FMFRP 0-63

Troop Construction in the Middle East

U.S. Marine Corps

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FOREWORD

1. PURPOSE

Fleet Marine Force Reference Publication (FMFRP) 0-63, Troop Construction in the Middle East, provides information on engineer-related support essential to military operations conducted in the Middle East.

2. SCOPE

This manual contains detailed engineer-related information useful at the tactical and operational levels of war. It is provided as a regional reference publication to assist in the planning and conduct of MAGTF operations in arid environments.

3. BACKGROUND

a. While the unique aspects of the desert environment have profound impact on MAGTF operations, most of the doctrine, tactics, techniques, and procedures employed in operations in other parts of the world apply to operations in the desert. The unique aspects to operations in the desert stem primarily from the effects of heat and the scarcity of moisture, terrain features, and vegetation. The challenge to MAGTF operations in a desert environment is adapting to the arid climate and conditions.

b. FMFRP 0-63 is a consolidated handbook originally prepared and published by the U.S. Army Civil Engineer Research Laboratory and the U.S. Army Waterways Experimental Station in 1982.

4. RECOMMENDATIONS

Comments on this manual are welcomed. Submit comments to --

Commanding General
Marine Corps Combat Development Command (WF12)
Quantico, VA. 22134-5001

5. **CERTIFICATION**

Reviewed and approved this date.

BY DIRECTION OF THE COMMANDANT OF THE MARINE CORPS

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PREFACE

The hot, barren desert environment of the Middle East requires special consideration in wartime planning and operations. The purpose of this report is to consolidate all engineer-related aspects of problems in base development into a single source handbook covering construction problems in the Middle East.

This document is designed to assist planners in the identification of resource requirements for both men and material when preparing engineering support plans and to provide builders in the field with various construction techniques to facilitate the use of their available assets.

FOR THE COMMANDER:

JAMES W. RAY
Colonel, Corps of Engineers
Chief of Staff

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TROOP CONSTRUCTION IN THE MIDDLE EAST

CHAPTER 1 - INTRODUCTION

1.1 Background

The planning efforts for base development and operational contingencies in Southwest Asia (SWA) (Figure 1.1) involve unique challenges. The extremely harsh environment of the desert and very limited local building construction materials contribute to these challenges. There is much published literature concerning not only the effects of the desert environment on material, equipment, and facilities, but also the unusual problems associated with construction and operation activities in such areas. A need exists to summarize all engineer-related aspects of the problem, and provide a single source of information for planners and engineer units to use for base development in SWA.

1.2 Objective

The purpose of this report is to consolidate all engineer-related aspects of the problem in base development and provide planners and engineers with a single source handbook covering construction problems and practices unique to the Middle East.

1.3 Assumptions

1. The areas of concern are the desert regions of SWA.

2. The facilities will be used for up to 12 months.

3. Strategic air and sea lines of communication (LOC) will be limited to existing facilities.

4. Some areas in the theater of operations (TO) will be subject to hostile fire; others will not.

5. The standard of construction will be austere. Joint Chiefs of Staff (JCS) Publication 3 initial standard (0 to 6 months) will govern.

6. The deploying forces will arrive in the TO per Time Phased Force Deployment Data with TOE equipment.

1.4 Characteristics of Desert Regions

To provide some insight into the challenges that will be faced in base construction, it is important to understand the characteristics of desert environments.

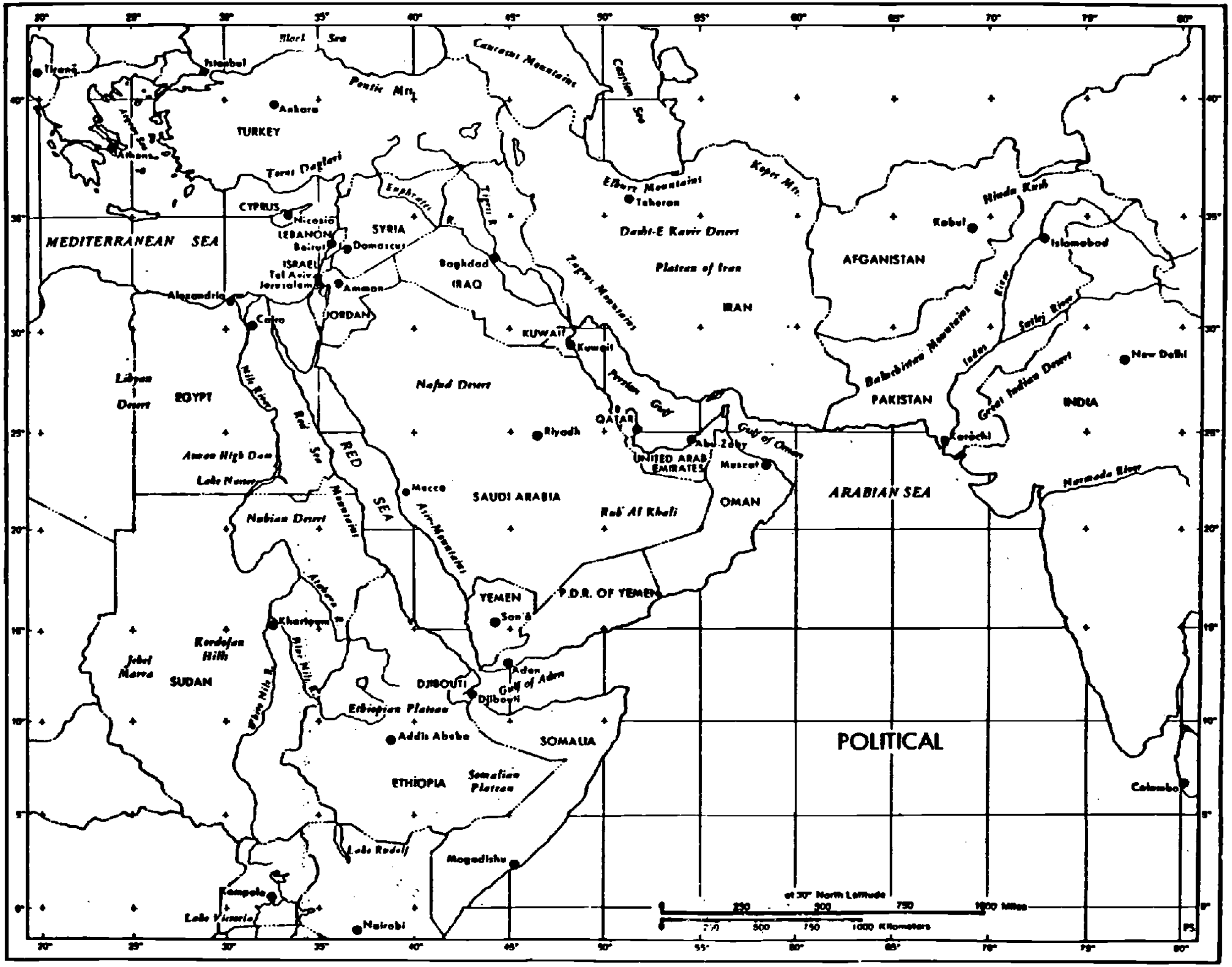

Figure 1.1. Political map of Southwest Asia.

1.4.1 *Terrain*

This region of the world contains three basic types of deserts: mountain, rocky plateau, and sandy or dune deserts. While each has its own distinctive characteristics, they share common features of barrenness, aridity, and severity. Because of such inhospitable conditions, most of the population is concentrated along the coasts and the few major rivers where one can find some relief from the heat and dust, and where water is more plentiful.

Mountain deserts are areas of barren hills and steep-sided mountains with intervening dry, flat basins. Rainfall is infrequent and runs off rapidly to produce flash floods that erode deep gullies and ravines. The ground surface is badly dissected, with areas of exposed bedrock and stony soil.

Rocky plateau deserts are extensive flat areas where the surface is strewn with broken rock, boulders and gravel. These areas are cut by steep-walled eroded valleys, known as wadis, and contain scattered oases around which small villages often are found. These deserts also contain salt flats, areas where the surface is crusted with salt and underlain with brine-saturated soil. They are normally dry in the summer and marshy in the winter.

Dune or sand deserts are relatively flat, wind-eroded areas covered with sand or gravel. Created and shaped by the wind, dunes consist of loose sand of various particle sizes and vary in height from a few feet to several hundred feet. Areas between the dunes are generally hard with no distinct landmarks except for an occasional oasis.

It must be kept in mind that all three terrain types are usually not devoid of vegetation. The vegetation can range from sparse straggly to continuous and varied depending on ground conditions. The native vegetation will usually be low to the ground, though commonly 3 ft to 4 ft (0.91 m to 1.22 m) high varieties can be seen.

An important feature of nominal desert soils is the surface compaction sometimes referred to as "desert pavement." This compaction is caused by action of rain (for compaction) and wind (to remove the fine particles). This "desert pavement" usually is 1/2 in. to 4 in. (1.77 cm to 10.16 cm) thick and somewhat fragile. Most of the time troops will not break through, but with few exceptions tracked or wheeled vehicles usually will. Once the "desert pavement" is breached, the heavy blowing sand and dirt conditions reported in WWII military reports is the rule. It is in general this "desert pavement" that is found between the dunes in the "sand deserts," the major portion of the "Rocky plateau deserts," and the dry flat basins in the "Mountain deserts."

1.4.2 *Climate*

While desert regions of the SWA are arid and generally have low humidity, some coastal regions have high humidity levels. Figure 1.2, a map of climatic zones, shows three climatic categories covering the Middle East: hot, dry desert; intermediate hot dry desert; and humid, hot coastal desert.

Desert areas of SWA experience a wide range of daily temperatures. During the day, solar radiation warms the air and ground to produce summertime

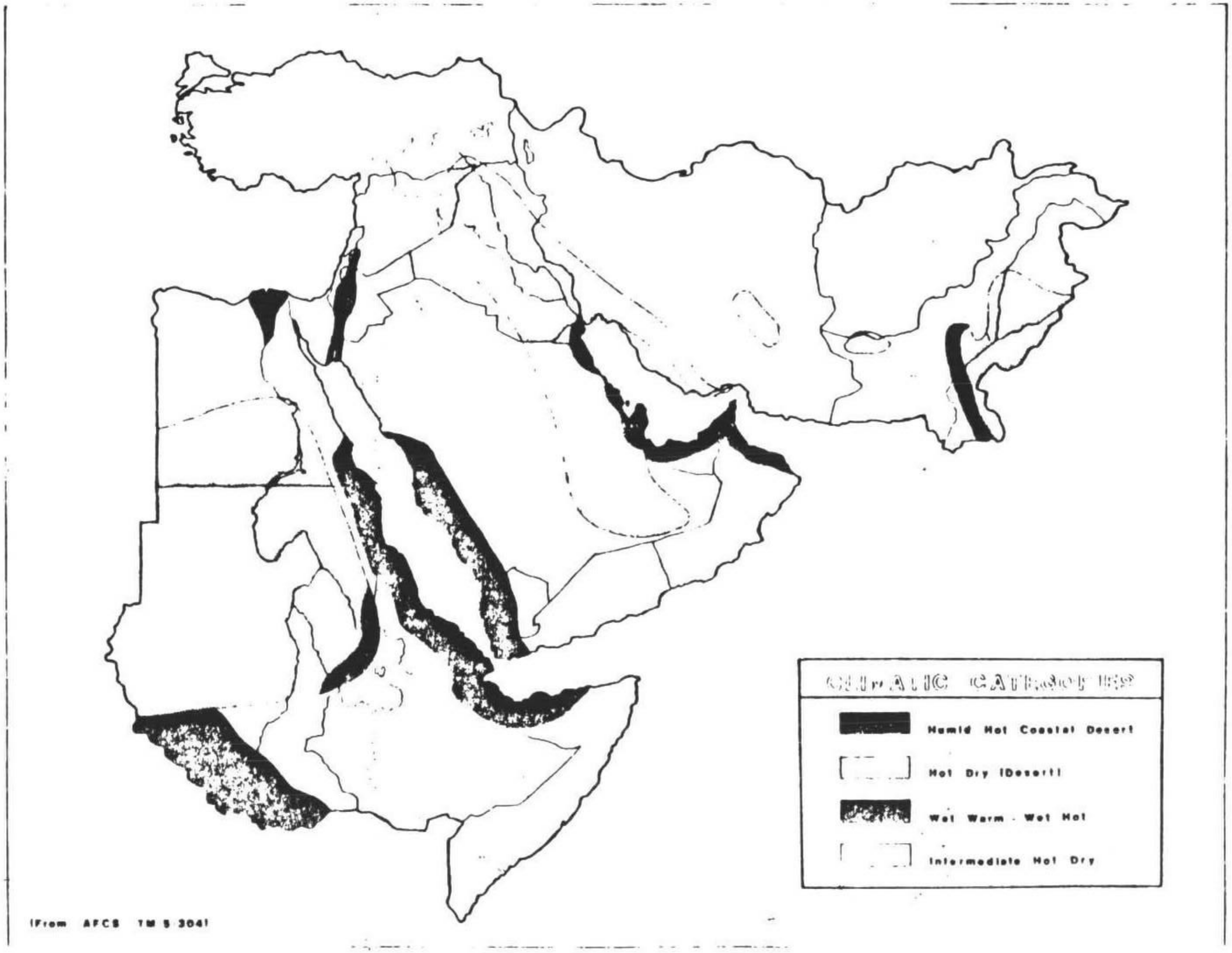

Figure 1.2. Climatic zones.

ambient temperatures well over 100°F (38°C). At night in the hot-dry regions, the heat dissipates quickly due to clear skies and low humidity, causing temperatures to drop 50° to 70°F (10° to 21°C). Wintertime temperatures are noticeably lower, ranging from 45° to 60°F (7° to 16°C) during the day to near freezing at night. Areas with high humidity have much lower day to night temperature swings.

Along with the daytime heat, the region is exposed to almost incessant wind. Velocities near hurricane force are not infrequent during the day and night throughout the year. Such wind storms, often lasting for several days, carry large quantities of dust and sand, and are frequently accompanied by rapid changes in temperature.

Characteristic of desert areas are the limited amounts of precipitation and rapid evaporation. In desert regions, rainfall is less than 10 in. (254 mm) per year, and frequently this is in the form of violent storms. In the mountains and hilly areas, runoff is rapid and destructive, while in the flatter areas it is channeled through wadis to depressions and salt flats where that which does not percolate into the soil quickly evaporates in the hot sun.

1.5 Approach and Scope

This study was conducted in two phases. Phase I involved: (1) compilation of information based on actual field experiences and knowledge of laboratory personnel and other U.S. Army Corps of Engineers employees, and on a review of literature pertinent to construction in desert regions, and (2) identification of research areas or problem areas requiring additional study. Phase II involved studying the identified problem areas and refining information from Phase I. This report documents the work of Phase II, and replaces the Phase I report, Theater of Operations Construction in the Desert: A Handbook of Lessons Learned in the Middle East.

As in the Phase I document, this report covers the various engineering disciplines involved in base development. These include base planning and siting (Chapter 2), base protection (Chapter 3), electrical generation and distribution (Chapter 4), water supply, distribution, and disposal (Chapter 5), vertical construction (Chapter 6), horizontal construction (Chapter 7), and port construction (Chapter 8). Factors affecting the engineer work force are also considered (Chapter 9). For definitions of abbreviations used in this report, see page Index-1.

CHAPTER 2 - BASE PLANNING AND SITING

2.1 Introduction

For a base to withstand a harsh environment and to keep occupants reasonably comfortable, the location of a facility or installation within a site should be determined by analyzing the constraints and features of the area. Overall siting analysis should include the climatic constraints of solar radiation, temperature, precipitation, and prevailing winds, as well as the natural features of the ground surface, such as topography, ground cover, and drainage patterns. This chapter provides some fundamental considerations for base planning and siting in the desert regions of SWA.

2.2 Site Selection

Several factors must be considered in the selection of a site in an arid region. The site shall preferably be in an area where water resources are available nearby (see Chapter 5). The site must be easily accessible by existing roads, or the landform must allow a landing strip to be built nearby.*

Areas where drifting sand is a problem should be avoided. If this cannot be done, a barrier or fence similar to the temporary snow fences used along highways in the United States can be used to hold the sand; unfortunately, the sand never melts but only grows and moves. Personnel may take advantage of this by placing fences where stockpiles of sand would be useful for construction or camouflage. Emulsified asphalt or crude oil can also be applied to temporarily stabilize the soil.**

The drainage of the site must also be considered because even though the desert receives little rain, when it does occur, it is usually sudden and intense and causes flash flooding even if the rainfall is miles from the site. Low-lying areas where there is a likelihood of ponding should be avoided. Natural drainage swales (wadis) should be located and avoided because of the likelihood of flash flooding.***

Drainage and mosquitoes may be a problem where there are salt marshes. These areas should also be avoided; however, if they are properly drained and graded, the hazards can be removed. Light oils can also be applied to marshy areas to kill mosquito larvae.

The hot summer wind is a problem because it blows sand. In addition, the wind should be blocked during the hot part of the day, but should be used in the evening to help cool the base.

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* Gideon Golany, Urban Planning for Arid Zones (New York: John Wiley & Sons, 1978), p 7.

** Martin Evans, Housing, Climate and Comfort (London: The Architectural Press, 1980), p 57.

***Golany, p 11.

There are seven landforms in the desert: piedmont, playa, alluvial fan, floodplain, coastal plain, eolian landforms — loess and sand dunes, and mesa. Of these, the mesa, coastal plain, and piedmont are most suitable for construction. These three landforms are the ones most likely to be located with water resources nearby.* However, the exact location will be dictated by the military requirements.

A site's elevation can influence its climate. An increase in elevation causes the temperature to decrease, and the relative humidity and the wind ventilation to increase. Mesas and piedmont regions have this characteristic; however, mesas are not as easily accessible because of the straight cliffs surrounding them.**

The piedmont region is the area sloping down from a mountain. Slopes facing away from the equator are preferable because they receive less direct solar radiation and therefore have lower temperatures (Figure 2.1). Slopes facing west and southwest should be avoided because of their increased solar radiation and higher temperatures.***

Coastal plains slope toward the sea; because of the high humidity along the coast, the wind is an important factor in cooling. There may be a problem with salt water entering the water table because of the nearness of the sea.

2.3 Site Planning

Two main factors must be controlled when designing a base in a hot, arid region. The intense solar radiation must be reduced at critical periods by orientation and shading, and the hot, dry daytime winds must be reduced.

Reducing the amount of solar radiation that reaches the building surfaces and ground surfaces is the best way to reduce the heat gain in the base. Buildings should be designed with their long axis oriented in an east-west direction to minimize the east and west wall exposure (Figure 2.2).+ Buildings should also be placed as close together as possible in order to shade each other. Building overhangs, cantilevers, or arcades should be used whenever possible to provide shade for walkways and building walls. A cloth canopy or some type of shade netting can also be installed between buildings to shade the streets and walkways.++

The streets should be as narrow as practical. Shade should be provided if practical in parking areas to keep the vehicles from becoming unbearably hot. Shade can be provided by canvas or some type of netting (Figure 2.3).

Only heavily traveled streets and pedestrian walkways should be paved since the pavement will re-radiate more of the solar radiation than will the

* Golany, p 12.
** Golany, p 16.
***Evans, p 54.
\+ Victor Olgyay, Design With Climate (Princeton: Princeton University Press, 1973), p 55.
\++ Kathleen Kelly and R. T. Schnadelback, Landscaping the Saudi Arabia Desert (Philadelphia: The Delaney Press, 1976), p 40.

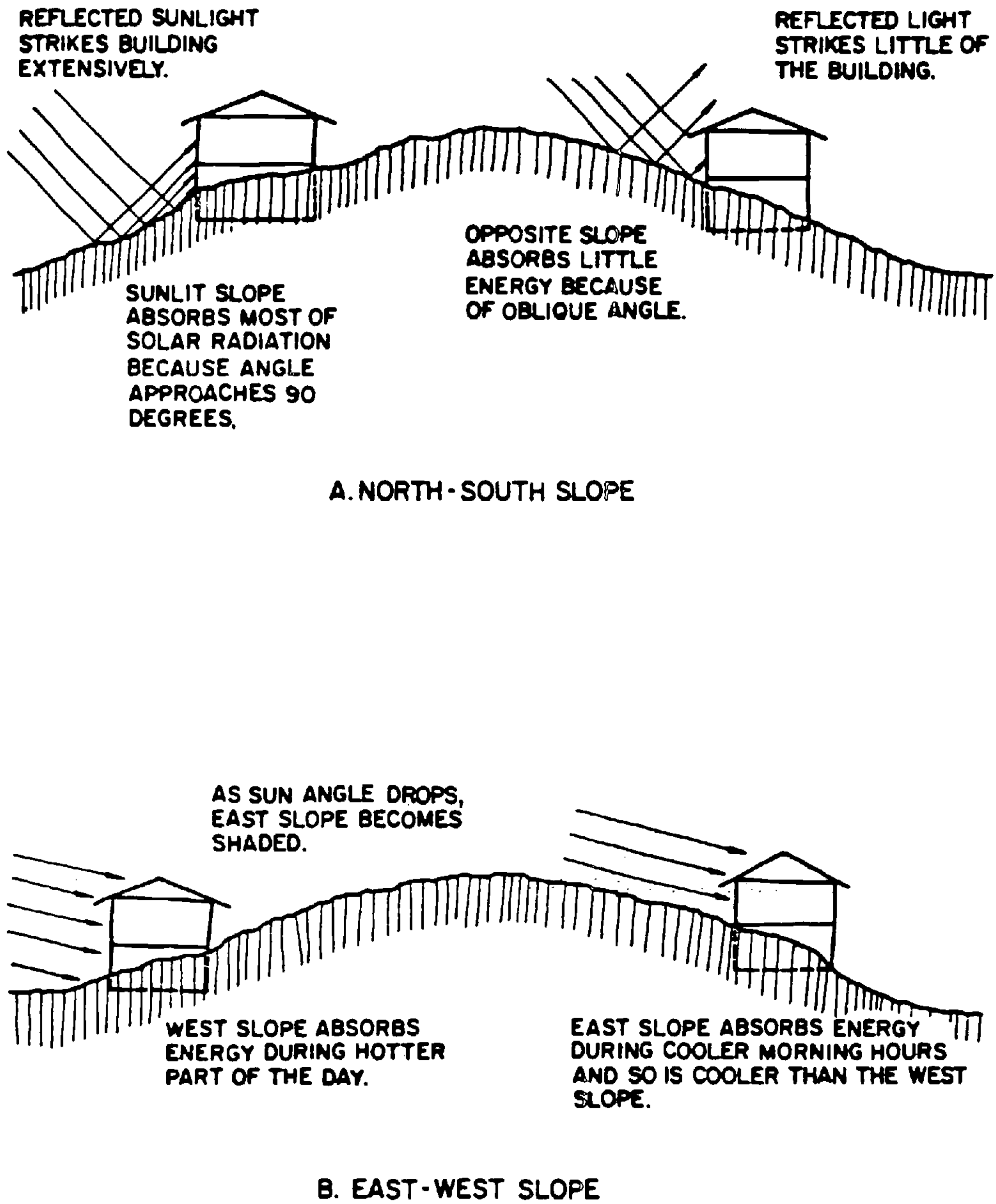

Figure 2.1. Building placement.

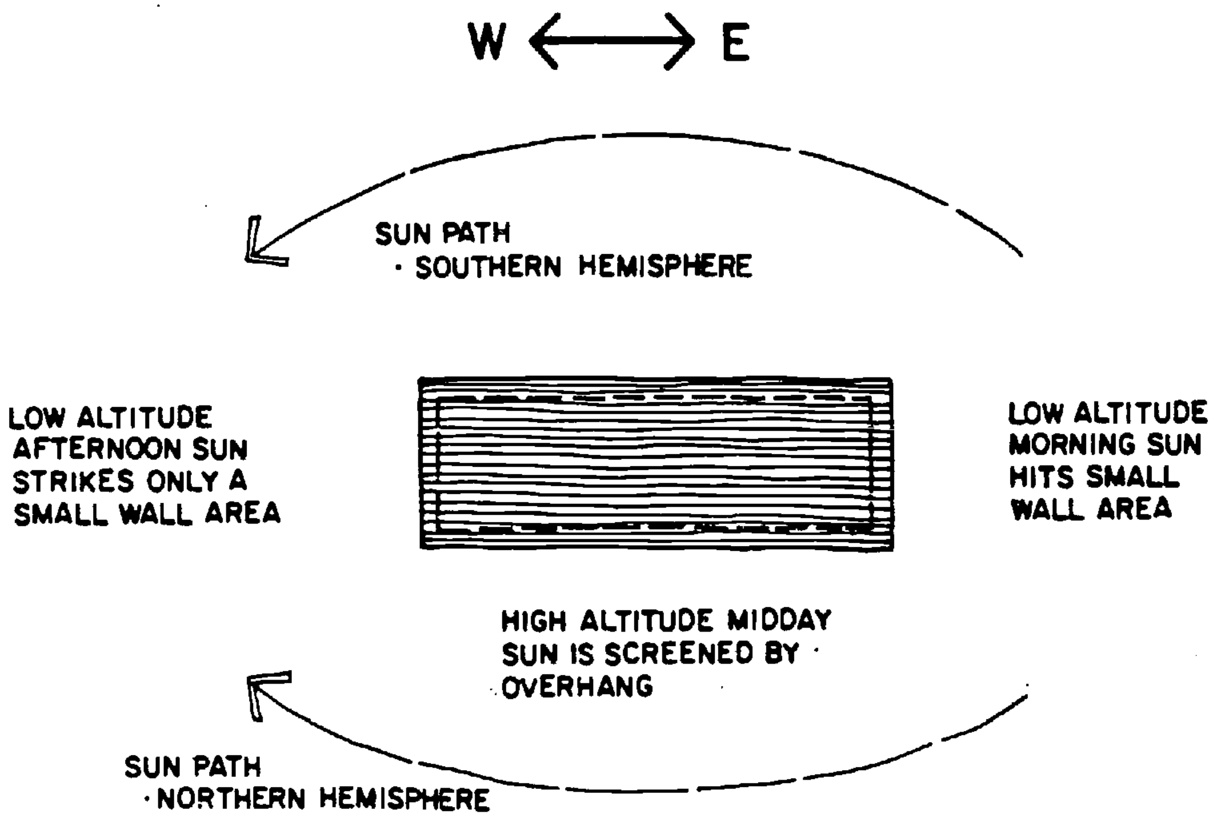

Figure 2.2. Building layout: East-West orientation.

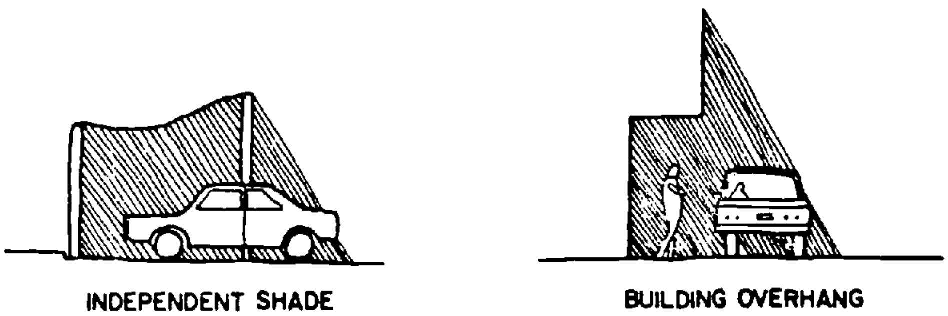

Figure 2.3 Parking shades.

ground surface. The streets should be paved in light earth colors rather than white (because of the glare) or dark colors, which would cause the area to become quite hot.

Large open plazas should be avoided because they do not provide shade and will become too hot to use. In addition, the wind will deflect into them and cause turbulence and blowing sand.

Vegetation helps to reduce the amount of radiation which reaches the ground, to hold the soil in place, and to reduce the amount of blowing sand (Figure 2.4).* Therefore, vegetation should be protected whenever possible during base construction.

* Balwant Singh Saini, Building in Hot Dry Climate (Chichester; John Wiley & Sons, 1980), p 86.

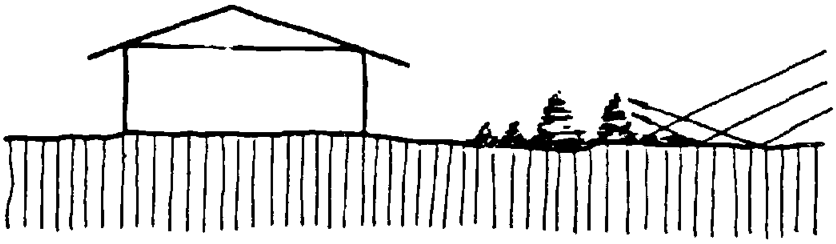

Figure 2.4. Vegetation.

The heights of the buildings should be kept as low and uniform as possible, with the distances between buildings no greater than the height of the structures so the wind stays above the base. Taller buildings will create turbulence and eddies in the base (Figure 2.5).

Wind towers can be used to catch the wind and provide ventilation and cooling for the building interiors. Walled courtyards will provide protection from the wind and offer shade.

Streets should be designed perpendicular to the prevailing winds and be as narrow as possible. Long, wide, straight streets should be avoided because the wind, blowing sand, and heat will make conditions unbearable.

Many of the factors discussed here contradict those which must be considered for base protection and concealment. Base protection has not been considered in this chapter; only the factors relating to climate-sensitive design have been discussed.

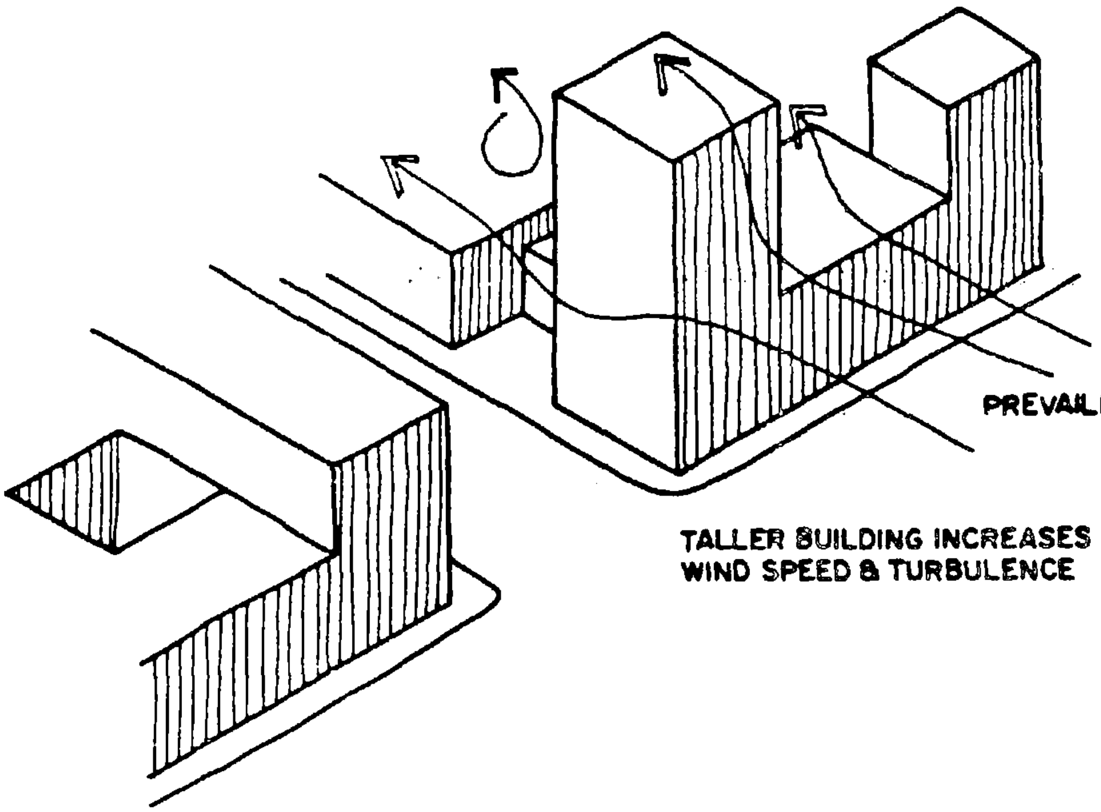

Figure 2.5. Effect of wind on high rises.

CHAPTER 3 - BASE PROTECTION

3.1 Introduction

This chapter discusses problems with base protection, which include camouflage, explosive excavation, mine utilization, field fortifications, and installation physical security. Most of these problems are common to all theaters of operation (TO) and are only slightly changed because of the peculiarities of the region under study. In particular, the lack of water, temperature extremes, and low humidity have little effect on (or affect only indirectly) base protection. However, two dominant characteristics of the region do have an effect: the soil conditions, including dust, and the lack of building materials.

3.2 General

A general rule is that successful camouflage is 80 percent proper siting and 20 percent treatment. In arid regions, featureless or flat terrain and limited vegetation make camouflage of key elements at fixed facilities particularly valuable. (See FM 90-3, Desert Operations.) Dispersing easily identifiable features into irregular or nongeometrical patterns, avoiding open plains, and keying into local natural terrain irregularities -- such as rock outcrops, ditches, and drainageways -- are basic practices that can significantly increase a base's chance of surviving air attacks. When keying camouflage to natural drainage features, however, caution must be exercised since such areas may be subject to flash flooding. Thus, their potential for incorporation into the camouflage plan may be somewhat limited. Since Army stock camouflage items may not be available for rapid deployment, local materials can be used to fabricate acceptable alternatives. In all cases, a total camouflage plan should be addressed on a force and unit basis, not on an item-by-item basis. Best results can be achieved by a small (6- to 10-man) team assigned camouflage responsibility.* Local labor should be used, if at all possible, to construct expendient camouflage measures. Contingency plans should be made ahead of time.

3.3 Explosive Excavation

The need may arise to excavate large soil volumes for tank obstacles, place storage below ground, or emplace field fortifications. The principal problems are (1) emplacing the explosives deep enough to use their full potential, and (2) predicting the resulting crater.

3.3.1 *Emplacement*

The emplacement problem will be difficult in many of the cemented desert soils. Drilling equipment and/or shaped charges offer the only practical

* Wherever the words "man," "men," or their related pronouns appear, either as words or parts of words (other than referring to a specific individual), they have been used for literary purposes and are meant in their generic sense to include both sexes.

solutions. The crater dimensions can be approximated from the curves in Figures 3.1 and 3.2. While these curves are recommended for general use, in the Middle East they will give most accurate results for TNT in dry granular sand and weak rocks, the case for which they were developed.

3.3.2 *Tank Obstacles*

The best explosive excavation system for tank obstacles is a 4-in. plastic pipe buried to about 6-1/2 ft (2 m) and pumped full of slurry explosive. This system can be primed with C-4 on one end, and the resulting linear ditch can run several hundred meters. Two to three hundred is probably practical without additional priming at intervals along the pipe. A system such as a large Ditch Witch or Badger Plow may not be available to emplace pipe, so Figures 3.3 and 3.4 are provided for explosives in boreholes. Note that in addition to the problem of providing enough boreholes, large amounts of explosives are also required.

3.4 Mine Use

Mine warfare has required major engineering and logistical efforts in previous desert combat. FM 90-3 points out that in most cases, desert minefields, because of the terrain, must cover large areas to be effective. Two possible problems that can arise in certain desert terrains and cause difficulty in using mines to prevent intrusion are: (1) certain cemented or gravelly soils will be difficult to dig for underground emplacement of mines, and, when dug, leave an obvious signature; and (2) drifting sands can cover scatterable mines, can cover buried mines too deeply for mine effectiveness, and can expose mines that have been previously buried. No solutions are suggested to these problems.

3.5 Field Fortifications

Command posts and underground bunkers will be difficult to construct due to lack of beams, timbers, and general construction materials. In one of the Sinai campaigns, existing railroads were torn up so that rails and ties could be used to roof bunkers and fighting positions. Full advantage must be taken of expedient items that can be salvaged from existing or demolished buildings in the TO. For the larger structures, such items as rails and railroad crossties, beams, and joists from demolished buildings, etc., may be available. Competition for such salvaged materials should be expected because of the general lack of timber and structural steel.

3.6 Overhead Cover for Prepared Positions

In arid regions there will be few natural materials from which to build overhead cover for prepared fighting positions such as positions for Dragon and Law antitank weapons and two-man fighting positions. Due to the extreme temperatures, it may be just as important for overhead cover to provide shade protection from incoming fire. Dust and blowing sands will be irritating to the troops, may cause damage to the weapons, and can obscure the field of fire during battle. For antitank weapons, the dust stirred up from the backblast

B = Optimum Depth of Burial
V = Apparent Crater Volume
R = Apparent Crater Radius
D = Apparent Crater Depth

Example: For Explosive Charge of 10 KG Buried at 1.3M (B), Crater Depth (D)= 0.95M, Crater Radius (R) = 2.0M, and Crater Volume (V) = $5.3M^3$

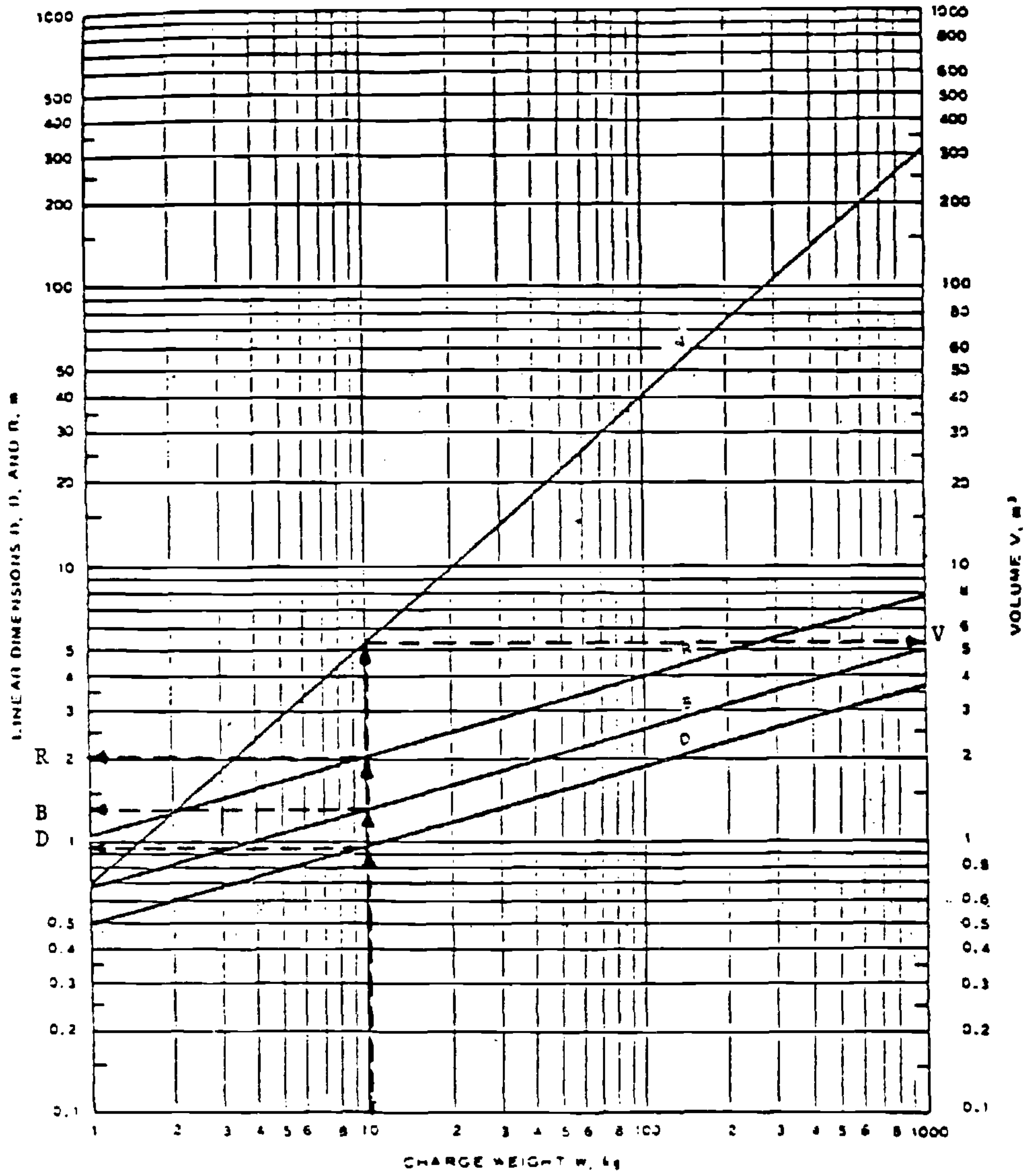

Figure 3.1. Optimum depth of charge burial and crater dimensions for optimally buried charges in dry gravelly sand as functions of charge weight.

