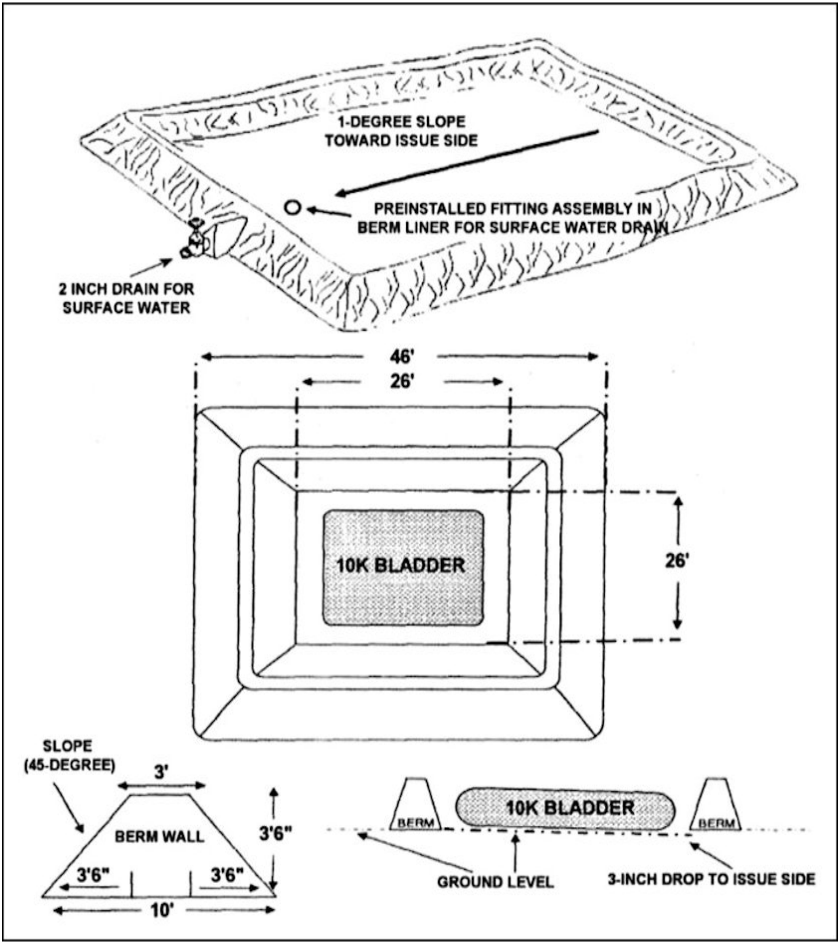


Figure 3.13. 50K and 210K Fuel Dike Layouts.

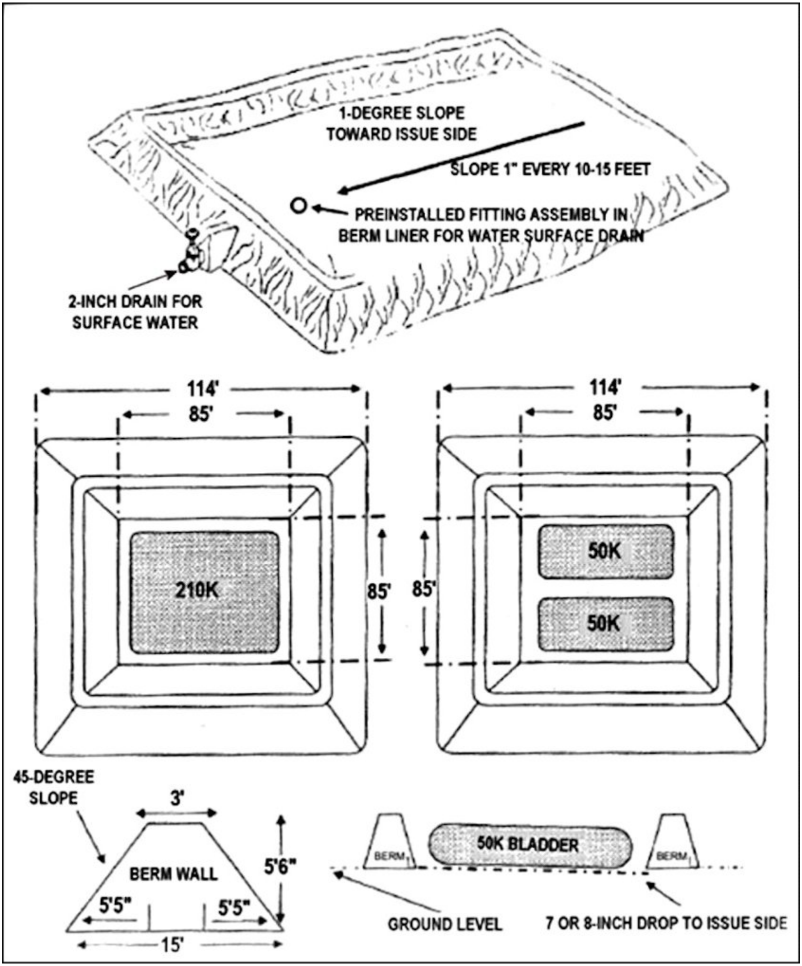
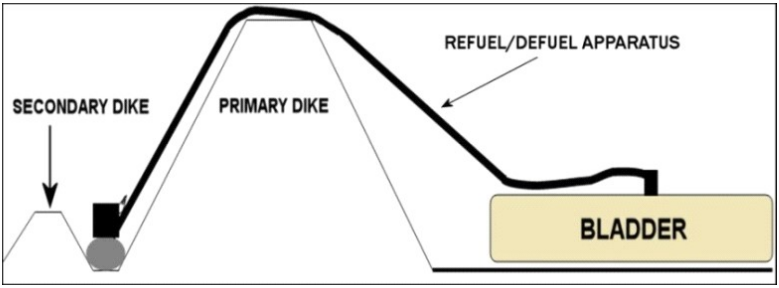


Figure 3.14. Illustration of Fuel Dike with Secondary Dike.



3.3.2. **Raised Flood Control Dikes.** Commonly, expedient raised flood control dikes or barriers (sometimes referred to as levees) consist of soil or sandbags. However, using soil-filled wire and fabric containers in lieu of sandbags is a contemporary option for building expedient dike walls because it requires less time and personnel than filling and placing sandbags. Expedient dikes provide emergency flood protection for periods of only a few days or weeks. Dikes and levees that are more enduring require additional planning, analysis, time, and materials to build and usually not considered expedient. Although there is typically 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 dike construction begins.

3.3.2.1. **General Dike Construction Design.** The design of raised flood control dikes is similar to that of freestanding soil berms discussed earlier; however, they serve two very different purposes. Since the purpose of flood control dikes is to hold back floodwaters, their failure could potentially result in devastation over a wide area and adversely affect many people. Build raised dikes to hold throughout the entire flood event. Anytime there is water against the embankment, there is a potential danger that the dike could fail. Even under emergency conditions, use proven construction methods when constructing raised flood control dikes—an emergency is not the time to experiment. The foundation soils and the materials available for construction generally dictate the standard design of a raised dike. Always attempt to make the dike or embankment compatible with the foundation. Information on foundation soils may be available from local officials or engineers. Use the information in **paragraph 3.3.2.5** as a guide when determining vertical and horizontal embankment design. Finally, actual dike construction will depend, in most cases, on time, materials, and right-of-way available.

3.3.2.2. **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. Keep the flood barrier as far landward of the body of water as possible to prevent encroachment on the floodway. Avoid sharp bends. 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.

3.3.2.3. **Foundation Preparation.** Prior to constructing a raised embankment, the foundation area along the dike alignment should be prepared.

3.3.2.3.1. Cut trees and the remove the stumps. Remove all obstructions above the ground surface, if possible. This includes brush, structures, snags, and similar debris. In snow-covered areas, push the snow riverward to decrease ponding when the snow melts.

3.3.2.3.2. Strip the foundation of topsoil and surface humus. Stripping may be impossible if the ground is frozen. In this case, rip or scarify the foundation, if possible, to provide a rough surface for bonding with the embankment. Make every effort 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 dike; but on thawing, soil strength can reduce 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 dike and, upon thawing, pressure may be sufficient to cause sudden blowouts. If this condition exists, monitor and 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 dike. **Note:** Perform clearing and grubbing, structure removal, and stripping only if time permits.

3.3.2.4. **Materials.** Earth fill materials for emergency dikes will usually come from local borrow areas. Attempt to utilize materials that are compatible with the foundation materials. However, due to time limitation, consider using local materials and follow reasonable construction procedures. The materials should be relatively clean (free of debris) and should not contain large frozen pieces of earth.

3.3.2.4.1. Clay. Clay is preferred because dike sections can be made smaller (steeper side slopes). In addition, 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 affect 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. Be sure to consider weather conditions because it could cause delays in the overall construction effort.

3.3.2.4.2. Sand. If sand is used, see the recommendations in **paragraph 3.3.2.5.1** below. Steep slopes without poly coverage on the riverside slope will result in seepage through the dike to outcrop high on the landward slope and may cause the slope to slump and potentially fail if it occurs over an extended period.

3.3.2.4.3. Silt. Try to avoid material that is primarily silt. If used, apply poly facing to the river slope. In addition to being very erodible, silt, upon wetting, tends to collapse if not properly compacted.

3.3.2.5. **Dike Sections.** As previously addressed, the foundation soils and available construction materials generally dictate dike or levee design. Therefore, even under emergency conditions, attempt to make the embankment compatible with the foundation. Consider any available information on foundation soils from local officials or engineers. The two dike sections cited below are classical and idealized, and usual field conditions depart from them to various degrees. However, the information can potentially lessen serious flood-fight problems during high water. In determining the top width of any type of section, consider whether a revised forecast can potentially require placing additional fill. A top width adequate for construction equipment will facilitate raising the levee. Dike height should provide at least 2 feet of freeboard above forecast flood crest.

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

3.3.2.5.2. Clay section. If the dike section will be made of clay, use 1V:2-1/2H for both slopes. While 1V:3H slopes are preferable, 1V:1-1/2H 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 (**Table 3.4**), and H is dike height. Readers should refer to UFC 3-220-10N for additional information related to foundation soil creep.

Table 3.4. Creep Ratios on Pervious Foundations.

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

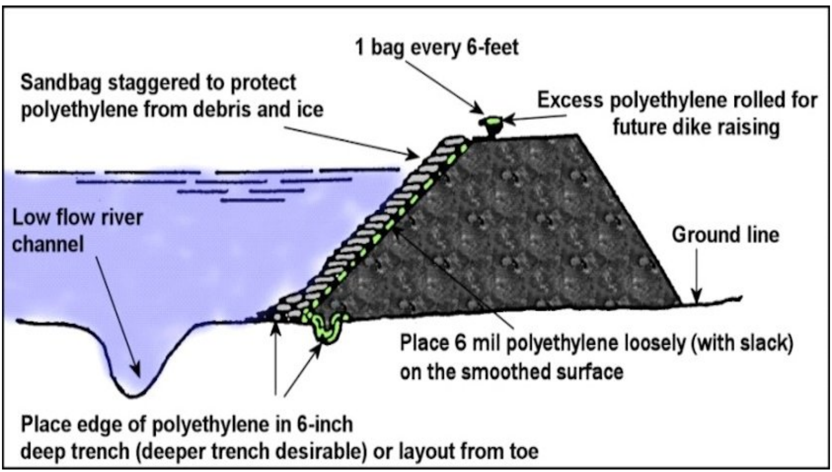
3.3.2.6. **Placement and Compaction.** Obtaining proper compaction equipment for a given soil type will be difficult. In most cases, the only compaction may be from hauling and spreading equipment; i.e., construction traffic routed over the fill.

3.3.2.7. **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.

3.3.2.7.1. Polyethylene and Sandbags. Experience has shown that a combination of polyethylene (poly) and sandbags is an effective, expedient, and economical method of combating slope attack in a flood situation. Personnel can use poly and sandbags in a variety of combinations. Time becomes the factor that may determine which combination to use. Ideally, place poly and sandbag protection in the dry. However, many cases of unexpected slope attack will occur during high water. Covered below are 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.

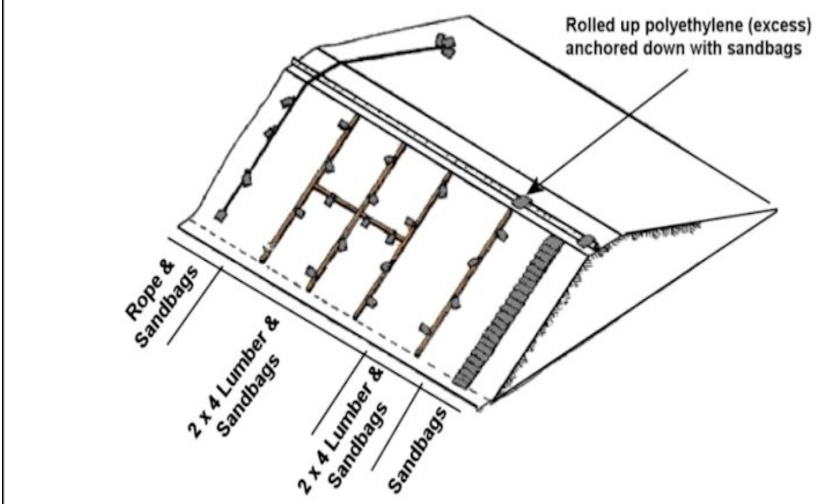
3.3.2.7.2. Toe Anchorage and Poly Placement. Anchoring the poly along the waterside toe is important for a successful job (see **Figure 3.15**). Accomplish placement in three different ways: (1) after completion of the embankment, excavate a trench along the toe and place poly inside the trench and backfill the trench; (2) place poly flat-out away from the toe and push earth over the flap; (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. Place the poly from downstream to upstream along the slopes and overlapping at least 2 feet. The poly is now ready for the "hold down" sandbags.

Figure 3.15. Placing Polyethylene.



3.3.2.7.3. Slope Anchorage. Anchor or hold down poly placed on raised embankments. An effective method of anchoring poly is a grid system of sandbags (**Figure 3.16**), unless anticipating extremely high velocities of water, heavy debris, or a large amount of ice. In those situations, use a solid blanket of sandbags over the poly. Workers can construct a grid system faster and with fewer bags and much less labor than a total covering. Various grid systems include vertical rows of lapped bags, 2 by 4-inch lumber held down by attached bags, and rows of bags held by a continuous rope tied to each bag. In addition, you can hold down poly using a system of two sandbags tied with rope and the rope saddled over the embankment crown with a bag on each slope.

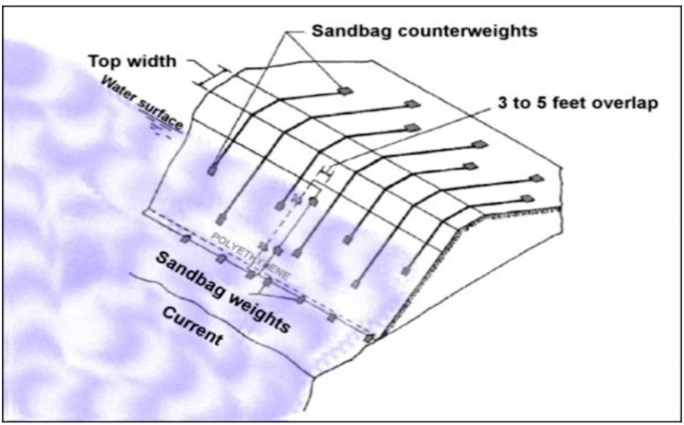
Figure 3.16. Anchoring Polyethylene.



6 mil black polyethylene is the most desirable, 6 mil clear second, 4 mil black third, 4 mil clear is the fourth, and 2 mil polyethylene should only be used as a last resort

3.3.2.7.4. 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 3.17** shows a typical section of embankment covered in the wet. Form the sandbag anchors 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. Use counterweights consisting of two or more sandbags connected by a length of 1/4-inch rope to hold the center portion of the poly down. The number of counterweights will depend on the uniformity of the dike 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. Add sufficient counterweights to ensure that no air voids exist between the poly and the dike 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.

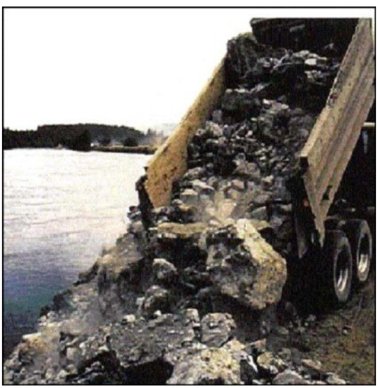
Figure 3.17. Placement of Polyethylene Sheeting in the Wet.



3.3.2.7.5. 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 velocities, use of poly would be unnecessary. In addition, workers should not place poly on landward slopes to prevent seepage. It will only force seepage to another exit and may prove detrimental. However, using poly on the landside slope of dikes to prevent rainwater from entering a crack where slope movement has occurred is an option, 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.

3.3.2.7.6. Riprap. Riprap is a positive means of providing slope protection (**Figure 3.18**) and its use may be an option in a few cases where erosive forces are 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 suitable rock is not available within economical hauling distance, soil cement slope protection may be a viable option.

Figure 3.18. Placement of Riprap.



3.3.2.7.7. Miscellaneous Measures. Several other methods of slope protection proved useful in the past. Small groins extending 10 feet or more into the channel were effective in deflecting current away from the dikes. Using log booms to protect dike slopes from debris or ice attack. Cable the logs together and anchor 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.

3.3.2.8. **Using Wire/Fabric Earth Filled Barriers.** Use earth filled barriers for fast construction of a water dike wall. Reinforce the walls on the opposite side (landside) of the water with earthen material filled with organic/rock mixture for strength.

3.3.2.9. **Other Considerations.** Potentially, someone could request to locate irrigation and/or drainage ditches in close proximity to the landside dike toe. This could lead to serious seepage and/or slope stability problems. Establish the location and depth of proposed ditches by seepage and stability analyses. This requires information on foundation soil conditions, river stages, and geometry of the proposed ditch. Consult local engineers before constructing drainage ditches, especially if raised dikes are in the immediate area. **Chapter 2** in this publication has information on expedient drainage construction measures. In addition to the other references in this section, find more information in the interactive *Berms & Dikes* course located on the CE Virtual Learning Center (VLC) website at https://afcec.adls.af.mil.

3.4. Anti-Vehicular Ditches. In addition to managing surface water runoff and floodwaters, consider using expedient ditch construction to support base defense efforts. Ditches offer a simple method of rapidly securing a lengthy perimeter against a moving vehicle tactic. They can function as permanent anti-vehicle barriers if crews maintain the required ditch profile, or the ditches can provide a temporary barrier before installing a permanent vehicle barrier system. The ditch profile, including the approach slope, is critical to its ability to function as a vehicle barrier. Secure the ends of ditches or blocked by some other obstacle to prevent easy bypassed. When excavating ditches, consider procedures addressed in **Chapter 2**. Most likely, work crews will need both a dozer and grader to excavate a properly sized anti-vehicle ditch barrier and approach slope. **Figure 3.19** and **Figure 3.20** illustrate construction designs for two optimized anti-vehicular ditches. For additional ditch design information, readers should refer to UFC 4-022-02, *Selection and Application of Vehicle Barriers*.

Figure 3.19. Ditch with Incline Slope Requiring Stabilization.

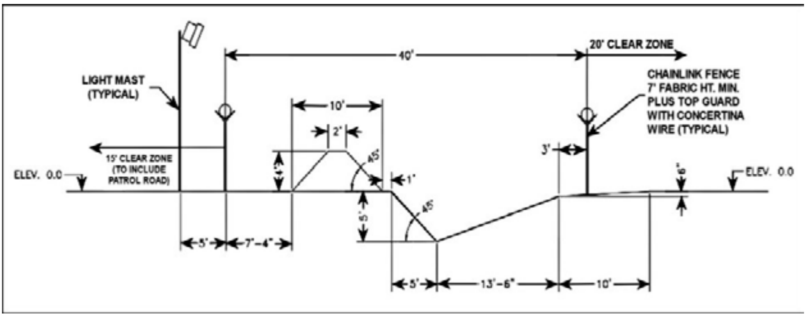
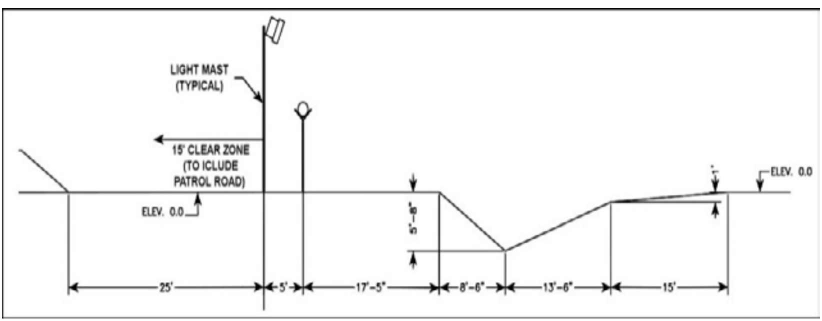


Figure 3.20. Ditch with Incline Slope Not Requiring Stabilization or Berm.

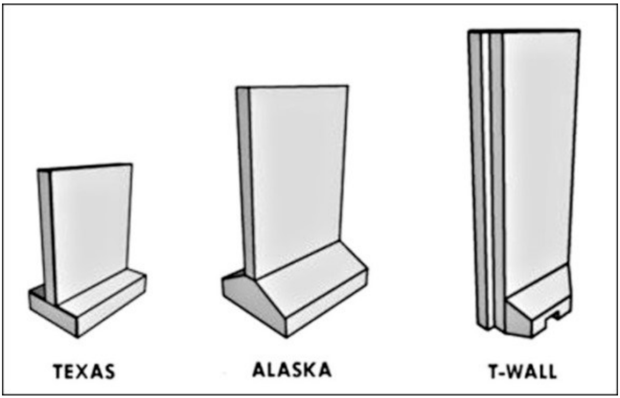


3.5. Expedient Walls and Revetments. For our purposes here, walls and revetments are protective structures made of concrete, timber, sandbags, soil-filled containers, or other suitable material designed to stop fragments, reduce blast effects, function as vehicle and pedestrian barriers, and provide standoff for facilities and potential targets. At contingency bases overseas, we rely heavily on maintaining standoff distances for force protection. In other words, we attempt to keep the enemy as far away as possible from our people and assets. Using items such as fencing, ditching, berms, and other perimeter defenses often accomplishes this. However, in some situations, additive buffers such as walls, revetments, and other complementary construction (i.e., shields, screens) may be necessary for protection. This section addresses contemporary, historical, and improvised methods for creating expedient protective walls and revetments. The stability and performance of expedient revetment structures is usually better when building structures on relatively flat foundations. If construction is not on improved surfaces such as concrete, asphalt, or stabilized soil, check the natural soil foundation to ensure it is strong enough to support the revetment over its intended life. GTA 90-01-011 has detailed site preparation and foundation construction considerations. More information is in UFC 4-022-02, AFTTP 3-32.34, *Civil Engineer Expeditionary Force Protection*, and AFH 10-222V14, *Civil Engineer Guide to Fighting Positions, Shelters, Obstacles, and Revetments*.

3.5.1. **Precast Concrete Sections.** Personnel can construct revetments relatively quickly with precast concrete sections. Precast concrete sections are effective in areas that require blast/fragment protection from weapons fire, or as vehicle and personnel barriers. A wide range of prefabricated portable concrete products (i.e., walls, barriers, pipes, culverts, etc.) is usable to shield vital assets or obscure them from line-of-sight. Use either a crane or a 10-ton forklift to place concrete sections. Before placing the concrete structures, ensure a stabilized ground base or foundation exists. Although a concrete foundation may be desirable, if concrete sections will rest on natural soil, prepare the site by clearing away vegetation, debris, and other unwanted material. If the soil foundation is unstable, concrete sections may crack or settle improperly, and tall concrete sections could overturn. When adding soil backing or berming to concrete walls, the soil backfill should be compacted to minimize post-construction settlements. Just as for soil berm construction, use heavy equipment, as needed to load, spread, or compact the soil.

3.5.1.1. **Concrete Modular Wall.** When available locally, consider using precast concrete modular walls to provide limited, expedient asset protection. If considering this option, determine if precast walls contain sufficient reinforcement to prevent collapse when damaged. Illustrated in **Figure 3.21** are three contemporary varieties of modular concrete wall sections.

Figure 3.21. Common Modular Concrete Walls.

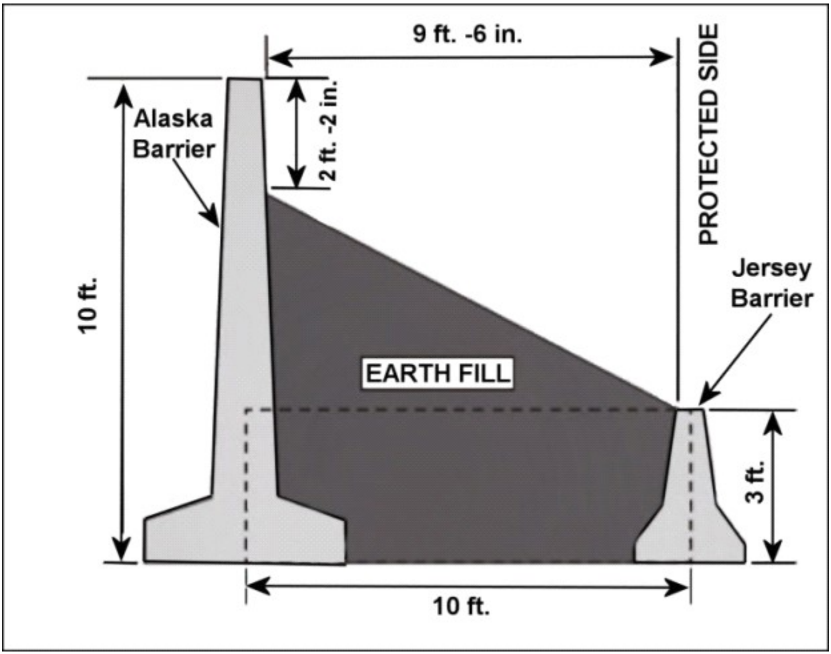


3.5.1.1.1. Walls built using these units can provide good protection from an initial enemy assault, but may provide only limited protection from follow-on attacks due to susceptibility to fragment damage, spalling, and displacement of the panel structures. During subsequent attacks, the weakened or displaced panels could allow fragments and blast to penetrate a protected position. These concrete modular units have a tendency to slide. For this reason, you should connect adjacent revetment units together into an array, although this is not as critical when the revetments are bermed. Use simple steel straps across the walls and the bases for this. These straps can be made of 3/8-inch thick steel plate, 2 inches wide and connected to the concrete by means of 1/2-inch diameter through bolts.

The edges of some concrete modular units do not have overlapping surfaces at the corners. Therefore, the corners may require additional reinforcing, such as with sandbags. When backed with soil (soil-filled or berming), protection is significantly enhanced.

3.5.1.1.2. **Figure 3.22** is a design example for a modular concrete wall with soil backing. Other design examples of precast concrete walls, bins, and barriers are on the WBDG website at **http://www.wbdg.org/ccb/browse_doc.php?d=9262**.

Figure 3.22. Example of Modular Concrete Wall with Soil Backing.



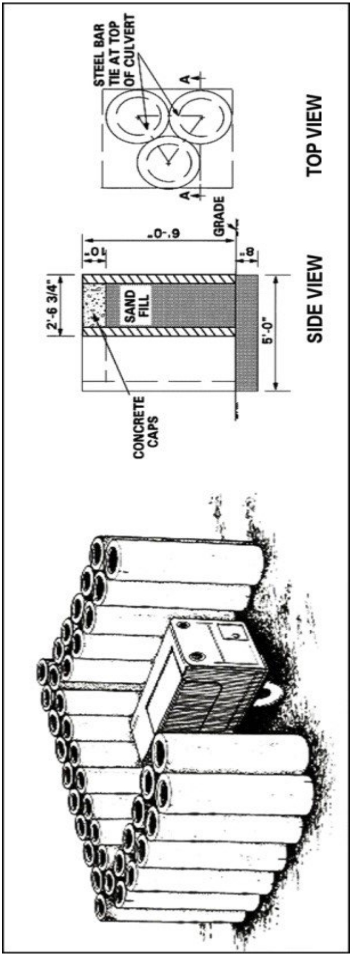
3.5.1.2. **Concrete Pipes or Culverts.** When material options are limited, expedient revetments can be improvised using soil-filled concrete pipe culverts. Precast concrete pipes come in numerous sizes. To ease handling and to limit damage during installation, revetments using these units is usually limited to about 6- and 8-foot sections. A minimum of a 30-inch (outside diameter) culvert should be used for this type of protection. Consider using larger diameter pipe (ranging up to more than 6-foot diameter) if available. Be aware that concrete pipes and culverts also come in various strengths to resist traffic loads. Those with little traffic loading capacity may have lower quality cement and less reinforcing, rendering them unsuitable for this purpose.

3.5.1.2.1. Install the pipes standing on end, on a stabilized ground base, as close as possible together. Most commercially available large culverts normally have bell and spigot or tongue groove ends. However, if possible, obtain straight-sided culverts, because they do not have flared ends that create a gap when placed side-to-side. If the culverts have belled ends, place the bell ends down and fill the gaps between rows with smaller materials, i.e., small diameter polyvinylchloride (PVC) pipe.

3.5.1.2.2. Use at least two rows of pipes/culverts with joints staggered (**Figure 3.23**). If available, drive steel rebar or pipes into the ground at the center of each pipe to aid in stabilizing the base.

3.5.1.2.3. Fill the pipes with dry sand or soil and, when time allows, cap the top with a minimum of 10 inches of concrete and a short length of exposed rebar or pipe. Also, tie these exposed extensions together by welding reinforcing bars to each row and between the opposite two adjoining pipes. Never stack pipes on top of each other—they should only be used one length high. If additional height is required, use another shielding method.

Figure 3.23. Concrete Culvert Revetment.



3.5.2. **Wire and Fabric Containers.** Soil-filled wire and fabric container systems (also referred to as Concertainer units) are potential options at many expeditionary contingency bases (**Figure 3.24**). The containers are available in various models, sizes, and configurations, and are quick to assemble; uses local soils, and are relatively easy to remove when no longer needed. The container kits consist of collapsible bins, connecting pins, and plastic ties. Most are lined with high-strength geotextile fabric; have galvanized or plastic-coated wire framing; and unfolds into open, square-shaped cells. Personnel often use these container systems to augment or replace modular concrete walls and revetments because they offer good protection and have low flying debris and fragment hazards. In addition to revetments, container applications can include rapid construction of barriers, bunkers, fighting positions, and other expedient protective structures. Just as for most other barrier structures, site preparations and a stable ground foundation are key construction considerations for revetments made with these containers.

Figure 3.24. Soil-Filled Wire and Fabric Container Revetment.

3.5.2.1. When assembled, the containers consist of a series of linked, self-supporting cells. Crews can quickly fill the bins with soil using front-end loaders, cranes with buckets, or conveyor systems. The type of fastening mechanisms on these containers depend on the model used. Join each bin section using a manufacturer-developed system or simply with common wire or tie wraps. Some manufacture's attachment systems may allow several rows and layers to be run with even faces or butted joints. However, other revetment system designs use staggered joints between rows. Generally, for stability, especially with the larger revetments, a pyramid shape with layers placed inward as it elevates is the desired construction method, as shown in **Figure 3.25**.

Figure 3.25. Example of Staggered Container Configuration.

3.5.2.2. Soil-filled wire and fabric container revetments have proven to be effective and resilience against multiple attacks. **Figure 3.26** shows a revetment during testing after undergoing numerous explosions. Although showing wear and tear from the assaults, it is apparent that the system retained its basic integrity and would have more than adequately protected any asset situated behind it. Further detailed information about revetment construction procedures are in the manufacturer’s construction guide and in the "*Revetments Course*" on the CE VLC website at **https://afcec.adls.af.mil**.

Figure 3.26. Container System Revetment after Testing.

3.5.3. **Soil-Filled Corrugated Metal Shields.** Portable corrugated metal shields have relatively thin walls. As illustrated in **Figure 3.27**, the walls are parallel to each other, usually only one-foot apart and filled with soil or sand once moved into position. Typically, these shields are relatively low in height and made in eight-foot sections to keep them from blowing over by proximity explosions. Once filled, the walls provide additional protection from blast and fragmentation compared to sheathing alone. **Table 3.5** lists materials required to complete an eight-foot corrugated metal shield section.

3.5.3.1. The ends of the walls are inverted "T" sections. These vertical “T” sections are 5-1/2 feet high by 3 feet wide and made with two layers of 2 by 12-inch boards or cut plywood. Line the bottom of the bin section with a 2 by 12-inch board fastened into place to help prevent the fill from leaking out. Typically, use poles or 2 by 4-inch lumber as parallel runners along the top, bottom, and middle of the wall to stabilize the sheathing. Ties or bolts hold the runners and sheathing together. Abut and fasten together the portable wall sections. Fasten additional 2 by 12-inch boards under the “T” sections as bearing plates to prevent wall settling into the ground; consider weighing down the fastened bearing plates sandbags to provide additional resistance to overturning from nearby blasts.

3.5.3.2. Once constructed, fill the completed revetment with a suitable soil material (sand if possible). Tamp fill material while being placed. Waterproof revetment top with sandbags, membrane, asphalt, concrete, etc. This shielding technique is an expedient option to protect supplies or equipment such as generators, POL, and ammunition. Properly constructed, this type of soil-filled wall can stop fragments from a mortar shell exploding as close as 5 feet away.

Figure 3.27. Corrugated Metal Shield Section.

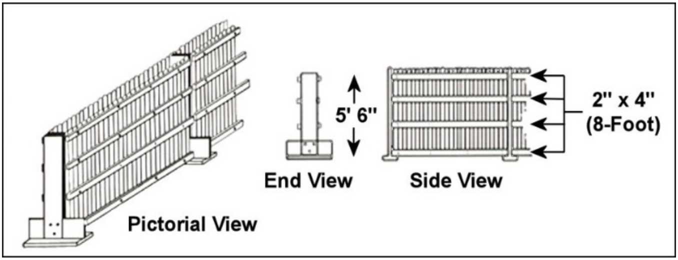


Table 3.5. Materials for 8-Foot Long Corrugated Metal Shield.

Item	Quantity
26 Ga. Corrugated Metal Siding 26 by 144-inch	4
2 by 4-inch by 8-foot Runners	8
2 by 12-inch by 7-feet 8-inch Bottoms	1
2 by 12-inch by 5-1/2-feet	4
2 by 12-inch by 4-1/2 feet	2
2 by 12-inch by 3-feet	4
5/8” Bolts w/Washers	6
50d Nails	25
3/8” Ø Bolts 19” Lg. w/Washers	16
8d Nails	75

3.5.4. **Plywood Walls.** Wood is not usually the best material option for protecting vital assets against weapons fire and munitions fragments because it has little penetration resistance. However, when expedient shielding is needed, wooden structures can provide effective protection; depending on wood thickness, number of layers, and if soil or other fill material backs the wooden structure.

3.5.4.1. **Multiple layers.** One or more layers of plywood make an effective field-expedient protective wall. Adding more layers of plywood increases the amount of protection. **Table 3.6** lists the construction materials required and **Table 3.7** lists the approximate effectiveness of up to three layers of 3/4-inch fir plywood. Although three layers of plywood stopped a high percentage of fragments from all munitions shown, there are still a large number of lethal fragments perpetrating the plywood. Brace and anchor the plywood to provide stability against blast.

Table 3.6. Materials for 8-Foot Long Plywood Protective Wall.

Items Required (8-foot long section)	Quantity
4 by 8-foot Plywood	3
2 x 4 x 8’ Runners	6
2 x 12 x 7’-8” Bottoms	1
2 x 12 x 5-1/2’	4
2 x 12 x 4-1/2’	2
2 x 12 x 3’	4
5/8” Bolts w/Washers 8” Long	6
50d Nails	25
3/8” Ø Bolts 19” Lg. w/Washers	12
8d Nails	75

Table 3.7. Approximate Effectiveness of Plywood Layers.

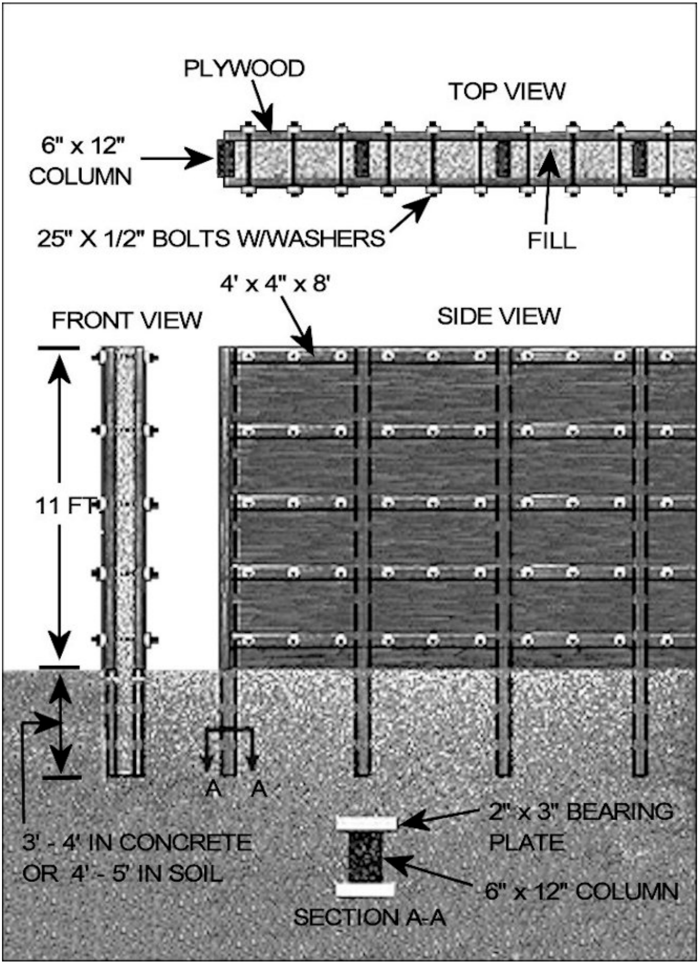
	1-Layer ¾-Inch Thick	2-Layers 1 ½-Inch Thick	3-Layers 2 ¼-Inch Thick
Threat	**% Effectiveness**		
81mm	60	82	91
82 mm	64	86	97
4.2in	24	55	71
107mm	47	71	85
120mm	60	84	91

*The percent effectiveness is the number of fragments completely stopped by the material and is expressed as:

$$\%\text{Effectiveness} = \left(\frac{\text{Number of Penetrating Fragments}}{\text{Total No. of Impacting Fragments}} \right) \times 100$$

3.5.4.2. **Soil-filled.** Forming plywood into a box-type structure in the same fashion as the corrugated metal wall and backfilling it with soil increases its protection considerably above that furnished by multiple plywood layers alone. Moreover, adding a soil berm to the face of the structure significantly improves the ballistic protection capability. **Figure 3.28** illustrates how to build one type of protective wall with vertical plywood panels separated by one-foot with a layer of soil in between. Additionally, bolts hold horizontal posts in place that fortify the plywood walls. Bury the columns three to four feet in concrete or four to five feet in soil. Add a bearing plate to the base of each column for additional support. Place and tamp soil fill material as previously addressed.

Figure 3.28. Soil-Filled Plywood Wall.



3.5.5. **Timber and Log Bin Revetments.** There is little difference between timber and log bin revetments except the raw materials. Construct these revetments like the plywood walls discussed previously, except use either rough-cut lumber or natural logs as the facing material. As a comparison, the facing wood of a log revetment is normally 2- to 3-inch sapling trunks laid parallel one on top of another; fitted together to minimize gaps. Whereas, the facing lumber of a timber revetment is usually a minimum 2-inch thick board or two inches of layered plywood sheathing. Below are additional details for timber revetment fabrication.

3.5.5.1. For a timber revetment, posts are normally 6-inch diameter round timber spaced approximately 2 feet apart. The posts are usually set 2 feet into the ground for bracing and have three tie cables run between opposite posts. One cable provides a tie at mid-height, while the other two cables are at about 1/6 the height from the top and bottom respectively. At a minimum, secure every other post this way.

3.5.5.2. Block the ends of the revetment with additional posts and timber; the minimum width of the revetment can be greater than the plywood revetment. As a minimum, build the walls in cells every 10 feet. A cross-braced wall is made within the lumber revetment by using two sets of 4 x 4s, set two inches apart, to create a slot on the inside of each wall. Then 2-inch thick lumber is stacked in the slot to create a cross-braced wall section. For the timber wall, two sets of 6-inch diameter posts are set about three inches apart on each side of the wall. Notch the cross members and stack to fit into the facing logs. Illustrated in **Figure 3.29** and **Figure 3.30** are variations of the timber bin revetment.

3.5.5.3. With the exception of a few variations, the construction procedures for log bin revetments are very similar to timber revetments. Assemble the inner and outer wall sections using the construction details illustrated in **Figure 3.31**. After completing the inner and outer wall sections and applying the waterproofing, place the opposing sections upright. Use sturdy spacer blocks to hold the walls apart at the specified distances while tightening the tie cables. Use a group of three tie cables every other post or as required. Once positioned, backfill the postholes, preferably with concrete. Carefully deposit the filler material to avoid displacing the spacer blocks or damaging the tie cables. Apply a waterproof cover and remove the temporary anchor cables.

Figure 3.29. Timber Revetment Variation (A).