B = Optimum Depth of Burial

V = Apparent Crater Volume

R = Apparent Crater Radius

D = Apparent Crater Depth

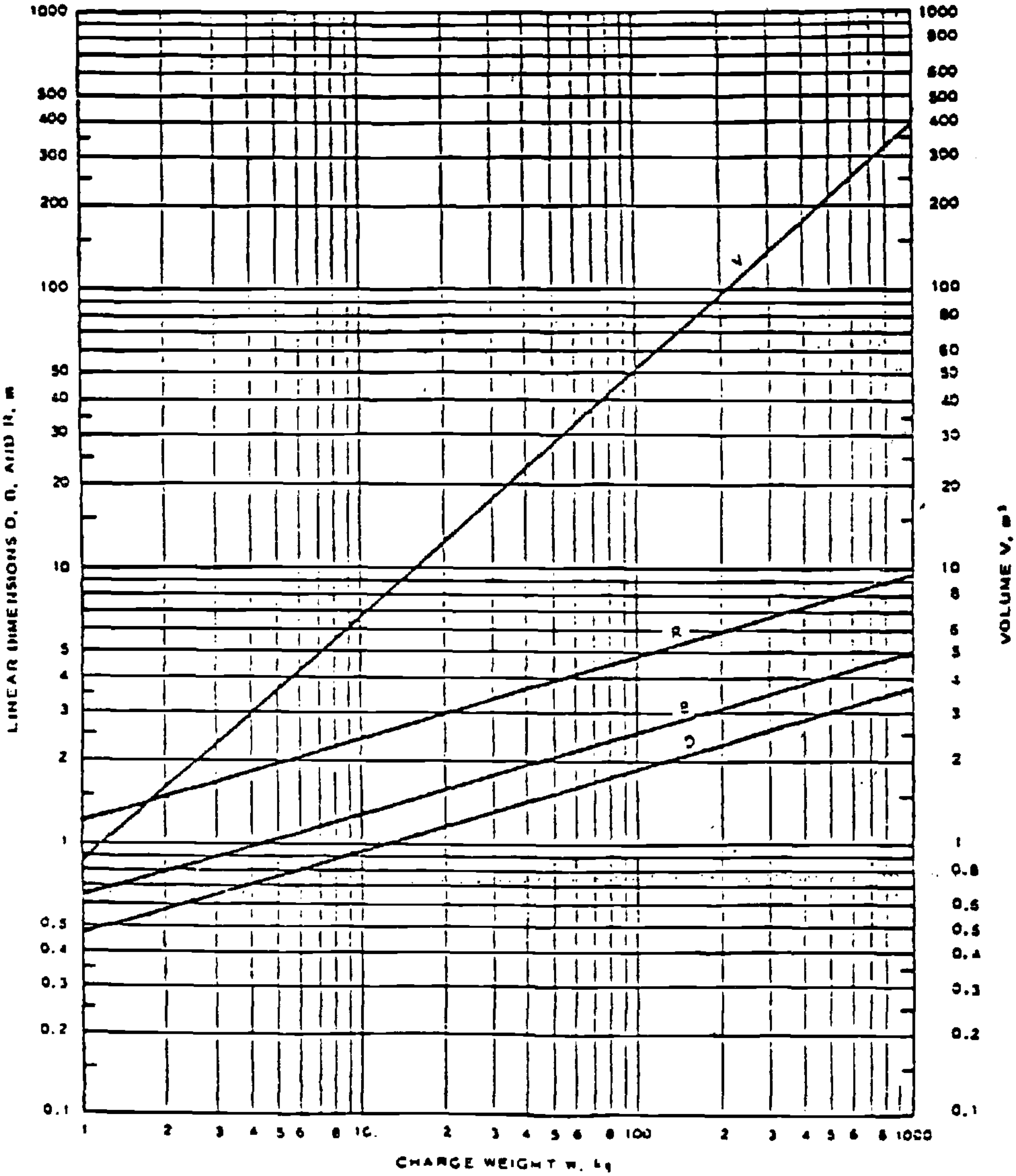

Figure 3.2. Optimum depth of charge burial and crater dimensions for optimally buried charges in weak sandstones and shales as functions of charge weight.

Material	TNT	Charge Wt (lb/hole) Blasting Agent (Slurry)
1. Dry Sand/Weak Rock	100	75
2. Dry Cemented Gravelly Sand	150	110
3. Dry Cemented Sandy Clay	275	175

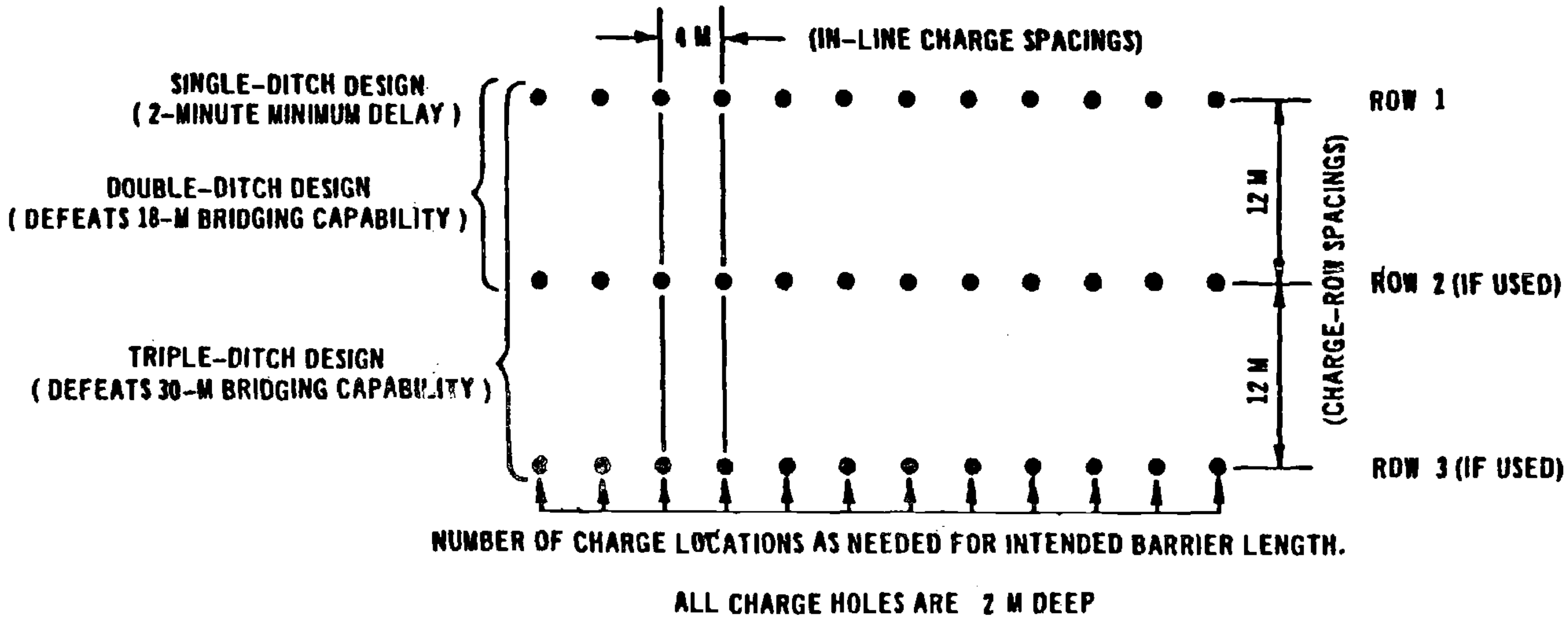

Figure 3.3. Explosive barrier ditching designs (plan view).

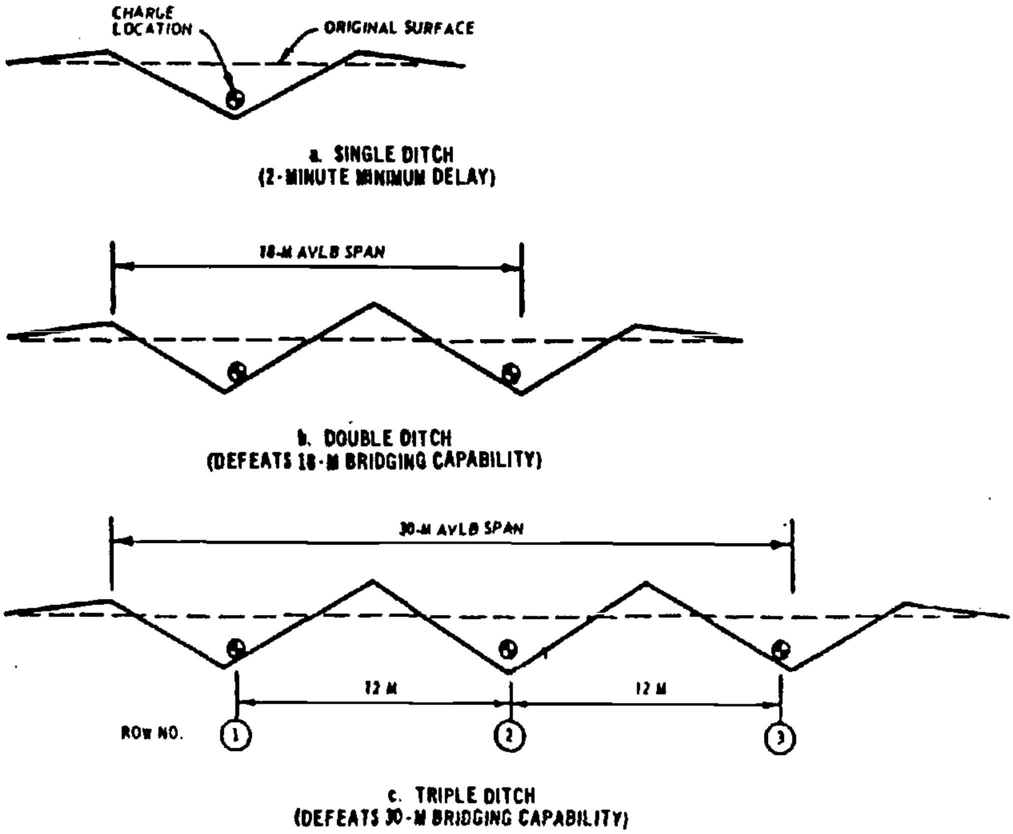

Figure 3.4. Explosive barrier ditch cross sections.

and missile will not only give away the location of the position, but can also decrease the gunner's field of vision to the point where he may lose his target.

3.6.1 *Possible Solutions*

Use tubular sandbags for overhead cover. These sandbags are about 79 in. (200 cm) long and 10 in. (25 cm) wide when empty. When filled and arched they can span a 24-in. (60-cm) wide trench, providing overhead cover for the Dragon and two-man fighting positions shown in TC 77-50, pp 49 and 12, respectively. The tubular sandbag should be filled using soil dug from the bottom of the position. The soil at the ground surface may be too dry for the filled bags to arch properly. The arched bags will provide overhead cover for both shade and protection from fragmentation. This method does not solve the problem of backblast.

3.6.2 *Special Considerations*

Tubular sandbags are used in Germany by the Army and by civilians for flood control. These bags should be considered for inclusion as part of the forces' sandbag supply.

3.7 Construction of Command, Control, and Communications (C^3) Bunkers

Construction of C^3 bunkers at operations bases and strong points using designs presently in Army field manuals requires large quantities of materials (concrete, timber, and corrugated metal) and considerable effort by engineer troops. A force operating in remote and arid regions will have neither the materials nor engineer support to construct C^3 bunkers using designs in the field manuals. Another problem in arid regions is the extreme temperature that, without adequate ventilation, could make staying in the bunker unbearable.

3.7.1 *Possible Solutions*

Use buried frame fabric shelters. These shelters can be fabricated from materials that will be found in built-up areas of the country and materials brought in by the force. The frame for the shelter can be made either from small-diameter (1-1/2- to 2-in.) steel or aluminum pipe connected with pipe fitting or from lumber taken from existing structures. Frame spacing should be a maximum of 30 in. (760 mm) and designed to support 18 to 24 in. (460 to 610 mm) of soil. The fabric cover should be a neoprene-coated nylon fabric, such as T-17 landing membrane, or possibly the fabric from which large water bladders are made. Excavation for the bunker can be done using engineer equipment or explosives. Entranceways should be placed on both ends of the bunker for ventilation. If available, blowers should also be used to increase the ventilation. Approximately 16 in. (410 mm) of soil cover will provide adequate fragmentation protection.

3.7.2 *Special Considerations*

Several frame-fabric shelters are being considered for type classification. These shelters are lightweight, require little shipping space, and can be erected rapidly by the users with engineer support required only for excavation and placement of soil cover. In recent years, these shelters have been used by the Israelis.

3.8 Special Camouflage Problems

3.8.1 *Tracks, Taxiways, Pipelines, and Other Linear Features*

1. Possible solutions. Bury pipes, avoid straight lines, and use thermal blankets and screens to break up lines and patterns of piping. Use adhesives and local soil to match background color. Shadows must be eliminated. Use discipline to curtail tracking. Rake out connecting tracks to camouflage installations. Taxiways can be patterned by use of adhesives and local soils. Special fireproof adhesives are required.

2. Don'ts. Do not employ common adhesives on taxiways. Loose sand and fire from common adhesives are hazards to jet engines.

3. Special considerations. Pipelines, off-road tracks, and taxiways are all highly visible linear signatures and keys to specific target locations. Brush and screens used randomly along pipelines help reduce detectability. Local materials such as canvas, shrimp netting, screen, sheeting, straw,

feathers, steel wool, and glass wool can be used to produce screens by tying them to a mesh base support of wire or cord.

3.8.2 *Electrical Power Generators*

1. Possible solutions. Emplace under cover of buildings. Bury in natural or dug ground cuts. Cover installation with screening. Use thermal blankets and radiation shields between generator and the expected angle of incoming attack aircraft. Distribute generators to avoid regular signature patterns. Employ antiradar screens. Insulate exhaust stacks and hot areas. Bury power cables where possible. Employ decoy thermal sources to destroy ground signature of site. Exhaust hot air and gases into the atmosphere from shielded vents. The detection and identification of generators by thermal devices is a principal threat to site, unit, and activity identification.

2. Don'ts. Do not restrict air flow through generators. Do not exhaust hot air onto objects and terrain (these will become secondary radiators). Do not rely on visual screens to hide from thermal detection. Where possible, avoid open terrain.

3. Special considerations. Use local materials and labor to fabricate needed camouflage. In a thermal region, the main objective is to let heat escape by convection while shielding radiation from detectors. Hot gases are not readily detectable, but surfaces warmer or colder than their backgrounds are. Straw, brush, and old fabrics of various kinds can be used to produce screening.

3.8.3 *Tall Towers and Antennae*

1. Possible solutions. Site tall features with concealment consideration. Employ open-web construction where possible for both towers and antennae. Pattern paint and apply shape distributors in accord with terrain using local brush or similar material. Bury cable to towers (thermal target). Use decoy towers to confuse force identity. Where feasible, use existing tall structures for antennae emplacements.

2. Don'ts. Do not cluster antennae. Do not add edge disruptors to rotating antennae. Do not pattern paint rotating antennae. Color tone antennae to match background terrain, not the sky. Avoid making tracks between guy wire anchor points. Do not add to visual cross section of towers.

3. Special considerations. Antennae on tall towers are easily identified reference points for attack from the air. High winds must be considered for all camouflage measures.

3.8.4 *Individual Buildings and Shelters*

1. Possible solutions. Use existing structures where possible and do not modify their exterior appearance. Disperse new structures, shelters, and tentage in nongeometrical patterns tied into existing terrain features. Bury structures where forced to use open areas. Use adhesive and local soils to tone down exposed surfaces. Conceal shadows and destroy geometric shape of structures by use of screening made from local materials applied to wire-netting base. Especially screen all openings to prevent "black-hole effect."

Extend ground pattern with soil treatments using oils, dark earth, etc. Maintain random road networks. Use decoy structures where appropriate to confuse the attacker and provide false targets. Metal screening can reduce detection by radar. Trash can be used to conceal vital buildings. Screening materials of local nature are available to help in the form of adhesives from milk, soybeans, flour, molasses, etc. Garnish from straw, fabrics, canvas, and trash can also be used. Supporting mesh can be made from materials such as chicken wire and old fish nets.

2. Don'ts. Avoid positions in open-plain areas. Avoid positions on crests or ridges. Do not alter exterior appearance of existing damaged buildings except to tone down. Do not permit traffic and parking near critical buildings or shelters. Do not use open geometric patterns for tents and vans. Keep antennae and other highly identifiable features at a distance from critical headquarters buildings.

3. Special considerations. Use local materials and labor where possible. Basic use of local soil adhered to structures is valuable for tone down. Screens made from straw, brush, rags, or shrimp netting tied to supporting netting are good substitutes for inventory screening. Adhesives can be made from molasses, oil, bituminous emulsions, resins, glues, starches, soybean and milk protein, and flour.

3.8.5 *Open Material Storage Sites and Fuel Storage*

1. Possible solutions. Use natural terrain features and lines to stock stores. Use broken ground, gullies, existing roadsides, and shadows of buildings to disperse supplies so that from a distance they appear as a part of the natural order of things. Employ local materials such as brush, straw, and fabrics to break up linear patterns of stock supplies. Use adhesive and local soils to fabricate screens for covering larger items. Disperse large items consistent with security. Create decoy storage sites in open areas using the usual military squares and piles of trash. Patterns can be created on the ground in arid areas with oil or other dark colorants to simulate stocks of stores by representing their shadow. Use existing buildings where possible to provide both concealment and cover. Where possible, employ existing fuel storage facilities. Bury bladders, keeping the shape of revetments irregular. Disperse into irregular geometric patterns. Use screening to cover shadow line and employ local soil as colorant. Vertical tanks should be emplaced against rocky outcrops or buried. Screening trash and treated paper can simulate rocky backgrounds. Thermal insulation (such as foam) on paper or fabric covering can reduce infrared detection when used over tanks and bladders. Screens of patterned canvas are suitable in desert areas if wind load is taken into account.

2. Don'ts. Avoid stereotyped geometric ground patterns in establishing storage sites. Avoid use of open-plain areas. Avoid creating more roads than necessary.

3. Special considerations. Material storage is an inviting target. While moderately increasing inventory and controlling access are valuable techniques, the use of passive measures to protect stores is worth the cost. Take precautions when using natural drainage features since they may be subject to flash flooding.

3.9 Placement of Mines in Shifting Sands

Placement of mines in areas known to have shifting sands may result in buried mines being uncovered, thus making it easier for others to detect mine locations. Mines placed in wadis or other intermittent water courses may be dislocated or even detonated when rains fill these channels. Burial of mines in desert plateau areas where the ground is flat and stony may prove difficult. (Information source, Landmine and Countermine Warfare, North Africa, 1940-1943 [Engineer Agency for Resources Inventories, June 1972].) Possible solutions include minefield locations carefully selected with full knowledge of the possible adverse environmental impacts.

3.10 Mine Removal

Featureless terrain without easily locatable landmarks makes finding and removing friendly minefields difficult. Possible solutions include starting points located and recorded by taking azimuths and distances from more than one landmark and ensuring the landmarks are the most permanent terrain feature available.

3.11 Effects of Temperature Extremes on Mines

Extreme temperatures and abrupt daily temperature changes can affect the functioning of buried mines and create increased dangers from mine detonations in open-storage dump areas. Surface laying of mines can increase the temperature extremes that mines are subject to. (Information source, Landmine and Countermine Warfare, North Africa, 1940-1943 [Engineer Agency for Resource Inventories, June 1972].)

3.11.1 *Possible Solutions*

This problem was noted from World War II experiences in North Africa. Current landmine manuals indicate that U.S. landmines are built to function in temperatures as high as 125°F (51°C) and may be stored in areas up to 160°F (70°C). Little information was found on what has been done to improve the ability of mines to function in these extreme temperatures since World War II. However, mines placed in a desert environment may reach temperatures greater than 150°F (65°C) due to solar heating, especially if they are surface laid.

3.11.2 *Dont's*

Do not store mines in enclosed buildings where temperatures might exceed 150°F (65°C).

3.12 Mine Detector AN-PRS-7

The current nonmetallic mine detector, AN-PRS-7, does not function well in soils with an extremely low moisture content. This problem was noted during the clearance of mines at the Suez Canal; however, no practical solution is known.

3.13 Visual Detection of Minefield Intruders

Visual detection of minefield intruders will be hindered by afternoon haze in deserts on clear, hot days. Between 1500 and 1700 hours, haze may limit visibility close to the ground to approximately 200 yd. (Information source, Landmine and Countermine Warfare, North Africa, 1940-1943 [Engineer Agency for Resources Inventories, June 1972].) Use sentry dogs or other sensors to detect intruders during periods when haze limits ground visibility.

3.14 Effect of Extreme Environment on Sensors

Extreme environmental factors such as high temperatures, haze, winds, and sandstorms can degrade sensor performance by creating excessively high false alarm rates, reducing effective detection ranges, and causing mechanical and electronic component failures. Sandstorms could even bury the sensor completely. Infrared sensors will be adversely affected by haze, ground fog, or sandstorms. Detection capabilities during high temperatures will be reduced because the temperature differentials between the target and the background will be small. Extreme temperature fluctuations will make it difficult to adjust the dynamic range of infrared equipment. The radar's effectiveness will be reduced during sandstorms due to reduced effective ranges and clogging of moving components (such as sweeping dishes) with sand. Acoustic sensors will be adversely affected by background noises created by high winds and blowing sand, which can clog or abrade microphones. Seismic sensors will be difficult to emplace and be less sensitive where bedrock is exposed. To solve such difficulties, electronic components should be shielded from the sun and cooled. Verifying sensors should be used to reduce false alarm rates. Low-frequency radars should be used during sandstorms (up to 1.0 GHz). When possible, alter terrain to extend effective ranges of sensors.

CHAPTER 4 - ELECTRIC POWER GENERATION, DISTRIBUTION, AND GROUNDING: SWA BASE CAMPS

4.1 Introduction

This chapter considers aspects of electric power generation and distribution that present significant challenges to Army deployment and operations in SWA environments. Field engineers can use this information as a guide to specific problems with electric distribution systems in a desert environment, and as an outline of typical distribution/generation equipment expected to be used. The information collected here is applicable to Army base camps or logistic complexes that may be built in areas forward of designated, prestocked, intermediate staging bases (ISBs), and therefore to any region of SWA.

This chapter is based on the following assumptions:

1. Base camps will be developed in an arid, sandy, and hot environment with high winds.

2. Logistics and re-supply capability will be limited.

3. Host nation power will be either unavailable or incompatible with power demand.

4. Use of organic TOE generators for more than a few weeks will not be acceptable because of troop unit operational degradation.

5. Engineer support will be overtasked; shortages of experienced electric distribution specialists are expected.

6. Base camps may have to be relocated for tactical or logistical reasons.

A very simplified electric distribution system is required. A more elaborate or extensive system would not be feasible to construct or maintain using presently available distribution equipment/materials. A limited and simplified power distribution system would be compatible with currently considered levels of austerity within the base camp. As an example of electric utilities' austerity, recent findings indicate that the average electric power available at typical OCONUS Army bases is between 0.75 and 1.6 kW per man. Base camp planning for SWA forward areas consider power levels of .10 to .20 kW per man. Certain ISB locations provide for total electric consumption of 5 MW, whereas base camps will provide about 1 MW for equivalent size units.

Other considerations in this chapter are reliance on field-expedient measures and common sense, along with tactical considerations that may become important at later phases of base camp operation. In most scenarios which include a base camp, both air superiority and positive region control are assumed. This assumption may not hold for extended periods.

The electric power distribution system considered here is intended to support a typical 1000-man base camp. Although larger base sizes of 3000- and

5000-man capacity are being planned, it is recommended, for simplicity and least demand on electric distribution expertise, that the 1000-man distribution network be duplicated as necessary to accommodate these larger camps. Extension of completely centralized distribution (i.e., using larger generators and longer trunk lines) would necessitate use of higher voltages, additional types of equipment, and personnel with more expertise in distribution.

At this stage in the planning for base camp development, exact -- or even approximate -- power demand profiles have not been specified because of ongoing revisions in Army Facility Component System (AFCS) facilities for use in SWA. Since any distribution system must be tailored to match a known demand, specific recommendations for generation/distribution equipment size are not included here. However, examples of typical distribution systems, and those proposed by other studies, are included. General principles for using these systems are considered.

4.2 Generation

Army standard tactical generators (TGs) are recommended for base camp use during initial and temporary phases of base camp occupation. The DOD's Mobile Electric Power Program (MEPP) monitors development, standardization, and procurement of these units. Particularly applicable to base camp distribution are the 60 kW, 100 kW, and 200 kW sizes. The entire line of available TGs is described in MIL-STD-633E. Recent base development studies* have incorporated the low voltage 100 kW TG with parallel operation to meet austere 1000-man camp demands of 100 kW or 200 kW. The 100-kW diesel generator produces 120/208 V 3 ϕ 4 wire or 240/416 V, 3 ϕ 4 wire electric power. Its specified mean time between failures (MTBF) is 24 days, which means a back-up generator is needed on site. For best reliability, the older TG should be used as the back-up. Principles of TG selection and matching of generator size to specific load balancing configurations are explained in TM 5-766 and TM 5-765.

TG sets are designed with an integral housing to permit free-standing operation in traditional environments. However, extended operation of TGs in the harsh desert environment must be approached with provisions for additional protection from intense solar radiation, wind blown dust, and encroaching sand dunes. Field experience has shown that with additional environmental protection, TGs can perform satisfactorily in desert areas. These generators have been known to continue satisfactory operation, though at reduced power levels, when so protected -- even at ambient air temperatures over 125°F (52°C).

Figure 4.1 is an example of a portable TG protective structure. This is used for the smaller 15-kW and 30-kW TGs. For larger TGs, it is recommended that a sandbag walled structure be partially buried in the soil. The floor should be reinforced with a layer of sandbags or 4 in. (100 mm) of concrete, if available, and provide for TG tiedowns. The structure must allow 3 to 4 ft (0.91 to 1.22 m) of ventilation space around all generator surfaces, except

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* Staff Study, Army Facility Component System (416th Engineer Command, 10 July 1981); Value Engineering Study, AFCS (416th Engineer Command, 25 March 1981).

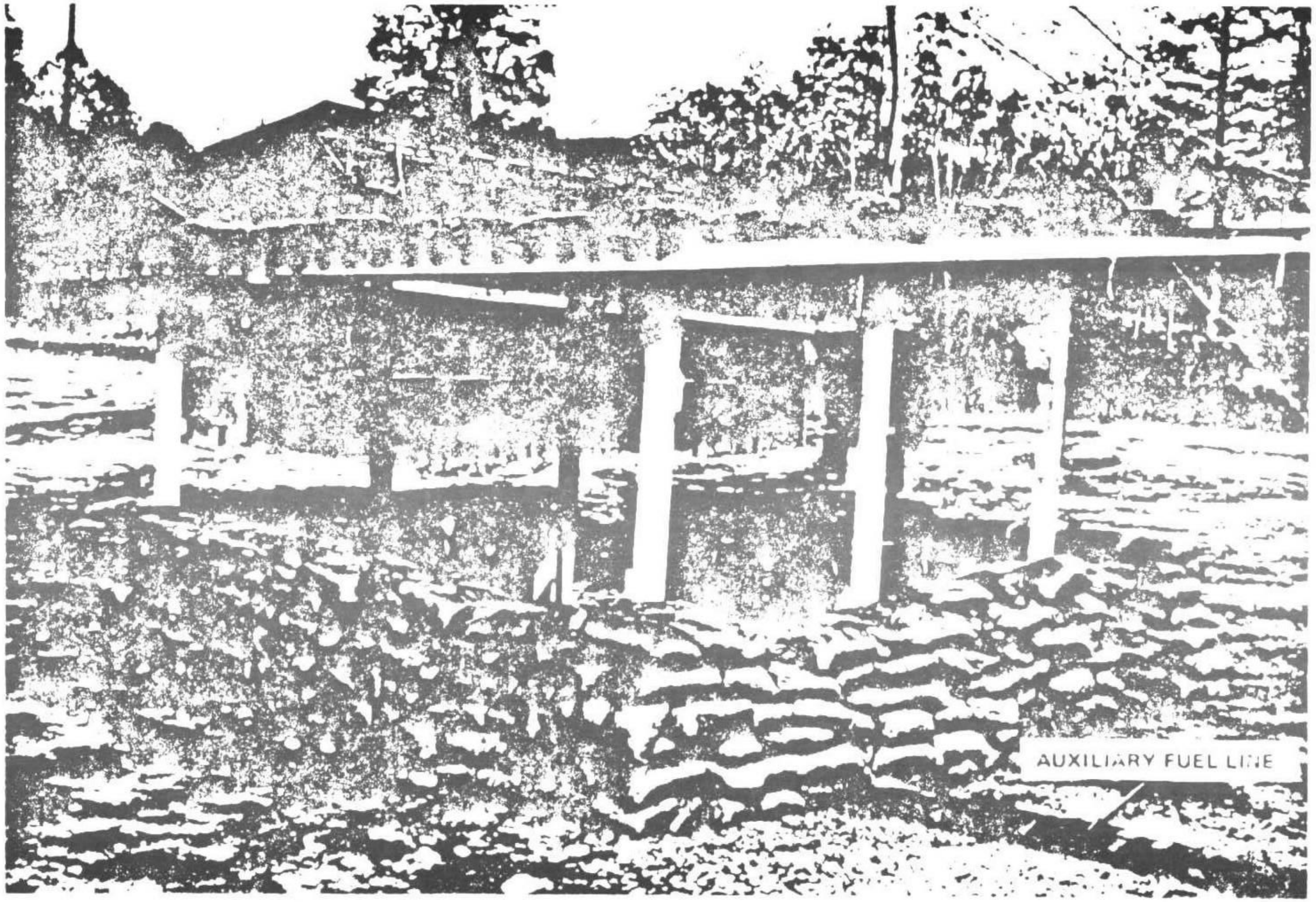


Figure 4.1. Typical semipermanent portable generator site.

the bottom. Where wood and roofing materials are not available, a pole and canvas system can be erected over the walls to provide a sun shade. A 2- to 3-ft (0.6096- to 0.9144-m) ventilation space must be provided between the wall top and canvas. Such a shelter is shown in Figure 4.2. Note that this arrangement can be adapted for evaporative cooling of radiator ventilation air, if water is available. The pole and canvas arrangement baffles the ventilation air and removes some sand and dust particles.

Siting of the TGs or TG shelter is also important in reducing environmental effects and in making the general distribution system as effective as possible. Factors to consider in TG siting include the following:

1. The demand for electric current over relatively long distribution cables produces significant voltage drops, which dictate the use of larger cables or transformers between the generator and load. To reduce the need for transformers in low voltage systems, generators should be placed as close as practicable to the largest power demand facilities. In austere base camps, these large power demands usually come from the dispensary and mess halls.

2. Existing terrain features and drainage contours should be used to minimize exposure of units to prevailing winds. Winds in most of SWA blow from either the northwest or southeast.

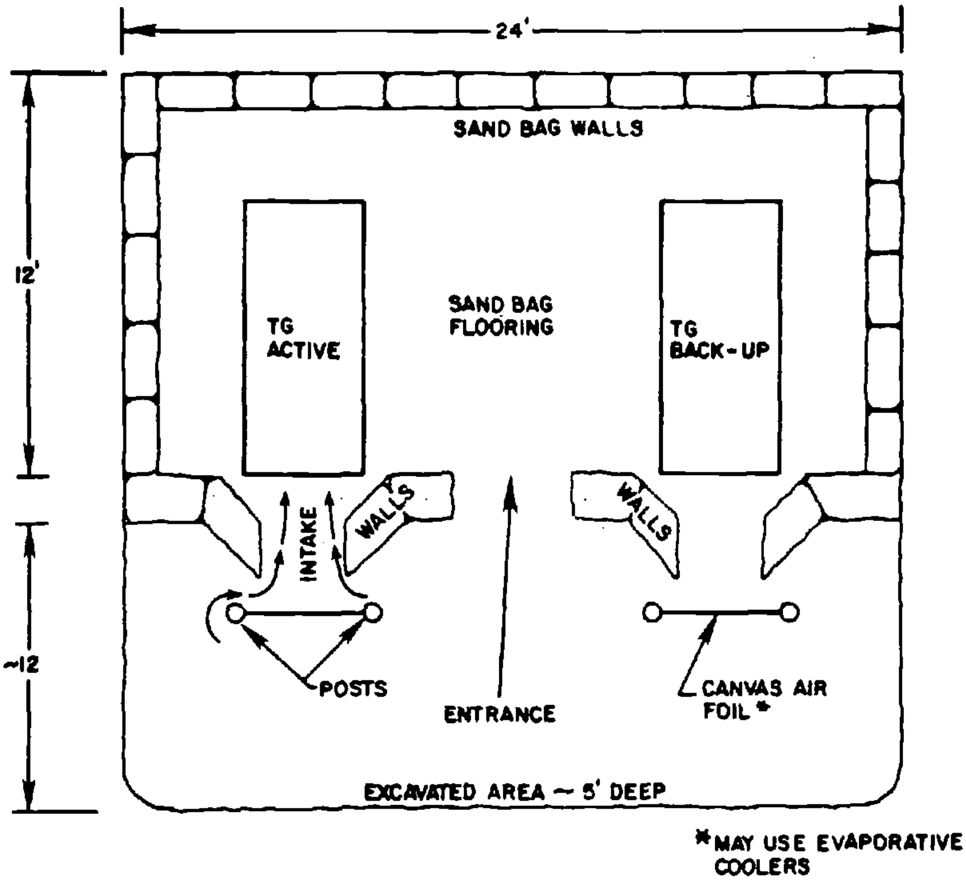
3. It will be easier to ground the generator if the TG is placed near natural or constructed water sources (i.e., near high water table, underground streams or piping systems, and near waste water disposal sinks). (See Section 4.4.)

Where multiple TGs are to be used in parallel or separately, on-line generators should be sheltered separately to minimize overheating potential. Backup generators used as standby may be sheltered with an on-line TG. Due to large amounts of heat given off by the generators, TGs should not be placed downwind of other operating generator units. It should be remembered that TGs are not designed for indoor operation, and should not be housed in a completely enclosed facility. The shelters described above are intended for use as a sunshade and windbreak.

Other options may become necessary in base camp power generation. Figure 4.3 shows an exhaust muffler used by several on-line generators. The exhaust from the TG shelter is piped into underground fuel drums and finally expelled above ground into a water-filled drum. A larger body of water is normally recommended where water is plentiful. The water level must not be higher than the generator set. This muffler system should be at least 25 ft (6.35 m) from the generator to normalize back pressure. Additionally, the muffler intake and exhaust pipe should be the same size and matched in cross-sectional area to the generator's exhaust pipes.

This muffler system and subsurface generator shelter significantly reduce noise and heat signature emissions, a drawback to conventionally emplaced TGs in base camps.

When experienced generation/distribution personnel are not available for extended periods, it is essential that generators (particularly those in



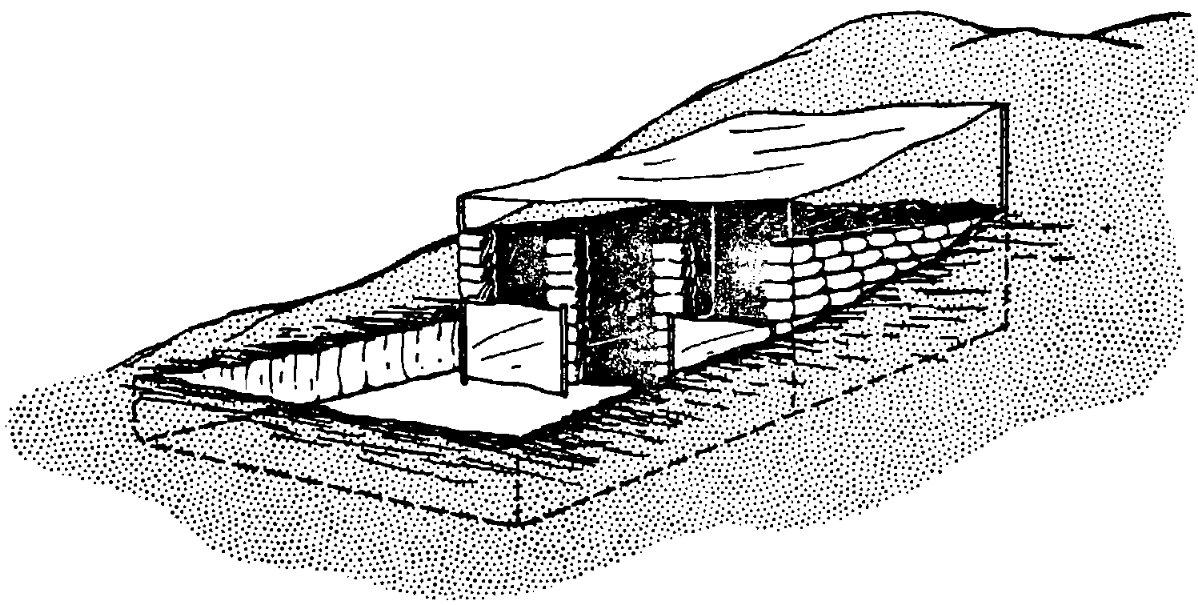
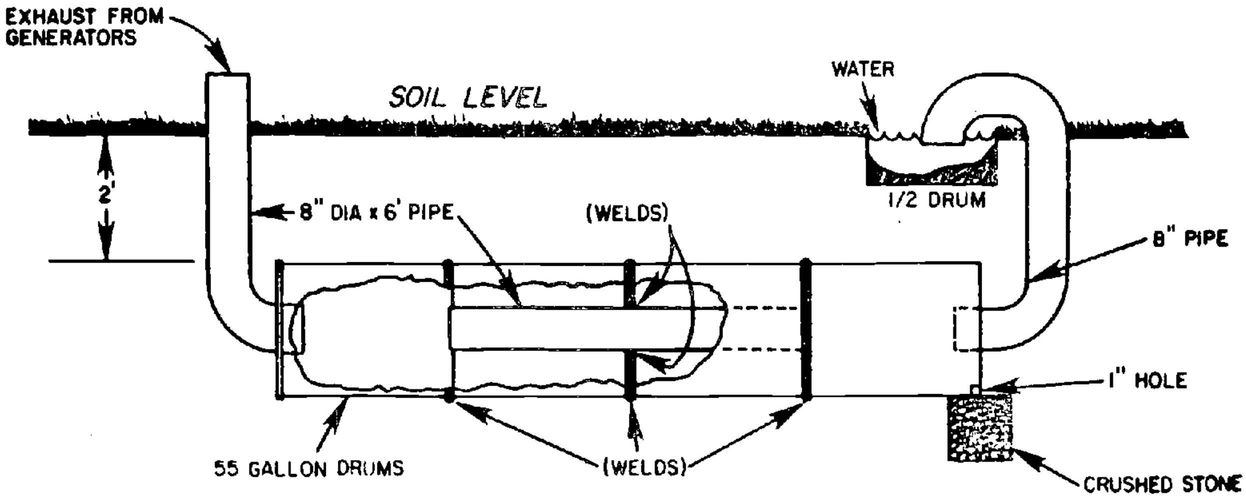


Figure 4.2. Expedient TG sunshade and windbreak.



EXPEDIENT NOISE MUFFLER AND EXHAUST SMOKE REDUCER.

Figure 4.3 Underground muffler.

parallel configurations) be equipped with appropriate power leveling governors and voltage regulators. This equipment allows startup, load transfer, and shutdown of generators with a minimum of personnel expertise and generator adjustments. The Woodward governor and Basler voltage regulator have been used reliably for this. Note, however, that compatible governing and regulating equipment to insure most efficient operation may not automatically be shipped with the TG. It must be specified or procured separately. Particular attention should be given to proper connection and adjustment when paralleling precise power generators.

For operations in extremely hot regions, additional radiator capacity can be obtained by using add-on cooling towers (for larger TGs) or add-on radiator extenders. Because Army generators have not generally been employed in extensive desert operations, these add-on devices are not commonly used. They are available, however, and have worked well in allowing continued operation of TG above its rated ambient temperature (normally 125°F [52°C]). Where water sources are available, evaporative cooling of TG ventilation air may be feasible. This method works well in hot and dry weather. Do not attempt to cool TG radiators by direct application of water to the radiator. In a very short time, the radiator will be damaged because of scale and oxide formations on the metal surfaces.

Another important aspect of power generation is TG behavior at ambient temperatures above the generator rating. At elevated temperatures, hot generator parts less efficiently convert mechanical power from the TG diesel engine to electric power. Therefore, TG output will be somewhat degraded above its rated temperature (ambient 125°F [52°C]). However, a TG will continue to operate until one of several protective devices is automatically triggered. Cut-off switches include:

1. High water temperature

2. High oil temperature

3. Low fuel level

4. Low oil pressure

5. High alternator temperature.

Exceeded safety levels of any of these switches will shut down the diesel engine. In mission-critical situations, these safety cut-offs can normally be manually overridden using the procedures in the TG operator's manual. However, it is recommended that low oil pressure and high alternator temperature cut-offs never be overridden. These two safety circuits prevent irreparable damage to the set. As noted earlier, TGs can continue operation above 125°F (52°C) ambient when adequate shelter and cooling techniques are used. Other protective devices on TGs deal with improper paralleling, poor load balancing, and distribution system short-circuiting. These cut-offs are not directly related to temperature.

The newer TGs are designed to operate in sandy and dusty environments. However, extended and continuous operation in conditions of wind driven dust and high temperatures can be expected to reduce TG MTBF. Older generator sets were often fielded with slip rings or brushes and unsealed generator housings. These units are particularly susceptible to premature failure because dust and sand accelerate wear to these components. At higher temperature operation, seals and lubrication boots tend to relax, allowing entry of dust or sand to bearings and rotating windings.

To prevent wear, personnel must maintain and clean TGs carefully. SWA contingency units should insure that adequate replacement parts are available for generator items particularly susceptible to sand and dust abrasion. Older units should be used as backup generators; their on-line use must be minimized during extremely dusty and windy periods. Use of low-residue cleaning solvents and compressed air on nonmoving parts is recommended for cleaning of TG components. Do not apply oil or grease to abrading surfaces because this will attract and bind more sand to the treated areas. Most importantly, generator operators and maintenance personnel must anticipate potential problems due to sand and dust.

4.3 Distribution

It is recommended that underground (UGD) and/or on-the-ground (OGD) distribution of electric power be used exclusively for Army base camps constructed in SWA. This recommendation is based on several considerations, two driving ones being construction/maintenance costs and timeliness of emplacement.

In most commercial applications, overhead distribution (OHD) is less expensive to install and maintain than the conventional UGD due to ample supplies of poles and easy access to the wires. However, Army units in SWA generally will not be able to take advantage of the economies associated with

OHD. Additionally, base camp time phasing may preclude the time-consuming construction of OHD and allow only OGD initially. The following considerations should be taken into account:

1. Poles and wood for crossarms would overtask logistics/transport systems because these items are not locally available in SWA.

2. Poles and wood structures warp and become brittle when exposed unprotected to dry and hot desert climates.

3. Use of poles will require special equipment and techniques for setting and for stringing conductors.

4. OHD systems expose conductors to intense solar radiation, high temperatures, abrasive blowing sands, and wind. These cause both reduced conductor rating and increased maintenance/repair costs.

5. Construction of OHD requires more on-site expertise than UGD.

6. OHD requires more construction time and labor.

7. OHD is more susceptible to enemy actions.

Although OHD systems are used in SWA, extensive expenditures of money, manpower, and time are involved in both their construction and maintenance. In general, Army engineers will not have the construction resources for OHD systems.

A simplified UGD is recommended for use at base camps because it eliminates many of the problems noted above. With this system, the conduits, manholes, and vaults are eliminated. Instead, the primary and secondary cables are buried directly in the ground, and the transformers and junction boxes are housed in enclosures above the ground. It should be noted, however, that this simplified UGD is not readily adaptable to distribution system growth or extension. Both the conventional UGD and OHD are adaptable to service extension.

The nature of deployment into a base camp may dictate that electric utilities be provided on short notice. In this case, OGD can be allowed. This method provides expedient layout and recovery of the distribution system and does not become as labor-intensive as UGD. For extended base camp operations, however, it is recommended that OGD be protected from sunlight and blowing sands as much as practicable. Conductors that cross roads or heavily traveled lanes must be routed underground. A recommended technique for crossing roads is shown in Figure 4.4. This sketch shows cables on either side of the road protected by sandbags from sun, wind, and foot movement. Sandbag protection is essential for OGD and can be used to help stabilize trenches for UGD. Schedule 40 polyvinyl chloride (PVC) conduit with a diameter of 3 to 4 in. (76 to 102 mm) is suitable for expedient raceways under roads. In applications where excessively high roadway temperatures are expected, schedule 80 chlorinated PVC (CPVC) should be used, if available. In temperatures over 90°F (32°C), there should be no more than three per raceway to prevent unnecessary cable derating. When used as a raceway, conduit must also have at least 60 percent air space in conduit cross-section.

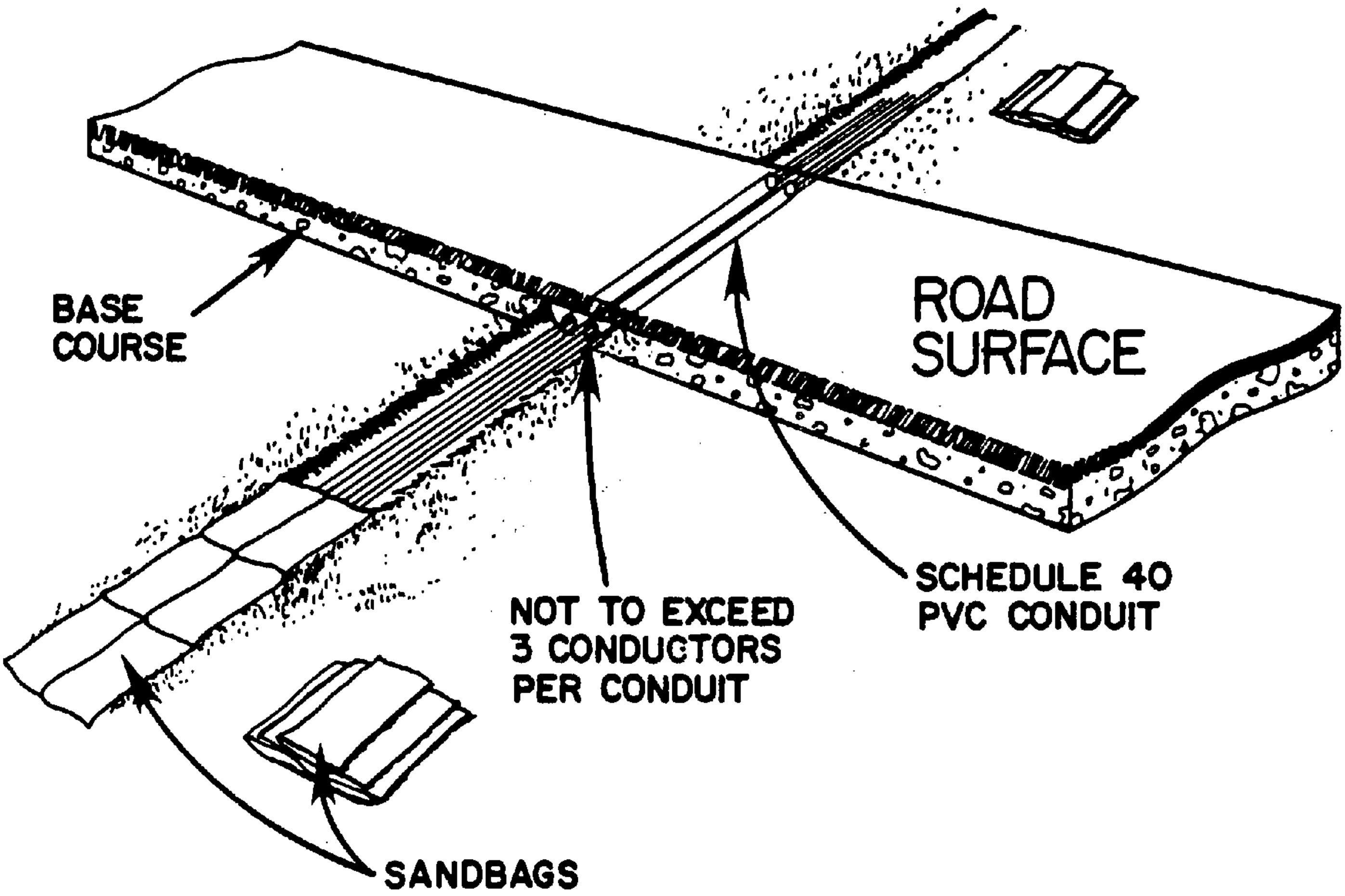


Figure 4.4. Typical expedient road crossing, UGD.

In particularly hot areas, or where OGD may present certain safety hazards, the simplified distribution system should be buried in a trench. Figure 4.5 depicts a typical trench raceway. The cables must be buried at a depth of at least 18 in. (460 mm) to take advantage of reduced soil temperature. Backfilling trenches with sandbags (never rocky soil) is recommended, followed by loose area topsoil. Other on-hand materials such as boards, logs, and angle iron, could also be used to protect OGD and UGD from penetrations and breakage.

Planning guidance for use of transformers, bus bars, junction boxes, pedestals, voltage sectionalizers, and cable types is given in TM 5-684, TM 5-765, TM 5-766, and Corps of Engineers Guide Specification CE 303.06. For base camp applications, the totally enclosed non-ventilated (TENV) dry transformer is recommended where high temperatures and blowing dust are prevalent. Dry transformers are generally lighter than the oil-insulated type,

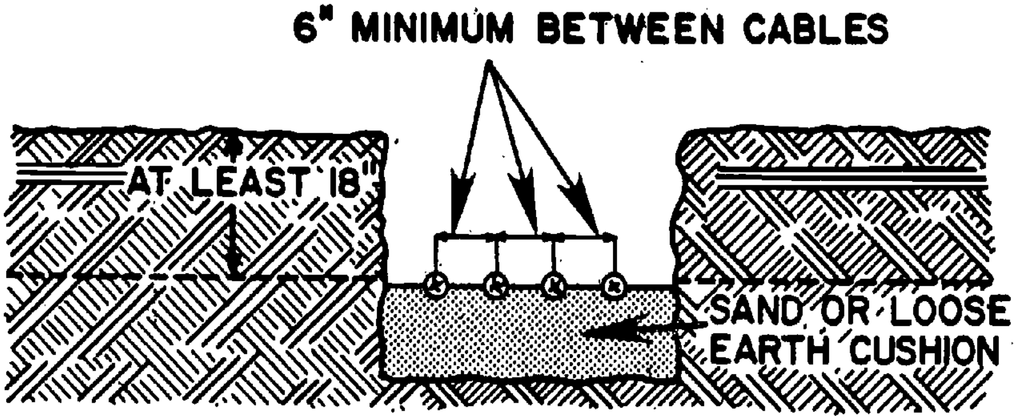


Figure 4.5. Direct burial of cable showing proper cable spacing and depth. (From Electric Power Generation in the Field, FM 20-31)

and are essentially maintenance-free. To reduce transformer derating at high temperatures, a sunshade and reflective painting on transformer surfaces should be provided.

In general, an overheating transformer will be too hot to touch with bare hands. When overheating occurs, the power load through the transformer must be reduced. Continued use at overheated conditions will permanently damage the windings and insulation materials. The Navy, in response to U.S. Marine Corps (USMC) demand for a rapidly installed distribution system, has recently developed a family of copper cable assemblies and skid-mounted distribution panels designed for use with Mobile Electric Power's (MEP) 15 kW, 30 kW, and 100 kW low-voltage TGs.

In general, the Army's distribution and generation equipment is intended to readily accept only copper wire cables. A recent base development study has proposed the use of aluminum-stranded conductors instead of copper conductors to reduce transportation/logistics loads.* An electrically equivalent amount of aluminum wire weighs only half as much as copper wire. If large amounts of distribution cable were needed for base camp utilities, then the weight savings with aluminum cable might justify its use. Also, relatively new processes in aluminum alloy applications to cable have eliminated much of the "creep" and "loosening" tendency so characteristic of earlier aluminum cables. Yet the use of aluminum cable in the construction of a distribution system matched to commonly available Army equipment and electric parts requires considerably more expertise and supervision to insure proper assembly. Particularly in the corrosive soils of many SWA regions, improper connections of copper to aluminum will result in system failures and safety

* Staff Study, Army Facility Component System (416th Engineer Command, 10 July 1981).

hazards. It is therefore recommended that copper conductors be used for base camp power distribution.

The recommended cable types for base camp use are those meeting Underwriters Laboratories (UL) requirements for type Underground Service Entrance (USE). This cable is designed for underground applications in wet or dry soil. The insulation is vulcanized or chemically cross-linked polyethylene rated to 194°F (90°C) at continuous operation. Stranded copper conductors in this type of cable are recommended to provide better cable flexibility and re-use potentials (as opposed to single-strand conductors). Where these cables are intended for extended OGD use, it is recommended that jacketed concentric neutral conductors be used. These will provide additional system safety if the cable is broken by rodents, or by personnel or vehicular movements. Typical wire sizes expected for base camp use are #4, #6, and #8 American Wire Gauge (AWG) copper-stranded USE. The use of corrosion-resistant disconnect/plug-in type cable connectors is recommended (particularly for OGD) to facilitate both repair and recovery.

Although this cable's insulation is rated up to 194°F (90°C), the cable's current-carrying ability, or ampacity, begins derating at an ambient air temperaturre of 86°F (30°C). This is because the current in the cable generates its own heat in addition to heat absorbed from the environment. Tables 4.1 through 4.4 give ampacity derating data for typical distribution cables. These tables show that at hot desert temperatures, the allowed current load is reduced to about 65 percent of the allowed current at 86°F (30°C). Neglect of this derating scheme at high ambient temperatures will compromise the distribution cable reliability, and can directly lead to both fire and safety hazards. Do not overload conductors. Normally, larger conductors can be installed to handle larger currents at high temperatures. Additionally, in low-voltage systems, larger conductors will be necessary to prevent excessive voltage drops for cables longer than a few hundred feet. In general, voltage drops of between 5 percent and 10 percent are acceptable. For example, allowing 10 percent voltage drop and using 3 ϕ 4 wire 120/208 V system, a 10-kW load using #8 AWG stranded copper can be placed a maximum of 700 ft (213.4 m) from the generator; #6 AWG allows a maximum run of 1100 ft (335.3 m). Other voltage drop configurations are discussed in detail in TM 5-765.

Figures 4.6 through 4.8 are examples of conductor layout patterns that may be adopted for base camp use. These examples are presented only to illustrate "order of magnitude" distribution system sophistication (or simplicity). A dispersed and nonlinear approach to the 1000-man base camp is shown in Figure 4.6; Table 4.5 gives facility power loads. No lighting is supplied to troop barracks, and other facilities are electrically austere. This system uses low-voltage and one 100 kW TG with one 100 kW TG standby. A more typical and slightly less austere base camp is outlined in Figure 4.7; the legend for the figure is in Table 4.6. This 1000-man base camp also provides no lighting to enlisted troop areas. In most base camp developments, these troop areas may initially be a "tent city" with improved levels of electric power becoming available as the camp moves into temporary construction phases. Figure 4.8 illustrates a typical "generic" layout which includes some higher voltage distribution to outlying areas. For this layout, dry transformers rated at 5 kVA are used to step up to and down from a 2400-V transmission line voltage.

Table 4.1

Allowable Ampacities of Insulated Conductors
Rated 0-2000 Volts, 60 to 90°C: Not More Than Three Conductors
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Not More Than Three Conductors in Raceway or Cable or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

Size	Temperature Rating of Conductor. See Table 310-13								Size
	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	
AWG MCM	TYPES RUW, T, TW, UF	TYPES FEPW, RH, RHW, RUH, THW, THWN, XHHW, USE, ZW	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †FEP, †FEPB, †RHH, †THHN, †XHHW*	TYPES RUW, T, TW, UF	TYPES RH, RHW, RUH, THW, THWN, XHHW, USE	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †RHH, †THHN, †XHHW*	AWG MCM
	COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM				
18	....	....	....	21	....	....	....	....	....
16	....	....	22	22	....	....	....	....	....
14	15	15	25	25	....	....	....	....	....
12	20	20	30	30	15	15	25	25	12
10	30	30	40	40	25	25	30	30	10
8	40	45	50	50	30	40	40	40	8
6	55	65	70	70	40	50	55	55	6
4	70	85	90	90	55	65	70	70	4
3	80	100	105	105	65	75	80	80	3
2	95	115	120	120	75	90	95	95	2
1	110	130	140	140	85	100	110	110	1
0	125	150	155	155	100	120	125	125	0
00	145	175	185	185	115	135	145	145	00
000	165	200	210	210	130	155	165	165	000
0000	195	230	235	235	155	180	185	185	0000
250	215	255	270	270	170	205	215	215	250
300	240	285	300	300	190	230	240	240	300
350	260	310	325	325	210	250	260	260	350
400	280	335	360	360	225	270	290	290	400
500	320	380	405	405	260	310	330	330	500
600	355	420	455	455	285	340	370	370	600
700	385	460	490	490	310	375	395	395	700
750	400	475	500	500	320	385	405	405	750
800	410	490	515	515	330	395	415	415	800
900	435	520	555	555	355	425	455	455	900
1000	455	545	585	585	375	445	480	480	1000
1250	495	590	645	645	405	485	530	530	1250
1500	520	625	700	700	435	520	580	580	1500
1750	545	650	735	735	455	545	615	615	1750
2000	560	665	775	775	470	560	650	650	2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.								Ambient Temp. °F
31-40	.82	.88	.90	.91	.82	.88	.90	.91	86-104
41-50	.58	.75	.80	.82	.58	.75	.80	.82	105-122
51-60	....	.58	.67	.71	....	.58	.67	.71	123-141
61-70	....	.35	.52	.58	....	.35	.52	.58	142-158
71-80	....	....	.30	.41	....	....	.30	.41	159-176

† The load current rating and the overcurrent protection for these conductors shall not exceed 15 amperes for 14 AWG, 20 amperes for 12 AWG, and 30 amperes for 10 AWG copper; or 15 amperes for 12 AWG and 25 amperes for 10 AWG aluminum and copper-clad aluminum.

* For dry locations only. See 75°C column for wet locations.

Table 4.2

Allowable Ampacities of Insulated Conductors
Rated 0-2000 Volts, 60 to 90°C: Single Conductors
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Single conductors in free air, based on ambient temperature of 30°C (86°F).

Size	Temperature Rating of Conductor. See Table 310-13								Size
	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	
AWG MCM	TYPES RUW, T, TW	TYPES FEPW, RH, RHW, RUH, THW, THWN, XHHW, ZW	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †FEP, †FEPB, †RHH, †THHN, †XHHW*	TYPES RUW, T, TW	TYPES RH, RHW, RUH, THW, THWN, XHHW	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †RHH, †THHN, †XHHW*	AWG MCM
	COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM				
18	....	....	....	25	....	....	....	....	....
16	....	....	27	27	....	....	....	....	....
14	20	20	30	30	....	....	....	....	....
12	25	25	40	40	20	20	30	30	12
10	40	40	55	55	30	30	45	45	10
8	55	65	70	70	45	55	55	55	8
6	80	95	100	100	60	75	80	80	6
4	105	125	135	135	80	100	105	105	4
3	120	145	155	155	95	115	120	120	3
2	140	170	180	180	110	135	140	140	2
1	165	195	210	210	130	155	165	165	1
0	195	230	245	245	150	180	190	190	0
00	225	265	285	285	175	210	220	220	00
000	260	310	330	330	200	240	255	255	000
0000	300	360	385	385	230	280	300	300	0000
250	340	405	425	425	265	315	330	330	250
300	375	445	480	480	290	350	375	375	300
350	420	505	530	530	330	395	415	415	350
400	455	545	575	575	355	425	450	450	400
500	515	620	660	660	405	485	515	515	500
600	575	690	740	740	455	545	585	585	600
700	630	755	815	815	500	595	645	645	700
750	655	785	845	845	515	620	670	670	750
800	680	815	880	880	535	645	695	695	800
900	730	870	940	940	580	700	750	750	900
1000	780	935	1000	1000	625	750	800	800	1000
1250	890	1065	1130	1130	710	855	905	905	1250
1500	980	1175	1260	1260	795	950	1020	1020	1500
1750	1070	1280	1370	1370	875	1050	1125	1125	1750
2000	1155	1385	1470	1470	960	1150	1220	1220	2000
	CORRECTION FACTORS								
Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.								Ambient Temp. °F
31-40	.82	.88	.90	.91	.82	.88	.90	.91	86-104
41-50	.58	.75	.80	.82	.58	.75	.80	.82	105-122
51-60	....	.58	.67	.71	....	.58	.67	.71	123-141
61-70	....	.35	.52	.58	....	.35	.52	.58	142-158
71-80	....	....	.30	.41	....	....	.30	.41	159-176

†The load current rating and the overcurrent protection for these conductors shall not exceed 20 amperes for 14 AWG, 25 amperes for 12 AWG, and 40 amperes for 10 AWG copper; or 20 amperes for 12 AWG and 30 amperes for 10 AWG aluminum and copper-clad aluminum.

* For dry locations only. See 75°C column for wet locations.

Table 4.3

Allowable Ampacities of Insulated Conductors
Rated 110 to 250°C: Not More Than Three Conductors
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Not More Than Three Conductors in Raceway or Cable Based on Ambient Temperature of 30°C (86°F).

Size	Temperature Rating of Conductor. See Table 310-13								Size
	110°C (230°F)	125°C (257°F)	150°C (302°F)	200°C (392°F)	250°C (482°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	
AWG MCM	TYPES AVA, AVL	TYPES AI, AIA	TYPE Z	TYPES A, AA, FEP, FEPB; PFA	TYPES PFAH, TFE	TYPES AVA, AVL	TYPES AI, AIA	TYPES A, AA	AWG MCM
	COPPER				NICKEL OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM			
14	30	30	30	30	40	....	....	....	....
12	35	40	40	40	55	25	30	30	12
10	45	50	50	55	75	35	40	45	10
8	60	65	65	70	95	45	50	55	8
6	80	85	90	95	120	60	65	75	6
4	105	115	115	120	145	80	90	95	4
3	120	130	135	145	170	95	100	115	3
2	135	145	150	165	195	105	115	130	2
1	160	170	180	190	220	125	135	150	1
0	190	200	210	225	250	150	160	180	0
00	215	230	240	250	280	170	180	200	00
000	245	265	275	285	315	195	210	225	000
0000	275	310	325	340	370	215	245	270	0000
250	315	335	....	....	....	250	270	....	250
300	345	380	....	....	....	275	305	....	300
350	390	420	....	....	....	310	335	....	350
400	420	450	....	....	....	335	360	....	400
500	470	500	....	....	....	380	405	....	500
600	525	545	....	....	....	425	440	....	600
700	560	600	....	....	....	455	485	....	700
750	580	620	....	....	....	470	500	....	750
800	600	640	....	....	....	485	520	....	800
1000	680	730	....	....	....	560	600	....	1000
1500	785	....	....	....	....	650	....	....	1500
2000	840	....	....	....	....	705	....	....	2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.								Ambient Temp. °F
31-40	.94	.95	.96	....	....	.94	.95	....	87-104
41-45	.90	.92	.94	....	....	.90	.92	....	105-113
46-50	.87	.89	.91	....	....	.87	.89	....	114-122
51-55	.83	.86	.89	....	....	.83	.86	....	123-131
56-60	.79	.83	.87	.91	.95	.79	.83	.91	132-141
61-70	.71	.76	.82	.87	.91	.71	.76	.87	142-158
71-75	.66	.72	.79	.86	.89	.66	.72	.86	159-167
76-80	.61	.68	.76	.84	.87	.61	.69	.84	168-176
81-90	.50	.61	.71	.80	.83	.50	.61	.80	177-194
91-100	....	.51	.65	.77	.80	....	.51	.77	195-212
101-120	....	....	.50	.69	.72	....	....	.69	213-248
121-140	....	....	.29	.59	.59	....	....	.59	249-284
141-160	....	....	....	....	.54	....	....	....	285-320
161-180	....	....	....	....	.50	....	....	....	321-356
181-200	....	....	....	....	.43	....	....	....	357-392
201-225	....	....	....	....	.30	....	....	....	393-437

Table 4.4

Allowable Ampacities for Insulated Conductors
Rated 110 to 250°C, and for Bare and Covered Conductors
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Single Conductors in Free Air,
Based on Ambient Temperature of 30°C (86°F).

Size	Temperature Rating of Conductor. See Table 310-13.										Size
AWG MCM	110°C (230°F) TYPES AVA, AVL	125°C (257°F) TYPES AI, AIA	150°C (302°F) TYPE Z	200°C (392°F) TYPES A, AA, FEP, FEPB, PFA	Bare and covered conductors	250°C (482°F) TYPES PFAH, TFE	110°C (230°F) TYPES AVA, AVL	125°C (257°F) TYPES AI, AIA	200°C (392°F) TYPES A, AA	Bare and covered conductors	AWG MCM
	COPPER					NICKEL OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM				
14	40	40	40	45	30	60	....	....	....	....	....
12	50	50	50	55	40	80	40	40	45	30	12
10	65	70	70	75	55	110	50	55	60	45	10
8	85	90	95	100	70	145	65	70	80	55	8
6	120	125	130	135	100	210	95	100	105	80	6
4	160	170	175	180	130	285	125	135	140	100	4
3	180	195	200	210	150	335	140	150	165	115	3
2	210	225	230	240	175	390	165	175	185	135	2
1	245	265	270	280	205	450	190	205	220	160	1
0	285	305	310	325	235	545	220	240	255	185	0
00	330	355	360	370	275	605	255	275	290	215	00
000	385	410	415	430	320	725	300	320	335	250	000
0000	445	475	490	510	370	850	345	370	400	290	0000
250	495	530	....	....	410	....	385	415	....	320	250
300	555	590	....	....	460	....	435	460	....	360	300
350	610	655	....	....	510	....	475	510	....	400	350
400	665	710	....	....	555	....	520	555	....	435	400
500	765	815	....	....	630	....	595	635	....	490	500
600	855	910	....	....	710	....	675	720	....	560	600
700	940	1005	....	....	780	....	745	795	....	615	700
750	980	1045	....	....	810	....	775	825	....	640	750
800	1020	1085	....	....	845	....	805	855	....	670	800
900	....	....	....	....	905	....	....	....	....	725	900
1000	1165	1240	....	....	965	....	930	990	....	770	1000
1500	1450	....	....	....	1215	....	1175	....	....	985	1500
2000	1715	....	....	....	1405	....	1425	....	....	1165	2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.										Ambient Temp. °F
31-40	.94	.95	.96	....		....	.94	.95	....		87-104
41-45	.90	.92	.94	....		....	.90	.92	....		105-113
46-50	.87	.89	.91	....		....	.87	.89	....		114-122
51-55	.83	.86	.89	....		....	.83	.86	....		123-131
56-60	.79	.83	.87	.91		.95	.79	.83	.91		132-141
61-70	.71	.76	.82	.87		.91	.71	.76	.87		142-158
71-75	.66	.72	.79	.86		.89	.66	.72	.86		159-167
76-80	.61	.68	.76	.84		.87	.61	.69	.84		168-176
81-90	.50	.61	.71	.80		.83	.50	.61	.80		177-194
91-100	....	.51	.65	.77		.80	....	.51	.77		195-212
101-120	....	....	.50	.69		.72	....	....	.69		213-248
121-140	....	....	.29	.59		.59	....	....	.59		249-284
141-160	....	....	....	....		.54	....	....	....		285-320
161-180	....	....	....	....		.50	....	....	....		321-356
181-200	....	....	....	....		.43	....	....	....		357-392
201-225	....	....	....	....		.30	....	....	....		393-437

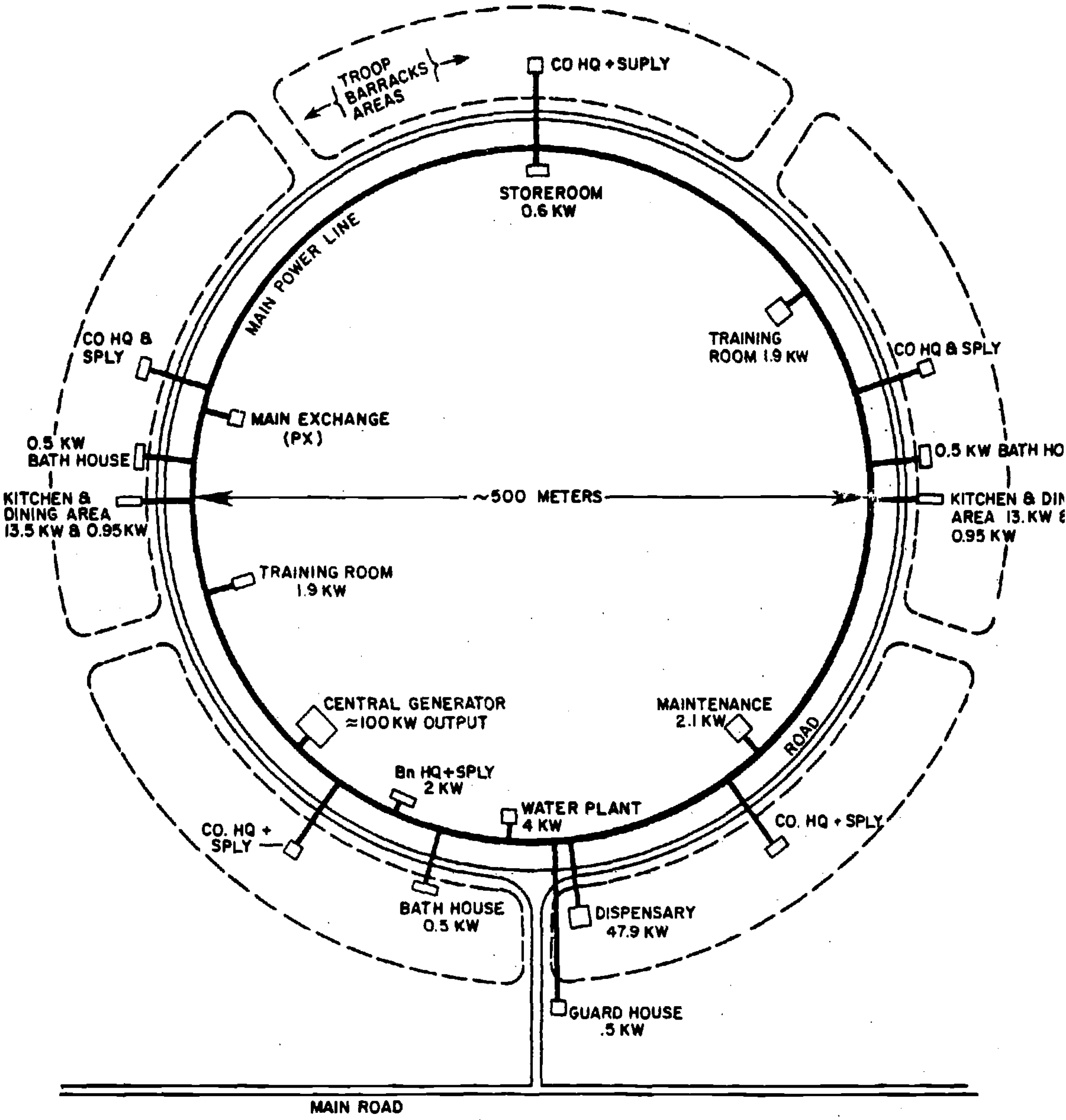
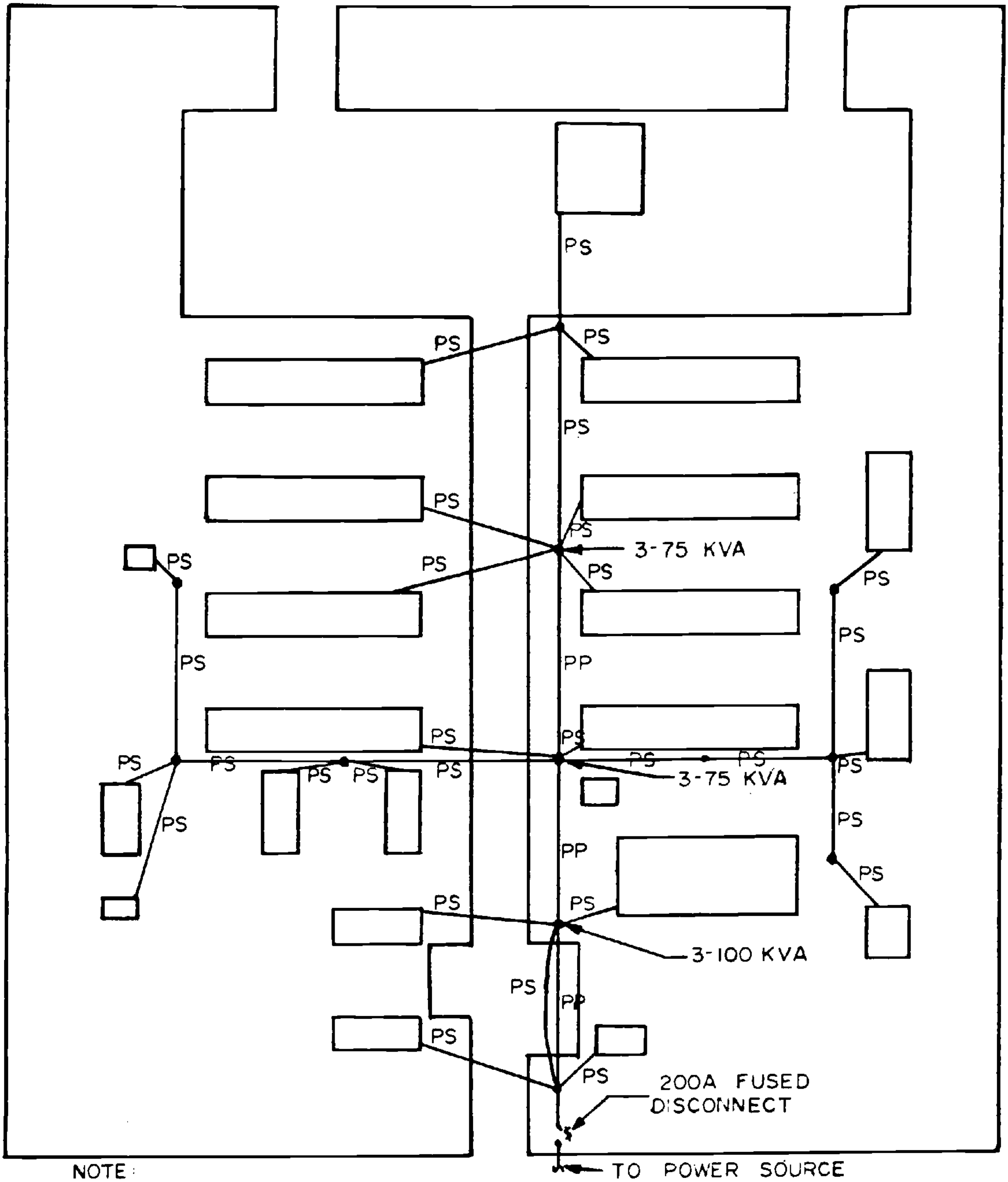


Figure 4.6. Conceptual low-voltage distribution layout (1000-man base camp). (From Staff Study, Army Facility Component System [416th Engineer Command, 10 July 1981].)



NOTE:
PP - POWER PRIMARY
PS - POWER SECONDARY

Figure 4.7. Electric distribution layout (1000-man base camp). AFCS Concept.

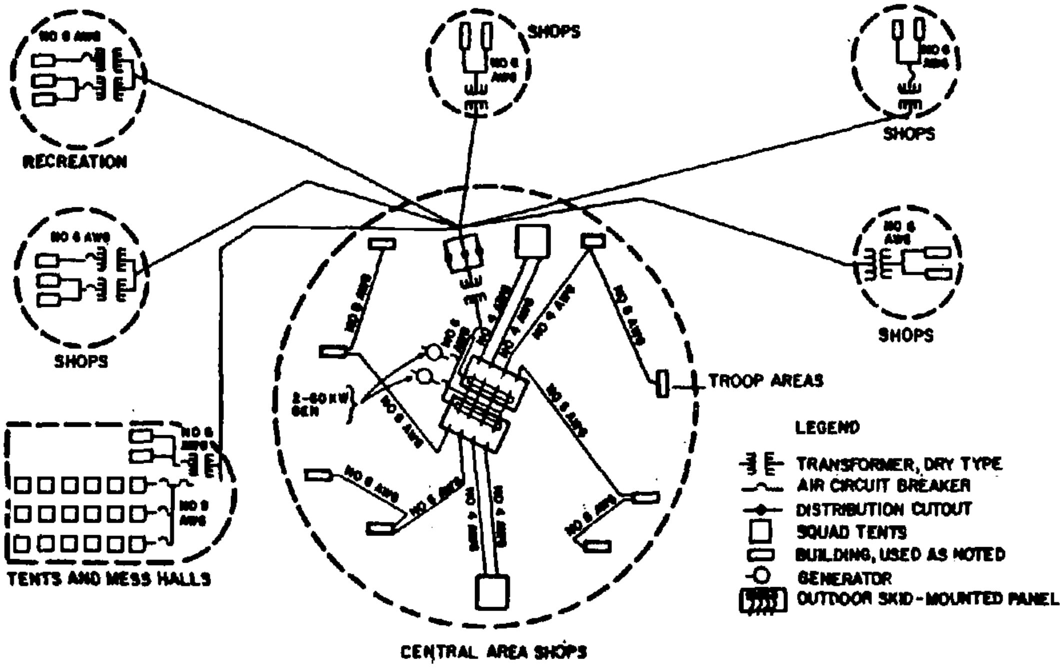


Figure 4.8. Typical high-voltage distribution layout. (From Electric Power Generation in the Field, FM 20-31)

Any distribution system constructed in the field will be susceptible to corrosion of unprotected metal surfaces. In SWA, many regions contain soils with both mineral and salt deposits that, when combined with moisture, form a very corrosive environment for electrical power equipment either on or under the ground. In dry and sandy areas, this corrosion is a problem wherever Army operations introduce water to the soil (i.e., latrines, water purification unit (WPU) discharge, mess kitchens, dispensary, etc.). In coastal regions where local water tables are relatively high, the soil and sand are usually moist enough to produce severe corrosion problems for exposed electric distribution equipment. Many SWA coastal regions also have prevailing sea breezes carrying salty mists that can cause high rates of damaging corrosion. For example, at several locations in the Persian Gulf, painted chain link fencing has corroded so much that it is falling off its posts. The fences had been built less than a year earlier.