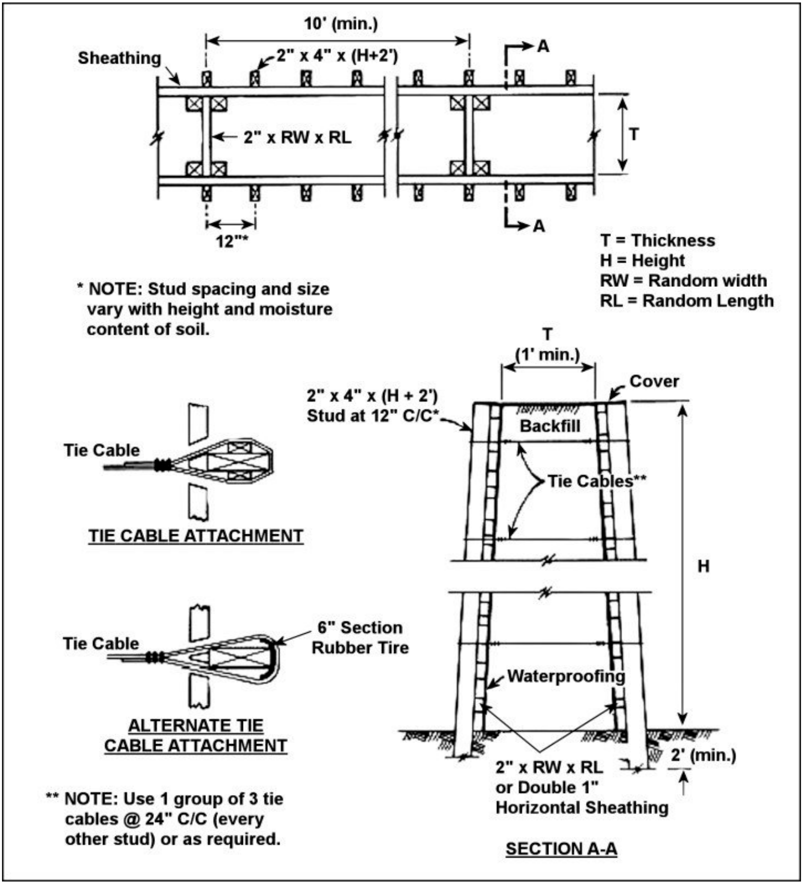


Figure 3.30. Timber Revetment Variation (B).

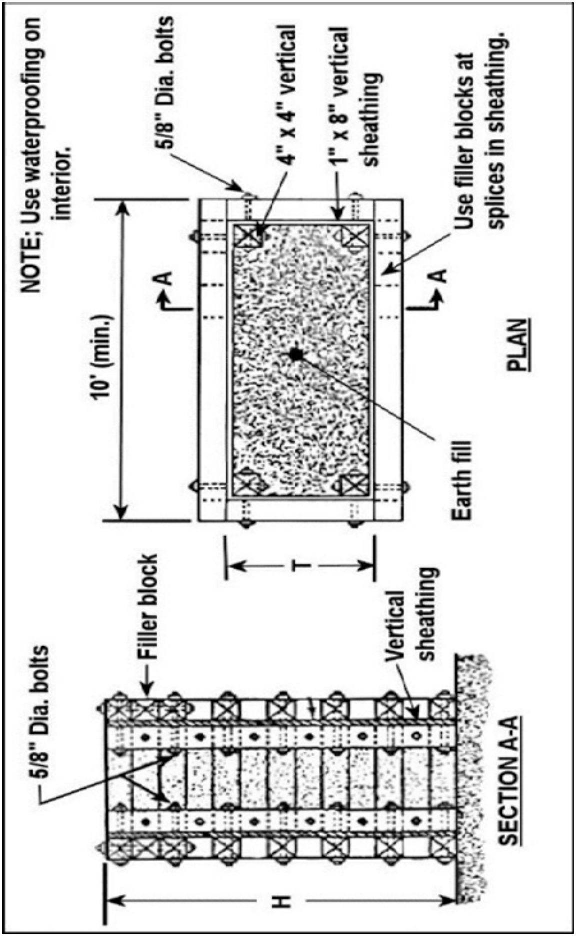
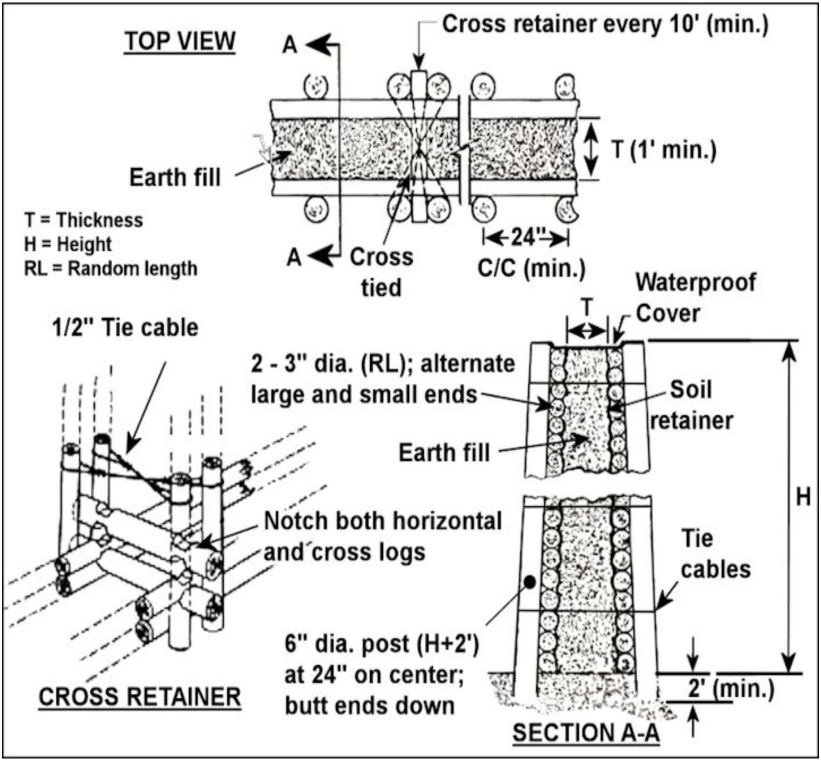
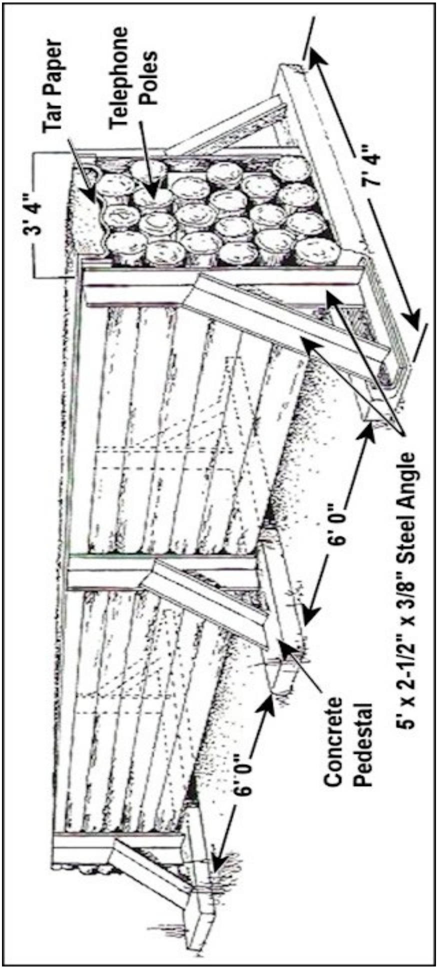


Figure 3.31. Log Revetment Construction Specifics.



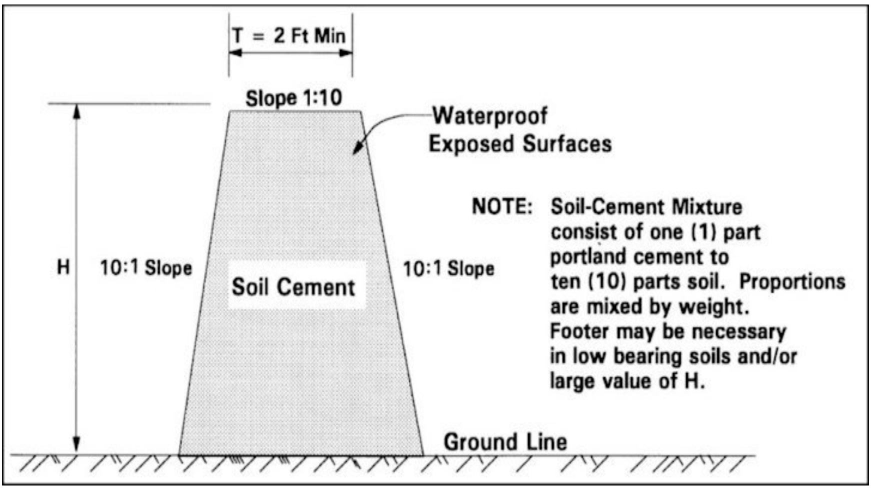
3.5.5.4. In addition to plywood, timber, and logs, personnel may use other wooden materials to fabricate expedient revetments when other resources are unavailable. Items such as utility poles or empty munitions boxes are two examples. **Figure 3.32** illustrates how to fabricate a utility pole revetment. While these and other improvised methods are far from ideal, wooden revetments and similar applications may serve the purpose until better structures become available.

Figure 3.32. Utility Pole Revetment.



3.5.6. **Soil-Cement Wall.** Sometimes referred to as a soil-cement revetment, the soil cement wall (**Figure 3.33**) is a soil berm variation that requires considerably less space to use. Build these structures using a mixture of one part Portland cement (by weight) with 10 parts of soil (by weight). By adding the cement, personnel can build the berm wall slopes considerably steeper. It does require extra work and equipment to make and place the forms to contain the soil until the cement sets up, mix the cement with the soil, and place the mixture into the forms. You should check the moisture content of the soil and add water as required to hydrate the cement. Generally, you can remove the forms the next day, but check one section before you remove all of the forms. You need a foundation (footer) for a soil-cement wall when it has a high berm height or when placing the wall on low weight bearing soils. This reduces differential settling and possible tipping over of the wall.

Figure 3.33. Soil-Cement Wall.



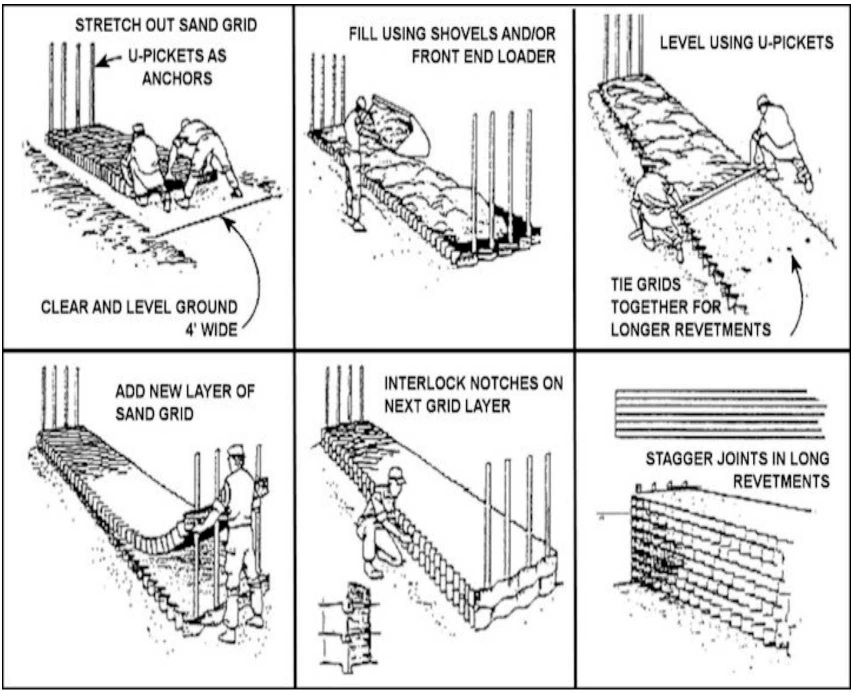
3.5.7. **Sand-Grid Revetment.** Sand-grids can provide an expedient means of building field fortifications and revetments. Standard sand-grid sections used in protective construction are essentially the same as those used in expedient roadway construction, except they are narrower (**Figure 3.34**). Revetments made of sand-grids can provide protection from small arms weapons fire, blast and fragments. See GTA 90-01-011 (JFOB Handbook) for specific performance factors).

Figure 3.34. Sand-Grid Revetment Construction.

3.5.7.1. Illustrated in **Figure 3.35** are basic procedures involved in constructing a standard sand-grid revetment. When constructing the revetment, place the sand grid on a firm, level foundation to increase the stability of the revetment construction. Use U-pickets in each of the four corners of the grid to secure it after stretching the grid to the proper length. If the revetment under construction is longer than one section of grid material, attach another section of grid to the first. Punch small holes in the top, bottom of the plastic, and then secured with wire or rope. Use soil, sand, or gravel as fill material. Some compaction of the material is advised, especially if the revetment will be over 6 feet tall.

3.5.7.2. After filling one layer of grid, level it in preparation for the next layer. Place a sheet of filter material, geotextile fabric, or plastic between each layer of grid to provide support for the next grid section and to help prevent excessive fill leakage. The joints of each successive layer should be staggered to provide additional stability, and total height should not exceed nine layers of grid.

Figure 3.35. Sand-Grid Fabrication Steps.



3.5.8. **Sandbag Revetments.** Traditionally, sandbags have been the most frequently used material for creating expedient protective walls or revetments. Special skills or equipment is not required and the resource is usually readily available. Sandbags are the one expedient hardening method that every unit on the base can construct. CE crews should be prepared to deliver sand or soil to buildings or resources requiring protection with sandbags and provide upfront guidance on how to place sandbags. Then the unit can proceed by itself. Although simple to build, there is a correct and wrong way to construct sandbag revetments. Consider factors such as drainage, slope, and component interlocking during the building process to attain satisfactory results. In addition, sandbag structures involve a high maintenance cost. Weather exposure or repeated fragment penetration can rapidly reduce their effectiveness.

3.5.8.1. **Sandbag Variations.** Sandbags are made from various materials including treated burlap (or other heavy coarse cloth), polypropylene, and acrylic. The polypropylene bag lasts roughly seven months, twice as long as the coarse cloth bag. The acrylic sandbag is rot and weather resistant and under all climate conditions has a life of at least 2 years with no visible deterioration. In addition, it is slip resistant when stacked to form a sandbag revetment or breastwork. Furthermore, holes in an acrylic bag caused by bullets or fragments do not enlarge due to continued weakening or unraveling of the bag material around the holes. Make periodic inspections of sandbags; replace any split or damaged sandbags.

3.5.8.2. **Freestanding Sandbag Revetments.** Sandbag revetments may be constructed either as sloped or partially braced structures. Build sandbag revetment walls in much the same way as laying bricks. For freestanding revetments, slope the walls inward at a 4V:1H or 5V:1H. Use alternating rows of headers and stretchers as shown in **Figure 3.36** and **Figure 3.37**. The freestanding revetment example in **Figure 3.38** illustrates proper sloping. Use these illustrations as a guide to place sandbags in the different rows. However, they may be altered to achieve the proper slope or for other valid purposes. To be effective, prepare and place sandbags as follows:

3.5.8.2.1. Verify that the bag is not “inside-out.” Fill the bags 3/4 full with dry, loose earth or sand. The bags should not be too full as to prevent flattening and shaping when placed. This partial filling should prevent voids between bags after placement. If voids develop, fill the bags with less soil.

3.5.8.2.2. Tie the choke cords and tuck the bottom corners in after filled. Place the bags so that the choke end of each bag (i.e., the end where the bag is closed) and the side seams turn inward away from the threat. Place the bags in such a manner so that they lay flat and are set solidly in place. This will help prevent the wall from shifting or sagging.

Figure 3.36. Freestanding Sandbag Wall Construction Plan A.

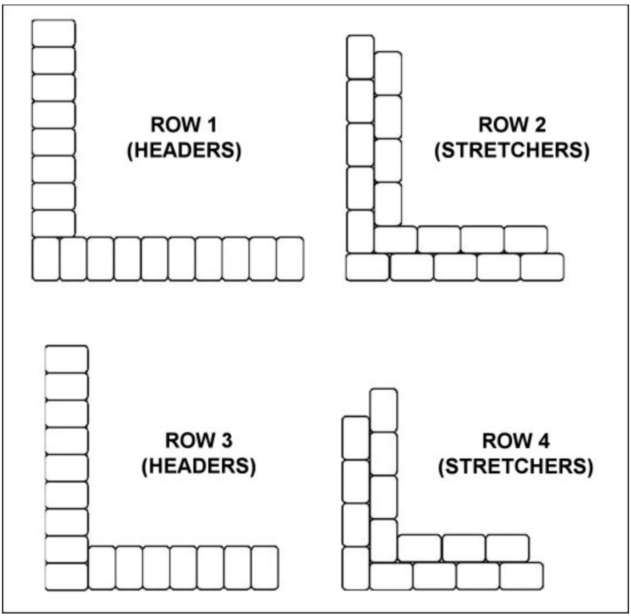


Figure 3.37. Freestanding Sandbag Wall Construction Plan B.

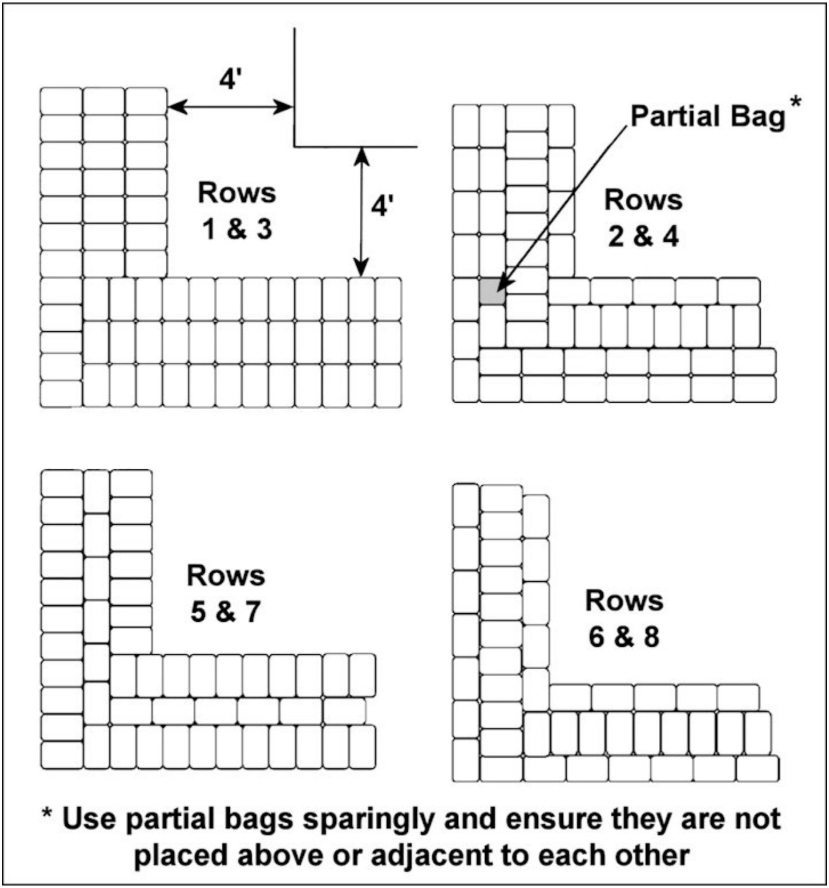
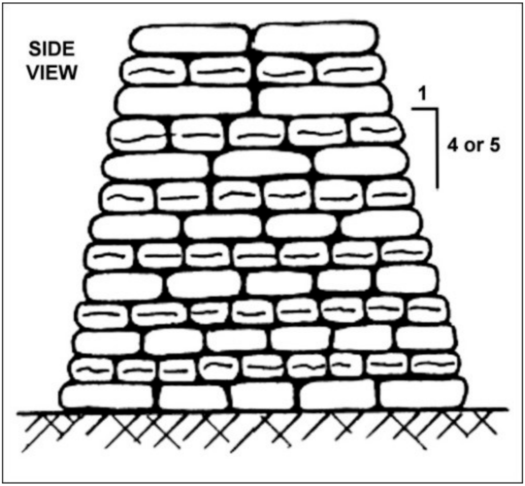


Figure 3.38. Freestanding Sandbag Revetment Slope Layout.



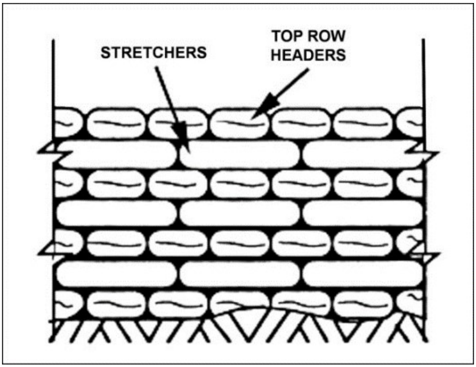
3.5.8.2.3. When laying out revetment plan, leave 4 feet of space between sandbag wall and protected assets. This allows personnel to carry a stretcher around corners and for two persons to pass comfortably without placing the wall so far away from the asset it creates a large unprotected area behind the sandbag wall.