To counter these adverse effects of high temperatures and corrosive soils, personnel must strictly comply with distribution equipment derating criteria, and the entire distribution systems must be inspected frequently. If personnel are not aware of the effects of corrosion and high temperature, and do not maintain distribution systems regularly, Army distribution of electric power in SWA will be less reliable and less safe. General maintenance of UGD/OGD consists primarily of continuous inspection of cable connections, distribution equipment, and equipment housings for signs of overheating and corrosion; then hot spots are removed and corroded areas cleaned, tightened, and

Table 4.5

Electric Power Requirements

(From Staff Study, Army Facility Component System
[416th Engineer Command, 10 July 1981])

Facility/Function	Number	Unit Load (kW)	Total Load (kW)
Bath House	3	0.5	1.5
Camp Exchange	1	0.65	0.65
Training/Work Area	2	1.9	3.8
Dispensary	1	47.9	47.9
Guard House	1	0.5	0.5
HQ & Unit Supply-Co.	5	0.36	1.8
HQ & Unit Supply-Bn.	1	0.36	1.8
Kitchen (Limited Facility)	2	13.5	27.0
Dining Facility	4	.95	3.8
Maintenance Shop	1	2.1	2.1
Store House	1	0.6	0.6
Water Plant	1	4.0	4.0 (est)
		Total:	95.65 kW

protected. Where splices are made in distribution cables, the connectors should be coated with an electrical grade anti-oxidant grease, then tape-wrapped to enclose the grease and connector. Where possible, UGD splices should be made in aboveground junction boxes or pedestals. These aboveground connection housings should be constructed of non-metallic materials, if available. In dry dusty areas, aboveground connections to distribution panels, pedestals, and junction boxes should not be grease-treated (unless aluminum to copper contact is made), but should be cleaned regularly with solvent to remove dust or sand, then tightened. In moist coastal regions, all exposed connections should be treated with anti-oxidant grease and protected from soil contact. Corrosion-resistant paint can also be used to protect nonelectric parts of distribution equipment from the environment. Light-colored or even reflective white paints can be applied to equipment housings to help reduce overheating problems.

When exposed to SWA intense sunlight, cables with less than 194°F (90°C) insulation rating, or any cable carrying current above rated load, may experience plastic flow of conductor insulation due to molecular relaxation at high

Table 4.6

Proposed Schedule of Facilities

(From Value Engineering Study, AFCS
[416th Engineer Command, 25 March 1981])

No.	Facility	Quantity	Total Sq Ft
T1	Troop Housing Enlisted	920 Man	
T2	Troop Housing Officer	80 Man	
	Buildings		
1	Bathhouse -- 80 Officer	1	400
2	Bathhouse -- 500 Man	2	2000
3	Camp Exchange	1	2000
4	Day Room	2	4800
5	Dispensary -- Troop	1	1600
6	Guard House	1	1200
7	HQ & Unit Supply -- Co	5	4000
8	HQ & Unit Supply -- Bn	1	2000
9	Kitchen & Messhall 400 Men	2	15,000
10	Kitchen & Messhall 70-Officer	1	1600
11	Latrine, Composite	6	1200
12	Shop -- Motor Repair	1	2400
13	Storehouse	1	2000
14	Fire Protection -- Water	2	(20,000 gal)
15	Water Supply -- Potable	-	(10,000 gal)
16	Generator/Bldg (3-100/kW 3 0 120/208)	-	300 kW

temperatures. This condition allows the contours of the enclosed wire stranding to become visible. Where actual thinning of the insulation accompanies this relaxation, damaging short-circuiting may occur. To minimize this problem, first insure that the highest-rated cable is made available (usually 194°F [90°C]). The cable should be protected from direct sunlight in storage, and extreme care should be used when handling the cable in hot temperatures. Where this plastic flow of insulation is observed, experienced distribution specialists should inspect the damage and perform cable tests as necessary. (TM 5-684 outlines typical UGD cable testing procedures.) If test equipment/personnel are not available, replace the damaged cable section.

Desert rodents have disrupted UGD/OGD systems by gnawing through insulation. Extended OGD trunk lines are particularly susceptible to this problem; however, rodent damage may occur even within the base camp. Where rodent attacks on OGD/UGD systems have been noted, common practice should include burial of poison (such as zinc phosphide) in the trenches as the cable is laid. Various traps and poisoned bait can be used for OGD. Most important, however, is an awareness of the potential problem. Indications are that human sweat on the cables attracts the rodents. The use of gloves in laying the cable, and regular inspection of OGD for signs of rodent attack will help eliminate this problem.

A major assumption often included in SWA scenarios -- and in this chapter -- is that host nation electric power will not be available for, or is not compatible with, base camp power demands. However, many countries in SWA do have limited electric power distribution networks that would be useful when troops start to build the base camp. If host nation power is available, its use should be planned to supplement existing base camp generation capability; this would vastly reduce fuel consumption. The base camp must, however, maintain its own internal generation/distribution system in case host nation power is cut off. Most power grids in SWA use power generated at 50 Hz, 1 or 3 ϕ, which can be used in many cases to power electric lights and heating elements. However, only equipment specifically designated as compatible with 50-Hz power should be so connected. Most Army equipment/utilities are designed for 60 Hz, and operating them at 50 Hz will cause permanent damage. Table 4.7 lists electric power characteristics available in various SWA countries. This table indicates the diversity of electric power within SWA. It should be noted that the quality of this host nation power is generally very poor; frequency stability and voltage regulation are substandard, and high-level voltage transients are possible. Appropriate power conditioner to convert and regulate host nation commercial power for Army uses is not available now.

4.4 Grounding

In any electric power generation/distribution system, appropriate electrical grounding of equipment such as generator sets, transformers, junction boxes, and bus bars is generally very important to insure both safe and reliable operation of the system. Traditional Army guidance requires 25 ohm resistance to ground, or less, at all normally grounded locations. However, the nature of the soils in many SWA locations will not permit this level of assured grounding with traditional ground rods or expedient techniques. In especially dry, rocky, or sandy regions, 25 ohm or less groundings to earth can only be obtained using more involved and equipment-intensive methods that may not be available to base camp engineers. Therefore, this chapter outlines grounding methods that are available to field engineers, and that will provide "adequate by expediency" grounding levels consistent with both time phasing of base camp construction and the distribution system used.

The basic objectives of grounding are:

1. To minimize damage and service interruptions due to all possible electrical faults, including lightning discharge.

2. To reduce overvoltages and resultant insulation damage due to both normal operation (switching surges, static buildup) and abnormal operation (lighting, faults).

3. To minimize injuries to persons near electrical equipment by providing a low resistance path to the earth.

4. To minimize noise in communication and control circuits by establishing a solid electrical reference.

Table 4.7

Electric Current Abroad -- Characteristics

Country and City	Type and Frequency of Current	Number of Phases	Nominal Voltage	Number of Wires	Frequency Stability-Stable Enough for Electric Clocks
Afghanistan					
Charikar	a.c.60	1,3	220/380	2,4	Yes
Farah	a.c.50	1,3	220/380	2,4	Yes
Ghazni	a.c.50	1,3	220/380	2,4	Yes
Gulbahar	a.c.50	1,3	220/380	2,4	Yes
Herat	a.c.50	1,3	220/380	2,4	Yes
Jalalabad	a.c.50	1,3	220/380	2,4	Yes
Kabul	a.c.50	1,3	220/380	2,4	Yes
Kandahar	a.c.50	1,3	220/380	2,4	Yes
Kunduz	a.c.50	1,3	220/380	2,4	Yes
Maimana	a.c.50	1,3	220/380	2,4	Yes
Mazar-i-Sharif	a.c.50	1,3	220/380	2,4	Yes
Paghman	a.c.50	1,3	220/380	2,4	Yes
Pul-i-Khumri	a.c.50	1,3	220/380	2,4	Yes
Egypt					
Alexandria	a.c.50	1	110	2	No
Asyut	a.c.50	1,3	220/380	2,3,4	No
Aswan	a.c.50	1,3	220/380	2,3,4	No
Benha	a.c.50	1,3	220/380	2,3,4	
Beni Suef	a.c.50	1,3	220/380	2,3,4	No
Cairo	a.c.50	1,3	220/380	2,3,4	No
Damanhur	a.c.50	1,3	220/380	2,3,4	No
Damietta	a.c.50	1,3	220/380	2,3,4	No
Heliopolis	a.c.50	1	110	2	No
		1,3	220/380	2,3,4	No
Helwan	a.c.50	1,3	220/380	2,3,4	No
Ismaila	a.c.50	1,3	220/380	2,3,4	No
Kafr el Zaiyat	a.c.50	1,3	220/380	2,3,4	No
Kena	a.c.50	1,3	220/380	2,3,4	No
Luxor	a.c.50	1,3	220/380	2,3,4	No
El Maadi	a.c.50	1,3	220/380	2,3,4	No
El Mansura	a.c.50	1,3	220/380	2,3,4	No
El Mahalla	a.c.50	1,3	220/380	2,3,4	No
Minia	a.c.50	1,3	220/380	2,3,4	No
Port Fouad	a.c.50	1,3	220/380	2,3,4	No
Port Said	a.c.50	1,3	220/380	2,3,4	No
Port Tewik	a.c.50	1,3	220/380	2,3,4	No
Sohag	a.c.50	1,3	220/380	2,3,4	No
Suez	a.c.50	1,3	220/380	2,3,4	No

Table 4.7 (Cont'd)

Country and City	Type and Frequency of Current	Number of Phases	Nominal Voltage	Number of Wires	Frequency Stability-Stable Enough for Electric Clocks
Tanta	a.c.50	1,3	220/380	2,3,4	No
Zagazig	a.c.50	1,3	220/380	2,3,4	No
Iran					
Abadan	a.c.50	1,3	220/380	2,3,4	Yes
Ahwaz	a.c.50	1,3	220/380	2,3,4	Yes
Behshahr	a.c.50	1,3	220/380	2,3,4	Yes
Ghazvin	a.c.50	1,3	220/380	2,3,4	Yes
Hamadan	a.c.50	1,3	220/380	2,3,4	Yes
Isfahan	a.c.50	1,3	220/380	2,3,4	Yes
Karaj	a.c.50	1,3	220/380	2,3,4	Yes
Kashan	a.c.50	1,3	220/380	2,3,4	Yes
Kerman	a.c.50	1,3	220/380	2,3,4	yes
Kermanshah	a.c.50	1,3	220/380	2,3,4	Yes
Khorramshahr	a.c.50	1,3	220/380	2,3,4	Yes
Masjed Soleyman	a.c.50	1,3	220/380	2,3,4	Yes
Meshed	a.c.50	1,3	220/380	2,3,4	Yes
Pahlevi	a.c.50	1,3	220/380	2,3,4	Yes
Qom	a.c.50	1,3	220/380	2,3,4	Yes
Resht	a.c.50	1,3	220/380	2,3,4	Yes
Rezaiyeh	a.c.50	1,3	220/380	2,3,4	Yes
Shiraz	a.c.50	1,3	220/380	2,3,4	Yes
Tabriz	a.c.50	1,3	220/380	2,3,4	Yes
Tehran	a.c.50	1,3	220/380	2,3,4	Yes
Yazd	a.c.50	1,3	220/380	2,3,4	Yes
Iraq[1]					
Baghdad	a.c.50	1,3	220/380	2.4	Yes
Basra	a.c.50	1,3	220/380	2,4	Yes
Kirkuk	a.c.50	1,3	220/380	2,4	Yes
Mosul	a.c.50	1,3	220/380	2,4	Yes
Israel[1,2,3]					
Beer Sheba	a.c.50	1,3	230/400	2,4	Yes
Haifa	a.c.50	1,3	230/400	2,4	Yes
Holon	a.c.50	1,3	230/400	2,4	Yes
Natanya	a.c.50	1,3	230/400	2,4	Yes
Petah Tiqva	a.c.50	1,3	230/400	2,4	Yes
Ramat-Gan	a.c.50	1,3	230/400	2,4	Yes
Rehovot	a.c.50	1,3	230/400	2,4	Yes
Tel Aviv	a.c.50	1,3	230/400	2,4	Yes

Table 4.7 (Cont'd)

Country and City	Type and Frequency of Current	Number of Phases	Nominal Voltage	Number of Wires	Frequency Stability-Stable Enough for Electric Clocks
Jerusalem	a.c.50	1,3	220/380	2,3,4	Yes
Jordan[4,5]					
Amman	a.c.50	1,3	220/380	2,3,4	Yes
Irbid	a.c.50	1,3	220/380	2,3,4	Yes
Nablus	a.c.50	1,3	220/380	2,3,4	Yes
Zerqa	a.c.50	1,3	220/380	2,3,4	Yes
Kuwait					
Kuwait	a.c.50	1,3	240/415	2.4	Yes
Lebanon[6]					
Aley	a.c.50	1,3	110/190	2,4	No
Beirut	a.c.50	1,3	110/190	2,4	No
Bhamdoun	a.c.50	1,3	110/190	2,4	No
Brummana	a.c.50	1,3	110/190	2,4	No
Chtaure	a.c.50	1,3	110/190	2,4	No
Dhour el Choueir	a.c.50	1,3	110/190	2,4	No
Sidon	a.c.50	1,3	110/190	2,4	No
Sofar	a.c.50	1,3	110/190	2,4	No
			110/190		
Tripoli	a.c.50	1,3	220/380	2.4	No
Tyre	a.c.50	1,3	110/190	2,4	No
Zahleh	a.c.50	1,3	220/380	2,4	Yes
Libya[7,8]					
Al Aziziyah	a.c.50	1,3	127/220	2,4	No
Barce	a.c.50	1,3	230.400	2,4	No
Ben Gashir	a.c.50	1,3	127/220	2,4	No
Benghazi	a.c.50	1,3	230/400	2,4	No
Derna	a.c.50	1,3	230/400	2,4	No
El Baida	a.c.50	1,3	230	2,4	No
Homs	a.c.50	1,3	127/220	2,4	No
Misurata	a.c.50	1,3	127/220	2,4	No
Sebha	a.c.50	1	230	1	No
Tagiura	a.c.50	1,3	127/220	2,4	No
Tobruk	a.c.50	1,3	230/400	2,4	No
Tripoli	a.c.50	1,3	127/220	2,4	No
Zavia	a.c.50	1,3	127/220	2,4	No
Oman					
Muscat	a.c.50	1,3	220/440	2,3	No

Table 4.7 (Cont'd)

Country and City	Type and Frequency of Current	Number of Phases	Nominal Voltage	Number of Wires	Frequency Stability-Stable Enough for Electric Clocks
Pakistan[9]					
Abbotabad	a.c.50	1,3	230/400	2,3,4	No
Bahawalpur	a.c.50	1,3	230/400	2,3,4	No
Hyderabad	a.c.50	1,3	230/380	2,3,4	No
Islamabad	a.c.50	1,3	230/400	2,3,4	No
Karachi	a.c.50	1,3	220/380	2,3,4	No
Lahore	a.c.50	1,3	230/400	2,3,4	No
Lyallpur	a.c.50	1,3	230/400	2,3,4	No
Montgomery	a.c.50	1,3	230/400	2,3,4	No
Multan	a.c.50	1,3	230/400	2,3,4	No
Murree	a.c.50	1,3	230/400	2,3,4	No
Peshawar	a.c.50	1,3	230/400	2,3,4	No
Quetta	a.c.50	1,3	230/400	2,3,4	No
Rawalpindi	a.c.50	1,3	230/400	2,3,4	No
Saudi Arabia[10,11]					
Al Khobar	a.c.60	1,3	127/220	2,4	Yes
Buraydah	a.c.50	1,3	220/380	2,4	No
Dammam	a.c.60	1,3	127/220	2,4	Yes
Hofuf	a.c.50	1,3	230/400	2,4	Yes
Jiddah	a.c.60	1,3	127/220	2,3,4	Yes
Mecca	a.c.50	1,3	230/400	2,4	Yes
Medina	a.c.60	1,3	127/220	2,4	Yes
Riyadh	a.c.60	1,3	127/220	2,4	Yes
Taif	a.c.50	1,3	230/400	2,4	Yes
Sudan[12]					
Atbara	a.c.50	1,3	240/415	2,4	Yes
Ed Daner	a.c.50	1,3	240/415	2,4	Yes
Ed Dueim	a.c.50	1,3	240/415	2,4	Yes
El Obeid	a.c.50	1,3	240/415	2,4	Yes
Hassa Heissa	a.c.50	1,3	240/415	2,4	Yes
Juba	a.c.50	1,3	240/415	2,4	Yes
Kassala	a.c.50	1,3	240/415	2,4	Yes
Khartoum	a.c.50	1,3	240/415	2,4	Yes
Khartoum N	a.c.50	1,3	240/415	2,4	Yes
Kosti	a.c.50	1,3	240/415	2,4	Yes
Malakal	a.c.50	1,3	240/415	2,4	Yes
Omdurman	a.c.50	1,3	240/415	2,4	Yes
Port Sudan	a.c.50	1,3	240/415	2,4	Yes
Sennar	a.c.50	1,3	240/415	2,4	Yes
Shendi	a.c.50	1,3	240/415	2,4	Yes
Wadi Halfa	a.c.50	1,3	240/415	2,4	Yes

Table 4.7 (Cont'd)

Country and City	Type and Frequency of Current	Number of Phases	Nominal Voltage	Number of Wires	Frequency Stability-Stable Enough for Electric Clocks
Wau	a.c.50	1	240	2	Yes
Syria					
Aleppo	a.c.50	1,3	115/200 115/200	2,3,4	No
Damascus	a.c.50	1,3	220/380	2,3,4	No
Dayr-Al-Zawr	a.c.50	1,3	115/200	2,3,4	No
Hama	a.c.50	1,3	115/200	2,3,4	No
Homs	a.c.50	1,3	115/200	2,3,4	No
Latakia	a.c.50	1,3	115/200	2,3,4	No
Turkey[13]					
Adana	a.c.50	1,3	220/380	2,3,4	Yes
Adapazari	a.c.50	1,3	220/380	2,3,4	Yes
Afyon	a.c.50	1,3	220/380	2,3,4	Yes
Ankara	a.c.50	1,3	220/380	2,3,4	Yes
Balikesir	a.c.50	1,3	220/380	2,3,4	Yes
Bursa	a.c.50	1,3	220/380	2,3,4	Yes
Eskisehir	a.c.50	1,3	220/380	2,3,4	Yes
Gaziantep	a.c.50	1,3	220/380	2,3,4	yes
Istanbul	a.c.50	1,3	220/380	2,3,4	Yes
Izmir	a.c.50	1,3	220/380	2,3,4	Yes
Izmit	a.c.50	1,3	220/380	2,3,4	Yes
Kayseri	a.c.50	1,3	220/380	2,3,4	Yes
Konya	a.c.50	1,3	220/380	2,3,4	Yes
Malatya	a.c.50	1,3	220/380	2,3,4	Yes
Manisa	a.c.50	1,3	220/380	2,3,4	Yes
Mersin	a.c.50	1,3	220/380	2,3,4	Yes
Samsun	a.c.50	1,3	220/380	2,3,4	Yes
Sivas	a.c.50	1,3	220/380	2,3,4	Yes
Trabzon	a.c.50	1,3	220/380	2,3,4	Yes
Zonguldak	a.c.50	1,3	220/380	2,3,4	Yes
Yemen (Arab Rep.)					
Hoeida	a.c.50	1,3	220	2,3	No
Sana	a.c.50	1,3	220	2,3	No
Taiz	a.c.50	1,3	220	2m3	No

Table 4.7 (Cont'd)

Notes

1 A grounding conductor is required in the electrical cord attached to appliances.
2 A grounding conductor is required in the electrical cord attached to appliances.
3 The neutral wire of the secondary distribution system is grounded.
4 The neutral wire of the secondary distribution system is grounded.
5 A grounding conductor is required in the electrical cord attached to appliances.
6 The neutral wire of the secondary distribution system is grounded.
7 Electric current is now continuous in most of the cities and large towns.
8 The neutral wire of the secondary distribution system is grounded except in the case of Sebha.
9 The neutral wire of the secondary distribution system is grounded.
10 Grounding conductors are not required and many houses are not wired for a separate ground.
11 Power supply being standardized at 60 Hz, 127/200 V.
12 A grounding conductor is required in the electrical cord attached to appliances.
13 The neutral wire of the secondary distribution system is grounded.

The key words in these objectives are "minimize" and "reduce." It is not possible to produce a system in which each of these quantities of risk and performance degradation is reduced to zero. Nevertheless, the objectives must be satisfied by any grounding technique known to be good engineering practice.

Levels of adequate grounding have been identified for Army base camp operations, where personnel expertise, materials, time, and special equipment may be limited or not available:

1. Low-voltage distribution system (i.e., generation at 600 V or less) deployed only for a short period of time (approximately 0 to 4 weeks) (LVST).

2. Low-voltage distribution system constructed for on-line use over longer periods of time (4 weeks to 2 years) (LVLT).

3. High- and medium-voltage distribution systems (i.e., generation at greater than 600 V) deployed for short-term operation (HVST).

4. High- and medium-voltage distribution constructed for on-line, long-term operation (HVLT).

The recommended grounding techniques to be used within each of these levels are discussed below. They apply to base camps constructed in arid, sandy, or rocky areas where local water tables are very low, and to scenarios where ample water supplies are not readily available. In coastal regions and other locations where water tables are high and soils are relatively moist, traditional grounding methods normally provide excellent grounding, because of the high mineral and salt content of most SWA soils. In these regions, corrosion of ground connections is a significant maintenance problem because corroded terminals/connections develop their own high resistance. This corrosion can be reduced by frequent, regular inspection, maintenance, and treatment of ground connections, as described earlier.

LVST: the generators should be grounded with a standard driven ground rod. Where rods cannot be driven, they should be laid horizontally in a trench about 18 in. (460 mm) deep and covered with soil (not rocks). The distribution system's neutral wire must be connected through the generator to this ground. As long as this three-phase system has a grounded neutral, further deliberate grounding at other locations is not required.

LVLT: this situation is probably most typical for small base camp operation. The generators should be placed on an electrically gridded platform (either concrete or sandbags) that is tied to a standard ground rod driven a few feet away from the platform. A gridded platform is shown in Figure 4.9. The platform must be large enough to permit the generator operator to stand on it while attending the generator. The generator and the distribution system neutral wire must also be connected to this ground grid and ground rod. Other distribution equipment (e.g., transformers, junction boxes, pedestals, distribution panels) must also be locally grounded by standard ground rods. As water availability permits, the generator and other local ground rods should be treated with salt solutions poured directly on and around the rod to saturate the soil. This treatment should be repeated as necessary to keep

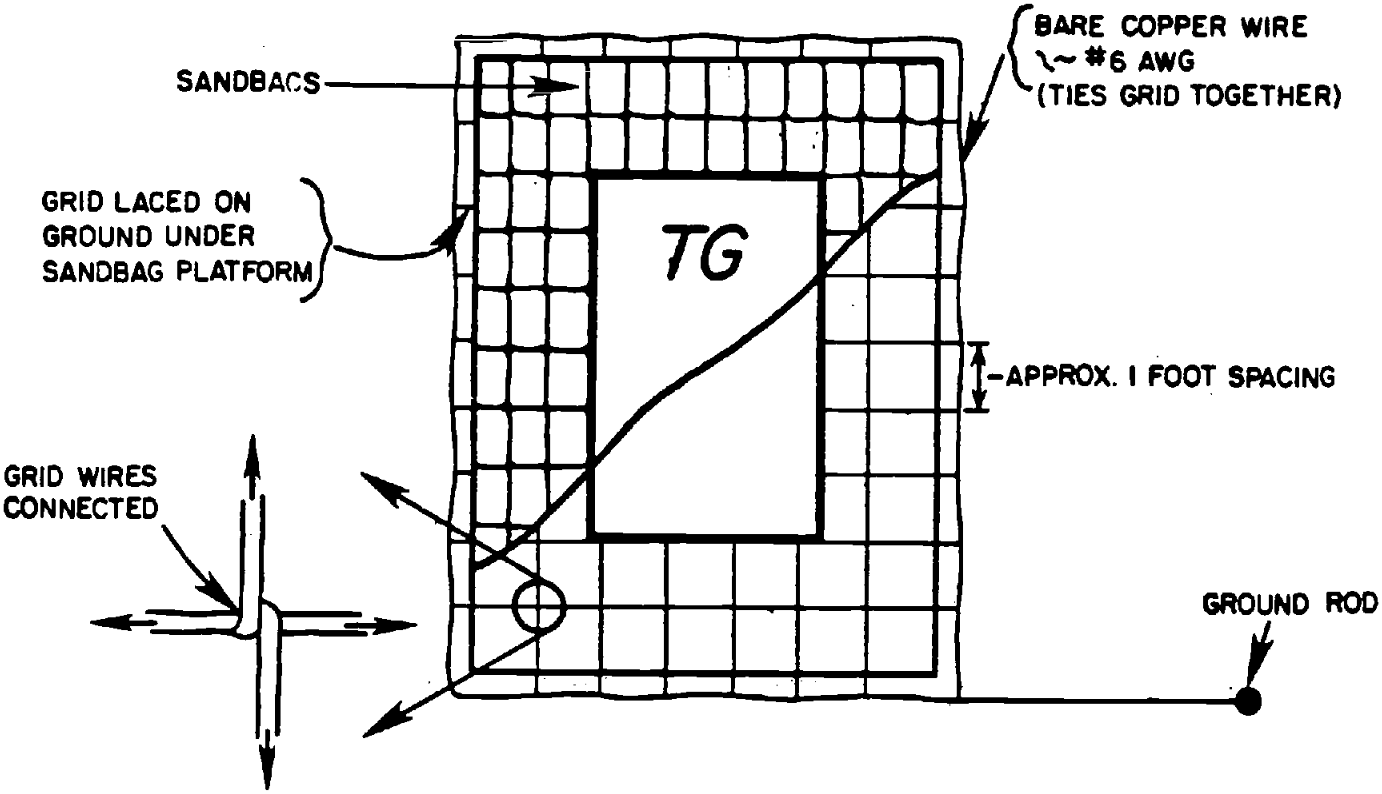


Figure 4.9. Expedient TG grounding grid.

moist the soil in contact with the rod. Normally, 3 lb of salt per gallon of water (0.36 kg/L) gives a good saturated solution for this application.

HVST: use of high or medium voltages in base camp operations may be necessary when:

1. The base camp receives electrical power from large Army electric distribution complexes.

2. Host nation power is used

3. Transformers are used to extend electric service within the base camp.

Along with traditional grounding of generators, transformers, and junction boxes for short-term use, it is essential to have grounded neutral distribution, using the standard driven ground rod or trench buried rod in rocky areas. In addition to this initial grounding, a dedicated ground wire must be run from the generator grounding rod to all grounded locations on the base. This extra wire, or cable, may be laid in existing OGD/UGD raceways or in separate trenching, or can be formed using the concentric neutral of 3 ϕ 4 wire cables. It provides a common ground plane that is normally provided by the soils. This grounding wire is necessary to provide adequate safety for personnel operating electrical equipment.

HVLT: for system reliability and personnel safety, this longer-term scenario requires that the HVST grounding system described above be augmented with:

1. Gridded ground planes for generators and surface-mounted transformers (see Figure 4.8).

2. Direct contact of the grounding system with a known permanent water source, such as the local water table.

It is anticipated that some form of water well will be present in base camps where HVLT applies. In this case, the grounding plane/dedicated ground wires should be connected to the metal well casing, or, a separate copper conductor can be lowered into the well to make contact with the water. If a water well is not available, other drilling operations will be necessary to establish positive electric contact with the local water table. Also of prime importance in this grounding system is the continuous and frequent inspection of grounding connections and dedicated ground wires for electrical continuity and low resistance of connections. Cleaning of corrosion from, and protection of, these connections is critical in maintaining good system reliability and safety.

The preceding outline of "adequate" grounding levels was developed based on assumptions of construction in very dry, sandy, and rocky terrain. Personnel standing on such soils form a relatively high-resistance electrical path to ground, as do driven ground rods. In low-voltage systems, then, even a direct short to ground through a soldier will not be a significant health hazard, though an unpleasant electrical shock could be sensed. In high- and medium-voltage systems, however, this type of short through personnel could produce fatal electrocution. Therefore, a dedicated ground wire should be used for high-voltage systems. In effect, this extra wire serves the same purpose as the soil in normal moist environments. It insures that faulting currents are driven back to the generator, thus tripping appropriate circuit protection devices. Concentric neutral cables used in UGD or OGD can be used to provide this dedicated ground wire.

The following discussion outlines site selection factors that should be considered before emplacement of the generation/distribution system to improve the system's grounding effectiveness. As noted earlier, arid and sandy areas of SWA with low water tables allow no ideal solutions for grounding electric distribution systems with traditionally available Army grounding equipment. However, other regions in SWA may provide at least reasonable opportunities for good electrical grounding when sites are selected carefully.

Existing water sources such as oases, river beds, or underground streams often indicate that local water tables are high enough to be contacted with driven ground rods. Deep wells can be used as described earlier to easily tie the entire grounding system to earth potential using dedicated grounding cables/grids. These water sources can also be used to dampen the soil around local ground rods.

If a base camp is developed in an area that is already built up, then electrical contact with existing water piping systems can provide excellent ground conditions. The rebar in reinforced concrete can also be used like horizontal ground rods. Another good location for grounding would be in-place metal sewage systems. Finally, existing metal fencing can be used to construct electrical grids for TG and transformer platforms.

In base camp locations where such structures or water sources are not available, distribution grounding can be improved by driving ground rods near or into operational waste water dumps or sinks. For instance, mess halls and latrines may use septic tanks or cesspools. Sewage liquids are normally very conductive. Site selection should provide enhanced grounding at least for TGs. However, care should be exercised to insure that this ground connection does not endanger personnel should a fault occur. Figure 4.10 shows grounding using wastewater drainage. The drain pipe must not be constructed with metal materials. Plastic or PVC is recommended if the sewage drain is used for grounding. This will prevent the possible injection of current into the water source (i.e., latrine or mess hall).

Two expedient techniques for local grounding are particularly applicable to the small, isolated TG in field applications. The first can be easily used in deep, loose, dry sand where a "quick-fix" ground is needed. Figure 4.11 shows how an 8-ft (2.4-m) section of galvanized steel or copper clad pipe can

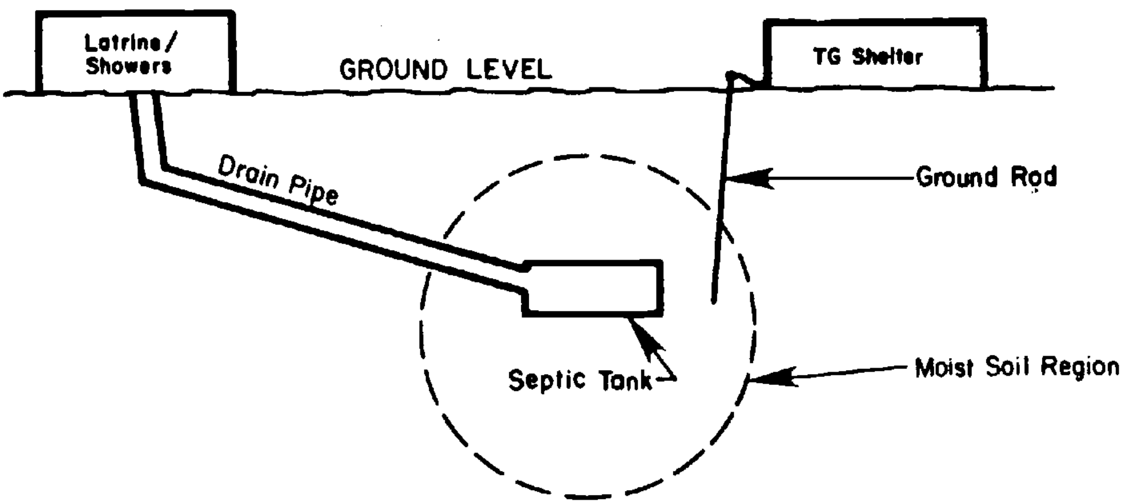


Figure 4.10. Grounding using sewage drain.

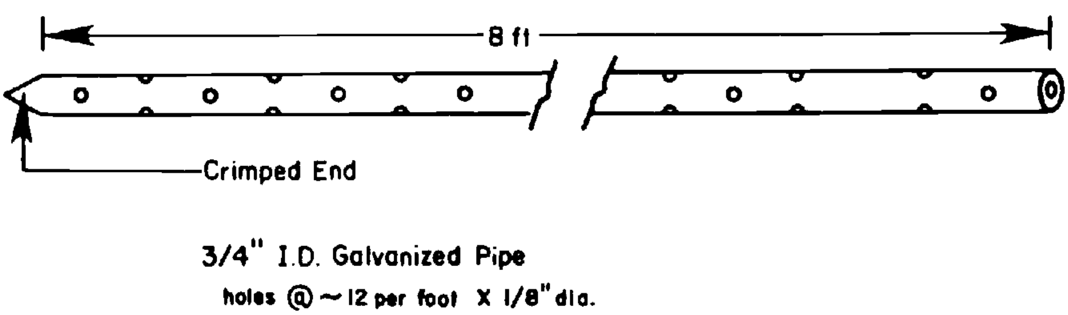


Figure 4.11. Expedient grounding pipe.

be modified to aid immediate introduction of salt solution to the rod/sand interface. After being driven into the ground, the perforated pipe is filled through a funnel with a solution of 15 lb salt/5 gal (6.8 kg/18.9 L) water. The salt solution percolates into the sand and provides a conductive soil for current flow. This ground remains effective until the solution either evaporates or drains away from the rod, usually in several hours or a few days. This procedure tends to corrode the pipe very quickly, however, so additional pipe will be needed occasionally. Also, the grounding clamp/wire connection must be kept clean and corrosion-free for good results.

The second technique, which is most useful in rocky terrain where rods are difficult to drive, has been loosely called a "counterpoise." Bare copper wire is laid in a horizontal trench and is covered with soil and salt solution treatment, if available. More wire in the trench, usually 1-1/2 ft (0.5 m) deep, provides a better ground. A "counterpoise" of this type is shown in Figure 4.12. With this technique, too, the wire becomes unrecoverable after several salt solution treatments. Note, however, that some field users have used this type of ground successfully without salt solution treatment. Another expedient grounding method that may be applicable is direct ground connection to field urinal tubes driven into the soil. This technique is recommended only for short-term use.

Though this chapter has outlined levels of grounding that are acceptable in an expedient sense, it is nevertheless emphasized that grounding protection of less than 25 ohms resistance to earth is desirable and should be a goal of

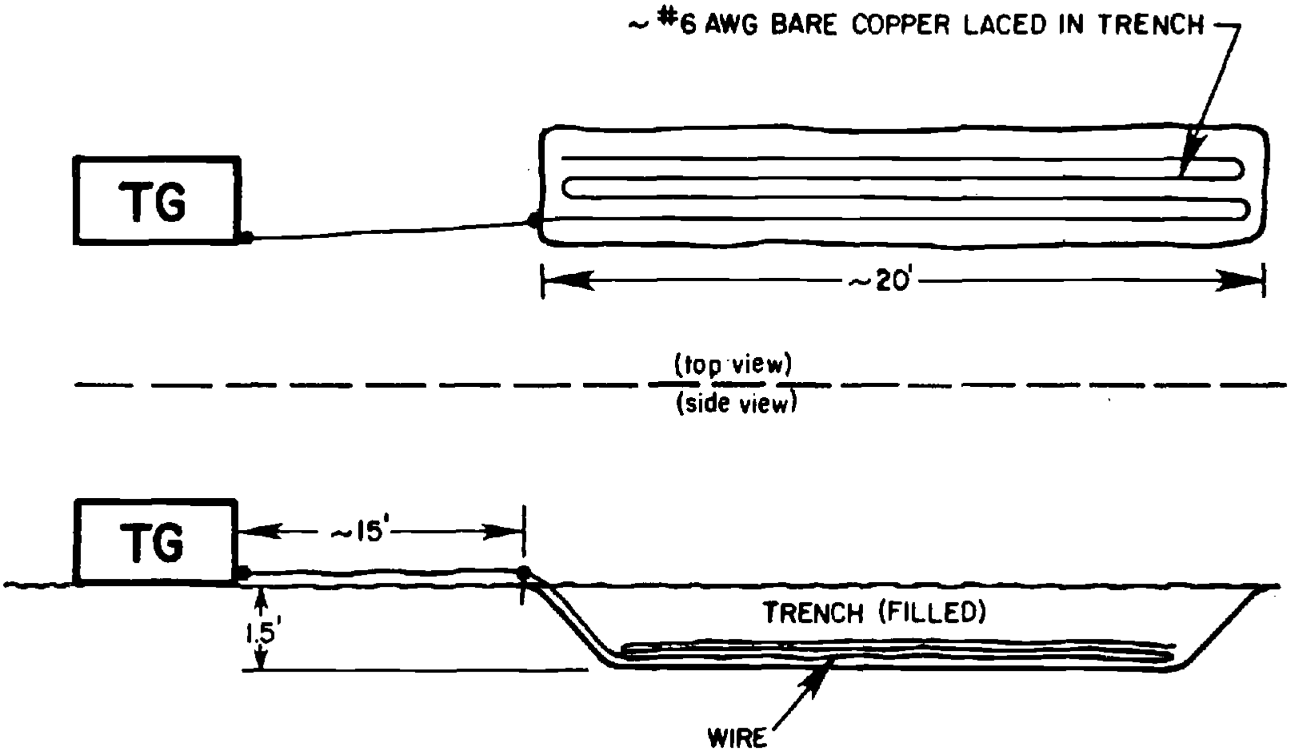


Figure 4.12. Expedient grounding trench.

the electric distribution engineer -- even in SWA base camps. To determine the grounding status of base camp grounded locations, it is recommended that on-site capability be provided for ground resistance testing. Testing procedures and appropriate test equipment are discussed in TM 5-765. Although grounding resistance of less than 25 ohms will not be possible in some dry, sandy areas of SWA, the traditional techniques of deeper ground rods, rods in parallel, and rods treated with salt solution will significantly decrease the high local resistance, and will improve electrical system reliability and safety.

CHAPTER 5 - EXPEDIENT WATER CONSERVATION TECHNIQUES

5.1 Introduction

The objective of this chapter is to identify practical and expedient water conservation measures that can help reduce the logistics burden of water supply in SWA. The selection of techniques and new equipment has been limited to those that would not overburden the military logistics system and would be consistent with the training and skill levels of those who would employ them under tactical conditions. In fact, selections reflect realistic, low-cost measures that can be readily implemented.

To accomplish this work, the water-consuming activities of a representative military force that might be deployed to SWA were examined. Then a detailed analysis was made of each activity to identify opportunities to:

1. Control excessive water usage

2. Minimize water loss through evaporation, spillage and contamination

3. Reuse water by internal recycling or elsewhere by some other activity

4. Substitute water of lesser quality where it has been customary to use fresh water.

5.2 Environmental Setting

5.2.1 *General*

The desert conditions found throughout SWA present a variety of problems for a military force operating there. For the U.S. Army deployed in desert warfare operations, major concerns will be the general shortage of water and ever-present dust. To provide some insight into the conditions that will be faced, especially those related to water availability, it is appropriate to understand the military implications of water in the desert environment.

Limited amounts of precipitation and rapid evaporation are characteristic of desert areas. In SWA rainfall is less than 10 in. (254 mm) per year and frequently this is in the form of violent storms. In the mountains and hilly areas runoff is rapid and destructive, while in the flatter areas it is channeled through wadis to depressions and salt flats where that which does not percolate into the soil quickly evaporates in the hot sun.

5.2.2 *Military Implications*

The single most important characteristic of desert areas is the lack of water. Surface water is limited to a very few rivers and intermittent streams that benefit from the sparse rainfall. Except for areas primarily along the coast, subsurface water is also limited, and that which can be obtained from wells is generally unfit to drink because of the high salt content and the presence of minerals such as calcium and magnesium. Consequently, a military force must be prepared to produce its own potable water from any available supplies, and to be diligent about conserving water, regardless of its quality and use.

The American soldier is not indoctrinated to use water sparingly. Consequently, part of his training before deploying to SWA must include intensive instruction on water conservation. Such training should be accompanied by measures to make water less available. This will reduce the temptation to return to wasteful habits. The most effective means of doing this, particularly for activities in Corps rear areas and the Communications Zone, is to prohibit the installation of piped water systems and waterborne sewage facilities in base development complexes.

Without a piped water system, each organization or troop complex must have enough storage capability for at least one day's water requirements. Some units which currently do not have storage facilities, but would need them for operational purposes, include the field laundry and bath, aviation, and engineer units. Any unit which uses collapsible fabric tanks must minimize water losses due to evaporation and dust contamination by securely covering the tanks at all times. Even careful attention to protecting potable and nonpotable water supplies might not prevent contamination; therefore, the capability to treat and recover such water should be available. This suggests retention of ERDLator equipment in the Army supply system to augment the portable reverse osmosis water purification unit (ROWPU).

Actual potable and nonpotable water consumption can be reduced below the 20 gal (76 L) per man per day water consumption planning factor for arid environments by diligent application of the conservation measures presented in this chapter. Conservation must begin with the individual soldier; he must be made aware of the need to save water and must be taught about the many opportunities to reuse wastewater for some other purpose. He must be assisted in this effort by everyone up the chain of command. There is no substitute for command emphasis on water conservation.

Planners can also play a major role in the conservation effort. For example, activities which require large amounts of potable water should be located near water terminals and tank farms to minimize transportation requirements and losses during handling. In addition, facilities that may use nonpotable water should be sited near a suitable generator of wastewater -- e.g., wastewater from laundry and shower units could be used for concrete mixing, soil compaction, and dust control needed for the installation of storage depots.

Planning should also consider installation of a pipeline for transporting seawater or brackish water, either of which can be used for concrete, soil cement, soil compaction, and dust control. The two latter tasks will probably be major engineering efforts because the limited existing road networks in many SWA countries will need to be expanded to provide adequate lines of communications, and the deterioration of roads from heavy truck traffic will demand continuous maintenance. Another significant advantage of a nonpotable water pipeline would be the convenience of large quantities of nonpotable water for Nuclear, Biological, Chemical (NBC) decontaminating purposes, should the need ever arise.

5.3 Near-Term Water Supply Concept for Arid Regions

5.3.1 *General*

This section describes the near-term operational concept for managing water resources in an arid environment. In addition, it includes background information about the various types of water resources of such areas and the uses that can be made of each.

5.3.2 *Water Supply Concept*

Within the Army, responsibilities in water resource management are shared by engineer, combat service support, and medical organizations. The engineers locate water supplies, drill wells, and install pipelines; combat service support units operate water purification equipment, pipelines, and waste distribution facilities; medical organizations insure that the quality of water is adequate for its intended purpose.

Water supply support of a force in an arid region is to be developed in three phases:

1. The deployment phase is the entry of combat units into a combat zone. Potable water (enough for immediate survival purposes) is to be carried in individual canteens, 5-gal (19-L) cans, and other authorized equipment. Resupply will be by tactical aircraft with delivery in 500- and 50-gal (1890- and 190-L) fabric drums or air-dropped in expendable 6-gal (23-L) bags/boxes. During this phase, potable water consumption is at the rate of 7.2 gal (27.3 L) per man per day.

2. In the lodgment phase, when follow-on forces arrive in the objective area, aerial water resupply is gradually replaced as an in-country water supply system is established. Combat Service Support units arriving with purification capability will start water management operations near the seashore or other major source of water. When additional water resources are required, Engineer elements will identify potential well sites and begin drilling. Large-scale purification, storage, and distribution operations are then followed, enabling combat units to replenish water supplies at supply points using organic water trailers. During this phase, when the ashore water supply system is put into operation, water consumption level increases to an austere rate of 11.7 gal (44.3 L) per man per day.

3. The buildup phase begins once the lodgment area is firmly established. This includes the arrival of additional support units to install and operate water pipelines/hoselines and tank farms, and to begin line haul operations using water tanker trucks. When the water production and storage system is fully developed, a 1-day reserve supply of potable water is to be maintained at brigade, division, corps, and task force levels for a total of 4 days within the area of operations. With completion of the buildup phase, water consumption reaches the full requirement rate of 18.9 gal (71.5 L) per man per day. This is enough to satisfy the demands for drinking, maintaining proper standards of hygiene, medical care, food preparation, equipment operations, and construction.

Much of the equipment required for the above water supply system has been developed by the U.S. Army Mobility Equipment Research and Development Command; the individual equipment items are illustrated in Figure 5.1.

5.4 Water Conservation Opportunities

5.4.1 *General*

This section discusses water-demanding activities that are expected to be performed by a U.S. military force deployed to a hot arid region such as SWA. For each activity, the related water requirements (quality, quantity, and possible sources) are described and specific potential water conservation measures are suggested.

Throughout this section, various qualities and types of water are mentioned. To aid the reader, the following descriptions of each are provided:

1. Potable water has been examined and treated to meet appropriate standards and declared fit for domestic consumption (food preparation) by responsible authorities.*

2. Nonpotable water has not been examined, properly treated, and approved by approporiate authorities as being safe for domestic consumption (food preparation). All waters are considered nonpotable until declared potable.*

3. Seawater obtained offshore at a location removed from a sewage outfall is normally relatively clean. It is very salty, and contains suspended particles of sand and probably some bacteria. This water can be used, without any adverse effects, for construction, housekeeping tasks, firefighting, showering and laundering. It should not be used where continued use could corrode critical metal surfaces. When used for showers, laundries, and personal hygiene purposes, calcium hypochlorite should be added to the water to protect against disease-causing organisms. Potable water can be produced from seawater using the ROWPUs.

4. Surface water and well water containing a high concentration of salt is called brackish. The salt content is much less than found in seawater, but is high enough to give the water a distinctive salty taste. Brackish water may contain dissolved calcium, sulfur, magnesium, and iron salts which make the water difficult to lather (forms curds), and when heated leaves hard mineral deposits on the wetted surface of the container. Surface brackish water may be expected to contain microorganisms, while brackish well water should contain few or none. As with seawater, brackish water can be used for construction, firefighting, and general housekeeping tasks. It is not generally recommended for those purposes where it is to be heated to near boiling temperatures. Potable water can also be produced from it by reverse osmosis treatment.

5. Fresh water has no apparent salty taste, but when found on the surface (river, stream, oasis) it may contain suspended materials, dissolved

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* TB MED 229.

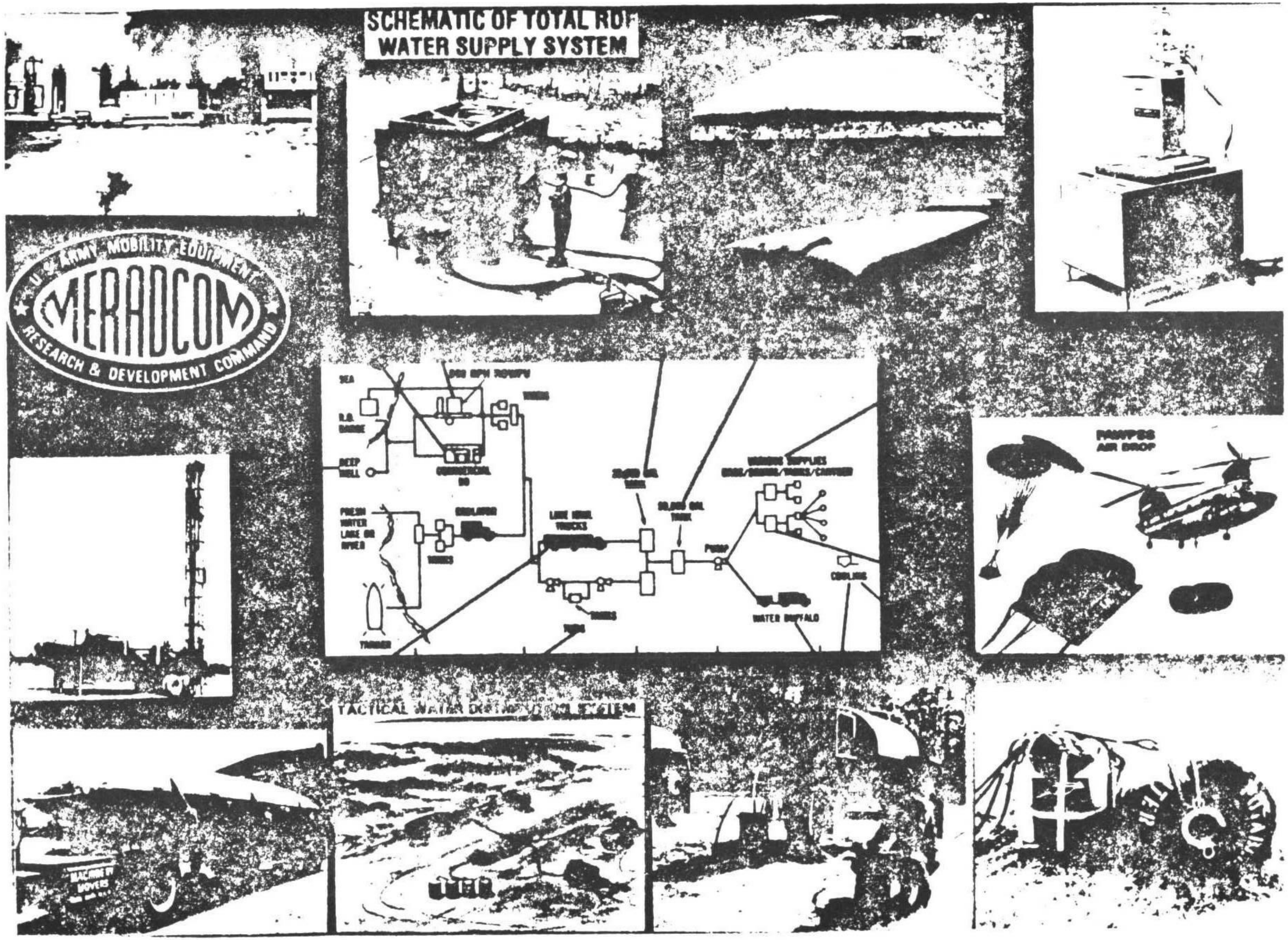


Figure 5.1. Schematic of total water supply system.

minerals, fecal matter, and bacteria and other disease-causing organisms. When obtained from wells or an in-country municipal water supply system it will normally be clean in appearance with no significant odor. On the other hand, it can dissolve mineral salts and bacteria. To make it drinkable (potable), disinfection through chlorination with specified residuals of free available chlorine (TB MED 229) is often the only treatment required. When it contains significant amounts of dissolved salts of magnesium, sulfur, and iron, drinking it may often cause an increased laxative effect. Fresh water can be used for most cleaning and nonconsumptive purposes without purification. To make it potable, treatment using conventional water purification procedures (ERDLator) is normally adequate. When dissolved mineral content is too high, it can only be purified by reverse osmosis treatment. To assume that any one municipal water supply in the Middle East is potable (by U.S. standards) would be a mistake. Most countries in the region do not treat water to the standards required by the Army. Therefore such water sources must first be examined and declared suitable for human consumption by medical authorities, as cited above. Surface fresh water sources can also be a major health hazard. These waters, primarily rivers, are used by nearby inhabitants to dispose of all forms of human waste, and hence are potential sources of pathogenic organisms. They also harbor a variety of other organisms which may infect the human body simply through bodily contact with the water. The most dangerous is a blood fluke (spawned from a snail) which may enter the body to cause a disabling disease known as Schistosomiasis.

The concepts and suggestions in this section are based on engineering judgment and military-tested experience and can save water in a desert environment. Although valid, a critical aspect in the implementation of any suggestion presented here is approval by appropriate U.S. Army Medical Department authorities at all levels of command. The Surgeon General of the Department of the Army is responsible for insuring that sanitary control and surveillance of field water supplies from source to consumer is accomplished and making such recommendations as may be necessary to protect the health of the individual soldier, and consequently the various commands.

Whenever in this report the use of water of a lesser quality than that prescribed for potable waters -- such as for showers, laundries, and bathing -- is suggested, it must be noted that the practice should only be implemented after the advice and approval of competent medical and engineer personnel have been obtained.

5.4.2 *Water Conservation*

Much can be learned from some of the water-conserving habits of the region's inhabitants. The basic water conservation principles below, which should be followed by a military force in the field, are generally observed by desert people:

1. Make each soldier aware of his responsibility to conserve water by avoiding wasteful practices and being ever-conscious that there is some useful purpose for wastewater or unsuitable (e.g., hot) potable water.

2. Place command emphasis on water conservation and water reuse.

3. Protect potable water from all sources of contamination, including sand and dust.

4. Do not dispose of water of any type without considering alternative uses.

5. Prohibit water thievery from storage containers and pipelines, and the indiscriminant use of expedient showers.

6. Avoid installation of centralized pressure water systems for temporary facilities needed to support a military force in the field.

7. Use expedient human waste disposal techniques instead of wasteborne sewage systems.

The potential savings in water to be realized by the application of the specific techniques discussed in the remainder of this chapter can be significant, as indicated in Figure 5.2. Estimates are shown for two groups of activities: those that require only potable water and those that can use nonpotable water if available. In each instance, the savings are measured against the water consumption planning factors contained in TRADOC Pamphlet 525-11.

The reduced water consumption levels shown in Figure 5.2 for each of the major activities reflects the benefits from: (1) installation of water saving devices and procedures (full figures), and (2) the additional savings if wastewater treatment and recycling are employed (ghosted figures). The latter savings are those associated with laundry and shower operations, and have been estimated to be an 80 percent reduction. These benefits should be verified by field testing treatment procedures. However, as indicated in the following discussion of various water-consuming activities, there are many opportunities to use the wastewater. Although the quantities of water are relatively small and difficult to quantify, they could be significant in the aggregate.

The use of water of lesser quality is also regarded here to be a viable method of conservation. Especially in SWA where the dissolved mineral content can be quite high, any opportunity to use local water and avoid the costly reverse osmosis treatment process has both logistic and economic advantages. These benefits are most apparent when it comes to water required for construction (concrete mixing, soil compaction, etc.). Untreated seawater or brackish water is quite satisfactory for most theater of operations construction that is only intended for short-term use.

As shown in Figure 5.2, the projected minimum savings in potable water from the application of all conservation measures discussed above is about 3.7 gal/man/day (14.0 L/m/d), or a reduction of 26 percent from the established consumption planning factor of 14.3 gal/man/day (54.1 L/m/d). Likewise, the amount (4.6 gal/man/day [17.4 L/m/d]) of fresh water required for activities that do not involve ingestion of water (lower portion of Figure 5.2) can be reduced about 80 percent by a combination of recycle/reuse and water quality reduction measures. If viewed from the standpoint that potable water only would be produced and used by all activities identified in Figure 5.2, the projected savings becomes even more significant. The overall savings in potable water could amount to 7.4 gal/man/day (3.7 gal/man/day + 3.7 gal/man/day)

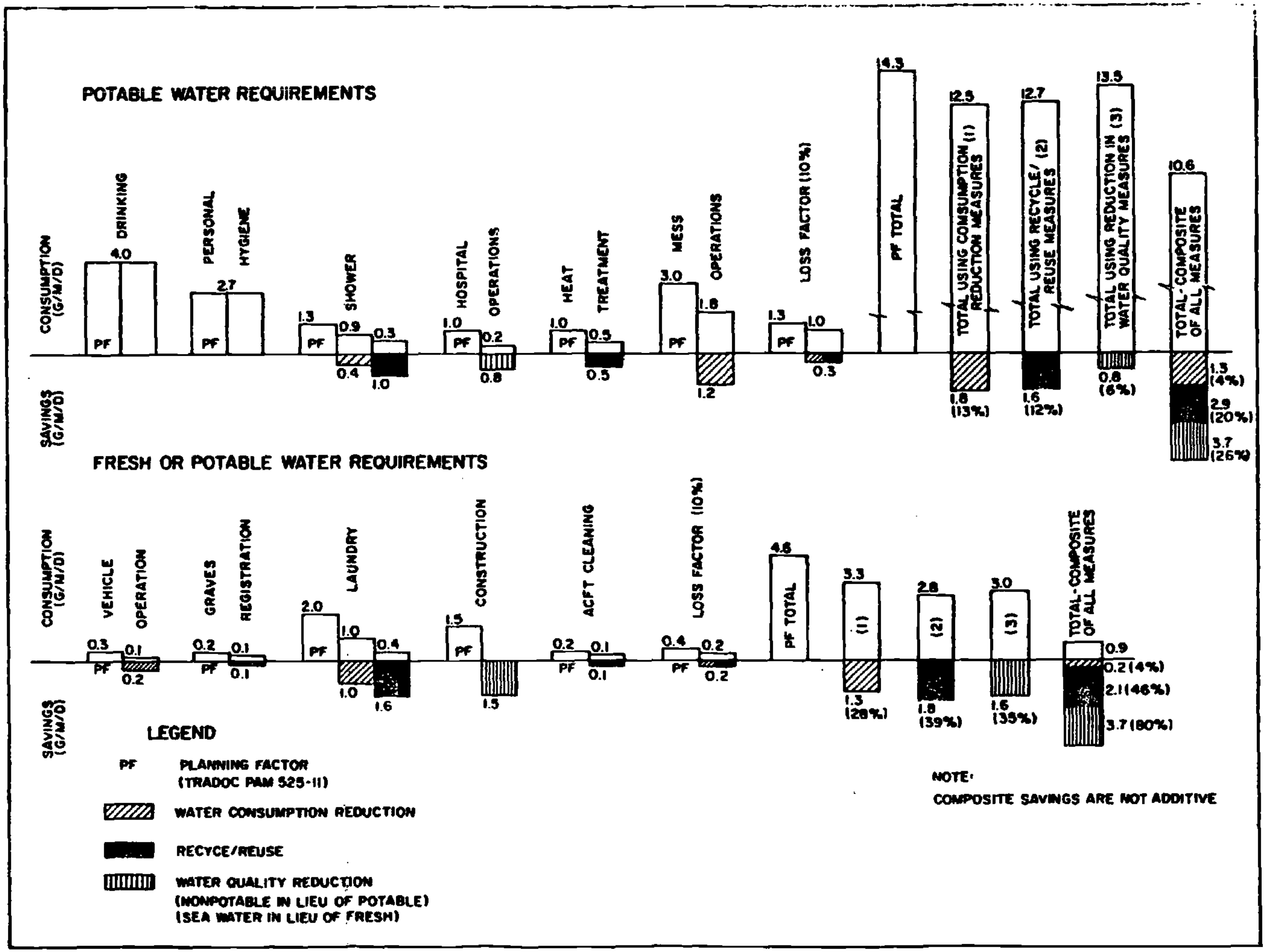


Figure 5.2. Savings.

(28.0 L/m/d) which is a 39 percent reduction from the unadjusted consumption planning factor of 18.9 gal/man/day (71.5 L/m/d).

5.4.3 *Activity: Drinking Water*

Hot, arid, external conditions and strenuous activity required of a soldier cause body temperatures to increase. The body rids itself of this heat by the evaporation of sweat. This natural cooling system is efficient, and the body continues to function well if its water losses are replaced. When they are not, dehydration takes place, and with it there is a corresponding loss in body function efficiency. If dehydration is allowed to progress, an individual can quickly become incapacitated and then must be treated for heat stroke. Without prompt treatment, a severe case of heat stroke could result in death.

The normal thirst sensation is not a reliable indicator of the water required. It will be necessary, therefore, for individuals to drink water frequently during the hot and most active part of the day.

5.4.3.1 Water Requirements:

Quality: Water for drinking should only be obtained from authorized potable sources. Although water from other sources may appear clear and drinkable, it will probably contain chemical and/or pathogenic contaminants that can cause a variety of intestinal disorders. Drinking water from sources used by local desert tribesmen should generally be avoided. Under emergency conditions, this water may be used, but only after being disinfected with iodine tablets or brought to a rolling boil for 15 seconds.

Quantity: Approximately 4 gal (15 L) of cooled potable drinking water will be provided for each soldier per day. Those engaged in strenuous physical activities will normally require this amount of water to maintain their strength during the hottest period of the day. Those who are less active will need to drink less. Under all circumstances, every soldier needs to develop a habit of drinking frequently during the day, whether he feels thirsty or not. To encourage the individual soldier to drink increased quantities of water, the U.S. Army has adopted "water chiller concept." This has resulted in the development of a small mobile chiller which is expected to be a part of the organic equipment for forces operating in arid regions (Figure 5.3).

Water Sources: Only water approved by Task Force Surgeon and provided through the established supply system should be used for drinking. Units will either obtain their water from designated distribution points or will have it delivered if they do not have the transport capability. Individuals should rely on unit Lyster bags, 5-gal (19-L) cans, or 400-gal (1510-L) water trailers (Water Buffalo).

5.4.3.2 Water Conservation Measures:

1. Extra care must be exercised when filling canteens or 5-gal (19-L) water cans to avoid any spillage. Unnecessary waste deprives others of water when they come for a fill-up.

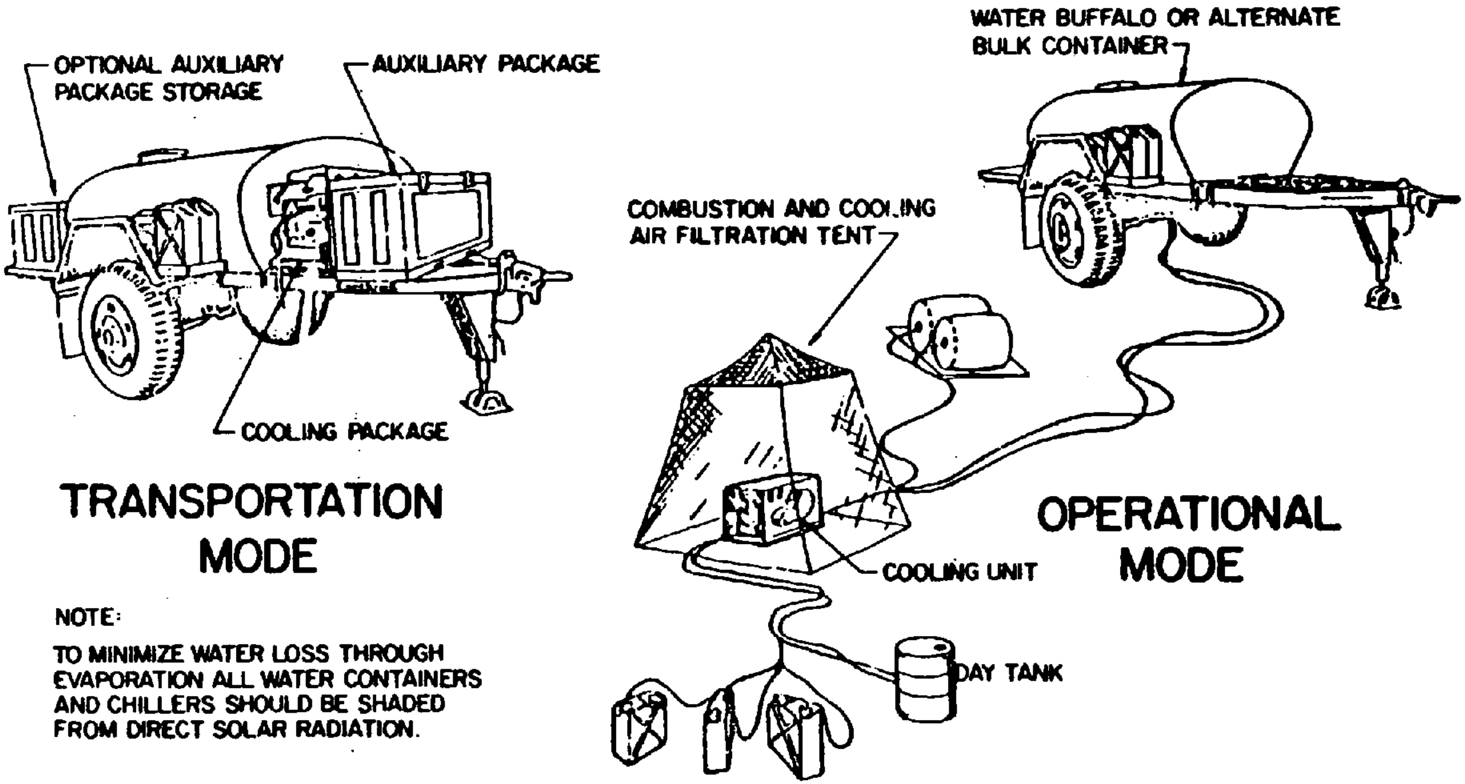


Figure 5.3. Water chiller concept.

2. After filling a canteen or 5-gal (19-L) can, the cap or lid should be securely fastened. This will prevent spillage or contaminants from getting into the water. In addition, water containers should be shaded to prevent loss of chlorine and to keep them reasonably cool.

3. Water that has become warm can be made more drinkable by blending it with cool water from the water chiller.

4. Water in canteens or 5-gal (19-L) cans which may have become too warm to drink, or otherwise degraded from potable quality, should not be discarded. It should be made available for other purposes, specifically:

- For washing and shaving.
- For vehicle radiator make-up.
- For some activity requiring water (hand washing, maintenance shop, latrine facility, cleaning equipment, helicopters, vehicle windshields, and photo laboratory film processing).

Water supplies should be shaded for protection against solar radiation even though containers themselves may be insulated. Survivor blankets or wet tarpaulins can provide effective shielding.

5.4.4 *Activity: Mess Operations*

Mess operations include food and beverage preparation and the cleaning of eating and cooking utensils. In hot and arid climates these activities will be simplified by relying primarily on processed foods rather than fresh meat, fruit, and raw vegetables, at least through the first 6 months of a military operation. In the Corps area and Communications Zone, except for hospital patients, two hot meals daily will usually be provided, and the remaining meal will be an operational ration. The hot meals will be the same rations as used in the combat zone, but may be augmented with limited perishables (e.g., salads, milk), when the situation permits. The food will be prepared at unit level in a field-type kitchen (soft frame-type shelter) and served on permanent plastic, compartmented trays or in individual mess kits. As soon as the situation in rear area permits, unit kitchens will be integrated into area kitchens, with a capacity to serve up to 800 to 1000 troops daily on a continuous basis.

In general, hospital patients will receive only the Standard B Ration, except those requiring modified dietary rations. The modified rations will consist of the B Hospital Ration or the B Hospital Liquid Ration. Patients would be routinely fed individual combat rations only under exceptional circumstances.

Following active combat operations, food service will offer three high-quality, hot meals each day. These meals may be a combination of T and A Ration items, with the latter consisting of fresh and frozen meat, fresh fruit and vegetables, and milk -- all of which require conventional cooking and refrigeration facilities.

The current B Ration is a nonperishable, bulk operational ration planned for a 10-day menu cycle. It consists largely of dehyrated, dehydrated compressed, or thermally processed items which allow for reasonably long storage periods and eliminate the need for refrigeration equipment.

Messing operations will require facilities to wash individual mess gear and cooking equipment and utensils. The use of T Rations (tray meals and disposable mess kit liners) will keep washing to a minimum. On the other hand, the introduction of A Rations will greatly increase need for washing facilities and the effort involved in washing.

5.4.4.1 Water Requirements:

Quality: Water for all aspects of mess operation must be potable. Thus, the initial supply must be potable and reserve supplies must be protected against contamination from dust, insects, etc.

Quantity: The amount of water for mess operations varies depending on the types of rations used -- C or MRE (Meal Ready to Eat) Rations require no water; B Rations require 0.5 gal (1.9 L)/ration/day, while A Rations could require 1.0 gal (3.8 L)/ration/day for cooking.

The mess kit washline assembled for sanitation purposes has four 32-gal (121-L) GI cans with immersion heaters attached for heating water. These facilities are also used by food preparers to clean cooking utensils, pots, and pans. The normal mess kit washline requires 80 gal (303 L)/meal of potable water.

Water Sources: Potable water for mess operations is normally obtained from the 400-gal (1510-L) water trailer organic to each company-size unit.

5.4.4.2 Water Conservation Measures:

1. Mess personnel need to minimize spillage in filling cooking containers and mess kit washline GI cans.

2. Open water containers should be covered to minimize evaporation and contamination from airborne dust. Washline GI cans could be fitted with plywood covers or tops cut from 55-gal (209-L) drums.

3. Mess kits or feeding trays and cooking utensils should be scraped clean with napkins or sanitary wipes provided to each diner to minimize the amount of food entering the washwater. Inserts for mess kits under development by the U.S. Army Natick Laboratories would achieve this objective even more effectively.

4. Predip, rinse, and final rinsewater from the mess kit washline can be saved and reused for making the soapy washwater at the head of the washline needed for the next meal.

5. Hot predip and rinse waters remaining after a meal are a source of hot water for shaving or vehicle radiator makeup water.

6. Sudsy washwater should not automatically be discarded. It can be filtered through cloth to remove food particles, soap and grease and used for hand washing at latrines and vehicle maintenance facilities, general purpose cleaning (e.g., vehicles, stoves, duckboards) or wetting the earth around any electrical equipment that needs to be grounded (see Chapter 4).

5.4.5 *Activity: Personal Hygiene*

Personal hygiene involves those sanitary measures required for an individual to keep the body clean and prevent disease. This is essential in maintaining combat effectiveness and high morale within a unit. Constant attention will have to be given to proper field sanitation because of the difficulties in maintaining body cleanliness in a hot and dusty environment.

5.4.5.1 Water Requirement:

Quality: To maintain proper standards of personal hygiene, the soldier is to be provided potable water each day for a helmet bath, shaving, brushing teeth, comfort cooling, and handwashing before eating and after using the latrine.

Quantity: Approximately 2.7 gal (10.2 L) of potable water is to be provided for personal hygiene each day. It is allocated for the following purposes: daily shaving (1-1/2 qt [1.4 L], or helmet capacity); helmet baths on alternate days (four helmets each); comfort cooling (1/2 qt [0.5 L] over the soldier's head, eight times a day); brushing teeth and handwashing (2-1/4 qt [2.1 L]).

Water Sources: The principal sources of water for these purposes are the unit water storage containers -- 400-gal (1510-L) water trailer, 5-gal (19-L) cans or Lyster Bag. Water of unknown quality from other sources should not be used; however, troops near the seacoast could use seawater for comfort cooling, bathing, and shaving.

5.4.5.2 Water Conservation Measures:

1. Individuals should avoid spillage when filling their helmets or other containers used to obtain water for shaving or bathing. When helmets are used, some means of support is needed to prevent tipping. See FM 21-10, Field Hygiene and Sanitation, for expedient procedures that can be used under field conditions.

2. During cool weather, hot rinse water from the mess kit cleaning line can be used for shaving.

3. Seawater should be used by those on the seacoast for comfort cooling, bathing, and handwashing.

4. No attempt should be made to recover or reuse water used for personal hygiene. When convenient, wastewater should be disposed of in soakage pits constructed to provide grounding for electrical equipment.

5. The use of waterborne sewage systems should be avoided. An exception to this policy could be made for a cantonment or major facility located near the coast where seawater could be readily used as the transport medium.

5.4.6 *Activity: Shower Operations*

Showers are necessary in any combat theater, and especially in hot arid regions, to help maintain an acceptable level of personal hygiene and sanitation among the fighting forces. This results in a decreased incidence of disease, which translates to increased combat effectiveness. For those engaged in strenuous activities, the availability of shower facilities can also contribute to their general morale. The primary means of providing showers in the field is the eight-showerhead Portable Bath Unit M1958, or the more recently type classified nine-showerhead Bath Unit (AMH). Expedient showers consisting of an elevated water storage tank (55-gal [209-L] drum) and dispensing piping and valve have been commonly fabricated in the past by individual units when regular bath units have not been readily available.

5.4.6.1 Water Requirements:

Quality: In hot and arid climates, it is prescribed that potable water be used in the Portable Bath Unit. However, there may be occasions when bacterially safe nonpotable water (e.g., river and stream water) can be used by military units. In these instances, however, approval to use water from rivers and similar sources without treatment should be obtained from the Unit Surgeons. As an additional precaution, soldiers should be warned against drinking nonpotable water while showering.

Quantity: Water is to be provided on the basis of a 3-minute shower, requiring 4.5 gal (17 L) of potable water per shower. For a nine-showerhead bath unit operating 20 hours per day, the maximum daily water requirement is about 16 200 gal (61 300 L) per day. However, if individual shower time is not controlled, the 4.5 gal (17.0 L)/person will probably be exceeded.

Water Sources:

1. Potable water:

a. Primary source is the nearest base water storage terminal or water tank farm, with delivery provided by tanker trucks of Water Transportation Teams (GJ).

b. An alternate source, when available, is a municipal water system approved for use by Corps or Task Force Surgeon.

2. Nonpotable water:

a. Surface water sources (e.g., river) that has been approved by Corps or Task Force Surgeon.

b. Pretreated wastewater from shower unit itself.

3. Brackish water and seawater: an expedient for short periods. Long-term use is not recommended due to residual salts left on the skin; these may irritate the skin and might not provide the degree of cleanliness desired.

5.4.6.2 Water Conservation Measures:

1. Limiting water consumption:

a. Prohibit the fabrication of expedient showers when regular controlled-time-of-use bath unit facilities are available.

b. Replace current showerhead valves on the M1958 and AMH Bath Units with spring-loaded valves to prevent continuous flow. An alternative means is to require an operator of the bath unit to manually control the flow of water to the shower with the shower stand control valve on top of the water heater.

2. Using nonpotable surface water: bath and laundry units serving a specified area should be near each other -- particularly when it is necessary to pretreat nonpotable surface water for a shower and laundry. TB MED 229 provides the guidelines to be used when employing nonpotable surface waters. The Unit Surgeon should also be consulted.

3. Using recycled shower water: shower wastewater may be reused after proper treatment and then recycled through the bath unit. To do this, it will be necessary to collect the wastewater for treatment. This involves the construction of a shallow basin (4- to 6-in. [100- to 150-mm] deep and large enough to accommodate the duckboards on which the bather stands to shower), and the installation of a system to transfer the wastewater to collapsible water storage tanks for treatment (Figure 5-4). Suggested equipment and procedures for pretreating shower wastewater are shown in Figure 5.5.

The quality of the treated water produced by the wastewater treatment process essentially meets potable water quality standards. However, its acceptability for showering should be tested using the Preventive Maintenance and/or Engineer Water Quality Analysis Kits for compliance with Corps or Task Force Surgeon procedures. In the absence of a 420 gph (0.442 L/s) diatomite filter, or in case of a filter malfunction, it is possible to use chlorinated water that has undergone clarification by coagulation and sedimentation. However, bathers should be warned not to drink the water during showering. The minimum standards to be observed under these circumstances are as follows:

pH	6.5 to 7.5 (after chlorination to point of user)
Turbidity	1 to 5 units
Chlorination	30-minute free available chlorine residual of 5 mg/L at 20°C and above.

4. Using brackish and seawater shower water: brackish water and seawater which are clean in appearance and free of obnoxious odors are suitable for showers. Continued use is not desirable because a bather will not feel as clean as with fresh water. For best results it will be necessary to provide saltwater soap. Brackish water and seawater are generally classified as "hard waters" and, therefore, require additional soap when used for showering or laundering. However, it is better for troops to use hard brackish water or

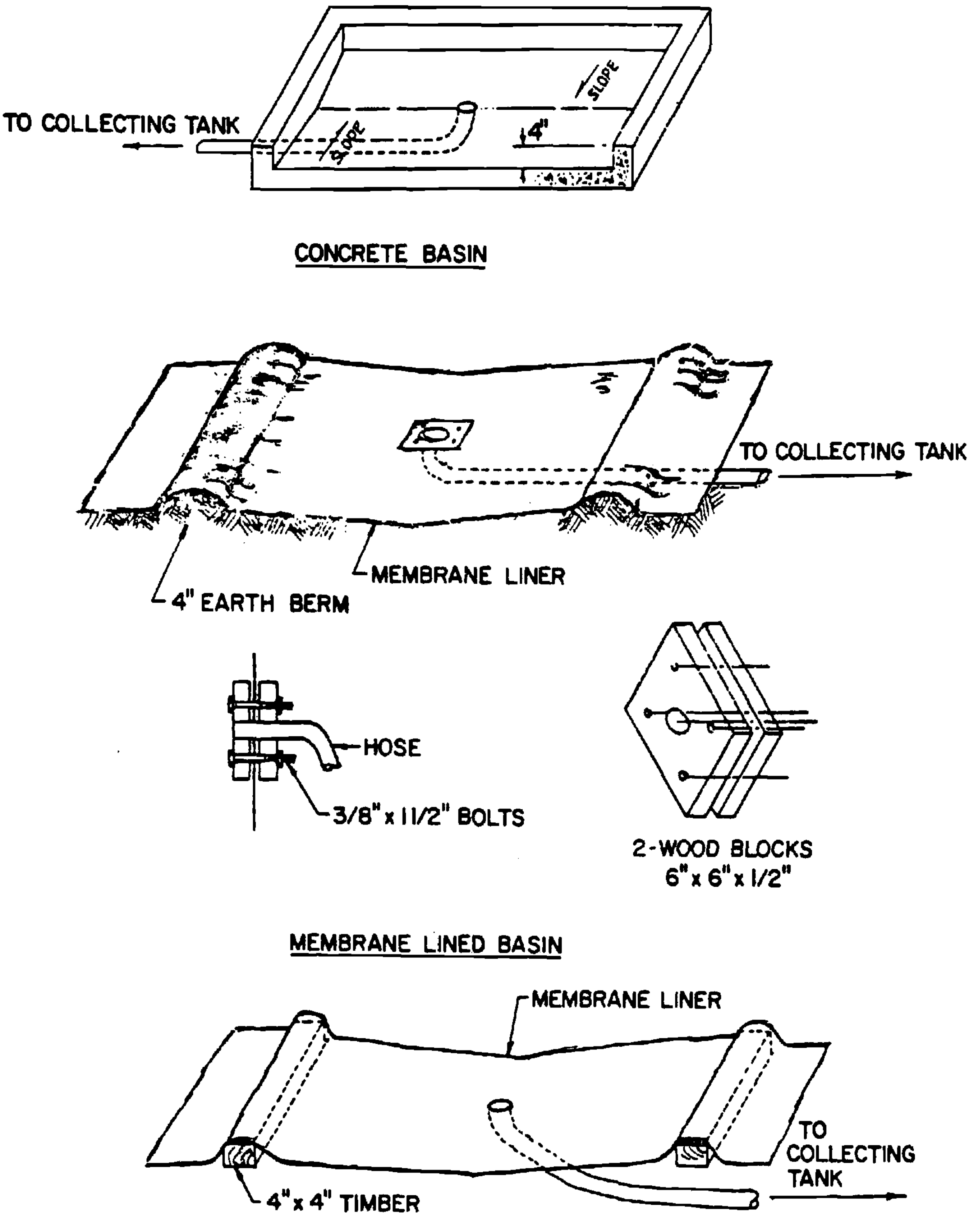


Figure 5.4. Shower water collection basin.