3.5.8.2.4. Construct the bottom row of the revetment with all bags placed as headers. Continue building the wall using alternate rows of stretchers and headers with the joints broken between courses. When working on the corner of a wall, slow down the process to work the bags into the corner as best as possible to avoid high or low spots.

3.5.8.2.5. Slope the sides as previously discussed. Adjust the width of the sandbags in-place to maintain the proper slope. Be sure to pound each sandbag with a flat object, such as a 2- by 4-inch board, to make the wall more stable.

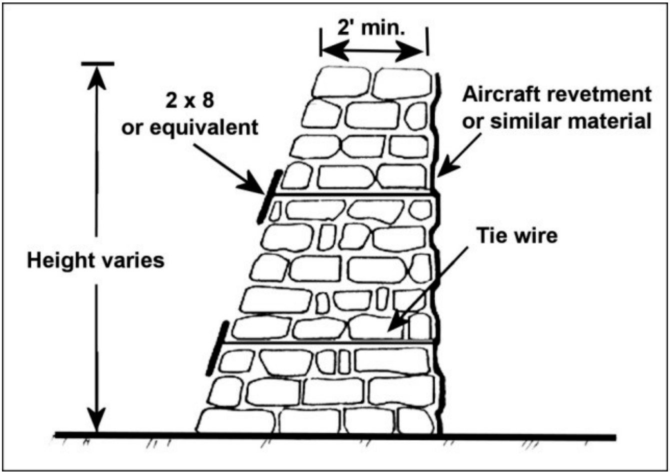
3.5.8.2.6. Continue laying sandbags according to the pattern from row to row until achieving the desired height. Design the thickness of the freestanding sandbag wall top layer for the ballistic threat, which is the design fragment or other projectile. Be sure to double the thickness for wet sand. The top row of the revetment wall has all headers as illustrated in **Figure 3.39**. Consider covering the completed wall with plastic to keep the sand dry and avoid contamination.

Figure 3.39. Sandbag Wall (Frontal View).



3.5.8.3. **Braced Soil-Cement Sandbag Revetments.** Provide additional strength and stability to a sandbagged revetment by creating a partially braced, soil-cement sandbag structure as shown in **Figure 3.40**. Improve durability by mixing the fill material with dry Portland cement (1 part cement to 10 parts soil or 6 parts sand/gravel). The cement sets as the bags take on moisture. Instead, the filled bags can be dipped is a cement slurry. Sandbag revetments constructed of soil-cement sandbags can last for many years with very little deterioration. Use corrugated metal sheets, reinforced plywood, airfield matting, or other structural facing material on the vertical face of the revetment and tied to the sloped face for support. With this design, normally only the outside facing of the revetment is sloped. This arrangement is a simplistic version of the structural configuration of an earth berm with a braced vertical face addressed earlier in the chapter.

Figure 3.40. Partially Braced Soil-Cement Sandbag Revetment.



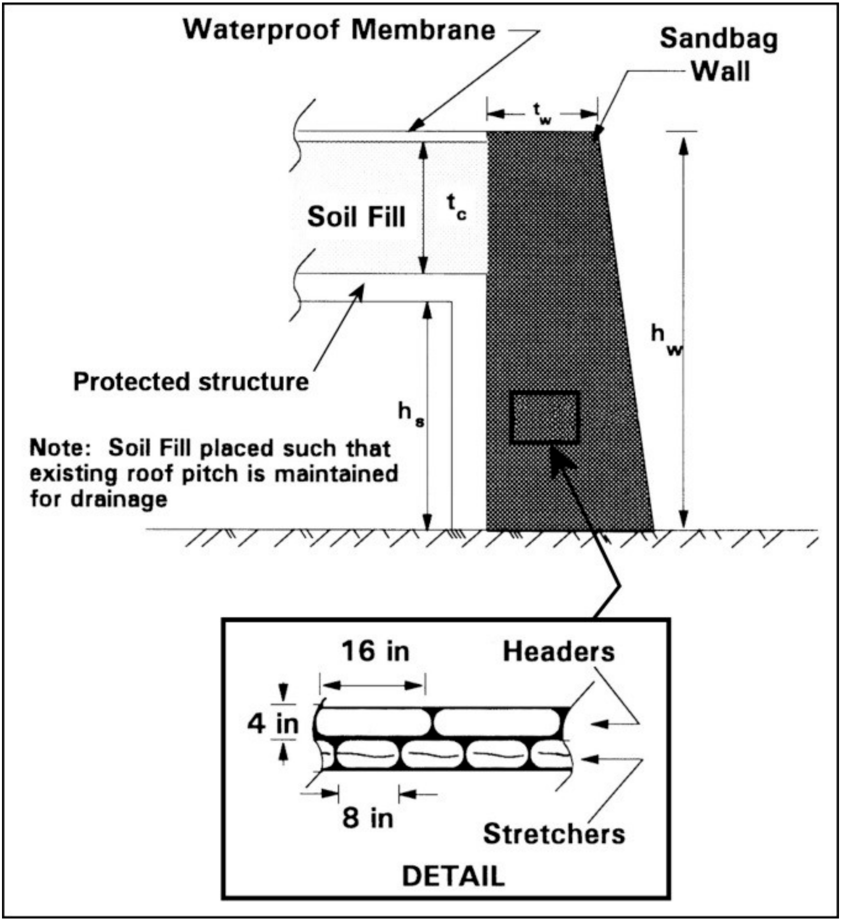
3.5.8.4. **Sandbag Against Walls.** If the structure requiring protection can withstand the additional side load, consider building the sandbag revetment with a straight face directly against the exterior walls of the building. Always provide drainage to route water away from the area to reduce settlement and consequent weakening of the revetment.

3.5.8.5. **Sandbags Revetments with Overhead Cover.** If necessary, sandbag revetments can be modified or upgraded to provide overhead cover protection if the structure's roof has the capacity to support the additional soil load. **Table 3.8** lists unit weights of typical soils in their natural state. Cover horizontal surfaces with layers of sandbags or construct a sandbag parapet wall around the perimeter of the surface and place loose fill inside the wall. The latter approach is more typical and can save a significant amount of time. **Figure 3.41** illustrates how to use sandbags to form a vertical wall with parapet to confine the soil placed on the roof. Sandbag wall height (h_W) should be equal to the structure height (h_S) for protection of the wall. For added overhead protection, extend the height (h_W) to form a parapet to confine the required soil cover (t_C). Again, design the sandbag wall width (t_W) for the ballistic threat, i.e., fragment or other projectile. It is usually best to place loose soil covers. In the case of a direct hit, a compacted soil transmits more energy and more damage can be expected even though the penetration resistance is somewhat reduced. A good practice when loose soil covers are used is to provide a waterproof barrier, such as a membrane, over the soil. In addition, place the soil so the structure maintains the existing roof pitch for drainage.

Table 3.8. Unit Weights of Soil Types.

Description	Water Content[1]	Unit Weight (lb./cubic ft.)	
		Dry Unit Weight	Saturated Unit Weight
Uniform sand, loose	32	90	118
Uniform sand, dry	19	109	130
Mixed-grained sand, loose	25	99	124
Mixed-grained sand, dense	16	116	135
Windblown silt (loess)	21	85	116
Glacial till, very mixed-grained	9	132	145
Soft glacial clay	45	76	110
Stiff glacial clay	22	106	129
Soft slightly organic clay	70	58	98
Soft very organic clay	110	43	89
Soft montmorillonitic clay (calcium bentonite)	194	27	80
Note 1: Water content when saturated, in percent of dry weight			

Figure 3.41. Sandbag Vertical Wall Protection and Overhead Cover.



3.5.8.6. **Expedient Sandbag Filling.** If filling a large number of sandbags from a stockpile of sand or other material, make the work easier and fill the bags faster by using a makeshift funnel apparatus as illustrated in **Figure 3.42**. Construct the funnel using either wood or metal. In addition, commercial baggers (**Figure 3.43**) designed to accelerate the bagging process may be available for purchase. The multi bagging versions shown can fill between 1,600 and 1,800 bags an hour. Keep in mind that loose soil is required for these devices to function properly, and dry loose material is necessary for the construction of effective sandbag revetments.

Figure 3.42. Expedient Sandbag Filling Funnel.

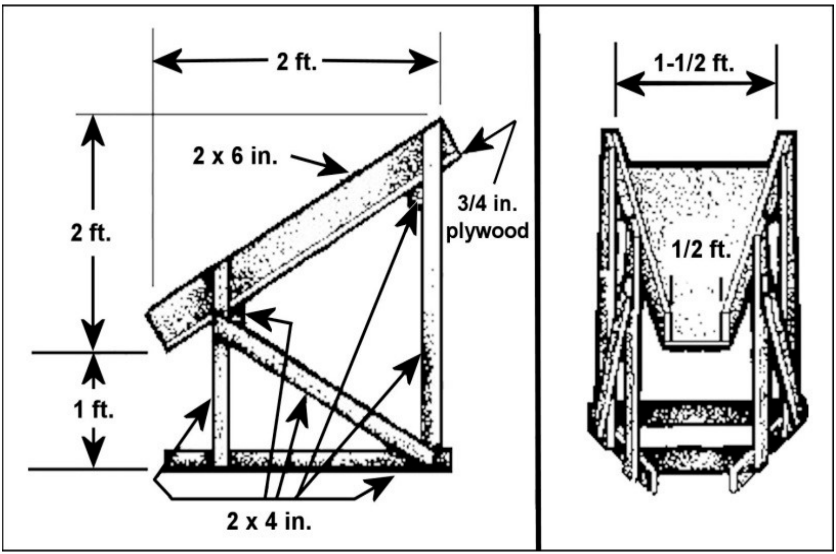


Figure 3.43. Commercial Sandbag Filling Device.

3.5.8.7. **Estimating Sandbag Construction.** When constructing sandbag walls, the slope is usually between 4V:1H and 5V:1H. A setback of one inch on each layer will result in a slope that is very close to the proper slope. Calculate the base width of a freestanding sandbag wall with a 4V:1H slope using the example in **Table 3.9**. For a sandbag wall (same H and T lengths) placed directly against a building or other structure, use the example calculation in **Table 3.10** to determine the base width.

3.5.8.7.1. To estimate the cubic yards of fill material needed for a freestanding sandbag wall use the formula shown in **Table 3.11**.

3.5.8.7.2. To estimate the numbers of sandbags needed for a freestanding sandbag wall, use the formula shown in **Table 3.12**. **Note:** This formula includes a 10 percent factor for broken and damaged bags.

Table 3.9. Calculating Base Width of Freestanding Sandbag Wall.

Base Width of Freestanding Sandbag Wall	
Formula: B = H/2 + T	
Where: B =	Width of wall at the base (___ feet)
H =	Height of wall (8 feet)
T =	Width of wall at the top (2 feet)
Example Calculation:	
B = H /2 + T B = 8’/2 + 2’ B = 4’ + 2’	
B = 6’	

Table 3.10. Calculating Base Width of Sandbag Wall on a Structure.

Base Width of Sandbag Wall Against Structure
Formula: B = H/4 + T
Example Calculation:
B = H/4 + T B = 8’/4 + 2 B = 2’ + 2’
B = 4 feet

Table 3.11. Estimate Cubic Yards of Fill Material.

Cubic Yards of Fill Material	
Formula: F = ((T + B) /2) x H x (L /27)	
Where: F =	Volume of fill material (cubic yards)
T =	Width of wall at the top (2 feet)
B =	Width of wall at the base (5.4 feet)
H =	Height of wall (8 feet)
L =	Length of wall (100 feet)
Example Calculation:	
F = ((T + B) /2) x H x (L /27) = F = ((2 + 5.4) /2) x 8 x (L /27) = F = ((2 + 5.4) /2) x 8 x (100 /27) = F = ((7.4) /2) x 8 x (3.7) F = (3.7) x 8 x (3.7) = 109.5	
F = 109.5 cubic yards	

Table 3.12. Number of Sandbags for Freestanding Sandbag Wall.

Number of Sandbags for Freestanding Sandbag Wall	
Formula: N = (F x 90) x 1.1	
Where: N =	Number of sandbags
F =	Volume of fill material (100.6 cubic yards)
Example Calculation:	
N = (F x 90) x 1.1 N = (100.6 x 90) x 1.1 N = (9,054) x 1.1 = 9,960	
N = 9,960 sandbags	

3.6. Predetonation Screens. If a position is hardened against fragmentation, but cannot withstand the direct hit of a weapon, then consider using a screen or shield to intercept and prematurely explode incoming rounds. When using a screen in this manner, refer to it as a predetonation screen. Predetonation screens protect a particular structure or position from specific weapons. The protected structure is often a fighting position, where occupants, when exposed to direct blasts, may not survive or be able to react for extended periods due to disorientation and deafness. On the other hand, by reducing the blast with a predetonation screen, the position's occupants may be able to continue functioning. The distance of the installed screen from a structure requiring protection is the "standoff distance." This space will depend on the weapons, warheads, types of fuzes, and the amount of protection required. In some cases, it may be as close as 10 feet. However, structurally stout screens are necessary to defeat direct-fired weapons with delayed fuzes. In such cases, the predetonation screen must be strong enough to absorb the impact of the warhead's detonation or deflect it away. Many of the shielding techniques discussed earlier also function as predetonation screens when penetrating weapons are not involved. Personnel can build effective predetonation screens from a variety of materials such as concrete, metal fabric, wire mesh, wood, or chain link fencing. Several can be easily mass-produced and rapidly erected. The following paragraphs provide ideas or design details for a number of expedient predetonation screens. However, any effort to defeat penetrating weapons requires a detailed design analysis; however, in some situations, it may be better to spend this time and materials hardening the actual structure.

3.6.1. **Timber Walls.** The construction of predetonation screens with dimensional timber is similar to plywood wall revetments except there is no box structure and fill material. The framing is normally the first step in screen construction. Assemble the walls on the ground before erecting them. Attach the sheathing after the frame is constructed. As illustrated in **Figure 3.44**, the framing consists of vertical and horizontal structural members and/or temporary scabbing.

3.6.1.1. If using logs instead of dimensional timber to frame the wall, lay out the exterior or exposed horizontal members first. Attach the two rows of vertical logs next. Finally, attach the interior horizontal members and sheathing, which completes the assembly of the rigid wall for erection. After attaching the sheathing to the frame, apply the waterproofing agent, mark anchor points on the walls, and adjust the anchorages. Dig the postholes and construct anchor points concurrently. Temporary anchorages may be required until construction of the main wall is completed.

3.6.1.2. After each wall section is completed, transport it to the erection site and tilt it into position. Place each section so that a gap of about 1/2 inch is left between it and the adjoining section to facilitate repairs and reduce battle damage. Loosely attach anchor cables and supports and align the wall. If using deadman anchoring or picket holdfasts to secure cables, see **Figure 3.45**, **Table 3.13,** and **Figure 3.46**, for configuration and anchoring details. Once aligned, tighten the cables, supports, and backfill the postholes, preferably with concrete.

Figure 3.44. Dimensional Timber Wall Construction Details.

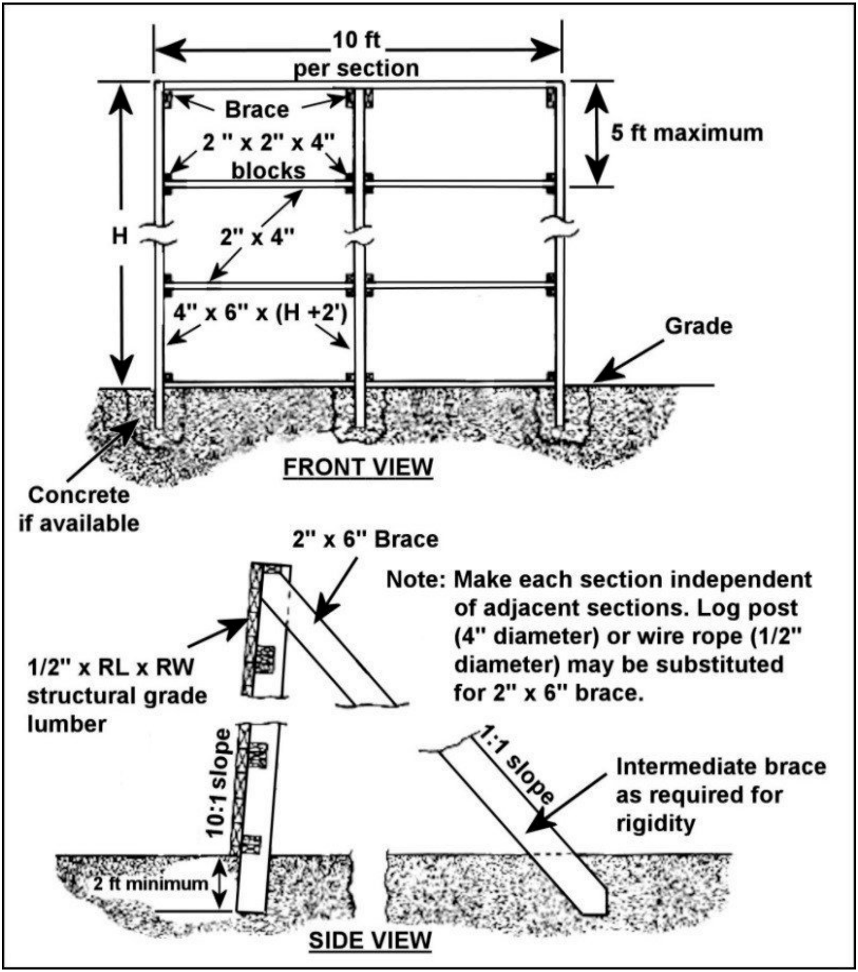


Figure 3.45. Log Deadman Anchoring Examples.

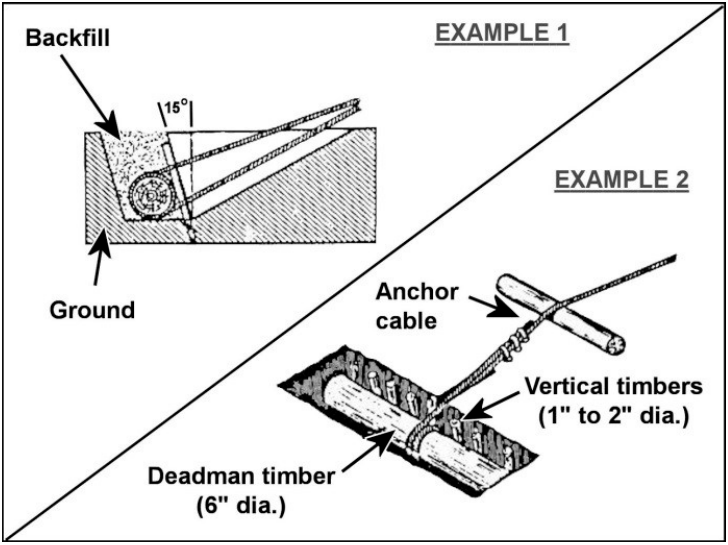
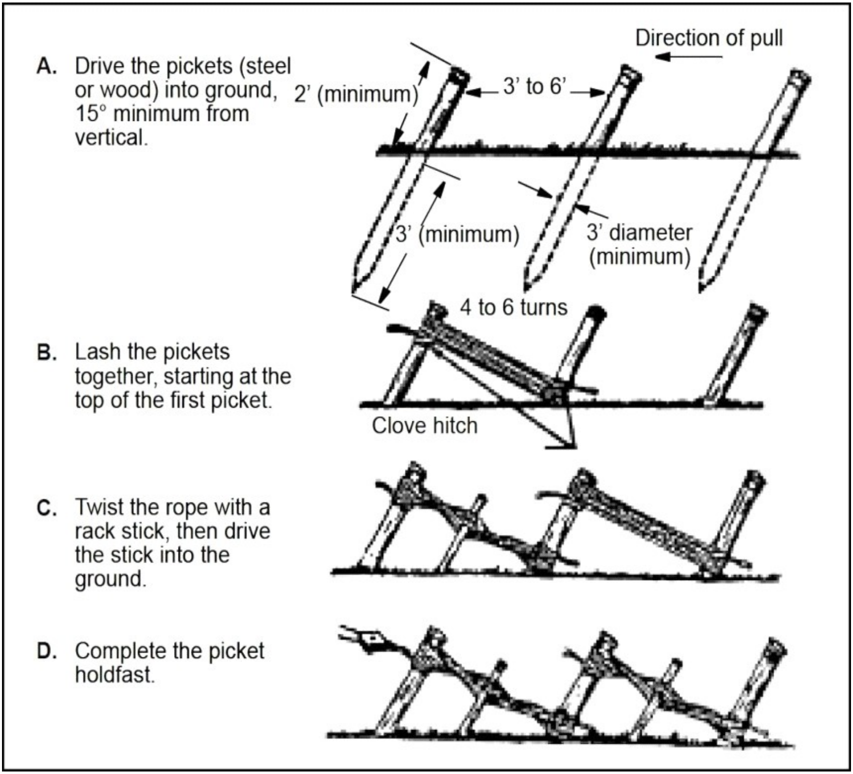


Table 3.13. Anchor or Tie Cable Size.