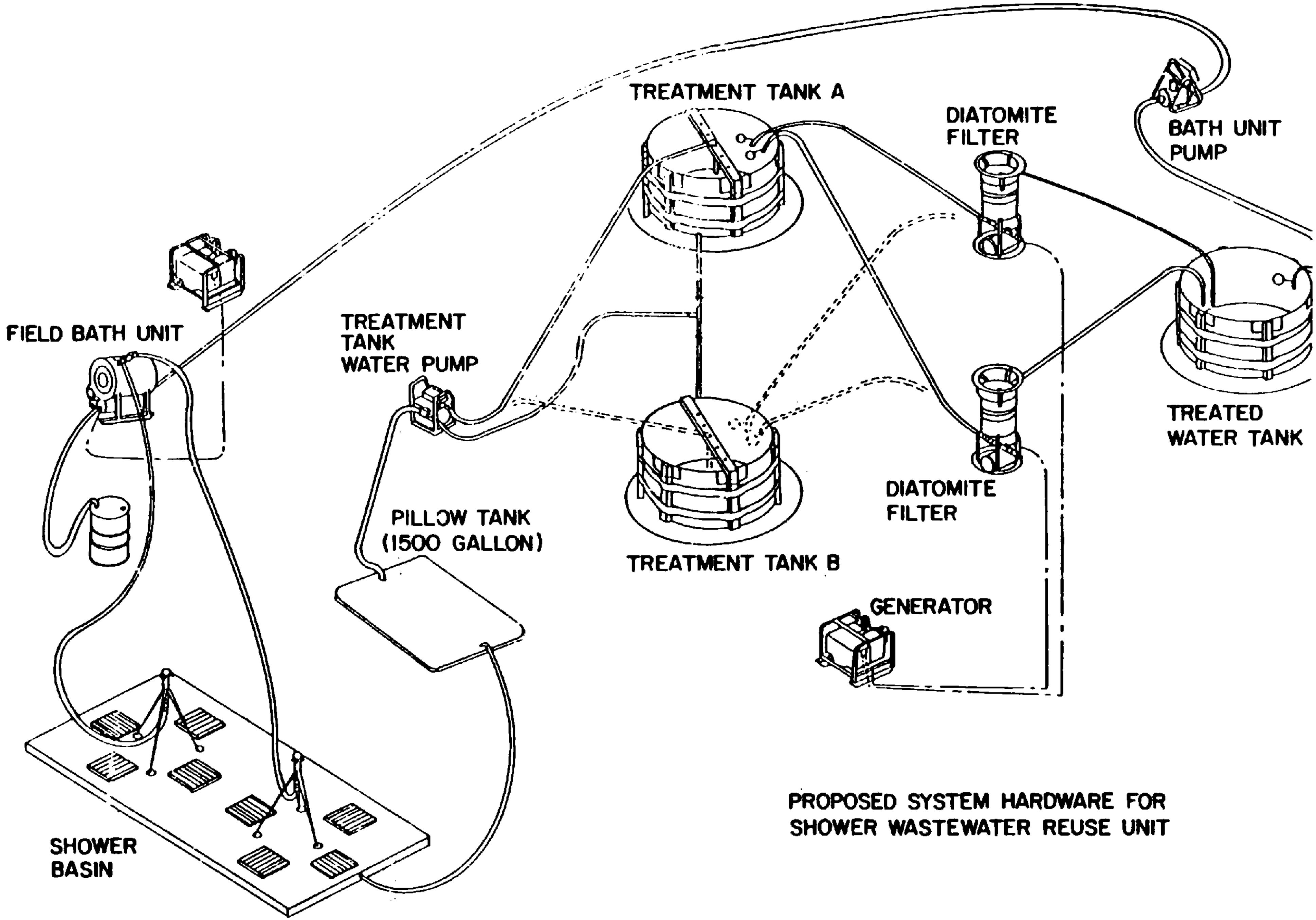


Figure 5.5. Shower wastewater reuse unit.

seawater to conserve potable water and not feel clean, than to waste potable water for showers.

5.4.6.3 Shower Wastewater Reuse Unit (SWRU): A typical arrangement of the SWRU installed with the standard Portable Bath Unit (NSN 4510-00-168-1963) is shown in Figure 5.5. A field bath unit consists of a raw water pump, water heater, 3-kW electrical generator, and two shower stands with four shower nozzles per stand. Since shower nozzles do not have control valves, the discharge rate is a 16 gpm (1.0 L/s) continuous flow. An improved bath unit scheduled for type classification in FY81 has the number of shower nozzles increased to nine and an individual control valve added to each nozzle. Under optimum conditions, the maximum rate of discharge of a shower unit is the capacity of the pumping unit, or 20 gpm (1.3 L/s). Normally, a field bath unit is near a water source such as a lake or river, and the raw water is pumped from the source through the water heater to the shower nozzles. Every effort is made to locate clean water sources. Each bath unit is provided an electrically driven raw water pump that delivers 18 to 20 gpm at 65 to 70 ft total dynamic head (1.1 to 1.3 L/s at 19.8 to 21.3 m TDH).

In semi-arid regions or areas where natural water sources are scarce, the SWRU system is designed to conserve fresh water. The basic procedure is as follows: 150-gal (5680-L) of potable water would be trucked or piped into the 1500-gal (5680-L) fresh water storage tank. The raw water pump with the bath unit is used to transfer the water from the storage tank through the heater to the showerheads. The shower stands are installed on a shallow rectangular coated fabric tank to collect wastewater. From there it flows by gravity or is pumped to a 1500-gal (5680-L) pillow-type storage tank. When the pillow tank is filled, the wastewater is pumped to one or two open, cylindrical, 1500-gal (5680-L) treatment tanks. Before wastewater is pumped into the tank, 24 lb (10.9 kg) of powdered activated carbon (1920 ppm) is manually added to the empty tank. Approximately 15 minutes is required to fill the tank and mix the activated carbon with the wastewater. When the tank is filled, 40 ppm of the cationic polyelectrolyte (Type I Polymer) is added and the three-way plug valve on the pump suction is positioned to permit recirculation of the wastewater in the tank for about 30 minutes. After mixing is completed, 0.5 ppm of the nonionic polyelectrolyte (Type II Polymer) is added and recirculation is stopped and the coagulated wastewater is allowed to settle for about 30 minutes.

After the 30-minute settling period, the water has been clarified and is ready to be filtered. Suction hoses attached to the filter are suspended by floats to permit withdrawal from the upper water level in the treatment tank. Two diatomite filters operating in parallel are used to maintain continuous delivery of 16 gpm (1.0 L/s) to the fresh water tank. The diatomite filter from the 420 gph (0.442 L/s) Water Purification Unit (NSN 4610-00-937-0222) was selected because it can operate as a separate component. The filter is lightweight and can be manually handled. Further, it is self-contained, with an electrically driven filter pump and has all necessary accessories for precoating and filter backwash. Body feed is not used because the precoat will provide enough cake thickness for one filter cycle, or time to filter the contents of one treatment tank. A Dole flow control valve is added to control filter operation at the constant rate of 8 gpm (0.5 L/s) over a variable pressure range.

A 3-kW engine-driven generator with circuit breakers and switch box would normally be required to operate the diatomite filter pumps. However, in hot, arid regions where ambient water temperatures are relatively high, the requirement to operate the heater is reduced. Consequently, the filter pumps could be operated from the 3-kW generator provided with the bath unit.

The filtered water is collected in the 1500-gal (5680 L) open-top tank. Periodically, on a predetermined schedule, a measure of calcium hypochlorite must be added to chlorinate the stored water. The treated wastewater is chlorinated because of the presence of bacteria or microorganisms which can increase in number, especially in hot, sunny locations. Further, calcium hypochlorination is effective in destroying a difficult-to-remove contaminant, urea.

Some make-up water is required periodically to compensate for losses. The principal losses are from evaporation and retention on the body as individuals leave the shower. However, about 98 percent of shower wastewater in each cycle should be collected for treatment, where the water losses are minimal. Other losses, estimated at less than 1 percent, include those associated with the periodic removal of sludge from the coagulation tanks and the backwashing of the filter. In a 20-hour operating day, the total water loss would be about 3 percent, or 575 gal (2180 L).

The SWRU, as described above and shown in Figure 5.5, is a simple and effective field treatment system. Many component items, such as chemicals, hoses, and the gas-engine-powered (GED) pump are the same as in the Shower Wastewater Treatment Kit, NS 4610-01-023-4537 (Pollution Abatement Kit). Additional items required include diatomite filters and a 1500-gal (5680-L) pillow-type water storage tank. The filters are available in existing 420 gph (0.442 L/s) ERDLator water purification units. Upon type classification of the 600 gph (0.631 L/s) ROWPU, the 420 gph (0.442 L/s) ERDlator filter could be made available for this set. The 1500-gal (5680-L) pillow-type tank is not currently in the Army supply system, although it has been tested and military specifications have been prepared. The diatomite filters are available in existing 420 gph (0.442 L/s) ERDLator Water Purification Units. With the type classification of the 600 gph (0.631 L/s) ROWPU, the 420 gph (0.442 L/s) ERDLator filter could be made available for this purpose.

5.4.7 *Activity: Laundry Operations*

Clean field clothing, socks, and underwear are needed to help maintain proper standards of hygiene and morale among soldiers in the field. In hot, arid climates where individuals are expected to perspire freely and become covered with dust, clean clothing will be needed each time an individual showers.

Clothes are laundered in the field by Laundry and Renovation Company, General Support, using the trailer-mounted laundry unit, M-532. Mounted on the trailer is a water heater, washer-extractor, air compressor, dryer-tumbler, engine-generator, and water pump. Each unit has a washer capacity of 60 lb (27 kg) of clothes and uses about 140 gal (530 L) of water per load, or 280 gal (1060 L) per hour. Normal operations are 20 hours per day, 7 days per week. A new and slightly larger model of the portable laundry is under development; the washer and extractor are separate units. This equipment is not expected to be available to troop units for 2 to 3 years.

An approach to laundering which was considered here especially for implementation in the temporary phase of troop deployment in an arid region is the use of "dry cleaning," rather than water wash, using the troop-issued, trailer-mounted laundry unit. Dry cleaning is a closed loop process using a solvent other than water, which is recovered and reused through many cycles before it must be replaced. In 1976, the U.S. Army Natick Laboratory conducted studies which tested, with "encouraging" results, a commercially available dry cleaning unit for use on individual military garments and gear. This potential for application in an arid region cannot be ignored. However, it must be weighed and compared with the water wash alternative in each specific case before the Army decides to use it.

5.4.7.1 Water Requirements:

Quality: Potable water is not required for laundry operations; however, there are certain constraints on what can be used. Hard water not only reduces the cleaning power of soaps, but can deposit insoluble residue on clothing. Brackish and saltwater can corrode metal parts of laundry equipment. However, both these problems can be overcome in an austere desert environment. Saltwater detergents in the DOD inventory and developed primarily for the Department of the Navy by the U.S. Army Natick Laboratory can be used. Although brackish water and seawater are more corrosive, the trade-off between immediate requirements vs. increased equipment wear and tear for a short time probably warrant the use of these waters.

Quantity: About 280 to 300 gal (1060 to 1140 L) of water per hour are required for each washer. When water conservation is not a concern, water is obtained from a lake or stream and the waste washwater and rinsewater discharged in a convenient area off-site.

5.4.7.2 Water Sources:

1. Nonpotable water:

a. Brackish water and seawaters, especially if seawater detergents are available.

b. Municipal water system.

c. Potable water which may have become contaminated with dust could prove to be usable.

2. Potable water: Potable water from the nearest water tank farm can be used if no other acceptable nonpotable source is available.

3. Recycled water:

a. Laundry rinsewater may be used without pretreatment for washwater or used in subsequent rinse cycles.

b. Laundry wastewater -- hot wash and rinsewater -- may be reused in a laundry unit, but some pretreatment is required.

5.4.7.3 Water Conservation Measures:

1. Control spillage: Exercise care in making hose connections and opening valves to prevent loss of water from leaks and accidental spills.

2. Water Reuse:

a. Reuse Laundry Rinsewater. Collect the rinsewater from the washer in either a bladder tank or a collapsible fabric tank and use for subsequent wash cycles. Wash-cycle water is not to be reused for subsequent washes, but should be collected and used for other purposes, e.g., dust control, vehicle washing, etc. Modification of the wastewater discharge line on the washer is required in order to direct washwater (70 gal [265 L]) to one storage tank and rinsewater (70 gal [265 L]) to another (see Figure 5.6).

b. Reuse Laundry Wastewater. All wastewater from a field laundry may be reused, but pretreatment is necessary to remove oils, dirt, and other contaminants from washwater (not rinsewater). Additional equipment is required for this purpose -- three 1500-gal (5680-L) collapsible fabric tanks three 420-gph (0.442-L/s) diatomite filters, and hoses. The process involves flocculation of contaminants using powdered carbon and polyelectrolytes.

3. Dry Cleaning: In the latter stages of deployment and if the tactical situation is relatively stabilized, this measure should be considered -- especially for implementation in base camp development.

5.4.7.4 Laundry Wastewater Reuse Unit (LWRU): A typical layout of the Laundry Wastewater Reuse Unit (LWRU) to treat wastewater from the standard 60-lb (27-kg) capacity, Trailer Mounted Laundry Unit, NSN 3510-00-782-5294, is shown in Figure 5.7. In many instances, field laundries operate as a team, with two laundry units per team. Wastewater generated by a laundry unit is about 250 gph (.26 L/s); two units at one location would generate about 500 gph (.53 L/s) of wastewater. Wastewater is discharged from the drain in the bottom of the trailer-mounted unit which can be connected by hose to a 500-gal (1890-L) pillow collection tank. If two laundry units are near one another, the drains would be manifolded before connection to the pillow tank.

The procedure for treating laundry wastewater is like that described for shower wastewater with two exceptions. The 1500-gal (5680-L) treatment tanks in the proposed Shower Wastewater Reuse Unit are replaced with 500-gal (1890-L) capacity tanks. This reduction in size is possible because the quantity of wastewater from two laundry units is less than from one bath unit. In addition, only one diatomite filter is required for the laundry units. The chemicals and dosages (ppm) are the same, as is the method of operation.

The set of equipment for the LWRU basically consists of the Pollution Abatement Kit (Laundry Wastewater Treatment Kit, NSN 4610-01-023-4536), and additional components, such as a 420-gph (.44 L/s) diatomite filter, portable generator, hose, tanks, and a variety of connectors.

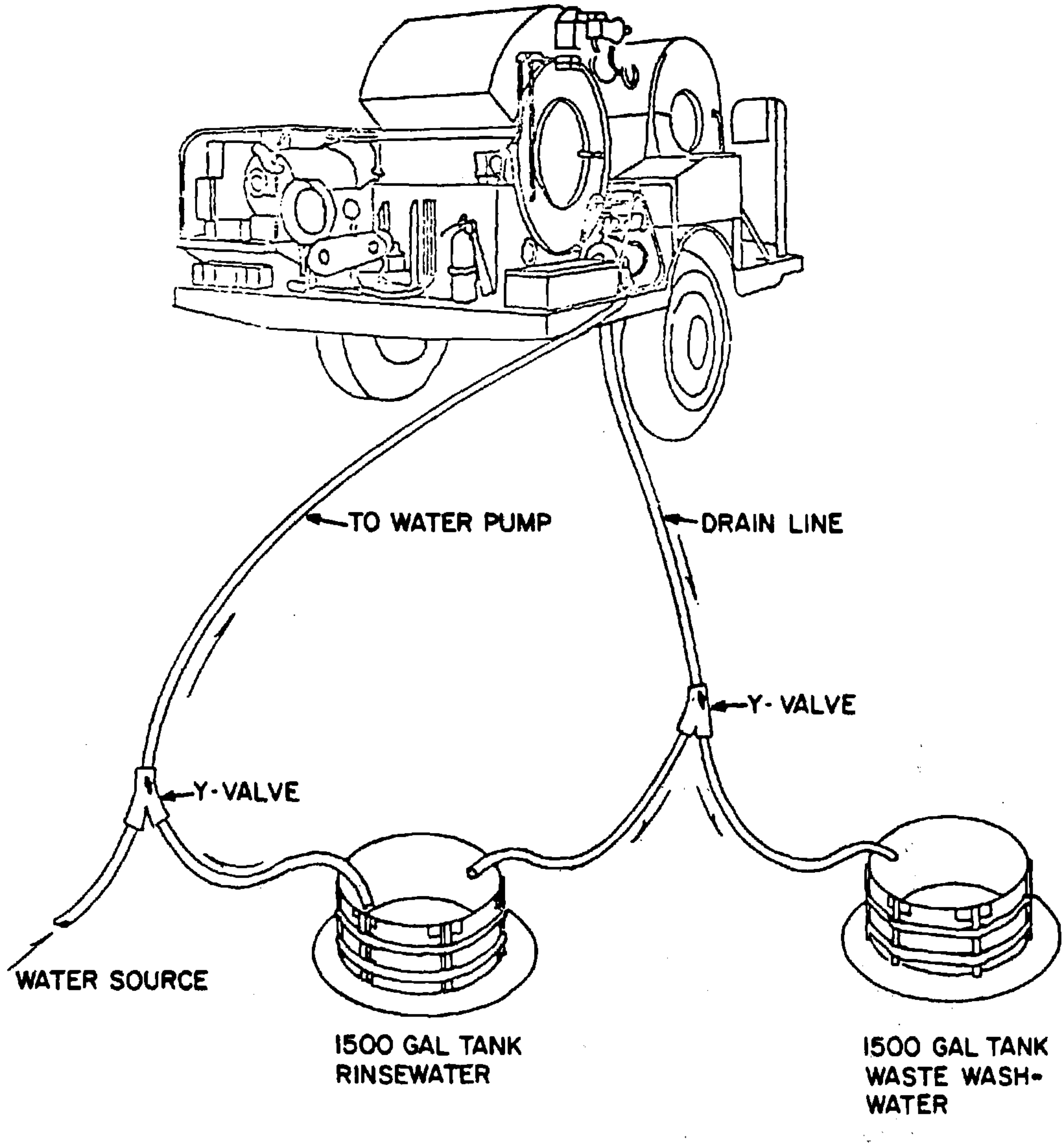


Figure 5.6. Rinsewater reuse system.

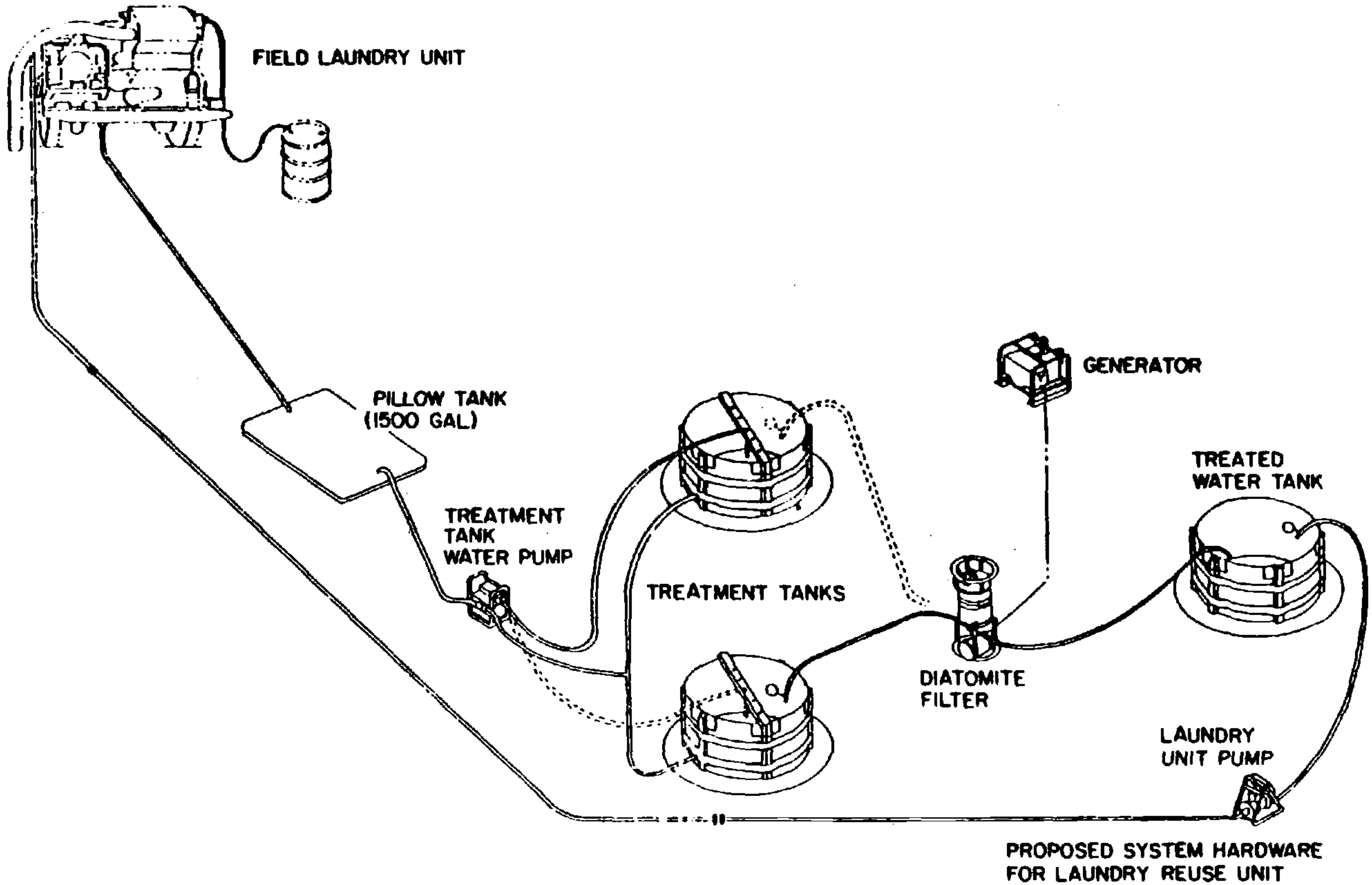


Figure 5.7. Laundry wastewater reuse unit.

5.4.7.5 Personnel and Training Requirements: It is estimated that two men can assemble the SWRU for operation in about 2 hours. The LWRU would require two men and approximately 1 hour for assembly. The LWRU requires less time because the 500 gal (1890-L) tanks are easier to field-erect than the 1500 gal (5680-L) tanks. One man would be required per shift to operate either the SWRU or the LWRU. Operator level of training would be equivalent to what the MOS 52N receives today for the operation of ERDLator water purification units.

5.4.7.6 Logistic Support: The consumable supplies used in operation of wastewater reuse units are primarily chemicals and fuels. It is noted that the chemical requirements for activated carbon are high because the dosages are based on the initial charge. In batch coagulation, the activated carbon settles to the bottom of the tank and is resuspended along with the new charge of carbon when the tank is refilled. The carbon particles not effectively used in the first treatment are returned to contribute to further treatment. If beneficial, the subsequent charges of activated carbon could theoretically be reduced. It is known that in the present batch coagulation system, the dosage of activated carbon is 1920 ppm. In field tests using continuous flow clarifier equipment for treating laundry and shower wastewater, effective results were obtained using 425 ppm activated carbon dosages.

5.4.8 *Activity: Hospital Operations*

The hospital consumption planning factor of 1 gal/man/day (3.8 L/m/d) is based on a projection of 65 gal/day (246 L/day) for each patient bed and 10 gal/day (38 L/day) per hospital staff member. These rather significant quantities of water are based on daily baths for the medical staff and the majority of patients; changes of uniforms and bedding each day; and the various general sanitation, food preparation and housekeeping operations done each day in support of patients and hospital staff. Although TRADOC PAMPHLET 525-11 indicates that only potable water is to be produced for hospital use, a number of medical support actuivities do not actually require water of this quality.

The primary factors influencing water consumption in a theater of operations are the casualty rate and the patient evacuation policy. In regard to the latter, the sooner in-patients are evacuated from the theater for continued treatment, the lower the amount of water will be.

5.4.8.1 Water Requirements:

Quality: TRADOC PAMPHLET 525-11, "Near-Term Water Resources Management" mandates that all waters intended for hospital use (65 gal/man/day [246 L/m/d]) be potable. However, since hospital operations comprise several subactivities, some of which offer an outstanding opportunity for water conservation, a hard consideration of their respective demands for potable quality water is indeed warranted. Existing U.S. Army Medical Department documents explore these possibilities, indicating the potential for using nonpotable waters to achieve selected functions within the scope of field hospital operations."

Quantity: The 1 gal/man/day (3.8 L/m/d) value translates to 65 gal/bed/day (246 L) potable quality. Of these, 10 gal/man/day (38 L/m/d) are estimated for human consumption; the remaining 55 gal/bed/day (208 L) are intended for non-consumptive purposes (e.g. laundry, showers, cleansing of equipment and areas, operation of equipment such as pumps and distillers), and could be satisfied using nonpotable quality water. (These waters may in fact have been treated and highly disinfected with chlorine or other suitable compounds, such as Wescodyne, so that they are nonpotable, but free of any pathogenic organisms.) In proportion, then, under austere water conditions, about 88 percent (62/72) of the water demand for hospital operations could come from other than the "potable" quality sources.

Water Sources:

1. Potable: From the field water distribution system. Authority to use other than potable water must be obtained from the Surgeon.

2. Nonpotable:

a. Fresh water from a municipal water system or from producing wells.

b. Brackish water and seawater low in suspended solids.

c. ROWPU brine.

5.4.8.2 Water Conservation Measures:

1. Use ROWPU brine water especially for cleansing operations.

2. See paragraph 5.4.3.

3. See paragraph 5.4.4.

4. See paragraph 5.4.5.

5. See paragraph 5.4.9.

6. See paragraph 5.4.20.

7. See paragraph 5.4.21.

8. See paragraph 5.4.23.

9. See paragraph 5.4.21.

10. See paragraph 5.4.23.

5.4.9 *Activity: Heat Casualty Treatment*

This section is not intended to be a guide to the identification and treatment of heat casualties, but rather presents field expedients suitable for conserving and/or maintaining the quantities of water required in their treatment. However, one must note that anticipated heat casualties will cover a broad spectrum of severity, from mild (heat exhaustion) to severe (heat stroke), with water being a prime factor in the degree of treatment applied. The victim must be re-hydrated and also cooled. Water for re-hydration must be potable and cool, but that required for cooling may be of a lesser quality.

5.4.9.1 Water Requirements:

Quality: Water used for re-hydration must be potable. For body cooling purposes, consideration can be given to a lesser quality, especially if large quantities are needed in a short time -- e.g., large influx of heat casualties. Ingestion of such waters must be avoided.

Quantity: The amount of water needed to treat each casualty could range from 5 to 10 gal (19 to 38 L), depending on the level of treatment. Present planning factors require 1.0 gal/man/day (3.8 L/m/d) for heat treatment -- this is in addition to the quantity allocated for drinking purposes (4.0 gal/man/day [15 L/m/d]). The concept is for water intended for heat treatment to be moved only as far forward as the combat battalion level, and that it will be distributed to the unit level in 5-gal (19-L) cans by an ambulance.

Water Sources: Potable water for heat treatment through re-hydration will usually be obtained from the storage capacity allocated each hospital (i.e., 20,000 gal [76 000 L] storage) or from the 400 gal (1510 L) water trailer organic to each company-size unit. Nonpotable water may come from a variety of sources.

5.4.9.2 Water Conservation Measures:

The following steps apply only to the use of nonpotable waters for body "cooling," thereby reducing the demand on potable sources.

1. Use ROWPU brine if the water temperature gradient is suitable and near a water production facility.

2. Install a casualty treatment reservoir which permits water to be reused for successive patients. The suggested field expedients illustrated in Figure 5.8 use the Small Mobile Chiller (SMC) and a 500 gal (1890 L) reservoir to treat successive heat casualty patients (if only about four-fifths full this will be within the capacity of the Small Mobile Chiller.

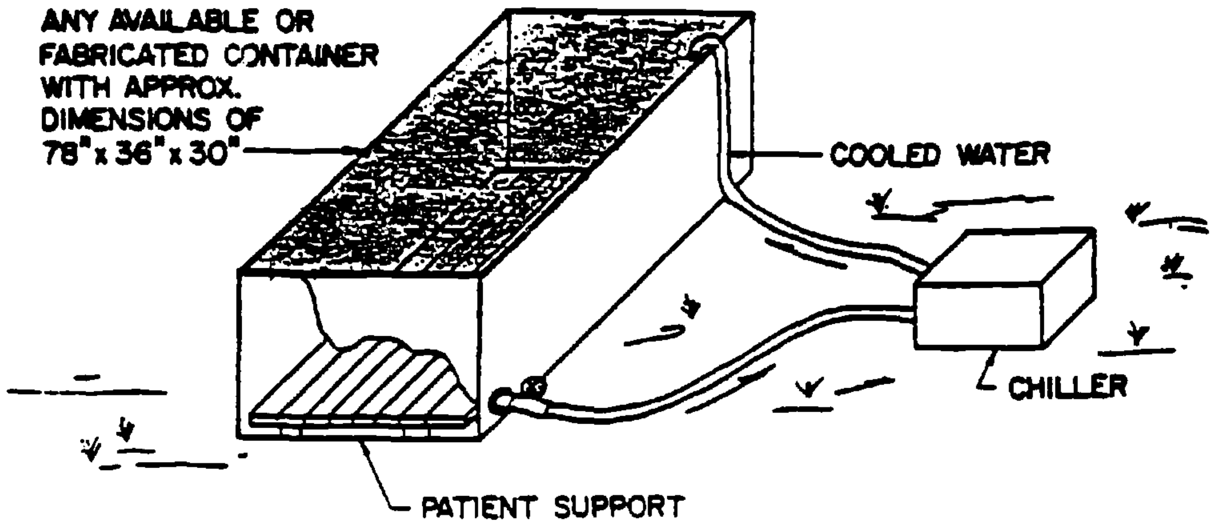
3. Rely on the high rate of evaporation in desert areas to cool heat stroke patients. Cooled water from a Small Mobile Chiller can be sprayed on a patient's body by fitting a spray device to the nozzle on the hose of the Chiller. Additional cooling will result as the water evaporates naturally or can be enhanced if a fan is available.

5.4.10 *Activity: Graves Registration*

Graves registration is carried out at several levels or echelons within a combat zone. It involves the handling of remains, which demands the application of good sanitation practices, especially among the Graves Registration Personnel. Some water is needed for washing remains, but most is used for hygiene. Handlers are required to wash and disinfect themselves frequently.

5.4.10.1 Water Requirements:

Quality: Water used for washing and preparation of remains may be of nonpotable quality. Handlers could disinfect themselves using a previously prepared chemical solution. Nonpotable water could be used when potable water



NOTE:
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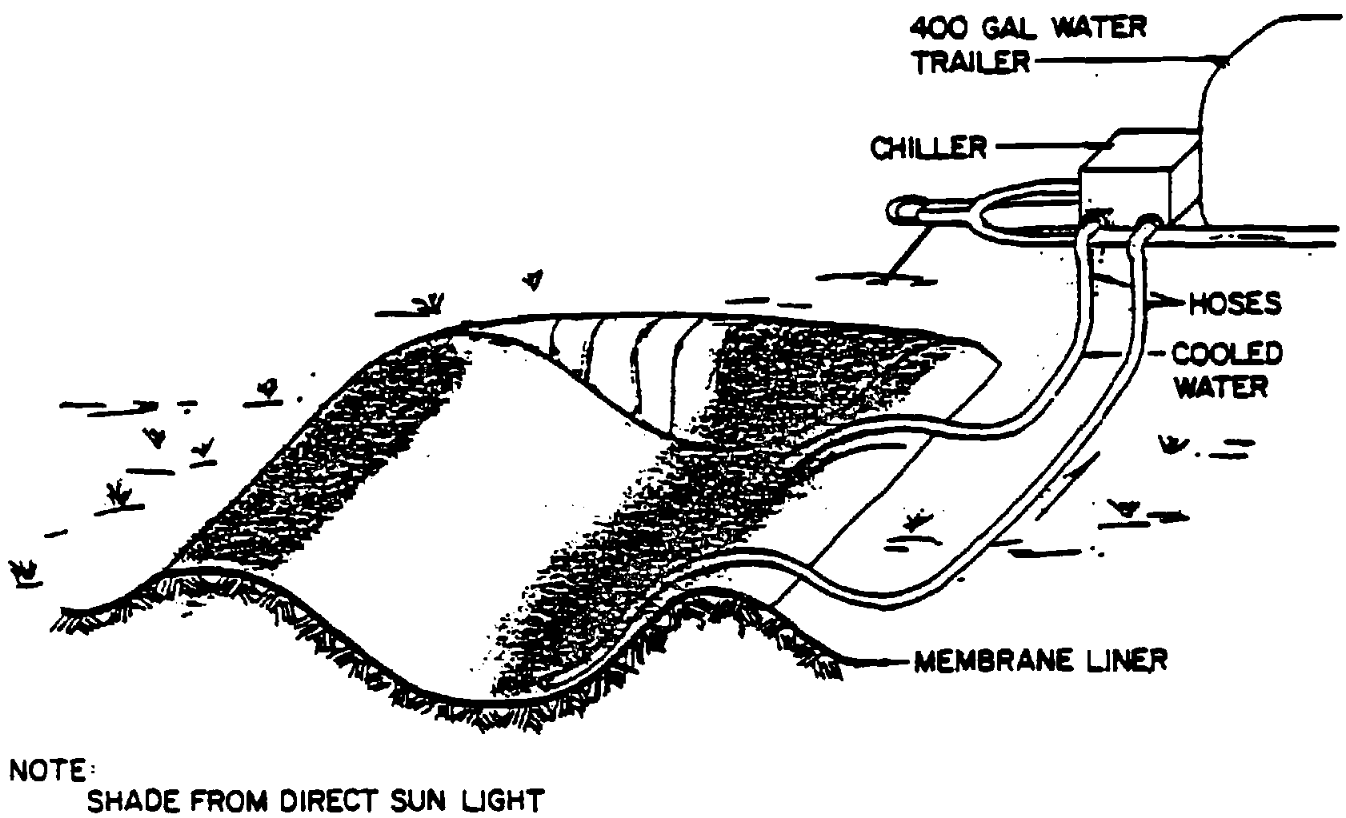

NOTE:
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AID STATION FACILITY

Figure 5.8. Multiple casualty treatment.

is not available or in short supply, but authority to use it should be obtained from the Corps or Task Force Surgeon.

Quantity: Approximately 50 gal (190 L) of water are required for each casualty for both the processing of remains and handler hygiene.

Water Sources:

1. Potable water from the field water distribution system. Authority to use other than potable water should be obtained from the Task Force Surgeon.

2. Fresh water from a municipal water system or from producing wells.

3. Brackish water, seawater low in suspended solids, or ROWPU brine.

5.4.10.2 Water Conservation Measures:

1. No attempt should be made to reuse wastewater from graves registration activities. Whenever convenient, disposal should be in a soakage pit next to a facility requiring electrical grounding.

2. Nonpotable water or brine from the water treatment process should be used wherever possible and when authorized by the Task Force Surgeon. Saline water will require the use of saltwater soaps.

5.4.11 *Activity: Construction-Concrete Mixing and Curing*

The requirement for concrete during the early stages of a military operation is projected to be minimal since units and activities will rely primarily on Table of Organization and Equipment (TOE) structures rather than on base development-type facilities. However, as the buildup matures, more engineer effort may be available for constructing temporary facilities that require concrete footings and floors. In addition, concrete may be required for road culverts, bridge abutments, headwalls, and footings for generators. Some of the concrete will require reinforcing steel. In addition, procedures insuring that the concrete cures properly will be needed.

Water for concrete mixtures is normally transported to the work site in water distributors issued to construction engineer units, which also have pumps to obtain water from available surface sources.

The requirements for concrete aggregate washing are discussed in paragraph 5.4.13.

5.4.11.1 Water Requirements:

Quality: Concrete mixes for most military field applications do not require better than nonpotable quality water. In general, satisfactory concrete can be mixed using natural surface water, brackish water and seawater, or any water that is free of oil, and suspended organic matter, especially sugar. Also, sewage effluent that has undergone the equivalent of secondary treatment is suitable for concrete.

Quantity: The water-to-cement ratio varies depending on the strength of concrete desired, quality and gradation of aggregrates available, and the type of structure being built. However, for general-purpose concrete, a rule of thumb for an average mix is 6 gal/sack (23 L) of regular Portland cement and 5 gal/sack (19 L) for underwater concrete, watertight structures, and mixtures using air-entrained cements, brackish water, or seawater.

Water will also be required for cleaning mixing equipment and curing concrete if curing compounds are not available. Allowing 2 gal/sack (8 L) for these purposes, approximately 40 gal (151 L) of water would be required per cubic yard of concrete.

Water Sources:

1. Nonpotable: Wastewater from field showers and laundries is a good source of mix water, but it must first be treated to remove organics, oils, and soap. The treatment processes involve all or a combination of the following: skimming to remove oils and soap, flocculation, filtration, and chemical additives if available.

2. Surface:

a. Water from rivers, streams, and canals will probably be high in organics, including fecal material from both humans and animals. Consequently, the requirement to treat such water before use should be anticipated. Surface water sources in the Middle East may contain the parasite which can cause schistosomiasis. Care should be taken not to touch surface water.

b. Brackish well water or surface water with a high mineral content (sulfate, calcium, sodium, magnesium, and some potassium) or salinity should also be filtered if it contains oils and other organics.

c. The salt content of seawater from the Mediterranean and Arabian Gulf is greater than 2 percent and will reduce the strength of concrete. These effects, however, can be compensated for by decreasing the water/cement ratio. Suspended organic material should be filtered out before use.

d. Where the ROWPU is used, the brine resulting can be used for concrete mixes, but only after dilution with equal parts of fresh water to reduce the salt concentration.

5.4.11.2 Water Conservation Measures:

Alternate Water Sources:

1. Avoid using potable water for mixing concrete. Instead, rely on available seawater or brackish water that is relatively free of organic matter.

2. Reduce water/cement ratio for minimum use of water where practical.

3. Wastewater from showers and laundries may be used for concrete mixtures. In producing small quantities of concrete (5 cu yd [3.8 m^3] or less), a convenient method of pretreating such wastewater is the use of a simple

expedient sand filter (Figure 5.9). (Paragraph 5.4.11.3 explains the operation of this filter.) For larger quantities, the ERDLator would be a more efficient means of producing larger volumes of acceptable water.

4. Avoid using water for curing concrete by employing commercial curing compounds. However, if none are available, wastewater-soaked burlap or sandbags could be an acceptable alternative.

5.4.11.3 Operating Procedure for Sand Filter:

1. Use: Produces small quantities of subpotable water for concrete mixes, general-purpose cleaning, radiator makeup water, etc.

2. Capability: Filters up to 1000 gal (3790 L) of wastewater per day.

3. Procedure: Wastewater (messkit washline, field laundry, and shower) is poured by hand through the burlap filter until drum is full. Maintain water level at top by periodically refilling drum. Adjust valve to control quality of water desired; the smaller the discharge, the higher the quality of water produced. Filtered water can be collected in a 1500-gal (5680-L) pillow tank or other available container.

If the sand filter is used continuously at one location, the top 2 or 3 in. (50 to 80 mm) of sand should be removed and replaced with clean sand after each 1000 gal (3790 L) filtered. A long-handled scoop will have to be made for this purpose. For small projects, dispose of the filter material upon completion of the job and reconstitute the filter at the next project site.

5.4.12 *Activity: Construction - Soil Compaction/Soil Cement*

Road networks and roadbeds themselves throughout SWA have capacities that will be inadequate for a military force that relies heavily on vehicle movement of supplies and equipment. Consequently, a significant amount of engineer effort is expected to be devoted to establishing and maintaining an adequate line of communications.

Tasks involved will be largely earthwork and roadbed construction, but can include culvert and bridge construction. In mountain and plateau deserts, the soil is generally hard and rocky, making road construction in flat areas simply a matter of rock removal and grading. In sand or dune deserts, the problem is much greater unless the dunes themselves are avoided.

Fill areas in roadbeds and backfill for culverts and bridge abutments will need to be compacted. Where there are loose granular soils, dry compaction using vibratory rollers or tracked vehicles can be effective. Clay and silty soils will require water to compact to optimum density.

In desert areas, opportunities to use soil cement surfaces appear to be numerous -- stabilization of storage yards and depots, expedient floors for maintenance tents and buildings. This construction technique not only provides a durable surface, but helps to minimize dust.

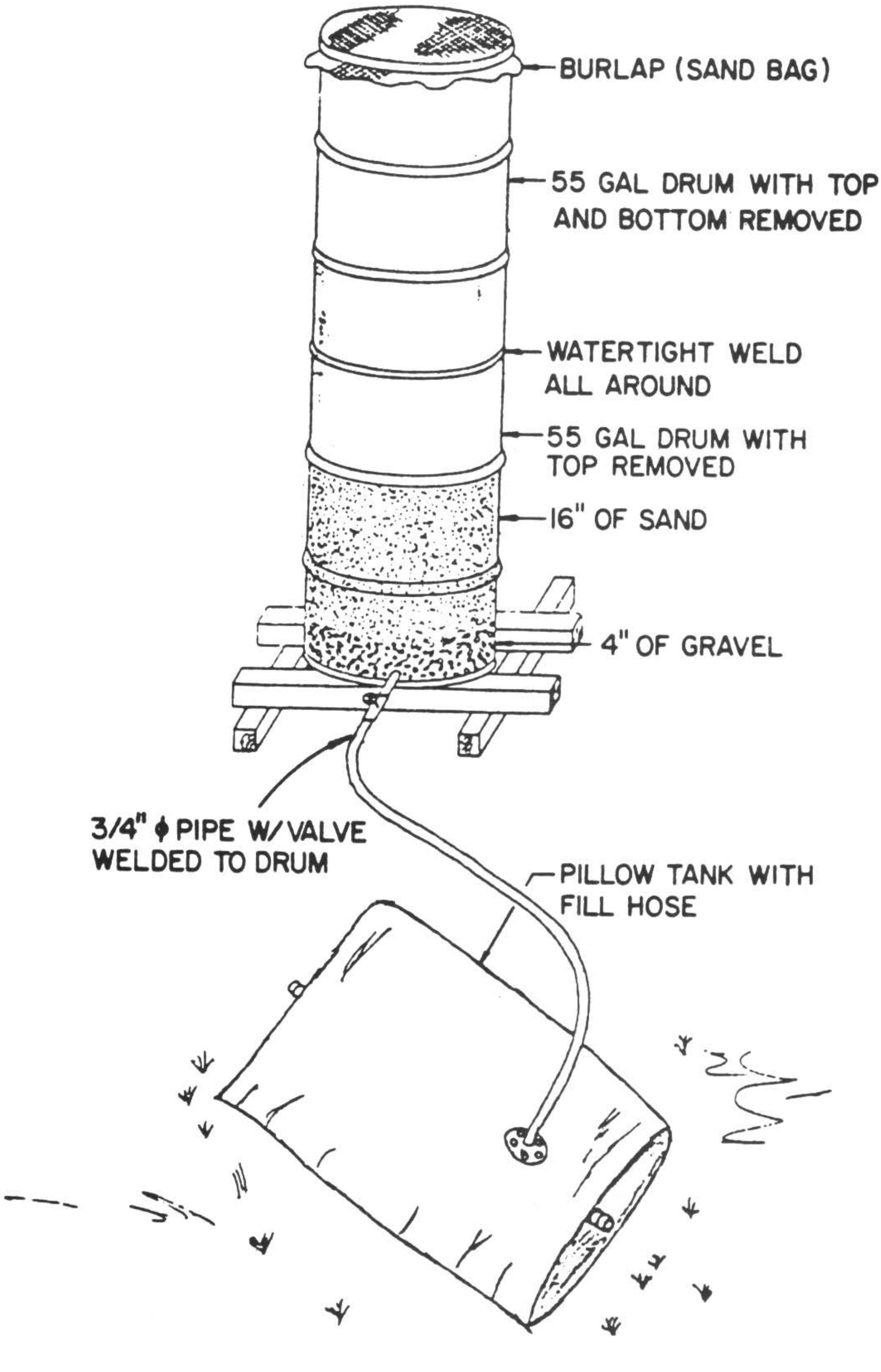


Figure 5.9. Sand filter.

5.4.12.1 Water Requirements:

Quality: Nonpotable fresh, salt, or brackish water is suitable for both soil compaction and soil cement.

Quantity: Water quantities will vary widely, depending on the types of soil encountered. Because of the general absence of soil moisture, that needed for compaction will have to be added. This would amount to 30 gal/cu yd (150 L/m^3) to reach a moisture content of 10 percent. On the other hand, soil cement requires 40 to 60 gal/cu yd (200 to 300 L/m^3).

5.4.12.2 Water Sources:

1. Nonpotable fresh water. Wastewater from showers, laundries, and ROWPUs are suitable for relatively small soil compaction and soil cement projects.

2. Surface. Rivers and canals provide suitable water for soil compaction/cement. Also, catchments could be constructed to collect rainfall.

3. Brackish. Water from wells, despite its high mineral content, is acceptable for these applications.

4. Seawater. Satisfactory soil compaction/cement tasks can be accomplished with seawater.

5.4.12.3 Water Conservation Measures:

1. Standard soil compaction tests to determine optimum density and moisture should be conducted before compaction operations are started. Equipment for this purpose is contained in the unit equipment issued to Construction Engineer Battalions.

2. Wastewater of any type should be used for small compaction tasks. Larger projects, demanding larger amounts of water, should rely on saltwater or brackish water supplies. A separate pipeline for this purpose could prove feasible.

3. When water is not available, or loose granular soils are encountered, vibratory compaction techniques, which require no water, could prove satisfactory. If an issued vibratory compactor is not available, passes with bulldozers, tanks, and large wheeled trucks can effectively compact most soils.

4. Application of water to raise soil moisture to optimum levels for compaction should be carefully regulated and closely monitored at the worksite. When a water distributor is used, control can be readily effected; for field expedient water distributors it is more difficult. Suggested designs for achieving a more uniform distribution of water are shown in Figure 5.10.

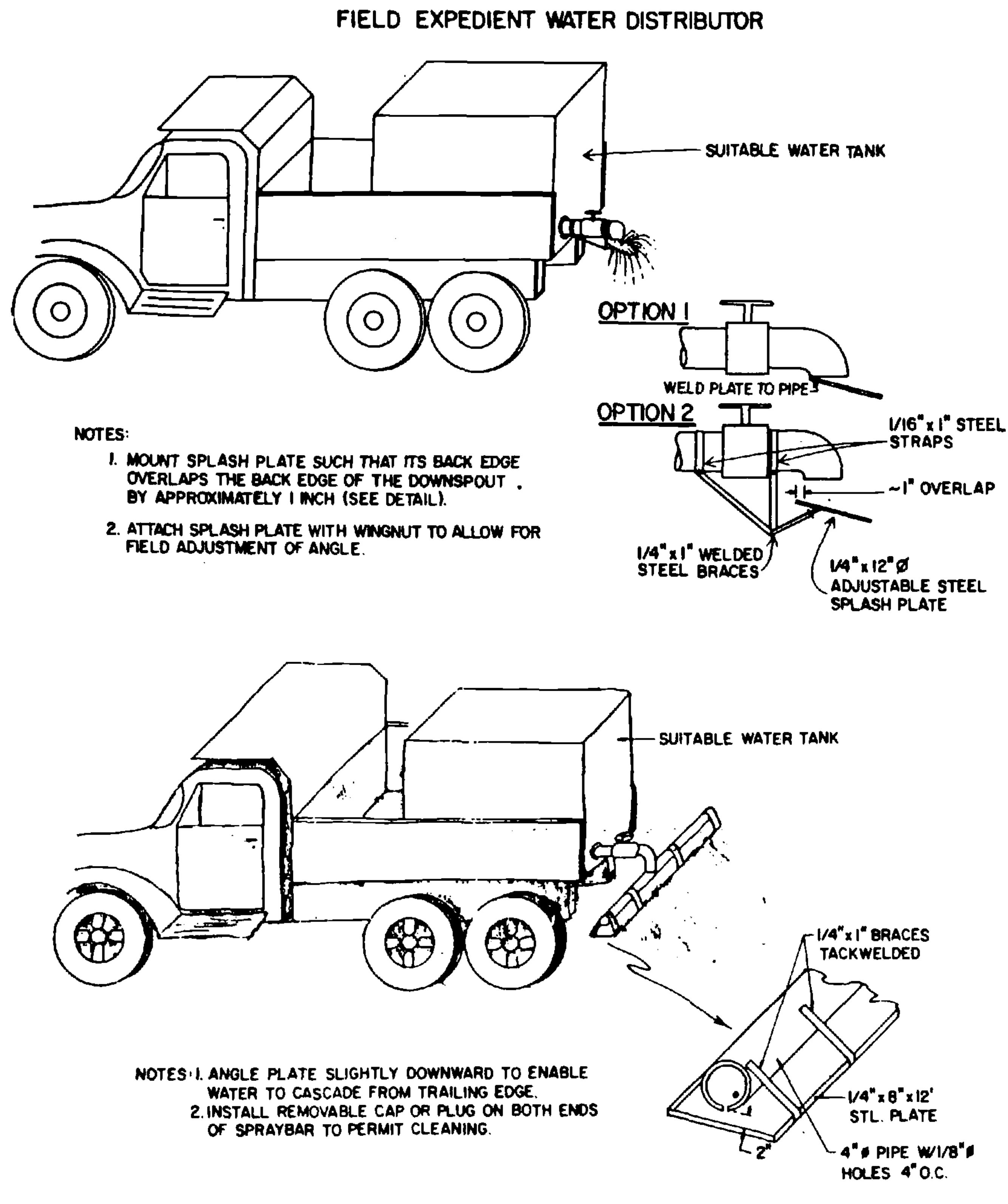


Figure 5.10. Field expedient water distribution.

5.4.13 *Activity: Construction - Aggregate Cleaning*

Large sources of clean angular sand are frequently found in dune desert areas but are not common to other types of deserts. Further, natural sources of good sand may not be close to the intended construction site. Likewise, well-graded gravel may not be readily available and must be produced from rock fragments and boulder by crushing.

These ingredients of concrete should be relatively free of fines, and less than 200 mesh, to insure good bonding with the cement. Clay and other fines can often be removed from gravel during crushing and screening. If fines are difficult to remove when dry, it may be necessary to apply a water spray or pressure air during the crushing and screening operation. Similarly, excessive fines can be washed from sand. In most instances, this can be done by constructing a simple sluice, putting sand in it, and filling it with water. Most of the fines can be washed away if water continuously flows into the sluice and the sand is simultaneously agitated in the water. Such an arrangement should be a closed system to permit the wash water to be reused once the fines have settled out.

5.4.13.1 Water Requirements:

Quality: Any clean water can be used for washing concrete aggregate. Salt and brackish water are suitable despite the salt residual that will remain once the material has been allowed to drain. Salt will decrease the strength of concrete, and in time the concrete will deteriorate. However, this is not expected to occur during the short period of time the structure is to be used by a military force.

Quantity: The amount of water required for cleaning aggregate depends on the condition of the sand and gravel and the amount of those materials required. Therefore, the quantity of water cannot be readily quantified. Under average conditions, about 500 gal per cu yd (2500 L/m^3) can be used for estimating purposes. Another useful estimate can be made according to the capacity of the rock crusher used. A 75 ton/hr (19 kg/s) crusher requires 25,000 to 50,000 gal/hr (26 to 53 L/s) and a 225 ton/hr (57 kg/s) crusher requires 100,000 to 200,000 gal/hr (105 to 210 L/s).

Water Sources:

1. Relatively clean water from a surface resource is preferred.

2. Salt and brackish water is acceptable and would probably be the primary source where large quantities of aggregate and sand require cleaning.

3. Clean nonpotable water from treating shower or laundry water could be used if the amount of material to be cleaned is relatively small.

5.4.13.2 Water Conservation Measures:

1. Pressure air (air compressor) should be employed where the fines are not firmly adhered to the sand and gravel.

2. Any washing facility established to continuously process large amounts of sand should include a closed-loop water system. Integral to the system should be settling ponds with enough capacity to permit fines to settle out of the wastewater while previously clarified water is being reused. This procedure would not be necessary if seawater could be obtained in generally unrestricted amounts.

3. Clean sand relatively free of dust and fines can be obtained in areas where loose sand is found on the ground surface by erecting a fence (equivalent of a snow fence) perpendicular to the prevailing wind. When the wind blows, the fine particles will pass through the openings in the fence and the coarser particles will collect along the fence line. Strips of camouflage netting about 4 ft (1.2 m) wide placed end to end and supported by long barbed wire pickets could be used as a field expedient.

5.4.14 *Activity: Construction -- Dust Control/Soil Stabilization*

The dry surface conditions and nearly constant wind throughout SWA keep the air full of dust during most of the year. Military operations -- with the continuous movement of vehicles, and landing and takeoff of helicopters -- only compound this problem. Ground visibility will be restricted, and men and equipment will become covered with dust.

Total control of dust is not possible, but measures can be taken to minimize its generation -- especially at airfields, heliports, and active storage areas and depots. Several materials, including water, can be used. However, water is probably the poorest choice for desert areas because its effect is only short-term due to the high evaporative rate in arid climates. Furthermore, water must be continually applied to be effective. Another common expedient dust suppressant material is waste engine oil from vehicles. This should be used; but because of the rather limited quantities produced at any one location, only localized use in unit motor parks is considered practical. Diesel fuel and other oil products have been employed by construction contractors in the Middle East for this purpose. However, in the quantities required by a military force, this technique would be a great logistics burden and too expensive, unless supplies could be obtained or captured in the region.

The following types of commercial suppressants have recently become available.

1. Magnesium Chloride Bitterns ($MgCl_2$) concentrate (a liquid) is used in large quantity applications and does not require dilution with water. It is applied like water, in initial quantities of about 0.5 gal/sq yd (2.3 L/m^2) for roads. Therefore, a water distributor could be used. The $MgCl_2$ is somewhat corrosive; hence, equipment compatibility should be determined. The initial application usually causes the road surface to become very hard, and in many cases only one or two applications a year are required. Obviously, weather, traffic levels, and soil conditions will affect the durability of the product.

2. Resin emulsions can suppress dust and stabilize soil. Some are petroleum-based products; others are acrylic. Both are diluted with water and are applied like water to the surface. Dilution ratios (agent to water) vary

from 1:4 to 1:15 or more. The degree of stabilization is determined by the amount of water used. Thick dust layers can be controlled by using a more dilute solution. This provides greater penetration, but the surface must be compacted for the adhesive characteristics to be effective. Heavily trafficked surfaces tend to become more hardened with use, and lighter or no-traffic areas become more resistant to wind and water erosion.

3. Oil-based commercial dust palliatives are available, and some experience has been obtained from their use in Viet Nam. PENEPRIME was most generally used for road and off-road dust control. It is applied undiluted using an asphalt distributor. A military disadvantage of this product is the dark residual on treated areas.

5.4.14.1 Water Requirements:

Quality: Water of any quality is suitable by itself for controlling dust and stabilizing soil. Freshwater, brackish water, or seawater can be mixed with commercial palliatives. In general, any water clean enough not to clog spray nozzles is acceptable.

Quantity: The amount of water required for mixing with commercial dust palliatives varies with the product and the nature of the application.

Water Sources: The nature of the dust problem in an arid region essentially dictates that only major sources be used, i.e., large producing wells or seawater.

5.4.14.2 Water Conservation Measures:

1. Because of the need to control dust, the use of water can hardly be avoided. It can be minimized, however, if some of the commercial dust palliatives on the market are used. Limited product evaluation and testing was completed in 1981 by the U.S. Army Construction Engineering Research Laboratory for Region VIII, U.S. Environmental Protection Agency. However, interferences from these tests on the use of these palliatives in arid tactical areas with salt water or brackish water as dilutents would be risky since this is a unique application. Further research on palliative selection to match specific soil types, dilutents, trafficability, and application rates is needed. If this becomes a validated, high-priority research need, the U.S. Army Engineer Waterways Experiment Station will be requested to undertake the research effort.

2. Saltwater or brackish water should be the only types used for major dust control programs. Brackish water, if available, may be the better choice since the magnesium salts in brackish water may form a longer-lasting crust than the sodium and calcium salts. Magnesium chloride is the active ingredient of one of the commercial palliatives tested for the U.S. Environmental Protection Agency.

3. Waste engine oil should be used instead of water for localized dust control.

4. Facilities that can be adversely affected by sand (e.g., hospitals, communications centers) can be given some protection from blowing sand by

erecting snow-type fencing around the perimeter. Open netting, such as camouflage netting, supported by long barbed wire pickets could serve as a field expedient fence.

5.4.15 *Activity: Potable Water Production*

Since municipal or fresh surface water resources are not expected to be available to a military force in SWA, it will be necessary to produce potable water from any available source. The primary military equipment used for this will be the ROWPU because it is mobile and can produce potable water from seawater, and brackish ground water and surface water sources.

Environmental conditions characteristic of desert areas also suggest that potable water supplies can easily become contaminated with dust and sand from frequent dust storms. It therefore appears prudent to have available the now-standard ERDLator equipment to treat water contaminated with dust and other solids so that it does not have to be disposed of or used for other, less critical, purposes. The advantage of the ERDLator treatment is that almost 100 percent of the water can be recovered for use.

Desert sun and heat can cause a variety of problems for those engaged in producing water. Equipment can become so hot as to make the handling of valves and other components difficult. Membrane elements, calcium hypochlorite, and water quality test reagents can deteriorate rapidly when not adequately protected.

5.4.15.1 Water Requirements:

Quality: Despite the great versatility of reverse osmosis to produce potable water from almost any source, some limitations may be encountered in purifying water in desert areas. The efficiency of the membrane in removing dissolved minerals increases as the temperature of the water rises above 25°C (77°F). However, should the temperature exceed 45°C (113°F), membrane compaction occurs more rapidly, membrane adhesives weaken, and a structural failure may develop that causes the element to become inoperative. Membrane life can be shortened when the pH of the water is below 4.0 and above 9.0. Fouling of membrane surfaces, reducing water production capability, occurs when iron, manganese, and silica are present in the raw water. Iron and manganese can be reduced by aeration (cooling concept) and filtration, but since such pretreatment may not always be practical in the field, frequent replacement of elements will have to be anticipated or allowance made for less water production.

When a military ROWPU is operating normally, only 1 gal (3.8 L) of potable water is produced from every 3 gal (11.4 L) of feed water, regardless of its quality. However, the brine from the treatment of brackish and nonpotable fresh water can and should be recycled to produce additional potable water. The limit on recycling these waters is reached when the dissolved mineral content of the brine reaches that of seawater.

Water Quality Analysis Sets and the skilled personnel to use them are essential in the production of potable water. For the most part, present equipment provides for making basic tests, e.g., chlorine residual, pH, turbidity, hardness. Certain test reagents normally have a short life, and when exposed to desert sun and heat can quickly become useless. Consequently, operating personnel should be alert to the expiration date of reagents and protect test equipment by keeping it shaded and as cool as possible.

Quantity: While any available water source may be used to produce potable water, every effort should be made to use the largest, highest quality, and most reliable source available.

Water Sources: It is expected that the sea and wells are the most productive sources for producing potable water. Surface water resources are generally preferable since less effort and cost is required to treat such water, given the equipment and manpower resources of a field fighting force.

5.4.15.2 Water Conservation Measures:

1. Control waste. Operators of water supply points should keep spillage of potable water produced to a minimum.

2. Make maximum use of all water. Brine produced in the operation of the ROWPU should not be discharged as waste, but collected and stored for other uses. This water, which is normally wasted, has been subjected to two stages of filtration before being processed through the membrane elements; therefore, the brine is practically free of all suspended matter. This water is adequate in supply and quality for purposes such as graves registration activities, soil compaction, soil cement, and dust control. When there is a general shortage of potable water, it can also be used for showers and laundries.

3. Renovation of contaminated water. Water that may have been contaminated with dust or other removable suspended substances should be retreated rather than wasted. ERDLator equipment is most suitable for this purpose since most troublesome dissolved salts and minerals are removed by the reverse osmosis process.

4. Water quality testing. Water quality tests should be done as accurately as possible to preclude unsatisfactory water being distributed and later having to be declared unsuitable for human consumption.

5. Equipment protection. ROWPU equipment, spare membrane elements, calcium hypochlorite, and Water Quality Analysis Sets should be protected from sun and heat to prevent deterioration and insure proper functioning.

5.4.16 *Activity: Well Drilling*

The general absence of surface water in desert areas and the prospect that in-country municipal water supplies may not be accessible require the deployment of fully trained and well-equipped drilling units to develop needed water supplies. Equipment now being procured by the Army to provide this capability includes modern 6-in. (150-mm) diameter high speed rotary drills.

Highly sophisticated geophysical and seismic systems and techniques are often used by professional well drillers to locate groundwater. In the absence of these techniques, Army drillers should, if possible, consult local inhabitants for assistance in identifying prospective drilling sites.

The depth to groundwater can vary from about 50 ft (15 m) in coastal regions to 500 ft (150 m) or more further inland. Also, the quality of groundwater can vary from one location to another. Often it will be brackish or high in mineral content (sulfur, calcium, magnesium, and iron) and, therefore, require treatment to make it potable.

A supply of water is essential to produce the drilling fluid — mud. This is a mixture of native clay and/or commercial clay (bentonite) and water. The mud cleans the drill bit, removes cuttings from the hole, cools the bit, and reduces friction between the drill rod and the sides of the hole, and plasters the sides of the hole to prevent loss of drilling fluid.

5.4.16.1 Water Requirements:

Quality: Water sources locally available usually dictate the type of water used in drilling fluid, but generally the water should be reasonably free of dissolved salts. Some salts soluble in water tend to alter the clay suspensions properties of the mud. Saltwater or water with a high chloride content tends to flocculate (curdle) the clay particles and destroy the colloidal properties of the mud, which are essential in wall building and in the sealing off of permeable formations. In an emergency, either brackish water or seawater could be used; but as soon as possible after drilling has been completed, pumps and equipment exposed to salt should be thoroughly flushed to prevent corrosion.

Quantity: The amount of water required for drilling varies with the porosity of the formation penetrated and the depth of the hole. A 6-in. (152-mm) diameter hole will require about 20 gal of water per foot (250 L/m) of depth.

Water Sources: Water may be available in the general area of the drilling site or from municipal resources in the region. If not, it will have to be transported to the site. Personnel should use supplies that may have become contaminated with sand and dust, or untreated water collected in catchments, before turning to potable resources.

Key indicators of groundwater in desert areas are the presence of habitation, localized green vegetation, and existing wells. Groundwater can also be found to shallow depths in alluvial fans at the base of any significant mountain range or in dry stream beds or wadis.

5.4.16.2 Water Conservation Measures:

1. Nonpotable water should be used for drilling whenever possible. If bacteria are suspected, the water should be disinfected by the addition of approximately 1 teaspoon of calcium hypochlorite per 50 gal (approximately 12 g/200 L).

2. Sheets of membrane liner or scrap tarpaulin may be used as an expedient to line a slush pit (container for drilling mud) to minimize the loss of water.

3. During the development of a well, pumped water should not be wasted but collected for treatment to produce potable water or used directly for other purposes -- e.g., concrete, soil compaction, fire fighting.

4. Fresh water is often found in relatively thin lenses overlying salty groundwater. In such cases, water should be pumped out at very low rates to prevent saltwater contamination. This procedure is only applicable to shallow coastal wells (less than 40 ft [12 m]), where the overburden is relatively unconsolidated.

5. Commercial drilling fluids, such as foam, can be used and thereby substantially reduce the amount of water needed. An example of a brandname drilling fluid is "Quick Foam" manufactured by Baroid of Houston, Texas.

5.4.17 *Activity: Water Distribution*

The distribution of large quantities of water under tactical conditions will be by pipeline, trucks carrying bladders, and 5000-gal (18 900-L) tanker trucks. Smaller quantities will be picked up from tank farms or storage and distribution points in 400-gal (1510-L) water trailers or in refillable fabric drums and 5-gal (19-L) cans.

Each action involving the transfer of water from storage to transporter and distribution to unit water containers can result in spillage. Despite all reasonable precautions, spills will occur. A means for collecting and storing spilled water for other uses is prudent.

Pipelines can also cause water losses. Leakage can occur at joints, and breaks can occur as a result of sabotage or vehicles crossing the line and crushing it. Major breaks could result in the loss of water in a 2-mi (3.2-km) segment, or about 15,500 gal (58 700 L) (normal interval between pumping stations). The loss of water from the entire pipeline is prevented by pressure sensors which shut pumps off when there is a drop below normal operating pressure.

A newly installed potable water pipeline must be flushed and disinfected. Water used for this need only be relatively clean because it will be dosed to 100 ppm free available chlorine which effectively kills any pathogenic bacteria using a contact time of 30 minutes. Flushing and disinfection can be done in 2-mi (3.2-km) segments to minimize water required; however, temporary storage facilities (tanks or storage basin) would be required at each 2-mi (3.2-km) interval. At the end of each pipeline, this water can be collected to be used for other purposes -- e.g., concrete, aircraft washing, dust control, disinfection of open storage tanks.

In a theater of operations there is always a chance the Army may have to take over the repair and operation of a municipal water system. Although most systems will be similar to those employed in the United States, problems can be expected in obtaining replacement parts and operating supplies. Sizes and dimensions of basic components can be expected to differ from those used in the United States and even require the use of metric tools. Also, certain nations may use ozone for water disinfection rather than chlorine. Under these circumstances the Army should consider the hire of former local employees who are familiar with the equipment to operate and maintain the system.

5.4.17.1 Water Requirements:

Quality: The only water needed for installing a water distribution system is for flushing and disinfecting the pipeline or an open tank that will be used to store potable water. Fresh water relatively free of suspended solids can be used.

Quantity: Approximately 17,000 gal (64 000 L) of water are required for flushing and disinfection.

Water Sources:

1. Water from a tanker ship could be used, if available.

2. Fresh water wells may have to be drilled, or potable water can be produced by ROWPU equipment.

5.4.17.2 Water Conservation Measures:

1. Water-dispensing equipment should be equipped with automatic shutoff valves or nozzles to prevent spillage.

2. Spillage at a major dispensing point should be anticipated and a container built to collect and store this water for other purposes. A membrane-lined basin could be used.

3. When the tactical situation permits and engineer effort is available, pipelines should be buried 2-1/2 ft (0.8 m) deep to prevent damage from crossing vehicles and minimize heat absorption. As an alternative, hoseline and pipeline suspension kits and road crossing guards should be installed for damage prevention. Expedient crossings similar to those shown in Figure 5.11 can be fabricated in the field at appropriate intervals.

4. Pipelines should be patrolled frequently and inspected for leaks and illegal taps.

5. Pipelines used to distribute potable water are vulnerable to sabotage and illegal tapping. Also, the large quantity of water required to fill them is susceptible to loss when the line is broken. A nonpotable pipeline does not present quite the same risks, and loss of nonpotable water would not be as critical. This suggests that the current short-term water resource management concept be revised.

6. Water used to flush and disinfect pipelines should be collected and used for other purposes.

5.4.18 *Activity: Water Storage*

Military tactical and supporting units are equipped with a variety of water storage equipment. The smallest is the individual canteen; for a company-size unit, the largest is the 400 gal (1510 L) water trailer. To enable these containers to be refilled, larger amounts of water are positioned throughout a theater of operations to be readily accessible for pickup by units or to be delivered by large tanker trucks to the larger water consumers.

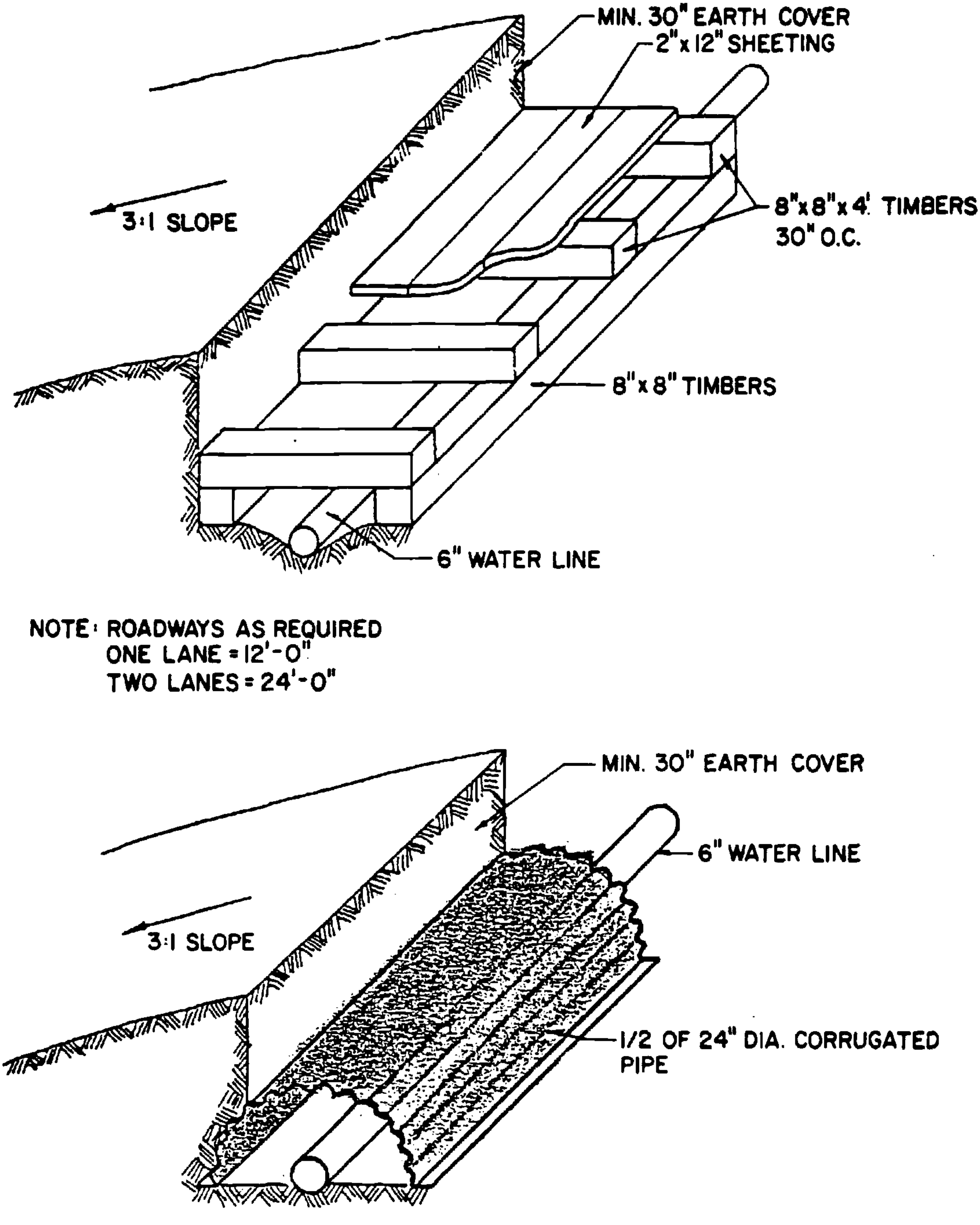


Figure 5.11. Expedient road crossing guard.

To insure an uninterrupted supply of water for all, a 4-day supply is normally maintained within a theater of operations.

In the Army's near-term water resources management concept, water is to be stored using a combination of flexible bladders ranging in size up to 50,000 gal (189 000 L) capacity, a family of smaller-capacity pillow tanks, various sizes of fabric drums, and expendable 6-gal (23-L) bags/boxes.

To implement a conservation program in which wastewater is collected and reused, additional storage capacity would be required. For these purposes, the collapsible fabric stave tanks now in the military supply system would be most suitable. In addition, expedient storage containers can be field fabricated using lumber and membrane sheeting (Figure 5.12) or storage basins can be excavated and lined with membrane sheeting (Figure 5.13). The latter can also be installed to provide a reservoir to collect rainfall and supplement available water resources.

5.4.18.1 Water Requirements:

Quality: Water is not required in the installation of water storage facilities. The water stored must be protected from loss, contamination, and sun. In hot desert areas, storage tanks should be shaded, since burying bladders and pillow tanks are not practical. A more practical technique would be to erect standard camouflage nets over tank farms and set up tarpaulins to protect small water storage facilities. In each instance, enough airspace should be provided between the container and sun shade to permit air circulation.

Quantity: The amount of basic water storage capacity would be 30 million gal (112 000 m^3) for a force of about 375,000. Supplementary storage for collection of wastewater and for nonpotable water needed for construction could increase the storage requirement up to 25 percent.

Water Sources: Water to be stored is produced from a variety of water sources, as discussed in paragraph 5.4.15. Likewise, wastewater that can be collected and stored temporarily before use is produced by a variety of activities, as discussed in paragraph 5.5.

5.4.18.2 Water Conservation Measures:

1. Water storage containers should be inspected frequently for leaks and repaired.

2. Stored water should be protected from solar radiation by some form of shading. Containers should be covered to prevent contamination from dust and loss from evaporation. Water that is too hot to touch may be spilled by those who distribute and handle it. Any shade is beneficial: a variety of field expedients can be used for this purpose -- camouflage nets, suspended tarpaulins, survivor blankets, and painting tanks a light color. Double covers, where a second layer is suspended over the primary shield, are even more effective. This technique creates a live air space between the two covers to allow air to circulate and produce a cooling effect.

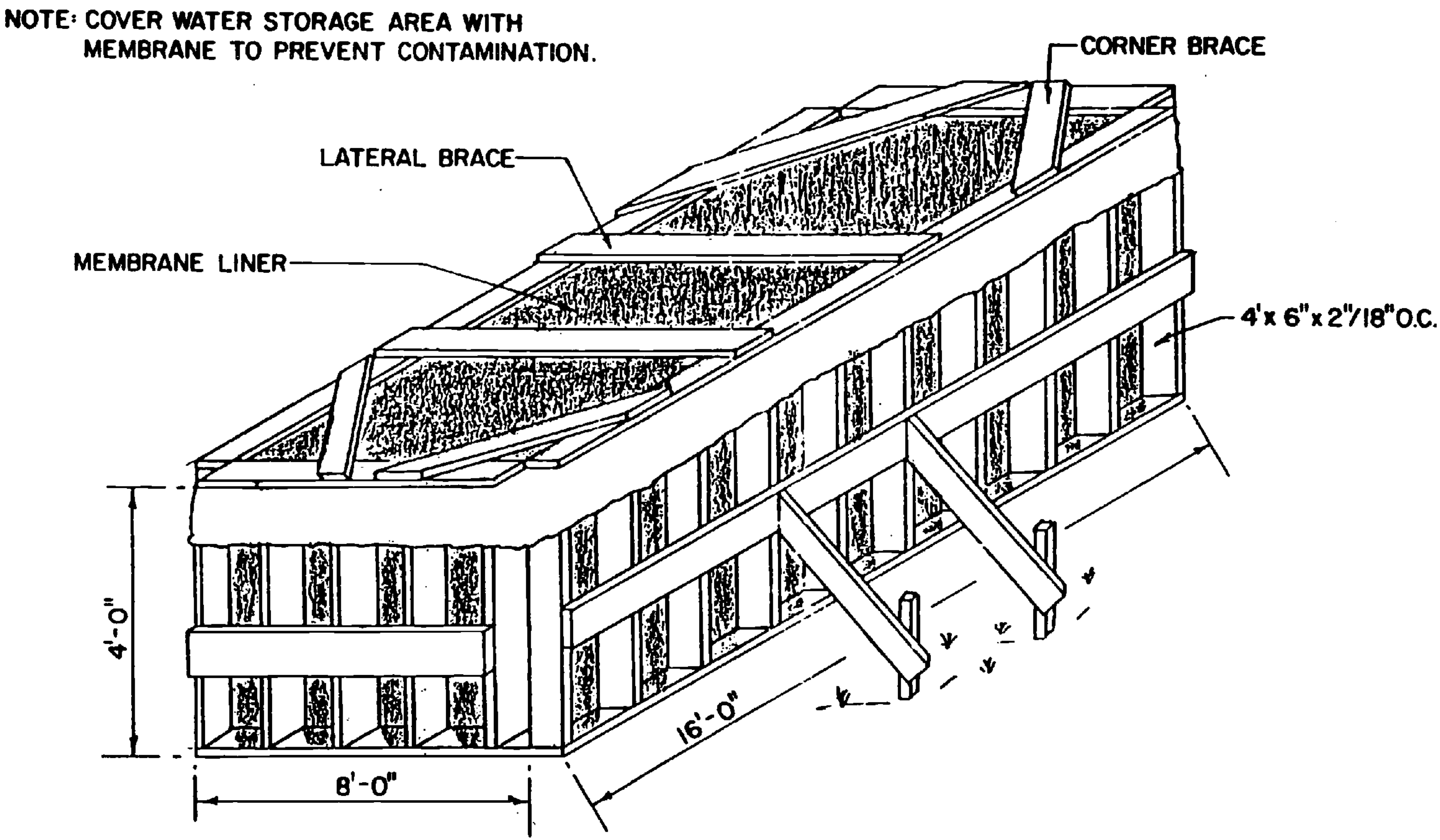
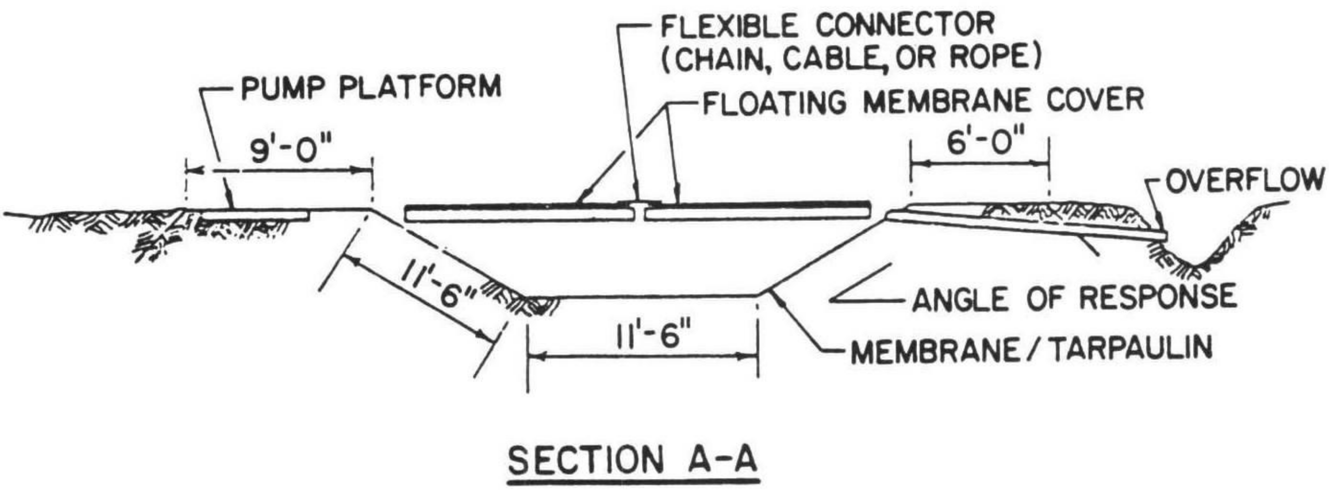


Figure 5.12. Storage container.