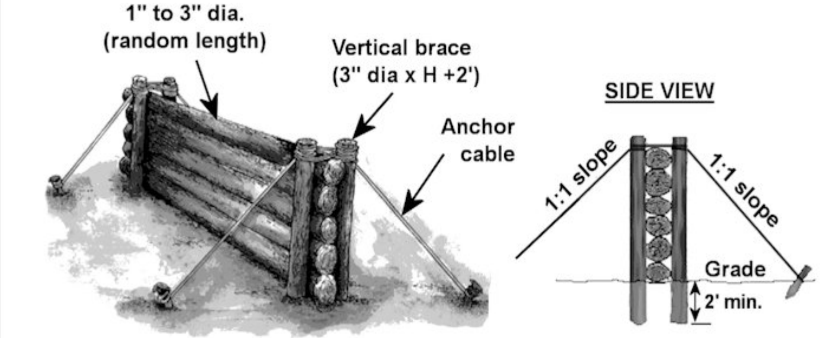
Wall Height	Cable Size
10 ft.	1/4 in.
12 ft.	1/4 in.
14 ft.	1/4 in.
16 ft.	5/16 in.
18 ft.	5/16 in.
20 ft.	5/16 in.
22 ft.	3/8 in.

Figure 3.46. Picket Holdfasts Anchor Details.



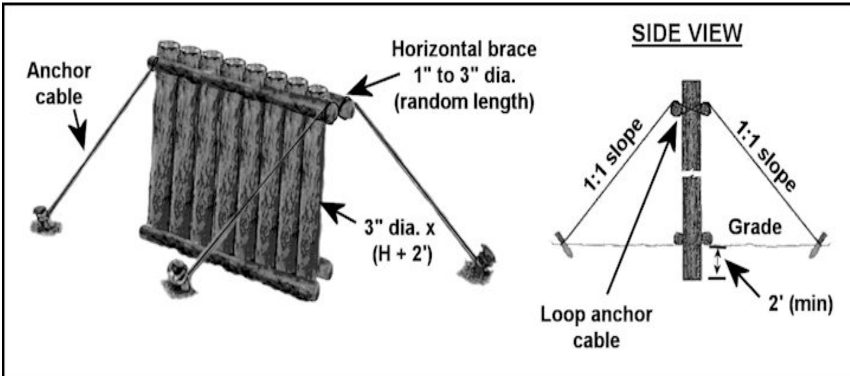
3.6.1.3. When making the entire wall from logs, a simple design supported with cable anchoring may be the most expedient method. As illustrated in **Figure 3.47**, create the wall structure using horizontal logs with vertical log bracing. A variation to this design uses vertical logs as the wall structure and horizontal logs as the braces or wales (**Figure 3.48**).

Figure 3.47. Simple Log Predetonation Screen Details.



Note: For heights over 10 feet, use additional cables and braces as necessary. Typical spacing is 5 feet. The number of anchor cables and braces depends on wall height and cable spacing.

Figure 3.48. Variation of Log Predetonation Screen.



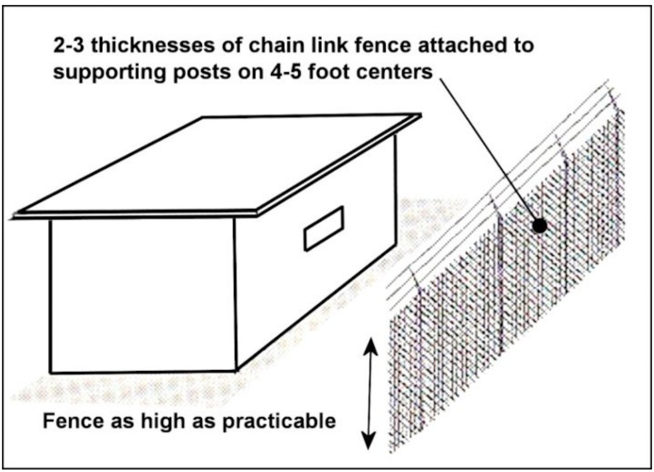
3.6.2. **Flexible Screens.** When a predetonation screen is needed, but the facility to be protected requires visibility for observation purposes (e.g., fighting bunkers, observation posts), then a flexible structure such as chain link fencing, expandable wire mesh, or woven or welded wire fabric may be an option. Though effective, these types of screens will permit more fragmentation and blast to reach a particular position than heavier, more rigid screens.

3.6.2.1. There are many ways to build flexible predetonation screens. For example, personnel can build the screens with or attached to other protective structures as shown in **Figure 3.49** and **Figure 3.50**, or as freestanding walls or fences supported with posts or braces as illustrated in **Figure 3.51**. When using chain link fencing, the wider weave of fence material may require two or three thicknesses to ensure fuze detonation. Likewise, construction type expanded wire mesh may also require three layers due to its general lack of strength. High strength wire mesh and larger gauge welded or woven wire fabric used for security cages and screens may provide adequate protection with only one or two layers. The following paragraph provides basic procedures to construct a flexible screen using expanded wire mesh materials with metal fence poles.

Figure 3.49. Wire Mesh Predetonation Screen.

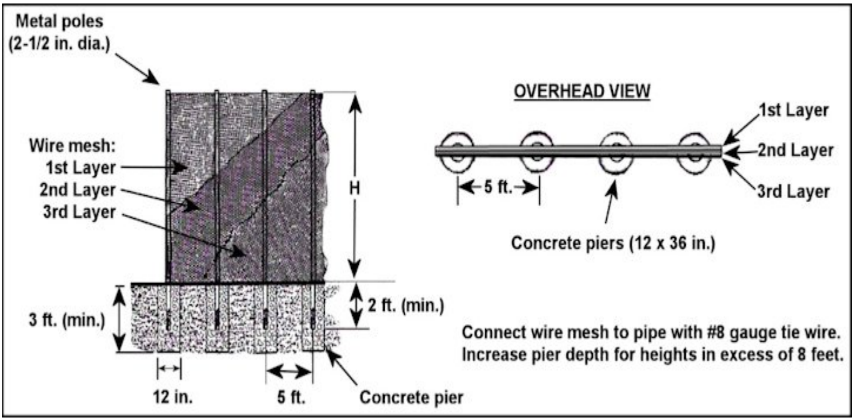
Figure 3.50. Flexible Screen Extends Protection of Perimeter Wall.

Figure 3.51. Fencing Used as Flexible Predetonation Screen.



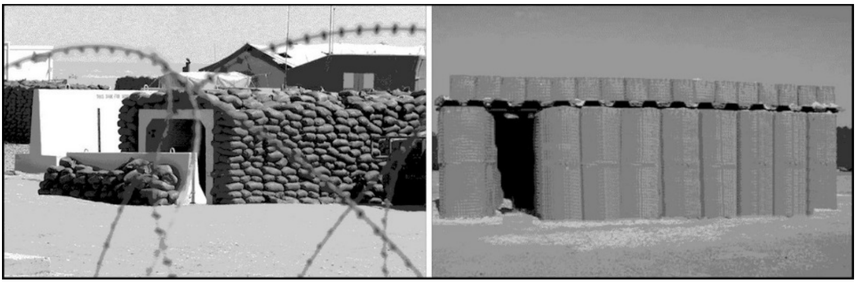
3.6.2.2. Expanded Wire Mesh Predetonation Screens. When constructing wire mesh predetonation screens, use metal tie-wires to anchor the wire mesh material to standard (2-1/2–inch diameter) metal poles used for chain link security fences. As illustrated in **Figure 3.52**, place the poles at 5 feet on center. If possible, set the poles 2 feet deep in concrete for material up to 8 feet high. Increase the buried depth of the pole at least 2 feet if placing poles in soil. Use wire cable and pickets or deadmen to anchor every other pole. Secure the cables at about 2/3 the height of the poles and an equal length away from each pole. See **paragraph 3.6.1.2** for details on deadman anchors and cable anchoring techniques.

Figure 3.52. Expanded Wire Mesh Screen Details.



3.7. Field Expedient Bunkers. Generally, personnel bunkers offer temporary protection from weapons effects and are occupied just before and during an attack. They may be located aboveground or belowground, should be strategically located throughout the base, and shielded with overhead protection. Field expedient bunkers can satisfy an immediate need until robust protective structures become available. In some situations, expedient bunkers might be the only protective option available, especially during bare base development, dispersed operations, or military operations other than war. This section provides examples of various field expedient personnel and equipment bunkers designs. The bunker designs should stimulate ideas for CE personnel faced with the challenge of creating expedient bunkers when resources and material options are limited. See **paragraph 3.8** for additional information on fighting bunkers. For contemporary bunker designs like those shown in **Figure 3.53**, readers should refer to GTA 90-01-011 (JFOB Handbook). **Note:** A structural engineer should review all field expedient personnel bunker designs before use.

Figure 3.53. Contemporary Bunkers.



3.7.1. **Basic Types.** Build field expedient bunkers using available materials or retrofit existing structures with blast and fragment protection. Construct bunkers with as much overhead cover as possible. Consider limiting bunkers to a maximum capacity of about 25 people and dispersed. When possible, hide bunkers next to buildings, behind hills, in woods, or in natural depressions in the terrain. Be sure to keep them out of drainage paths. Improve bunkers as time permits. Consider the following before constructing field expedient bunkers:

3.7.1.1. Belowground bunkers require the most construction effort but generally provide the highest level of protection from conventional and chemical weapons.

3.7.1.2. Cut-and-cover bunkers are partially dug into the ground and backfilled on top with as thick a layer of cover material as possible. These bunkers provide excellent protection from the weather and enemy action.

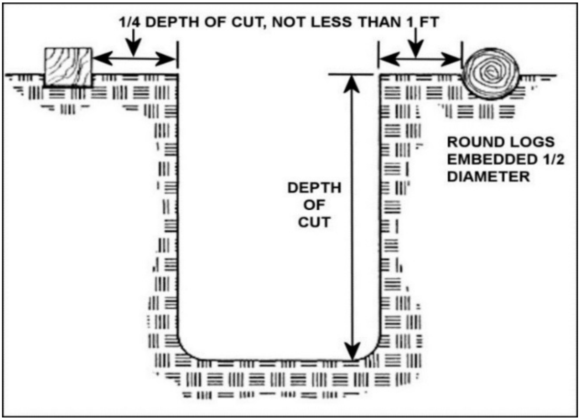
3.7.1.3. Aboveground bunkers provide the best observation and are easier to enter and exit than belowground shelters. They also require the least amount of labor to construct, but are hard to conceal and require a large amount of cover and revetting material. They provide the least amount of protection from conventional weapons; however, they do provide protection against liquid droplets of chemical agents. Use aboveground bunkers when water levels are close to the ground surface or when the ground is so hard that digging a belowground bunker is impractical.

3.7.2. **Structural Components of Bunkers.** The structure of a bunker depends on the weapon effects it has to defeat. Most bunkers have some configuration of floor, walls, and roof designed to protect the occupants or equipment. Those components support the shielding or make up that shielding, in themselves. The walls, floor, and roof should also resist blast and ground shock effects from detonations, which place greater stress on the structure than the weight of the components and the shielding.

3.7.2.1. **Floors.** Floors can be made from almost any material, but require resistance to weathering and wear. Soil is most often used, yet is least resistant to water damage and rutting from foot traffic. Wood pallets or other expedient materials, when cut to fit floor areas, may be a good option. If necessary, install drainage sumps or drains to remove unwanted water.

3.7.2.2. **Walls.** Construct bunker walls using earth or revetted earth, sandbags, soil-filled containers, concrete, or other materials. When belowground bunkers walls are made of the in-place soil remaining after excavation, the soil may need revetment or support, depending on the soil properties and depth of cut. When used to support roof structures, earth walls must support the roof at points no less than one fourth of the depth of cutout from the edges of excavation, as shown in **Figure 3.54**. Aboveground bunker walls built of revetted earth, sandbags, soil-filled containers, concrete, etc., may be stable enough for roof support if the walls have a thickness adequate for shielding from direct fire and fragments.

Figure 3.54. Earth Wall Roof Support Points.



3.7.2.3. **Roofs.** Earth cover roof designs should provide sufficient shielding from fragments and small caliber direct fire. Roofs supporting earth cover shielding can be constructed of almost any material that is normally used as beams or stringers and sheathing. **Figure 3.55** illustrates a basic roof design for a stringer roof consisting of single-ply or laminated sheathing covered with earth. To complete the design, engineers will need additional information, such as the soil parameters, available stringer materials, dimensions, and orientation (stringer characteristics), size and type of round the roof must defeat, and depth of the soil cover. **Table 3.14** and **Table 3.15** present guidelines for wooden roof structures (for fragment shielding only). **Table 3.16** converts dimensioned to round timber. In contrast to fragment shielding addressed here, if a position is subject to larger caliber indirect fire weapons (mortars, artillery, and rockets), substantial additional roof protection is required. Readers should consult UFC 3-340-01 for basic design criteria for a roof to resist the loads resulting from the detonation of a conventional weapon. **Note:** Improper construction of roofs can lead to collapse from the weight of soil cover. A structural engineer should review all field expedient personnel bunker designs before use.

Figure 3.55. Basic Design for Stringer Roof.

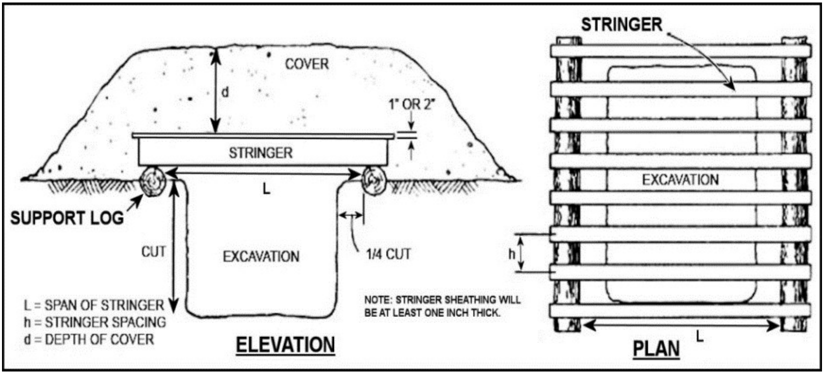


Table 3.14. Span of Wood Roof Sheathing for Earth Cover.

Thickness of Earth Cover (Feet)	Span Length (Feet)					
	2.5	3	3.5	4	5	6
	Wood Thickness (Inches)					
1.5	1	1	2	2	2	2
2	1	2	2	2	2	3
2.5	1	2	2	2	2	3
3	2	2	2	2	3	3
3.5	2	2	2	2	3	3
4	2	2	2	2	3	4
Note: For selected span lengths, this chart shows what thickness the dimensioned wood must be to support the load of the soil cover.						

Table 3.15. Span of Wood Stringer Roof Support for Earth Cover.

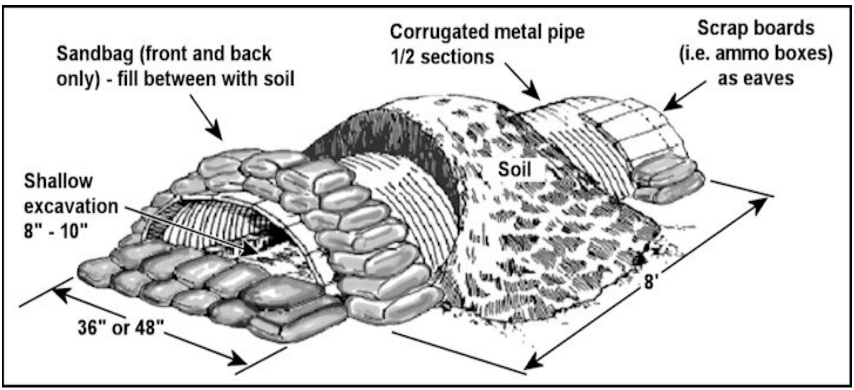
Thickness of Earth Cover (Feet)	Span Length (Feet)					
	2.5	3	3.5	4	5	6
	Center-to-Center Spacing (Inches)					
1.5	40	30	22	16	10	18*
2	33	22	16	12	8/20*	14*
2.5	27	18	12	10	16*	10*
3	22	14	10	8/20*	14*	8*
3.5	18	12	8/24*	18*	12*	8*
4	16	10	8/20*	10*	10*	7*
Note: Stringers are 2 x 4s (or minimum 5-inch diameter round timber) except those marked by an asterisk (*) which are 2 x 6s (or minimum 7-inch diameter round timber).						

Table 3.16. Converting Dimensioned Timber to Round Timber.

Dimensioned Timber Size	Equivalent Round Log Diameter (excluding bark)
4 x 4	5
6 x 6	7
6 x 8	8
8 x 8	10
8 x 10	11
10 x 10	12
10 x 12	13
12 x 12	14
Note: All sizes in inches. Sizes given are nominal and not rough-cut timber.	

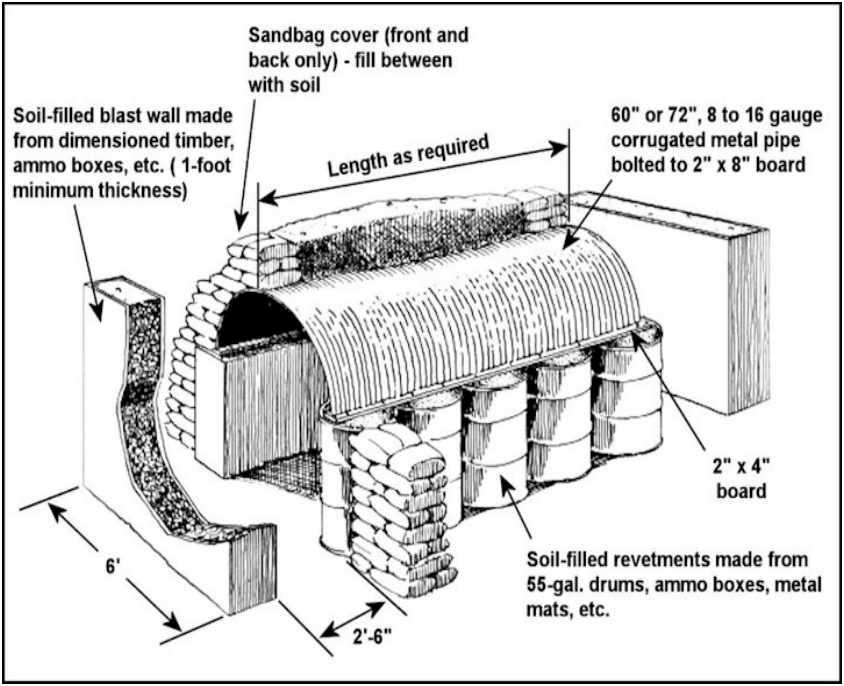
3.7.3. **Small Two-Person Bunker.** This two-person bunker example is very simple; employing culvert sections delivered to the site and assembled by the intended bunker occupants without any engineer support (**Figure 3.56**). Build the bunker by placing the culvert section as illustrated below; place sandbags at the front and back ends, then fill in between with a soil cover. Consider using scrap boards to fashion eaves by placing them under the sandbagged ends. A shallow excavation inside the bunker provides better cover and creates additional space. The low profile of the structure makes it a difficult target to hit. This bunker provides good protection from direct fire small caliber mortars and machine-guns, indirect fire fragmentation, and grenades. With additional cover, the protection level increases to include larger direct fire projectiles.

Figure 3.56. Small Two-Person Bunker.



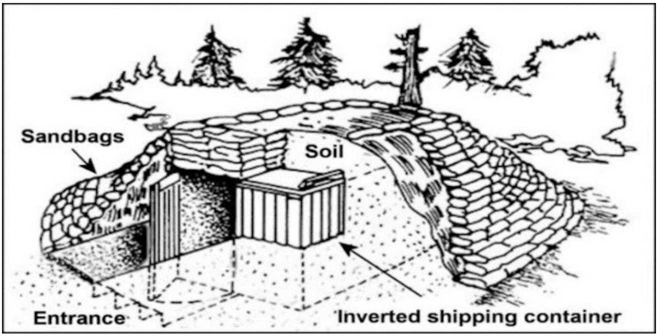
3.7.4. **Metal Culvert Bunkers.** A metal culvert bunker quickly constructed aboveground is another expedient option in areas where personnel live or work in conventional, non-protected buildings but need cover in case of attack. For example, place bunkers outside conventional billets, dining facilities, and large areas of living quarters. The bunker is 6 feet high and consists of two rows of 55-gallon drums (or other improvised wooden or metal container) with about a 4-foot span between rows (**Figure 3.57**). Center inside each drum two by four studs, measuring 4 inches higher than the drums. Fill the drums with soil. Connect a 2 inch by 8-inch top plate to the 2 by 4 studs lengthwise through the bunker. Bolt together the corrugated metal pipe halves and connect to the top plates. Place a 2-foot layer of sandbags along each row of drums. To protect the ends of the bunker, erect barrier walls 2 feet beyond the entrances. Provide additional protection on the sides and ends by increasing sandbag thickness. This shelter provides protection against mortars and small caliber direct fire weapons.

Figure 3.57. Metal Culvert Bunker.



3.7.5. **Metal Shipping Container Bunker.** Large metal shipping containers can sometimes be effective bunkers. If the container floor is stronger than its roof, invert the container to resist more blast and provide more overhead cover. The inverted container should be placed in an excavation half its height and then covered with earth and a layer of sandbags (**Figure 3.58**).

Figure 3.58. Metal Shipping Container Bunker.



3.7.6. **Transportable Bunker.** The transportable bunker (**Figure 3.59**) is a prefabricated plywood structure. Completely assembled structures (except the roof) are transportable. Because of its tapered walls, personnel can easily remove the bunker from the ground with a crane (or helicopter). On installation, excavate the ground 2 feet longer and wider than the actual floor area. This allows workspace during construction. Fasteners provided along the edges of each wall and the floor allows the bunker's components to lock together into a complete unit. The walls drop below the floor section so the floor acts as a brace for the bottom edge of the walls preventing cave-in. Use two large straps, placed completely around the structure during construction, to attach the bunker to a crane for bunker pullout. The roof overlaps the walls and supports itself on firm unexcavated ground—not on the bunker walls. The bunker weighs approximately 1600 pounds without the roof. The bunker is usually no more than 6.5 feet high, and the floor space is less than 100 square feet. See **Figure 3.60** through **Figure 3.62** and **Table 3.17** for bunker construction details.

Figure 3.59. Transportable Bunker.

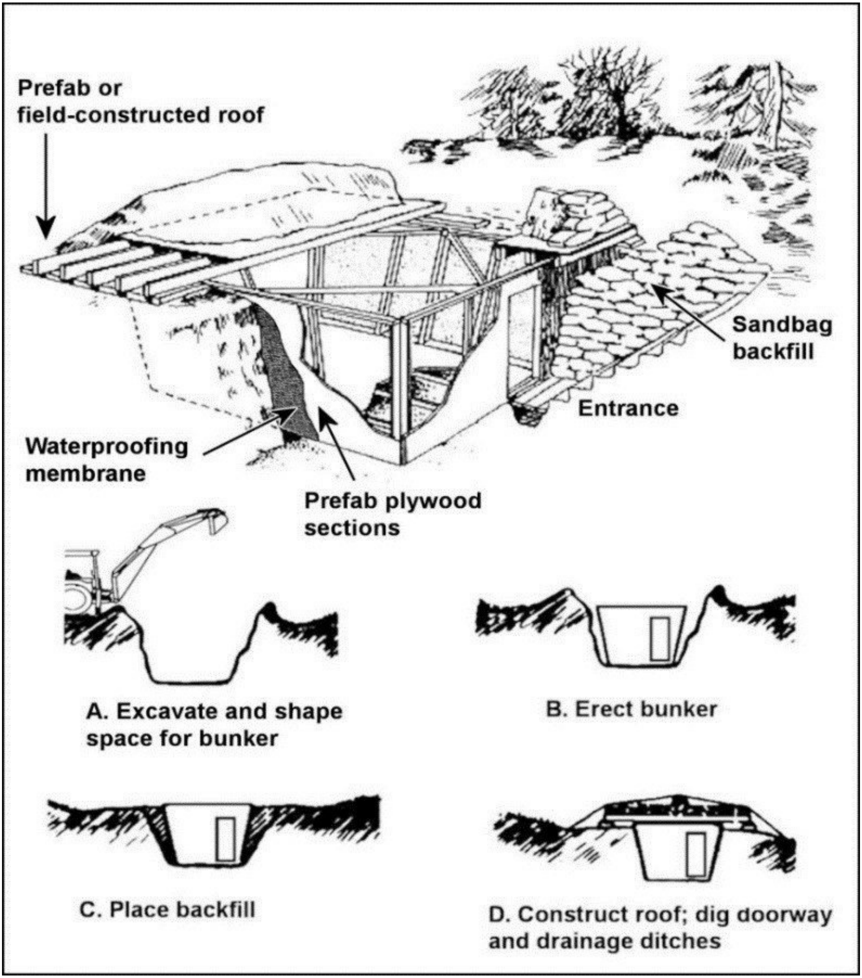


Figure 3.60. Transportable Bunker Construction Details (A).

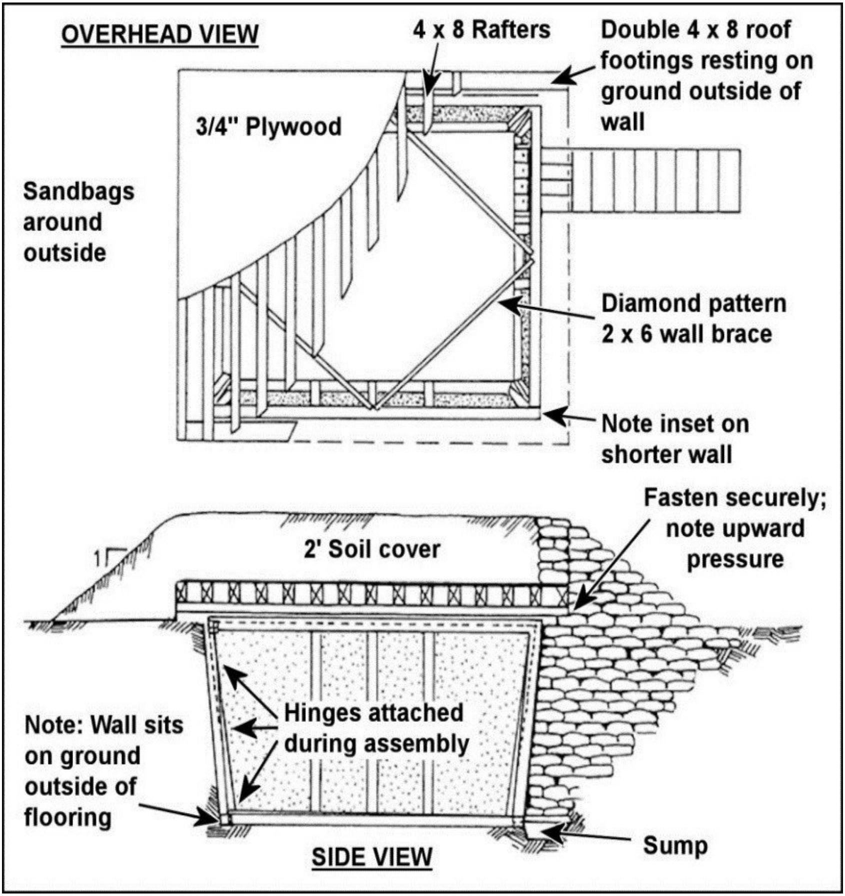


Figure 3.61. Transportable Bunker Construction Details (B).

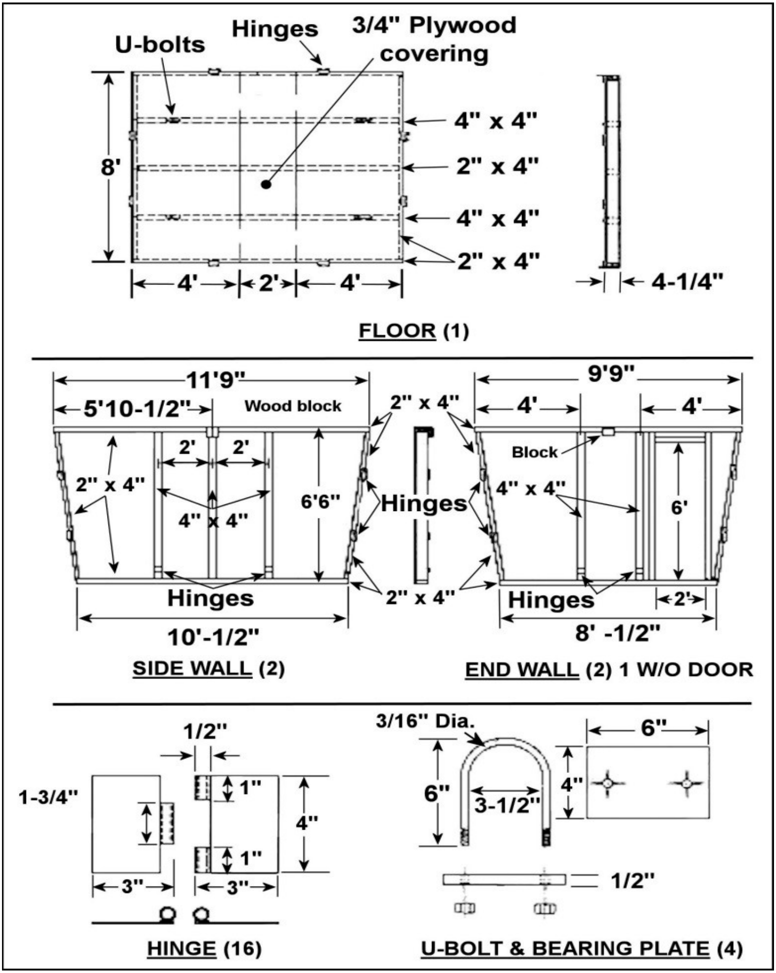
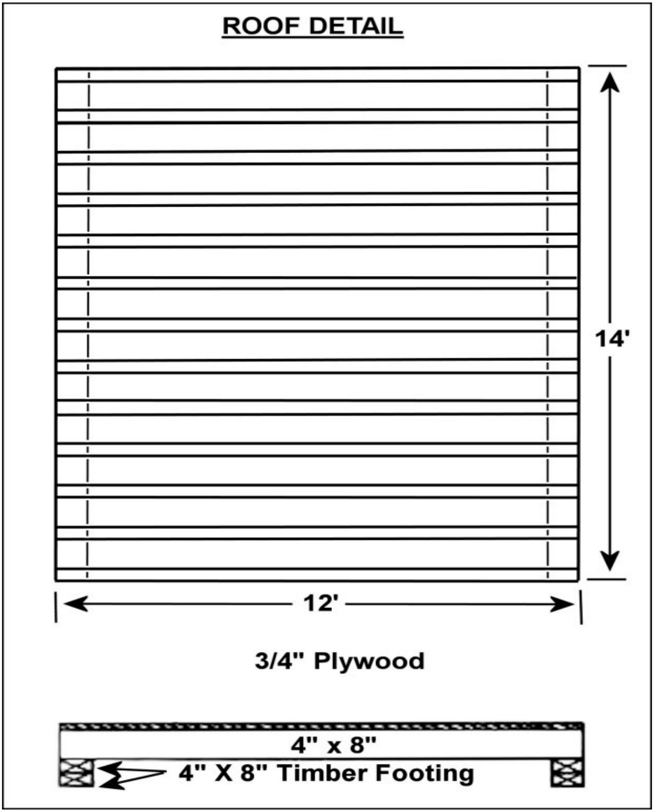


Figure 3.62. Transportable Bunker Construction Details (C).



3.7.6.1. Before backfilling, attach a sheet of plastic or other thin waterproof covering around the outside to minimize friction between the earth and the walls and to increase moisture resistance. To complete the bunker, provide a suitable entryway and drainage ditches around the shelter to carry away runoff.

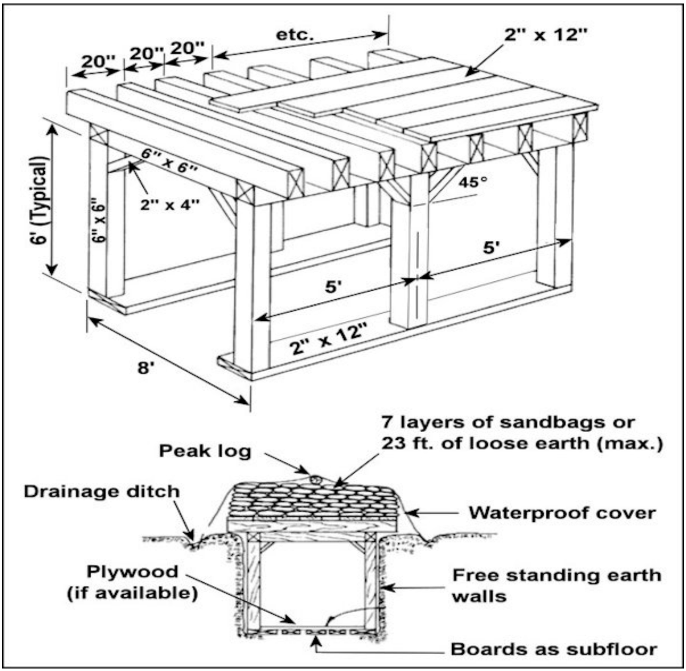
3.7.6.2. Excavation, assembly, backfilling, and construction of the roof and entrance are possible in less than 10 hours with a six-member crew. When preparing to lift the bunker from the installed position, remove some of the backfill with hand tools to reduce the effects of wall friction.

Table 3.17. Transportable Bunker Bill of Materials.

Bill of Materials		
Items for Walls and Floor	**Units**	**Quantity**
Plywood (4’ x 8’ x 3/4”)	Ea.	14
Dimensional Lumber		
4” x 4” x 8’	Ea.	10
4” x 4” x 10’	Ea.	2
2” x 4” x 8’	Ea.	10
2” x 4” x 10’	Ea.	9
2” x 4” x 12’	Ea.	4
2” x 6” x 10’	Ea.	4
Trim (Metal Edging) Optional	Ft.	190
Bolts (for Hinges)	Ea.	128
Wood Screws (or #8 Nails)	Lb.	5
Paint	Gal.	1
Hinges	Ea.	16
U-Bolts w/Bearing Plates	Ea.	4
Items for Roof	**Units**	**Quantity**
Plywood (4’ x 8’ x 3/4”)	Ea.	6
Dimensional Lumber		
4” x 8” x 12’	Ea.	13
4” x 8” x 14’	Ea.	4

3.7.7. **Timber Post Buried Bunker.** The timber post buried bunker is a wood frame support system for overhead cover material (**Figure 3.63**). Use this bunker only in soil or rock material that maintains the original vertical excavation in any weather. This bunker requires a sizable excavation effort by heavy equipment operators. Build larger shelters by joining several units together. Because it is below ground, the bunker provides excellent protection from indirect fire fragmentation and direct fire. The greatest threat to this structure is direct hits on the roof. **Note:** A structural engineer should review all field expedient personnel bunker designs before use.

Figure 3.63. Timber Post Buried Bunker.



3.8. Defensive Fighting Positions. Generally, defensive fighting positions (DFP) are located in areas supporting base defense operations. Commonly designed for individual, two-person, or squad-sized teams and positioned around the base perimeter and other areas as needed. Personnel may also use DFPs for work party security and in conjunction with dispersed operations. DFPs can range from hastily prepared positions (hasty position) and expediently constructed bunkers to elevated hardened observation towers. When time and materials are limited, base defense forces may have to resort to hasty positions located behind whatever cover is available. Hasty positions should provide frontal protection from direct fire. To protect against indirect fire, hasty positions should be located in a depression or hole at least 18 inches deep. In contrast, deliberate fighting positions are hasty positions improved by adding overhead cover and camouflage. Base defense forces often prepare hasty and deliberate fighting positions, clear their own fields of fire, and place reinforcing obstacles. However, when squad-sized and robust DFPs are required, the specialized skills and heavy equipment of CE units may be necessary. This section presents techniques for preparing DFPs that require additional resources and CE support to site and build. These measures are usually prepared when there is sufficient time for construction prior to an attack. Below are some basic design factors for DFPs.

3.8.1. **Basic Design Factors.** Normal characteristics of fighting positions should be simplicity and strength, providing the maximum amount of protection possible for personnel and equipment. Providing this protection using existing structures or readily available materials is typically the most desirable because it requires the least amount of engineer equipment to construct the position. Contemporary design information for soil-filled container fighting positions like that shown in **Figure 3.64** is available in GTA 90-01-011 (JFOB Handbook). However, when resources are limited, DFPs may need to be constructed using available materials. Effective fighting position designs provide protection against direct and indirect fire by using frontal, overhead, flank, and rear cover.

3.8.1.1. **Frontal Cover.** Frontal cover protects against small caliber direct fire. Natural frontal protection such as large trees, rocks, logs, and rubble is ideal because it is more difficult for the enemy to detect defensive positions. When natural frontal cover is inadequate, use soil excavated from the fighting position to build a small berm at least 3 feet thick to stop enemy small caliber fire. Protect from larger direct fire weapons by locating the fighting position where the enemy cannot engage it, and conceal it to prevent the enemy from pinpointing its location.

Figure 3.64. Soil-Filled Container Two-Bay Fighting Position.

3.8.1.2. **Overhead Cover.** Overhead cover protects against indirect fire. When possible, construct overhead cover to protect against airburst mortar and artillery shells. Overhead cover gives occupants at least ten times more protection from indirect fire than a position without such cover.

3.8.1.3. **Flank and Rear Cover.** Flank and rear cover protects defenders against the effects of indirect fire bursts to the flanks or rear, and from friendly weapons located in the rear. In the absence of natural flank and rear cover, construct a parapet as time and circumstances permit.

3.8.2. **Designed Fighting Positions.** Building robust fighting positions, fighting bunkers, or guard posts at contingency bases often require some engineer support. While certain tasks are within the base defense force's capabilities, tasks such as excavation using heavy equipment, building structures to design standards, cutting timber for roofs, etc., may require CE expertise. Adequate support for overhead cover is extremely important when building fighting positions. The support system must be strong enough to safely support the roof and soil material and survive the effects of weapon detonations. **Note:** A structural engineer should review field expedient DFP designs before use.

3.8.2.1. **Wood-Frame Fighting Position.** The wood-frame fighting position illustrated in **Figure 3.65** consists of prefabricated timber support elements that support a timber roof. This structure is a very effective two-person fighting position or observation post when dug into the ground. Build the structure using dimension lumber or cut timber. Illustrated in **Figure 3.66** through **Figure 3.68** are basic construction details. **Table 3.18** list building materials. The estimated construction time for this fighting position is 32 man-hours.

Figure 3.65. Wood-Frame Fighting Position.

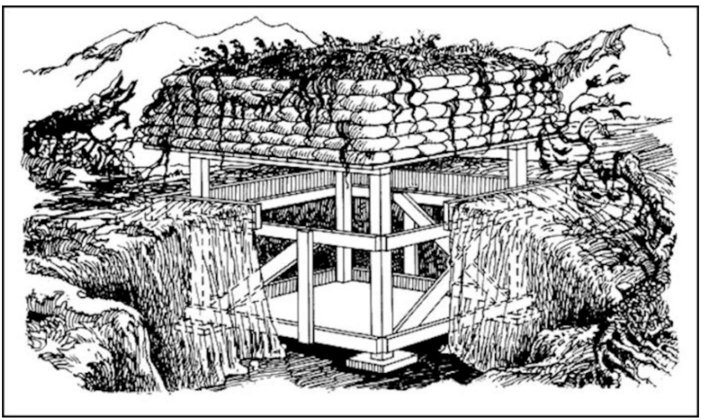


Figure 3.66. Details of Wood-Frame Fighting Position (1 of 3).

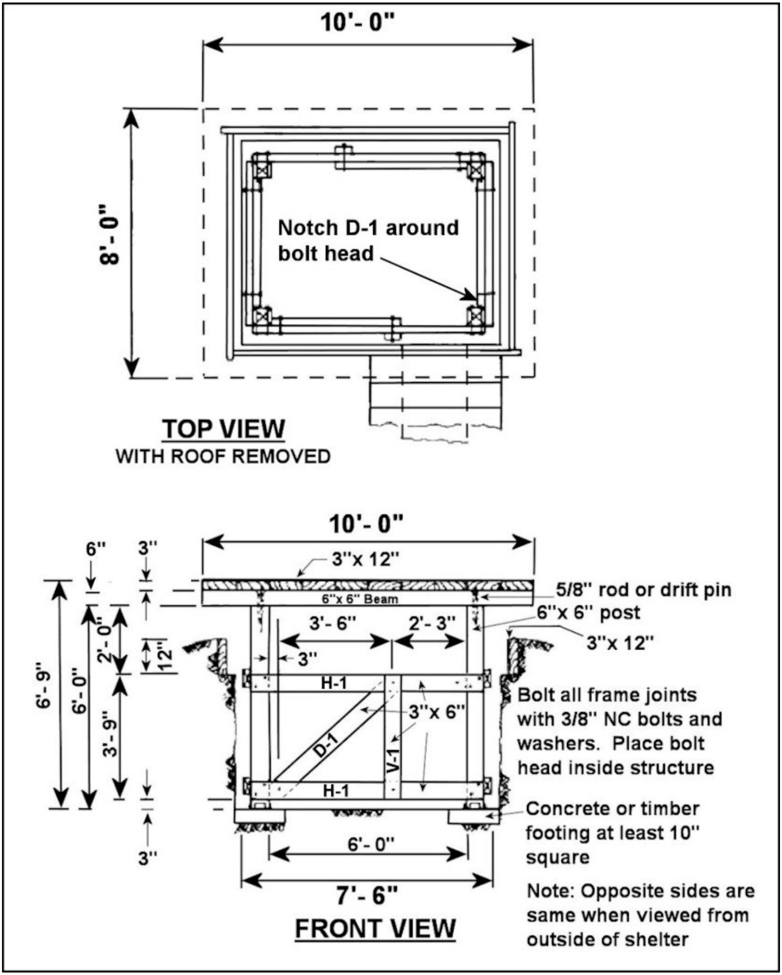


Figure 3.67. Details of Wood-Frame Fighting Position (2 of 3).

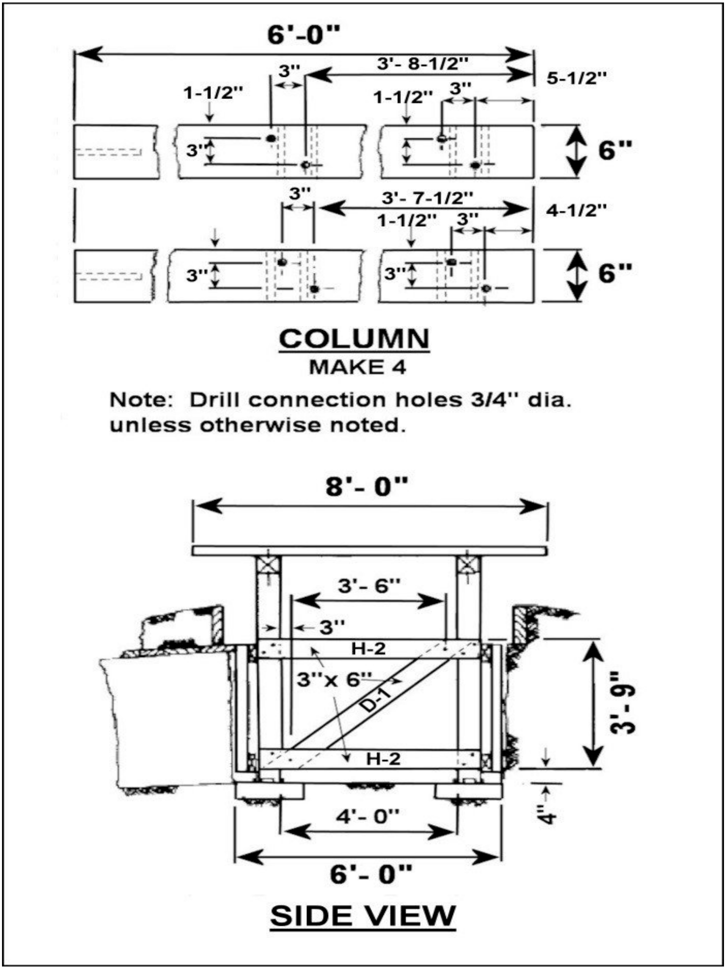


Figure 3.68. Details of Wood-Frame Fighting Position (3 of 3).

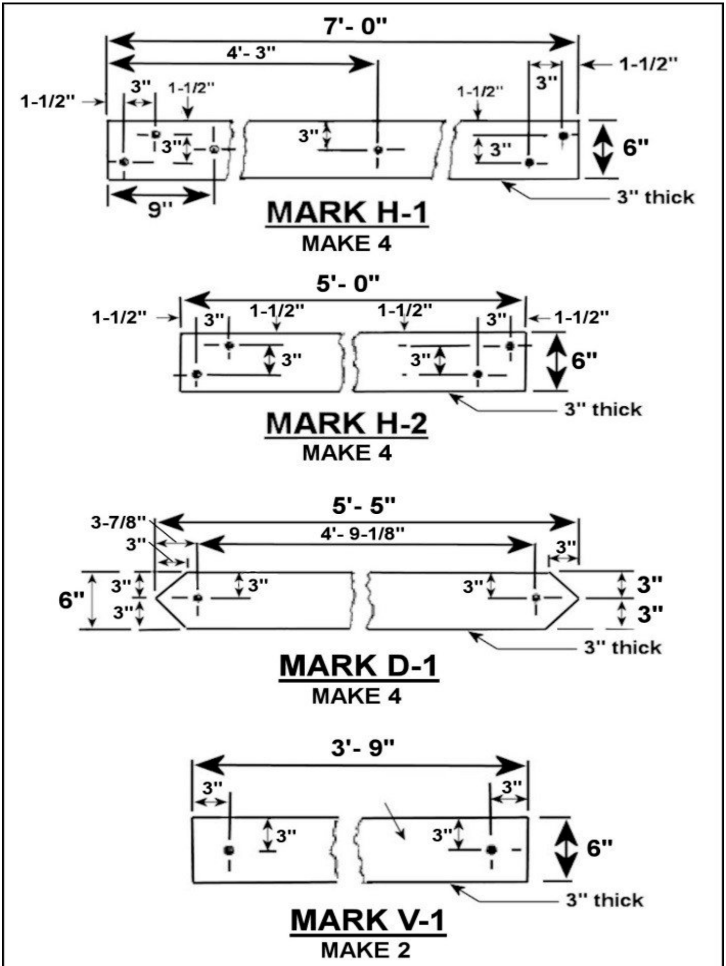


Table 3.18. Wood-Frame Fighting Position Bill of Materials.

Bill of Materials		
Item	**Unit**	**Quantity**
Bolt, Machine, 5/8 x 8-Inch w/Nut	EA	10
Bolt, Machine, 5/8 x 10 Thread Lg., 4 Inch	EA	60
Washer, Flat, 11/16	HD	1.4
Nail, Common, Wire, Steel, 60D	BX	1
Lumber, Softwood, Dim 2, Com, 3x12x12	BF	140
Lumber, Softwood Timber, 1 Com, 6x6x12	BF	72
Lumber, Softwood, BD 2, Com, 3x6xRL	BF	132

3.8.2.2. **Corrugated Metal Fighting Bunker.** Fighting bunkers are larger fighting positions constructed for squad-sized units who are required to remain in defensive positions for longer periods. Build these structures aboveground or belowground. Because fighting bunkers require more engineer effort to build, construct the bunkers during base preparations if sufficient time is available. **Figure 3.69** illustrates a fighting bunker constructed with corrugated metal walls. The bunker is suitable for use in areas where digging is not possible or practical and when other construction materials are unavailable. With 4-foot high, 18-inch thick, earth-filled walls, and 2-foot overhead cover, this fighting position provides protection against direct fire and blasts or fragments from near miss mortar and artillery ammunition. The upper portion of the bunker remains open for maximum visibility in all directions and the design incorporates firing ports in the walls near the floor. For additional protection, place sandbags or loose earth up against the walls. Illustrated in **Figure 3.70** through **Figure 3.75** are basic construction details for the corrugated metal fighting bunker; **Table 3.19** lists the building materials.

Figure 3.69. Corrugated Metal Fighting Bunker.

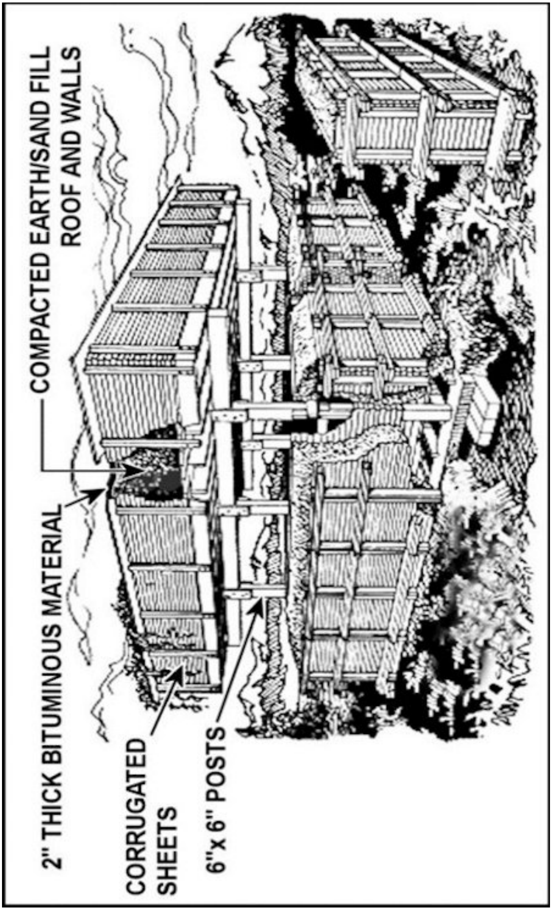


Figure 3.70. Details of Corrugated Metal Fighting Bunker (1 of 6).

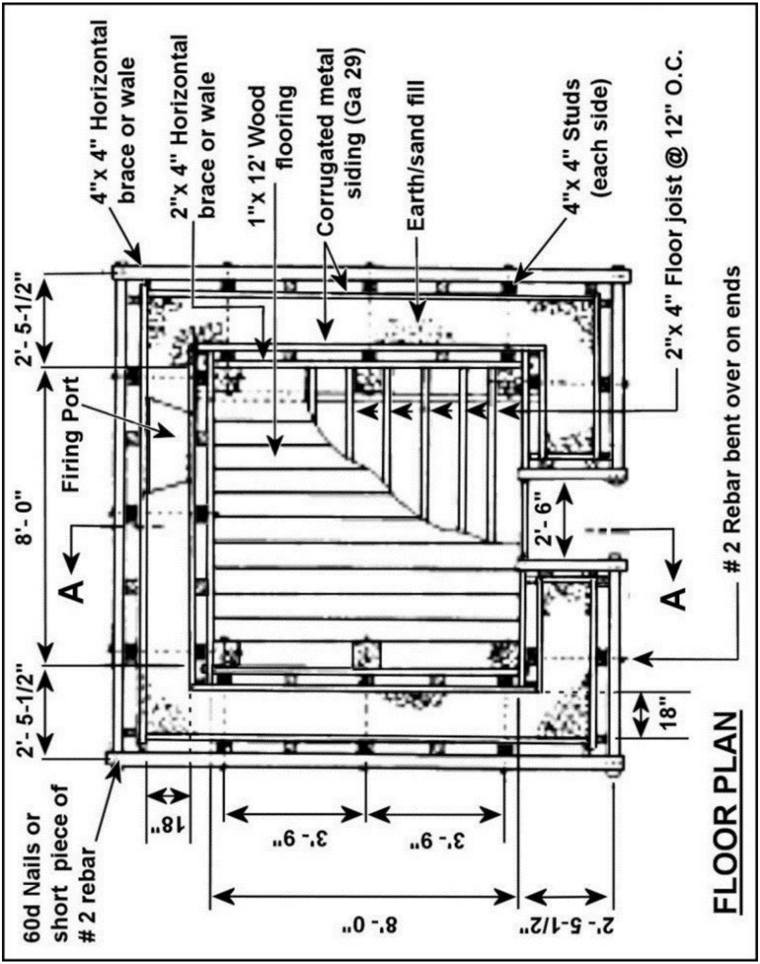


Figure 3.71. Details of Corrugated Metal Fighting Bunker (2 of 6).

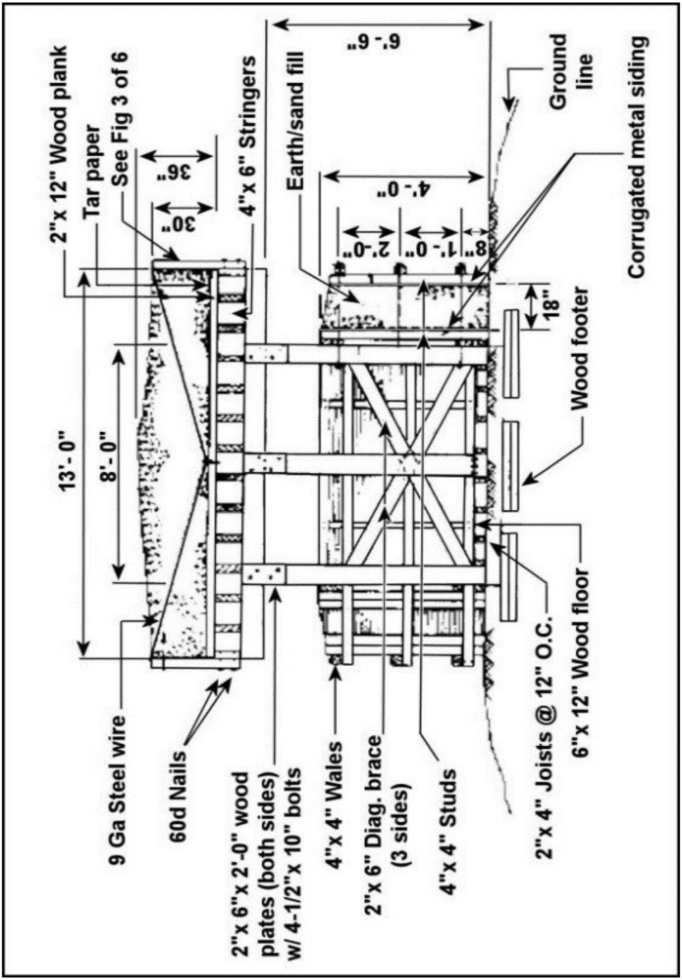


Figure 3.72. Details of Corrugated Metal Fighting Bunker (3 of 6).

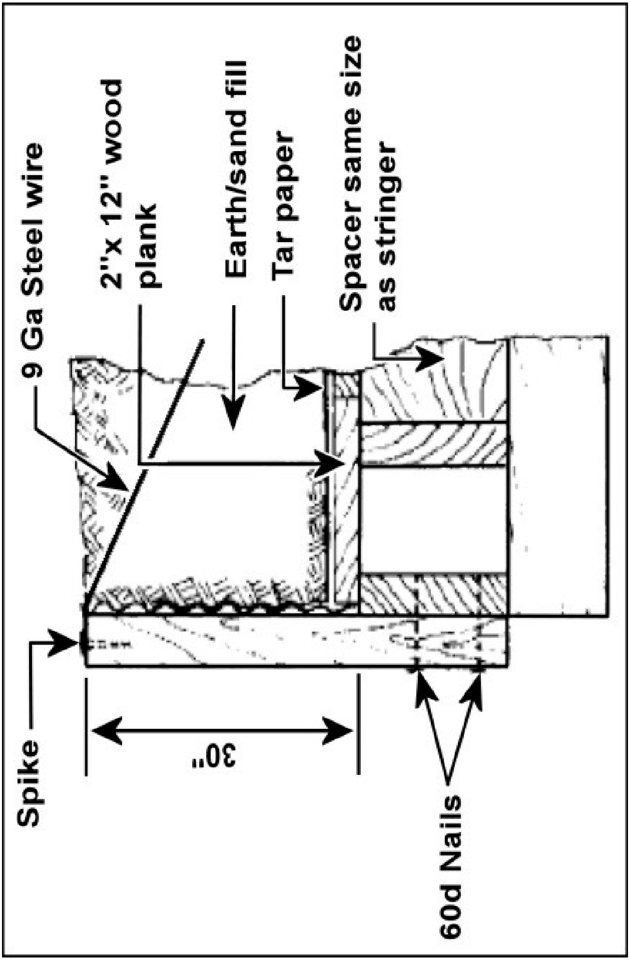


Figure 3.73. Details of Corrugated Metal Fighting Bunker (4 of 6).

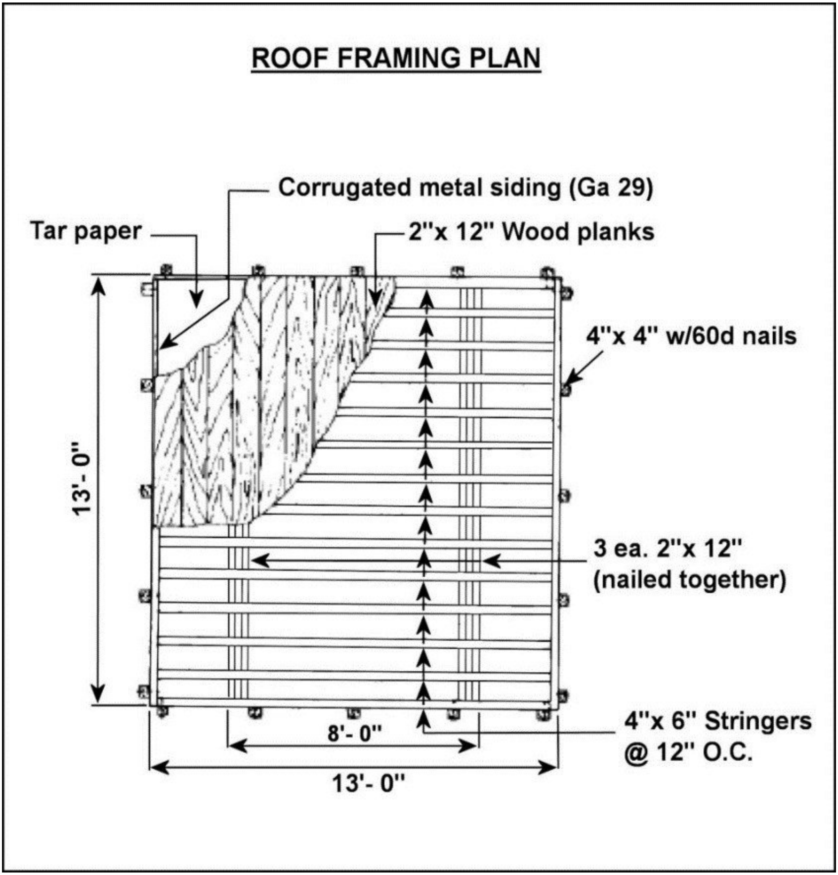


Figure 3.74. Details of Corrugated Metal Fighting Bunker (5 of 6).

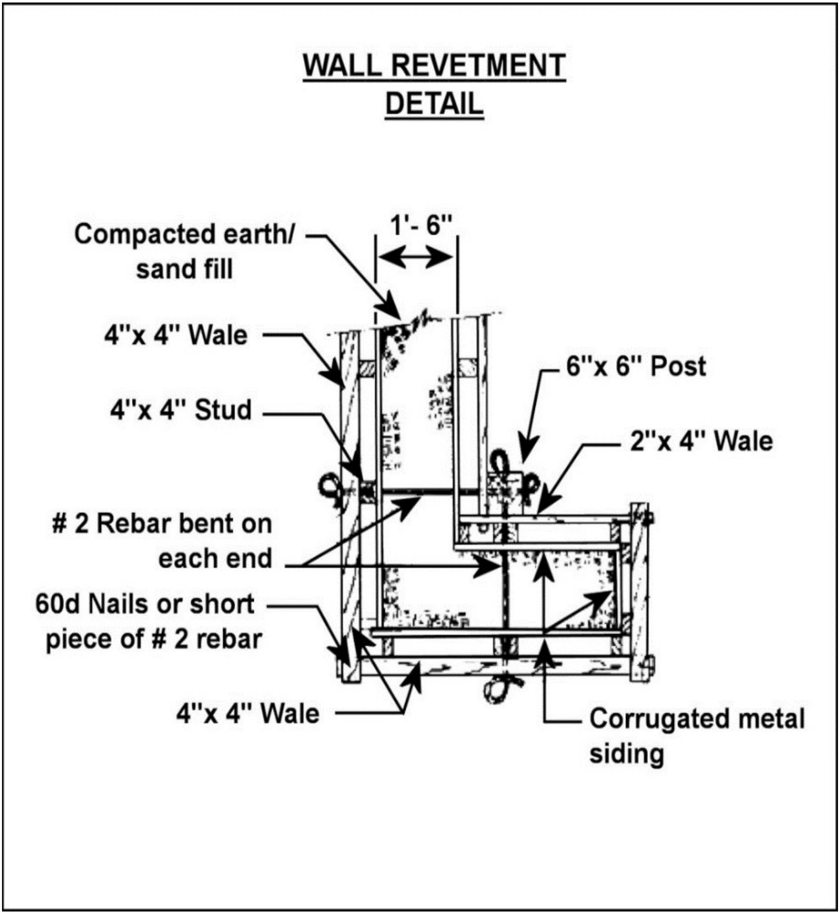


Figure 3.75. Details of Corrugated Metal Fighting Bunker (6 of 6).

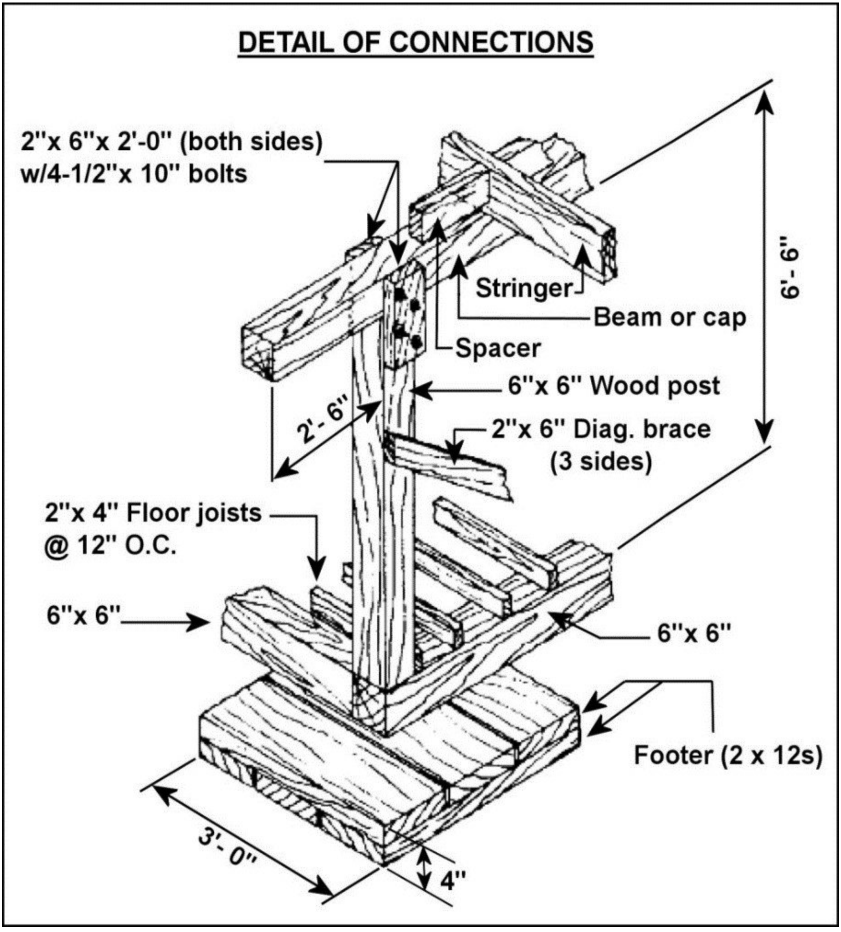


Table 3.19. Corrugated Metal Fighting Bunker Bill of Materials.

Bill of Materials			
Item	**Unit**	**Quantity**	**Remarks**
Lumber, 1"x 12"x 8'	EA	10	
Lumber, 2"x 4"x 10'	EA	25	
Lumber, 2"x 6"x 10'	EA	6	Diagonal Braces
Lumber, 2"x 12"x 14'	EA	24	Roof Decks/Beams
Lumber, 4"x 4"x 10'	EA	18	Studs
Lumber, 4"x 4"x 12'	EA	7	
Lumber, 4"x 4"x 14'	EA	9	Horizontal Braces
Lumber, 4"x 6"x 14'	EA	14	Stringers
Lumber, 6"x 6"x 8'	EA	6	Posts
1/2" Bolt 10" w/Nuts	EA	24	
# 2 Rebar, 4'- 6" Long	EA	35	
Corrugated Sheet Metal, Galv., 96"x 271/2" (29 GA)	SH	38	
Nails, 16d	LB	10	
Nails, 30d	LB	20	
Nails, 60d	LB	20	
Building Paper	SQ FT	170	

3.8.2.3. **Plywood Perimeter Bunker.** Plywood perimeter bunkers are expedient options for aboveground, protected observation posts. The bunker either has a post foundation or constructed on the ground. Another option is to build the wood bunker on top of one or two stacked CONEX boxes. Walls of this bunker will need to be earth filled or otherwise hardened to resist the applicable threat. When prefabricated (walls, floors, and roof), they afford rapid construction and placement flexibility. **Figure 3.76** is a typical elevated plywood perimeter bunker reinforced with sandbags and soil-filled wire and fabric containers. **Table 3.20** lists bunker construction materials. Illustrated in **Figure 3.77** through **Figure 3.79** are basic construction details.

Figure 3.76. Reinforced Plywood Perimeter Bunker.

Table 3.20. Plywood Perimeter Bunker Bill of Materials.

Bill of Materials		
Item	**Unit**	**Quantity**
Lumber, 2”x 4”x 12’	EA	120
Lumber, 2”x 4”x 14’	EA	30
Lumber, 2”x 10”x 14’	EA	40
Lumber, 4”x 10”x 14’	EA	17
Lumber, 8”x 8”x 16’	EA	4
Plywood, 4’x 8’x 3/4”	EA	32
Nails, 20d	LB	50
Nails, 60d	LB	25
Bolts, 3/4”x 14”	EA	8
Roof Paper	SQ FT	200

Figure 3.77. Details of Plywood Perimeter Bunker (1 of 3).

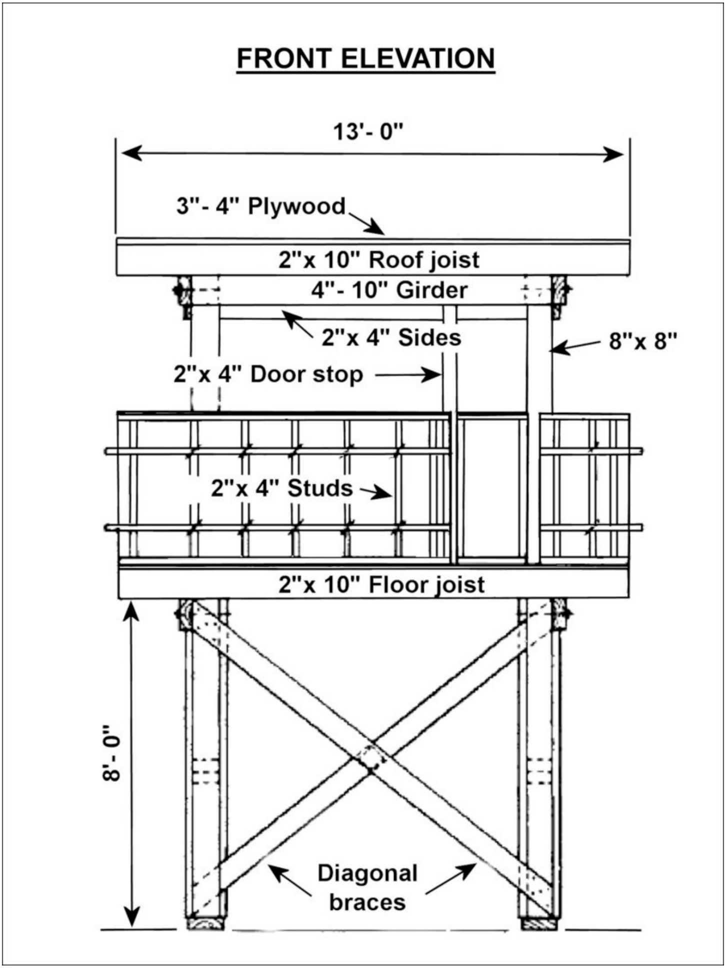


Figure 3.78. Details of Plywood Perimeter Bunker (2 of 3).

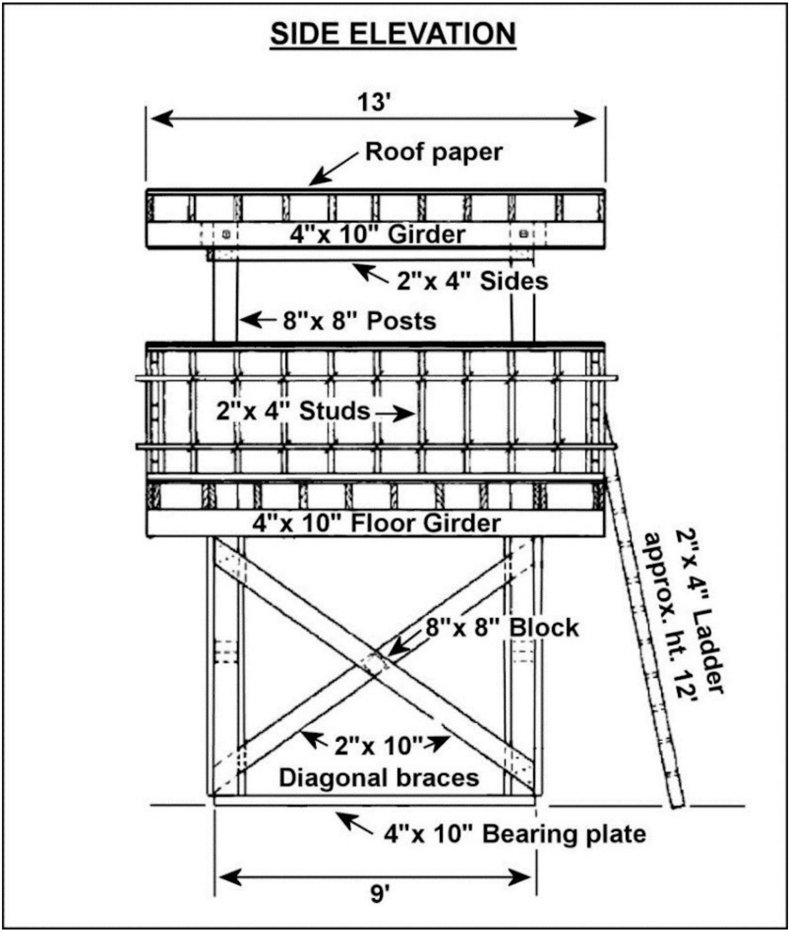
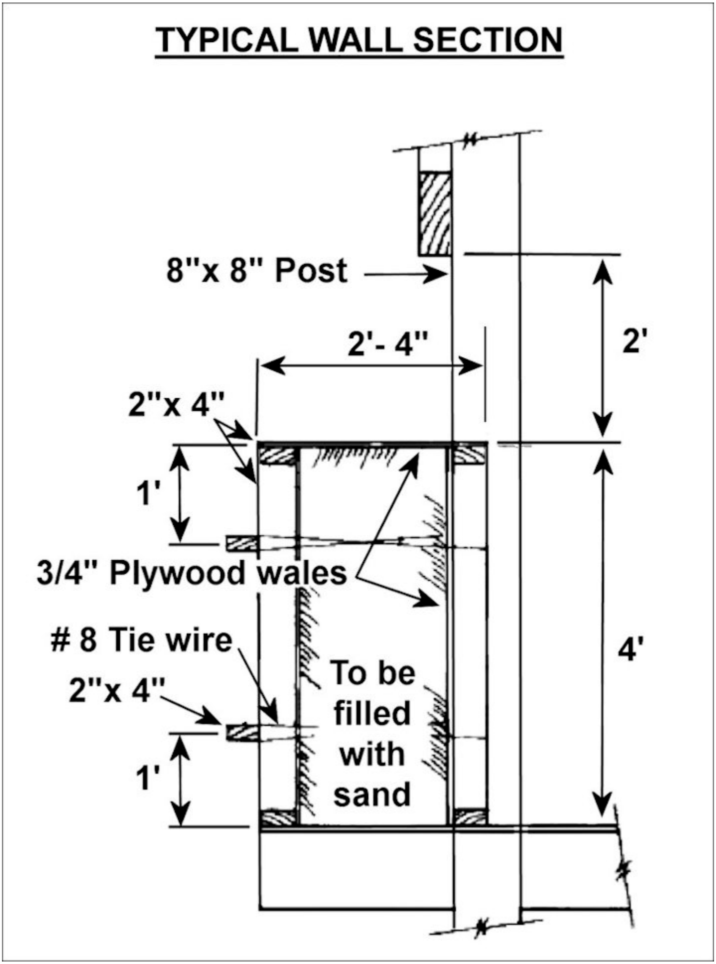


Figure 3.79. Details of Plywood Perimeter Bunker (3 of 3).



3.9. Summary. In the TO, contingency bases sometimes upgrade unhardened facilities to protect personnel and critical resources from the effects of conventional weapons. In addition, when facilities are unavailable or time and materials are limited during contingency beddowns, traditional construction methods may not be feasible. This chapter provided expedient and improvised construction options for personnel bunkers, fighting positions, revetments, perimeter fortifications, and other hardening methods. While some of the options provided detailed construction specifications, they are not mandatory and only intended to stimulate ideas for CE personnel faced with the challenge of creating protective structures using field-expedient methods and resources. A structural engineer should review bunker (and other structure) designs that provide cover for personnel before they are use. For additional information on expedient and improvised hardening methods and protective construction, consult the references listed in **Table 3.21**.

Table 3.21. Chapter 3 Quick References.

Protective Structures	
AFH 10-222V14	*Civil Engineer Guide to Fighting Positions, Shelters, Obstacles, and Revetments*
AFTTP 3-32.34V3	*Civil Engineer Expeditionary Force Protection*
GTA 90-01-011	*Joint Forward Operating Base (JFOB) Handbook*
AFPAM 23-221	*Fuels Logistics Planning*
ETL 11-18	*Small Arms Range Design and Construction*
T.O. 37A12-15-1	*Collapsible Fuel Bladder*
UFC 3-220-10N	*Soil Mechanics*
UFC 3-220-01	*Geotechnical Engineering*
UFC 3-340-01	*Design and Analysis of Hardened Structures to Conventional Weapons Effects* (FOUO)

UFC 4-022-02	*Selection and Application of Vehicle Barriers*
UFC 4-023-07	*Design to Resist Direct Fire Weapons Effects*

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DCS/Logistics, Engineering and Force Protection

Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

References

AFI 10-209, *RED HORSE Program*, 28 Aug 2017

AFI 10-210, *Prime Base Engineer Emergency Force (BEEF) Program*, 21 January 2015

AFI 32-1064, *Electrical Safe Practices*, 29 December 2016

AFI 91-203, *Air Force Consolidated Occupational Safety Instruction*, 15 June 2012

AFMAN 33-363, *Management of Records*, 1 March 2008

AFH 10-222V4, *Environmental Considerations for Overseas Contingency Operations*, 1 September 2012

AFH 10-222V14, *Civil Engineer Guide to Fighting Positions, Shelters, Obstacles, and Revetments*, 1 August 2008

AFH 32-1034, *Materials Testing*, 3 April 2015

AFPAM 23-221, *Fuels Logistics Planning*, 11 March 2013

AFTTP 3-32.34V3, *Civil Engineer Expeditionary Force Protection*, 1 March 2016

EM 1110-2-1913, *Design and Construction of Levees*, 30 April 2000

ETL 02-19, *Airfield Pavement Evaluation Standards and Procedures*, 12 November 2002

ETL 11-18, *Small Arms Range Design and Construction*, 19 April 2011

GTA 90-01-011, *Joint Forward Operating Base (JFOB) Handbook*, October 2011

T.O. 37A12-15-1, *Collapsible Fuel Bladders*, 30 June 2004

UFC 3-220-01, *Geotechnical Engineering*, 1 November 2012

UFC 3-220-08FA, *Engineering Use of Geotextiles*, 16 January 2004

UFC 3-220-10N, *Soil Mechanics*, 8 June 2005

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*, 14 November 2016

UFC 3-250-09FA, *Aggregate Surfaced Roads and Airfields Areas*, 16 January 2004

UFC 3-250-11, *Soil Stabilization for Pavements*, 16 January 2004

UFC 3-260-01, *Airfield and Heliport Planning and Design*, 17 November 2008

UFC 3-270-07, *O&M*: *Airfield Damage Repair*, 12 August 2002

UFC 3-340-01, *Design and Analysis of Hardened Structures to Conventional Weapons Effects* (FOUO), 30 June 2002

UFC 3-560-01, *Operation and Maintenance: Electrical Safety*, 24 July 2017

UFC 4-022-02, *Selection and Application of Vehicle Barriers*, 8 June 2009

UFC 4-023-07, *Design to Resist Direct Fire Weapons Effects*, 7 July 2008

NFPA 70, *National Electric Code*, 2017 Edition

Expedient Road Construction Methods for Sand and Soft Soil Subgrades, 3 October 2003, J. S. Tingle, U.S. Army Engineer Research and Development Center (ERDC)

Prescribed Forms

No prescribed forms are implemented in this publication.

Adopted Forms

AF Form 847, *Recommendation for Change of Publication.*

Abbreviations and Acronyms

ACP—Airfield Cone Penetrometer

AF—Air Force

AFCEC—Air Force Civil Engineer Center

AFH—Air Force Handbook

AFI—Air Force Instruction

AFMAN—Air Force Manual

AFPAM—Air Force Pamphlet

AFRIMS—Air Force Records Information Management System

AFTTP—Air Force Tactics, Techniques and Procedures

AI—Airfield Index

APSB—Asphalt Penetration Surface Binder

CaO—Calcium Oxide

CBR—California Bearing Ratio

CE—Civil Engineer

CCDR—Combatant Commander

CMP—Corrugated Metal Pipe

CMS—Cement-Modified Soil

DCP—Dynamic Cone Penetrometer

DFP—Defensive Fighting Position

DOD—Department of Defense

ETL—Engineering Technical Letter

FOUO—For Official Use Only

FP—Force Protection

GTA—Graphic Training Aid

HAZMAT—Hazardous Material

IAW—In Accordance With

IPE—Individual Protective Equipment

JFOB—Joint Forward Operating Base

LCF—Lime-Cement-Fly Ash

LF—Lime-Fly Ash

LL—Liquid Limit

LMS—Lime-Modified Soil

MB—Mechanical Blending

NFPA—National Fire Protection Association

NRCS— National Resources Conservation Service

NSN—National Stock Number

O&M—Operation and Maintenance

OMC—Optimum Moisture Content

OPLAN—Operation Plan

OPORD—Operational order

OPR—Office of Primary Responsibility

PI—Plasticity Index

PL—Plastic Limit

POL—Petroleum, Oil, and Lubricants

PPE—Personal Protective Equipment

PVC—Polyvinylchloride

RC—Rapid Curing

SA—Soil-Asphalt

SC—Soil-Cement

SL—Soil-Lime

SWA—Southwest Asia

TO—Theater of Operations

T.O.—Technical Order

UFC—Unified Facilities Criteria

US—United States

USACE—US Army Corps of Engineers

USAF—United States Air Force

USCS—Unified Soil Classification System

UXO—Unexploded Explosive Ordnance

VLC—Virtual Learning Center

WBDG—Whole Building Design Guide

Terms

Air Force Civil Engineer Center (AFCEC)—Headquartered at Joint Base San Antonio-Lackland, AFCEC is a 1,900-person primary subordinate unit, assigned to Air Force Materiel Command and attached to the Air Force Installation and Mission Support Center, responsible for providing responsive, flexible full-spectrum installation engineering services. AFCEC missions include facility investment planning, design and construction, operations support, real property management, readiness, energy support, environmental compliance and restoration, and audit assertions, acquisition and program management. The unit conducts its operations at more than 75 locations worldwide.

Base—1. A locality from which operations are projected or supported. 2. An area or locality containing installations, which provide logistic or other support. 3. Home airfield or home carrier. (JP 4-0)

Base Development—The acquisition, development, expansion, improvement, construction and/or replacement of the facilities and resources of a location to support forces. (JP 3-34)

Beddown—A location at which a deploying unit operates during a contingency. It is usually, but not always, in the area of responsibility. (AFDA 4-0)

Contingency—A situation requiring military operations in response to natural disasters, terrorists, subversives, or as otherwise directed by appropriate authority to protect US interest. (JP 5-0)

Contingency Location—A non-enduring location outside of the United States that supports and sustains operations during named and unnamed contingencies or other operations as directed by appropriate authority and is categorized by mission life-cycle requirements as initial, temporary, or semi-permanent. (DODD 3000.10)

Initial Contingency Location—A contingency location occupied by a force in immediate response to a named or unnamed contingency operation and characterized by austere infrastructure and limited services with little or no external support except through Service organic capabilities. (DODD 3000.10)

Theater of Operations—An operational area defined by the geographic combatant commander for the conduct or support of specific military operations. Also called TO. (JP 3-0)

Unexploded Explosive Ordnance—Explosive ordnance which has been primed, fused, armed or otherwise prepared for action, and which has been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installations, personnel, or material and remains unexploded either by malfunction or design or for any other cause. Also called **UXO.** (JP 3-42)

Attachment 2

ENGINEER REACHBACK AND OTHER LINKS

Table A2.1. Useful Organizational and Product Links.

Useful Links
Air Force Civil Engineer Center (AFCEC): www.afcec.af.mil/
AF Publications and Forms: www.e-publishing.af.mil/
AF Design Guides (AFDG):c=129
AF Engineering Technical Letters (ETL): c=125
Whole Building Design Guide (WBDG): www.wbdg.org/
Unified Facilities Criteria (UFC): c=4
Construction Criteria Base (CCB)/(WBDG): www.wbdg.org/ccb
USACE Reachback Operations Center (UROC): https://uroc.usace.army.mil
USACE Protective Design Center (PDC): https://pdc.usace.army.mil/
Army Publications and Forms: www.apd.army.mil/ProductMap.asp
Navy Doctrine Library System: https://ndls.nwdc.navy.mil
DOD Issuances: www.dtic.mil/whs/directives/
Joint Publications: www.dtic.mil/doctrine/new_pubs/jointpub.htm
NRCS World Soil Resources: http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/worldsoils