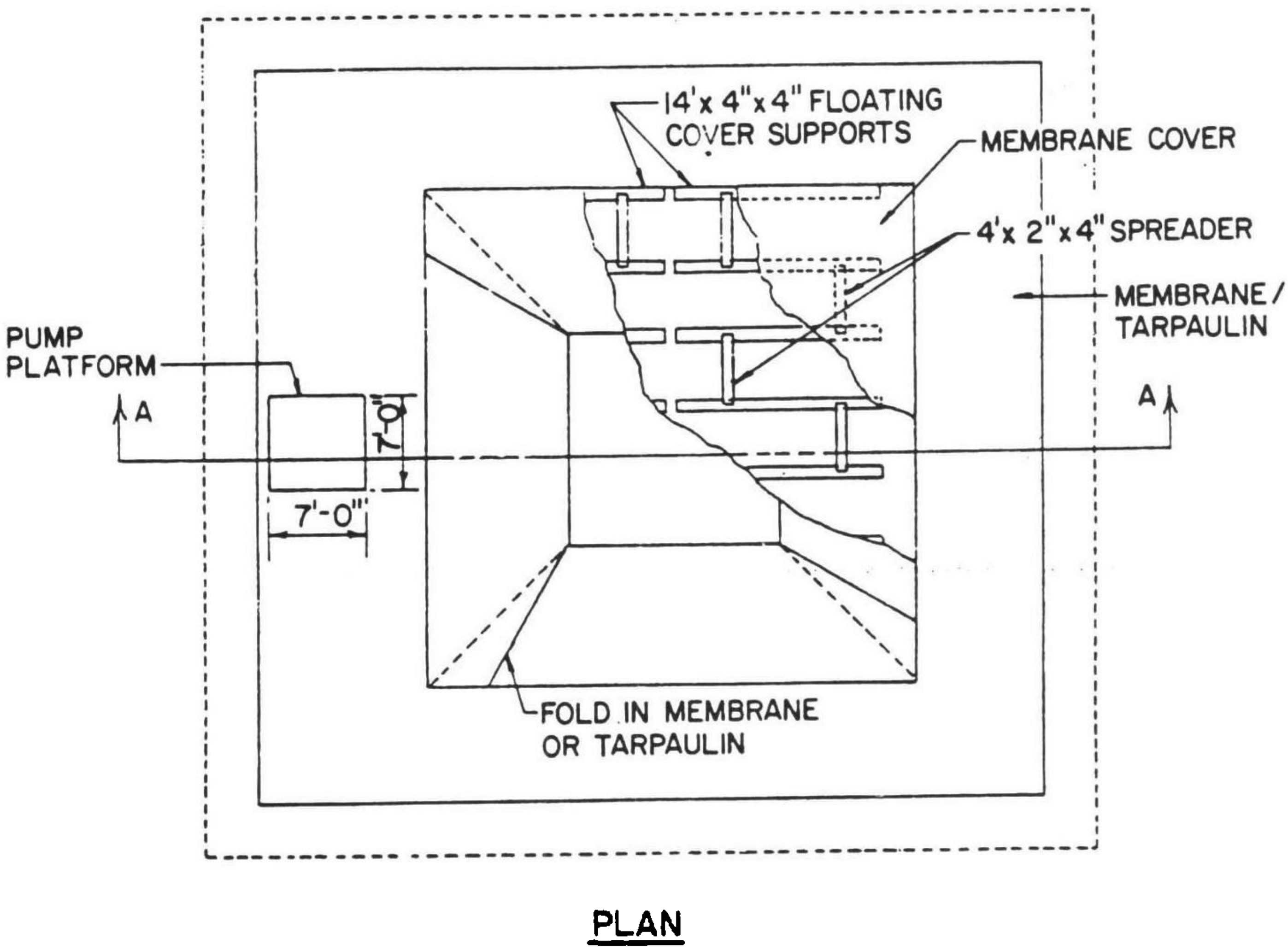


Figure 5.13. Storage basin.

3. Tank farm bladders should be placed in shallow excavations or in a bermed area to protect them against enemy fire and reflected solar radiation.

4. Supplementary water storage capability should be available to enable wastewater to be collected, treated, and reused wherever possible. Collapsible fabric stave tanks or field-fabricated tanks using membrane sheets can be used. Such containers should be clearly and distinctively marked to indicate they contain nonpotable water.

5. Simple storage basins or large catchments for collecting rainfall runoff can be constructed by excavation and installation of membrane sheeting to provide leakproof storage. Floating covers of lightweight and light-colored membrane sheeting supported by timbers would be needed to protect water from dust contamination and to limit water loss from evaporation.

5.4.19 *Activity: Aircraft Thrust Augmentation (Water Injection)*

Certain U.S. Air Force Strategic Air Command (SAC) aircraft use a water injection thrust augmentation system. When water is injected into the air intake of a jet engine, it cools the intake air, which becomes more dense. When the air is mixed with the hotter fuel, the result is a beneficial combustion mixture producing added thrust. Water injection is generally used under heavy aircraft loads and in hot dry weather. Water injection is not used in Army aircraft.

Currently, the following SAC aircraft employ water injection: B-52D, B-52G, and KC-135. About half of the KC-135s have been equipped with fan-jet engines, which do not use water injection.

Water used in thrust augmentation must meet certain standards of purity over and above usual potable water standards; therefore, SAC TO&E includes portable ion exchange demineralizing equipment. Such units are deployed with aircraft and maintenance personnel.

Additionally, SAC FB-111 aircraft contain an internal environmental control (cooling) system which uses water as the coolant.

5.4.19.1 Water Requirements:

Quality: Potable water should be provided for the demineralization processing required for thrust augmentation. Specifications call for water that contains no more than 10 ppm total solids and a pH of 6.0 to 9.5. In tactical situations, water up to 50 ppm is acceptable.

Quantity:

Water consumption, by aircraft, is as follows:

B-52D - 300 gal/sortie (1100 L)

B-52G - 1200 gal/sortie (45 000 L)

KC-135 - 670 gal/sortie (2500 L)

FB-111 - 27 gal/sortie (100 L).

To obtain 1 gal (3.8 L) of demineralized water, it will be necessary to process 1-1/2 gal (5.7-L) of potable water.

Water Sources: Water normally would be supplied for thrust augmentation from the U.S. Air Force organic self-sustaining potable water supply. However, the Army-operated Base Terminal would supplement any U.S. Air Force shortfall through the Tactical Water Distribution Set (TWDS) and Storage/Distribution network.

5.4.19.2 Water Conservation Methods:

The waste concentrate from the demineralization process could be reprocessed to produce potable and/or nonpotable quality, or used without treatment for other purposes -- e.g., aircraft washing -- thereby reducing the demand upon potable water supplies.

5.4.20 *Activity: Aircraft Cleaning*

The dusty environment common to desert areas is harmful to aircraft engines and operating mechanisms. Consequently, care must be taken to avoid hovering helicopters close to the ground and moving craft on the ground under their own power, and to cover all apertures when the aircraft is not in use. Regardless of all the care taken, dirt and dust does accumulate and can only be removed by washing. Normally, helicopters -- the predominant Army aircraft -- undergo scheduled maintenance every 25 flying hours. The turbine engine, rotor blades, and fuselage are thoroughly washed with water soluble cleaner and a soft brush, then rinsed with clean water in a pressurized spray. Equipment needed to spray-clean water under field conditions is not available now, but a cleaning and de-icing unit is being tested. Current practices discard all wastewaters to the surrounding environment.

5.4.20.1 Water Requirements:

Quality: Water for aircraft washing does not have to be potable, but should be low in salt and mineral content (soft water) and suspended solids. Bacteria levels are not considered critical since they can be easily controlled through field disinfection using chlorine. As a rule, brackish water and saltwater should be avoided due to their corrosive action on metals.

Quantity. About 25 gal (95 L) of water are needed to clean the air inlet area, inlet guide vanes, and compressor rotor blades of a turbine engine. An additional 100 gal (380 L) are required for the remainder of an aircraft.

Water Sources: If at all possible, the source of water should be other than the potable water distribution system. Alternatives could include surface water, if it is of suitable quality; municipal water; potable water which may have become too contaminated to use for drinking or food preparation -- e.g., dust-contaminated water; and rainwater collected in an expedient catchment basin.

Wastewater from activities such as a central shower or laundry would also be suitable for aircraft washing if it is treated to remove grit, oils, and soap, and chlorinated. See paragraphs 5.4.6 and 5.4.7 for shower and laundry field treatment procedures.

Water collected from aircraft washing operations can also be treated and reused.

5.4.20.2 Water Conservation Measures:

1. Employ and enforce a standing operating procedure for aircraft washing to insure that a minimum of water is used for cleaning.

2. Consolidate aircraft washing operations, where practicable, by installing an area-wide washing facility serving multiple aviation units. Such a facility could be colocated with General Support Aircraft Maintenance units.

3. Reuse aircraft wash water. Wastewater from aircraft cleaning should be collected wherever, in the judgment of the aviation unit commander, reuse offers an advantage over obtaining fresh water. A suggested layout for a washing facility is shown in Figure 5.14.

4. Collect and use wastewater under any circumstances for other purposes, e.g., general-purpose cleaning, moistening soil for electrical ground, dust control.

5.4.20.3 Helicopter Washing Facility

1. Use: Washing six or more aircraft using recycled washwater.

2. Materials: Membrane Surfacing Outfit, Airfield Roads, SC 5680-97-CL-E01, Part 1 (66 ft x 100 ft [20 m x 30 m]), or 40-mil nylon reinforced membrane sheeting.

3. Procedure: A suitable area is graded for a parking apron and covered with T-17 membrane surfacing. Integral with the apron is a lined collection ditch with sump to permit the recovery of washwater.

Wastewater is transferred from the sump to one of two 1500-gal (5680-L) collapsible collecting tanks where grit and other heavy particles are allowed to settle out, and oil and scum to rise to the surface. Once the tank has been filled, the contents should be allowed to stand for 24 hours. At the end of this period, floating materials need to be skimmed from the surface before the water can be reused. This can be done by skimming with a field-expedient scoop or by installing a flexible hose to the tank drain and attaching a funnel to the other end. By slightly submerging the funnel, floating materials can be quickly withdrawn by opening the drain at the bottom of the tank.

Some chemical cleaning solution will be retained in the treated water, but not enough to preclude its use as rinsewater. When withdrawing water from the tank, care must be taken not to disturb sediment collected in the bottom. When the tank is empty, the valve at the base should be opened to drain it before refilling. This wastewater could be used for dust control near the washing facility rather than discharging it to waste.

Some fresh water will be required periodically to make up for water lost by evaporation and retained on the aircraft. The number of times wastewater

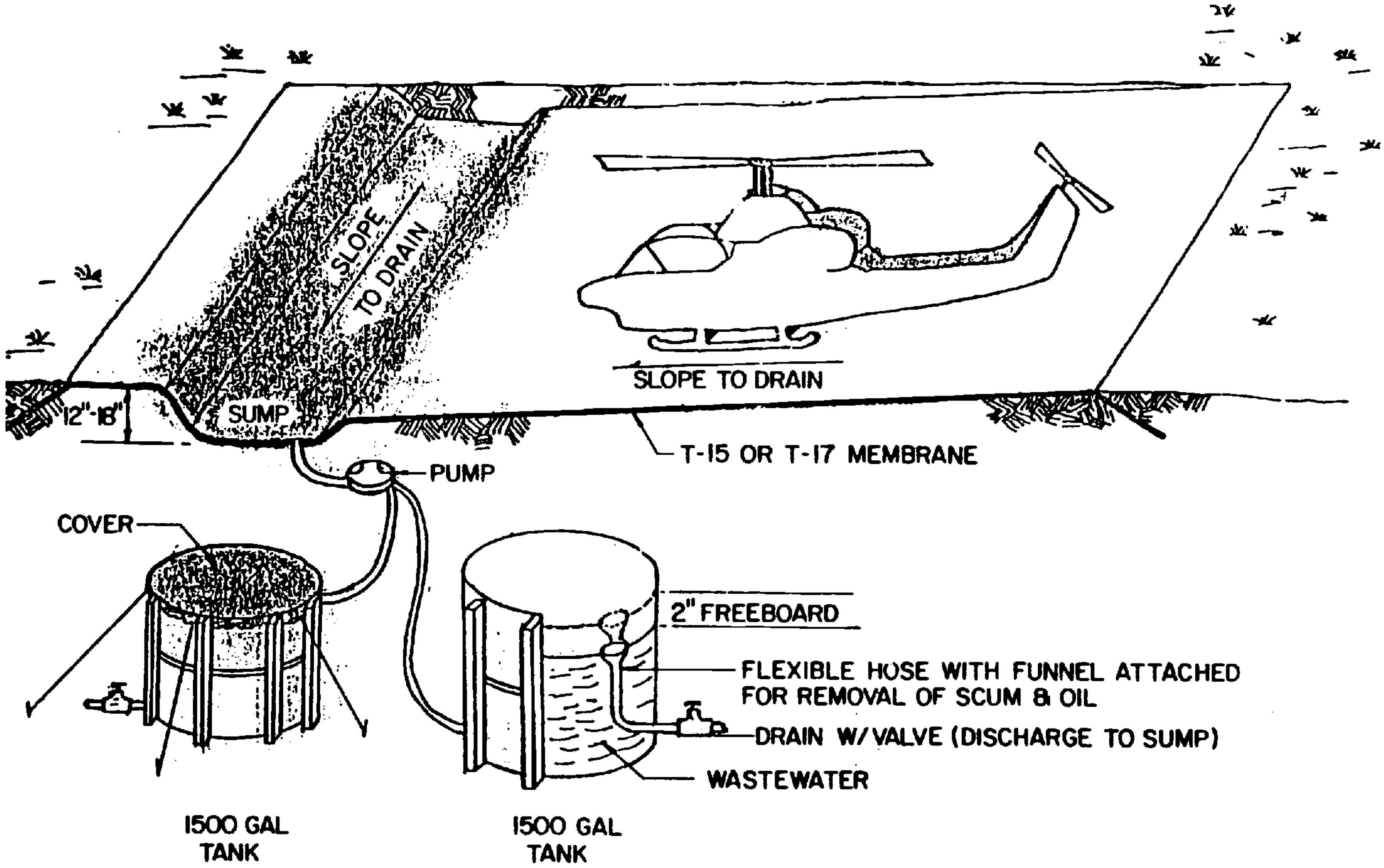


Figure 5.14. Helicopter washing facility.

wastewater may be reused before it becomes too dirty must be determined by operating personnel.

If a central aircraft washing facility is established to clean many helicopters in a day, a 420-gph (0.442 L/s) Water Purification Equipment Set (ERDLator could be much more efficient and effective in treating the wastewater than the settling tank.

5.4.21 *Activity: Vehicle and Equipment Cleaning*

Dusty roads and frequent dust storms in desert areas make vehicles and equipment dirty, abrade unprotected moving parts, and contribute to malfunctions. Consequently, equipment operators must diligently perform prescribed maintenance, including cleaning. Because water supplies are limited, the construction of washracks or equipment washing facilities should be prohibited. Therefore, cleaning would be performed primarily by such mechanical methods as brooms, high-pressure air, and dry wiping. In certain instances, however, it will be necessary to use water to clean critical surfaces and parts: e.g., windshields, head and taillights, mirrors, and gauges.

Every effort should be made to protect equipment and thereby minimize the need for cleaning. Small equipment items, in particular, should be covered with tarpaulin or membrane sheeting to protect them from dust when not in use.

5.4.21.1 Water Requirements:

Quality: Water of any type or quality can be used for cleaning, provided it is generally free of oil, grease, and soap. In addition, water with high salt content (seawater and brackish water) should not be used on unpainted surfaces, or where corrosion could develop and interfere with the operation of the equipment.

Quantity: The amount of water needed for cleaning is not readily quantified. It could become excessive if strict restrictions are not imposed by commanders.

Water Sources:

1. The use of potable water for cleaning equipment should be prohibited.

2. Potable water that has been contaminated with dust and dirt, and where a means of restoring it to potable quality is not readily available, could be used for cleaning.

3. The primary sources of wastewater that can be used for cleaning are showers, laundries, and messkit washlines. Some type of fabric should be used to filter oil, grease, and putrescible material before using the water.

5.4.21.2 Water Conservation Measures -- Operational Procedures

Commanders should issue specific instructions regarding the equipment and vehicles to be cleaned, give guidance on how cleaning will be performed, and restrict the use of water to what is absolutely essential to insure safety and operational effectiveness.

5.4.22 *Activity: Vehicle Radiator Makeup Water*

High daytime temperatures in hot, arid climates cause water in vehicle radiators to boil; with continued use, engine coolant can become dangerously low. To prevent engine damage, the operator must check the radiator often (perhaps even several times each day) and add water when needed.

5.4.22.1 Water Requirements:

Quality: Water for vehicle radiators does not have to be of potable quality, but should be relatively clean and contain only small amounts of dissolved minerals. Certain surface and well waters are normally high in dissolved salts and minerals and will eventually leave deposits that will clog radiator cores. Consequently, seawater and brackish water should not be used as engine coolants.

Quantity: Based on estimated loss of 25 percent of the engine coolant capacity per day, the average amount of makeup water required is about 7 gal/truck (27 L). For trucks transporting water and other supplies from rear areas to forward units, the loss by evaporation could be much larger. Any water added should be adjusted by the amount of additives (e.g., rust, inhibitor, glycol coolant, etc.) that may be prescribed for the area of operations.

Water Sources: Makeup water will normally be obtained from a potable source such as a municipal water system unit water supply. However, contaminated potable water should be used whenever possible.

5.4.22.2 Water Conservation Measures:

Water Reuse: Water from canteens or 5-gal (19-L) cans which has become too hot to drink should be put into radiators. Also, any potable water which may have become contaminated with sand and dust can be filtered through cloth or sandbags and used as coolant.

Coolant Recovery System: Installing coolant recovery equipment on radiators of tactical vehicles could essentially eliminate water loss.

5.4.23 *Activity: Electrical Grounding*

Electrical generators and critical electronic equipment -- such as radio transmitters, radars, and computers -- must be grounded to protect operating personnel and the equipment itself. In the inland areas of SWA, the lack of soil moisture makes special measures to establish an effective ground.

An effective expedient technique for fabricating a grounding system is to add moisture to the subsoil to improve its conductivity. However, for the electrical ground to remain effective, it will be necessary to keep the subsoil wet because of the high rate of evaporation common to arid regions. Water used for this purpose should be relatively free of putrescible matter to avoid creating a source of odors and an attraction for flies and other insects (see Chapter 4).

5.4.23.1 Water Requirements:

Quality: Water of any quality, wastewater from all sources, and even urine can be used to add moisture to soil.

Quantity: The amount of water needed to establish and maintain an effective grounding system depends on the capacity of the electrical equipment and cannot be quantified here.

Water Sources:

1. Saltwater is ideal for establishing a grounding system. Therefore, seawater, brackish water, and brine from water treatment (ROWPU) can be used when available. Urine is a suitable alternative to these waters.

2. Any wastewater from other activities -- such as mess operations, laundry, showers, aircraft washing -- can effectively be used.

3. Potable water should not be used since lesser-quality water ought to be available.

5.4.23.2 Water Conservation Measures:

1. Use only wastewaters, seawater, or brackish water for constructing an electrical ground.

2. Locate field urinals where an electrical ground is to be constructed. When larger grounds are required, a leaching field using perforated or unjoined pipe and installed at least 3 ft (1 m) below the surface may be appropriate.

5.4.24 *Activity: Photo Processing*

Photographic activities in a theater of operations involve taking both ground and aerial photographs and developing and printing black and white and color film. Film processing is done largely at the Division and Corps levels where units performing this function employ specially equipped shelters designed for this purpose. There are, however, a few units, such as engineer construction battalions, which are issued cameras and photoprocessing kits for just their limited needs. Only the latter requires water to produce prints. All other systems use a dry printing process. New processes that would entirely eliminate the need for water are under investigation.

X-ray equipment is available at each field hospital facility. That at the Mobile Army Surgical Hospitals uses a dry process to produce the films. The equipment used by the Combat Support and Evacuation Hospitals, which usually operate in the Corps Rear Area or Communication Zone, employ a wet process.

5.4.24.1 Water Requirements:

Quality: Water for both photo and X-ray film processing has to be of potable quality and contain relatively small amounts of dissolved minerals.

The water te.:erature should not exceed 110°F (43°C) for black and white film amd 98°F (37°C) for color film.

Quantity: Approximately 3 gal (11 L) of water are needed to develop 20 rolls of black and white or color film used for still photographs. Aerial and movie film are processed using automated equipment which requires about 10 gal per hr (38 L/hr). Hospital X-ray film processors require about 40 gal per hr (150 L/hr).

Water Sources -- Potable:

The primary source of potable water is the 400-gal (1500-L) water trailer. Aerial photoprocessing units and hospitals are issued water trailers for film processing.

5.4.24.2 Water Conservation Measures:

Water Reuse: Wastewater from film processing should not be reused for any purpose other than creating an electrical ground for equipment.

New Processes: The need for water could be eliminated if new film-developing processes under investigation prove satisfactory and could be adopted for field use.

5.4.25 *Activity: Fire Fighting*

The capability to fight fire in base development cantonments is essential to minimize loss of life and equipment. Because water will be in short supply and fire trucks may not be available, reliance will be on the use of portable chemical extinguishers, sand buckets, and shovels, and water dispensed by the bucketful by those nearest the fire. Even under the most austere living standards, planning for a fire emergency must begin early.

In the absence of mechanized fire equipment with integral chemical extinguishers or on-board water, fire fighting will be primarily a manual operation, relying on a number of strategically located water-filled 55-gal (208-L) drums with dispensing buckets. Drums should be placed near structures, equipment, and materials that require protection. Additionally, manual chemical extinguishers and buckets of sand should be located conveniently near areas where fires could originate in materials not extinguishable with water.

5.4.25.1 Water Requirements:

Quality: The lowest-quality water available should be used. Potable water should be used only when no other is conveniently available.

Quantity: Water quantities cannot be determined; however, about 50 gal (190 L) should be available per general purpose (GP) tent and up to 100 gal (380 L) per facility where the potential for fire is great -- e.g., aircraft and vehicle maintenance.

Water Sources: Any source of nonpotable water is acceptable. The sources could be streams, seawater, brackish well water, and ROWPU brine water. Even wastewaters from mess operations, showers, and laundries can be used if nececessary.

5.4.25.3 Water Conservation Measures:

1. Keep 55-gal (210-L) water storage drums covered to minimize evaporation.

2. Fill drums with water of such quality that others will not be tempted to take it for other purposes. Salt and brackish waters are excellent candidates.

3. Use sand buckets and shovels instead of water wherever possible.

5.4.26 *Activity: Pest Control*

A variety of insects and rodents live in arid environments. Among the more common pests that carry disease and damage military supplies are lice, fleas, flies, ants, scorpions, locusts, and a variety of rats.

Insecticides and rodenticides adopted by the Army can be effectively employed in arid areas. The common formulations of insecticides come in powder form, premixed in oil, and emulsions that are mixed with water before use.

5.4.26.1 Water Requirements:

Quality: Potable or fresh water is required for mixing emulsified insecticides. Saltwater and brackish water degrade the effectiveness of pesticides and should not be used.

Quantity: The amount of water required cannot be readily quantified. Overall, it is relatively small and should place an insignificant demand on the water supply system.

Water Sources:

1. Use water from a municipal water system or surface fresh water, if available.

2. Potable-quality water contaminated with sand or dust is suitable after filtering through cloth to remove particulates that could clog spraying equipment.

5.4.26.2 Water Conservation Measures: Relatively few benefits are to be derived from limiting the amount of water used to prepare insecticide solutions. Army entomologists should examine types and formulations of pesticides to be used in hot, arid climates. Perhaps those that have to be mixed with water should not be used.

5.4.27 *Activity: Decontaminating Personnel and Equipment*

Enemy troops might use NBC warfare. Under these circumstances, it will be necessary to have the capability to decontaminate personnel and equipment that have been exposed to chemical and biological agents and radioactive fallout. In doing this, water is the most critical item and the major problem.

Units, decontamination equipment, and operating procedures employed in decontamination procedures are discussed in the 3 series FMs and TMs. In general, equipment is decontaminated by washing the items thoroughly with water. When chemical agents are present, STB or DS-2 is applied after the initial wash and then rinsed off.

Personnel are decontaminated by taking showers. However, investigations at the U.S. Army Chemical Systems Laboratory indicate that showers may not be an absolute necessity for decontamination, but suggest the "morale" factor needs careful consideration if showers are excluded.

5.4.27.1 Water Requirements:

Quality: Any available water source is suitable for decontamination operation (i.e., seawater, brackish water, surface water, treated wastewaters).

Quantity: The total amount of water required depends on the type and concentration of the agent involved, and the number of personnel and equipment affected. An average quantity for a medium-size truck is about 200 gal (760 L); for a shower, the amount could be as much as 13 gal (49 L) per bather or more.

Water Sources: Because large quantities of water would be required, major sources such as rivers, lakes, high production wells, and seawater should be relied on. If at all possible, uncontaminated potable water should not be used in order to conserve it for drinking and food preparation.

5.4.27.2 Water Conservation Measures: The demand to start decontamination operations quickly will probably override any thoughts of conserving water. Soldiers involved at the time of a chemical or biological attack will use freely water from any convenient source; usage probably will exceed the quantities stated above. It would therefore be prudent to plan for large quantities of nonpotable water (seawater or brackish water from surface water sources or wells) to be available for immediate use. One method of doing this would be to install pipelines from the most accessible sources to areas of major troop/equipment concentrations. At selected points, water-dispensing facilities would be provided for use when needed. Such a nonpotable water distribution system could also serve as a convenient source of water for firefighting, construction, and dust control.

Recovery and treatment of wastewater from decontamination operations to produce potable water are not considered practical. Radiological contaminants can accumulate during treatment in the purification equipment and the chlorine from Super Tropical Bleach (STB) used in decontamination of chemical and biological elements is extremely harmful to ROWPU membrane elements.

5.4.28 *Activity: POW/Refugee Camp Operation*

Combat operations often result in taking prisoners of war (POW) and displacement of civilians from their homes. Prisoners are normally detained in prisoner-of-war camps established within the theater of operations and provided certain facilities and accommodations. Refugees are generally collected and put into temporary camps in rear areas to provide them some measure of safety and to prevent interference with military operations. Among the amenities to be provided these individuals under the Geneva Convention is water for consumption, food preparation, and personal hygiene.

5.4.28.1 Water Requirements:

Quality: Water provided POWs and refugees should be of equivalent quality to what they are accustomed to using. That used by U.S. forces will have undergone extensive treatment and chlorination, and can cause digestive tract problems for people not accustomed to drinking this type of water. The need to cool their drinking water is probably not essential, but a means of shading water storage should be provided.

Quantity: The amount of water to be furnished each person per day will be less than for a soldier. The following estimates are based on limited activity by camp inhabitants:

	Amount (gal[L]/man/day)
Drinking	2.0 [7.6]
Food Preparation	1.0 [3.8]
Personel Hygiene	2.0 [7.6]
Medical Treatment	1.0 [3.8]
TOTAL	6.0 [22.7]

Water Sources: The optimum sources would be a municipal water supply system or freshwater wells. If they are not available, potable water would have to be provided from Army resources.

5.4.28.2 Water Conservation Measures:

1. Adjust quantities of water supplied to be consistent with ethnic and religious customs on eating and personal hygiene.

2. Establish a regime for the distribution and use of water in camps to insure water is not wasted.

3. Blend potable and moderately saline well water to produce water of acceptable palatability for inhabitants of the region.

5.4.29 *Activity: Locomotive Enginer Water Makeup*

Under certain circumstances, the Army could take over the operation of railroad system in SWA or operate trains over existing trackage. Currently both narrow- and standard-gauge trackage are used by the nations in the area, but all are gradually converting to standard gauge. Also, diesel-electric locomotives are replacing steam engines.

Although the diesel-electric locomotive would be more desirable, the Army might be required to rely on steam locomotives. Under these circumstances, it would be necessary to provide water for the engines.

5.4.29.1 Water Requirements:

Quality: Freshwater relatively low in mineral content would be required to prevent buildup of scale in boiler tubes.

Quantity: Between 18,000 and 25,000 gal (68 000 and 95 000 L) of water are carried by tenders on reciprocating steam locomotives and steam turbine-electric locomotives. In desert areas, water consumption is about 50 gal (190 L) per mi.* Diesel-electric locomotives require up to 800 gal (3000 L) of water, but because the cooling systems are closed, little makeup water is needed.

Water Sources: Municipal water supplies would be suitable for steam engines and should be available in most railroad yards. If separate water service is required, the Army could supply water from potable supplies or from wells producing water of acceptable quality.

5.4.29.2 Water Conservation Measures:

1. Service engines in operating railroad yards with established water service.

2. Employ diesel-electric locomotives which require a small amount of water for engine cooling.

5.5 Water and Wastewater Use Opportunities and Priorities

This section, in part, contains a tabular summary of selected findings developed in this report. It is essentially a guide to sources of water and wastewater that can be used for the various activities listed. The numbers shown under each activity (Figure 5.15) indicate the water sources in an order of preference (1, 2, etc.) that minimizes the burden on the overall water production and distribution system. In addition, the lower portion of the figure indicates those activities, again in order of preference, that can use wastewater from selected major sources.

The types and locations of water sources as well as the distribution of units or military activities within an area of operation will be different for each military operation. Consequently, the optimum source of water and the use to be made of wastewater will ultimately be selected based on local and site-specific conditions.

* "The Military Water Problems in the Western Egyptian Desert, 1940-1943," COL W. G. Fryer, O.B.E. The Civil Engineer in War, Vol 3, 1948; The Institute of Civil Engineers, London.

WATER SOURCES	Drinking Water	Mess Operations	Personal Hygiene	Shower	Laundry	Hospital Operations	Heat Treatment	Graves Registration	Const.-Conc. Mixing/Curing	Const.-Soil Compaction/Soil Cement	Const.-Aggregate Cleaning	Const.-Dust Control	Water Production	Well Drilling	Water Distribution	Water Storage	Aircraft Thrust Augmentation	Aircraft Washing	Vehicle/Equipment Cleaning	Vehicle Makeup Water	Electrical Grounding	Photo Processing	Firefighting	Pest Control	Decontamination	POW/Refugee Camp Ops	Locomotive Engine Water
Unit Water Supply	1	1	1			1	1	2									3			2		1		1			
Tactical Water Distribution System	1	1	1	3	3	1	1	2	3	3				3			2	3		2		1		1		2	2
Surface Water Resources			3	1	1	2	2	1	1	1	1	1	1	1				2	1	2	1		1	2	1	2	
Municipal Water Supply			2	1	1	1	2	1	2	2	3	3	1	2			1	1	2	1	1		3	2	2	1	1
Wells			3	2	2	2	2		2	2	2	2	1						3		1		3		2	1	
Sea Water			3	3	3		3	1	1	1	1	1	1	1					3		1		1		1		
Brine (ROWPU)							3	2			1	1		2							1		2		1		
Not Applicable															X	X											
WASTEWATER SOURCES	NOTE: THE CATEGORIES LISTED BELOW WILL REQUIRE VARYING DEGREES OF TREATMENT.																										
Shower				2	2						2	2		2						3	2		3		2		
Laundry				2	2						2	2		2						3	2		3		2		
Mess		1																		3	3		3				
Aircraft Washing											2	2						1	2	3	2		3		2		
Water Storage Water Distribution				3	3	3	3	3	2	2	2	2		2			3	2	2	2	2		1	2	2		
Not Applicable	X		X										X		X	X						X				X	X

LEGEND: 1 = BEST
2 = BETTER
3 = GOOD

Figure 5.15. Water and Wastewater Use Opportunities and Priorities.

5.6 Membrane Sheeting (Liners)

Description: Membrane sheeting materials are commonly used today as watertight liners in excavated storage basins for various liquids, including potable water. The expedient method is to form an earthen basin with conventional earthmoving equipment, compact the embankments and berms, and then smooth the earth by removing exposed rocks and other sharp objects. With the basin thus prepared, the liner panels are placed in the basin and manually positioned with seam overlap for subsequent sealing. The panels are long enough to extend over the embankment top and into a prepared ditch. The seams are then sealed, the embankment ditch is backfilled to secure the liner in place, and then, depending upon liner or seam cure time, the basin is ready for use.

Certain membranes lend themselves to use as water storage covers, sealing out dust and other contaminants, reducing evaporation, and preventing algae growth.

One type of liner material can be sprayed, troweled, or applied by squeegee.

Theory: The construction of effective water storage facilities can be a lengthy, costly process, particularly if steel tanks or concrete are used. Equivalent and expedient water storage facilities can be built in a fraction of the time at a fraction of the cost with membrane linings.

Case History: Membrane liner supplier/installer firms have many documented histories of unique and difficult water storage applications of their products.

Cost: Membrane liner material is currently not in the Federal Supply System. Procurement from the manufacturer is for a specific project. An average cost for 30 mil (0.76 mm) reinforced Hypalon is $0.55 to 0.65 per sq ft ($5.92 to 7.00 per m^2).

Reliability: The membrane materials have been developed with such physical properties as tensile strength, tear resistance, temperature (hot/cold) resistance, and resistance to degradation from exposure to sunlight, submersion in water, and burial in soil. Records of use to indicate durability under such conditions are claimed by the manufacturers. In addition, ASTM test standards are imposed on producers to insure the sheeting provides adequate service.

Applications: Membrane liners have been used effectively in many areas of the world for water containment and for water/sewage treatment applications. Reports from certain liner manufacturers and installers indicate that some satisfied customers are located in Middle East countries. It is suggested that the time/cost factors are most attractive for using membrane sheeting in water containment basins for RDF deployment applications which involve potable water storage, water harvesting, and treatment. In addition, the membranes could be used in covering vehicles and equipment as protection against dust, thereby reducing water usage in cleaning such items.

Safety Factors: Membrane materials for water containment should not present significant safety problems except when used for a potable water storage basin. Certain types of liner materials contain chemical components that can leach into the water and prove harmful if not removed.

O&M Needed: A torn liner would have to be repaired. Also, after long-term use, it would be necessary to drain storage facilities to remove collected sediment.

Instrumentation and Other Ancillary Considerations: Not applicable.

Ease of Implementation: The size of the intended water containment basin, thickness (weight), and size of the membrane panels will determine ease of installation. Membrane panels could weight up to 5000 lb 2.3 MT) and specific gravity ranges from 1. 24 to 1.50 for the various membranes. Thickness may be selected between 10 mils (0.25 mm to 1.52 mm), to 60 mils and panel widths up to 150 ft (48 m) are available.

Cranes, forklifts, flat bed trucks, and front-end loaders can be used to place panel rolls upon the basin embankment from which the accordian folds are unrolled manually and accurately positioned by the installation crew. Panel sections overlap one another by 2 to 4 in. (51 to 102 mm) to permit a sealable seam. The solvent or adhesive can be manually applied or a seam welding device is used.

A crew of four can install a 20,000 sq ft (1860 m^2) liner in less than a day, and a crew of eight to ten can install 1 hectare (2.5 acres) of liner in one day. All types of membrane sheeting of simlar size and weight have similar ease of installation.

5.7 Water Consumption Planning Factors for Construction

5.7.1 Water Consumption Planning Factors

Table 5.1 summarizes water consumption for various activites in a hot, arid climate.

5.7.2 Assumptions

The following assumptions were used in deriving the water consumption planning factors in Table 5.1.

1. Road Construction:

a. Compaction

(1) Consumption on a 1-mi (1.6-km) section of Class A road.

(2) Subbase will be compacted to 6 in. (152 mm).

(3) Best moisture variance between desired and actual moisture content is 2 percent; worst case is 10 percent.

(4) Maximum dry density is the desired dry density which is 120 lb/cu ft (1920 kg/m^3).

(5) Construction is to be conducted over level terrain.

(6) Amount listed is for one 6-in. (153-mm) compaction effort on a 1-mi (1.6-km) road.

Table 5.1

Water Consumption Activities for
Desert/Arid Climate

ACTIVITY	QUANTITY	REMARKS
1. Road Construction		
a. Compaction	122-245 k gal/mile of Class A Road	Nonpotable acceptable
b. Soil Stabilization	100-850 k gal/mile of Class A Road	Same as 1a.
c. Bituminous Treatment		Based on asphalt plant requirements.
d. Dust Control	845,000 gal/hr/ mile of Class A Road	Same as 1a.
2. Airfield Construction		
a. Compaction	151-300 k gal/ Medium Lift Support Area Airfield (MLSA)	Same as 1a.
b. Soil Stabilization	140-700 k gal/MLSA	Same as 1a.
c. Bituminous Treatment		Same as 1c.
d. Dust Control	1,050,000 gal/hr MLSA A/F	Same as 1a.
3. Quarry Operations		
a. Washing/Screening Requirements		
(1) 75 TPH Crusher	23,000-47,000 gal/hr (reusable)	Same as 1a; subject to design specifications for clean aggregate.
(2) 225 TPH Crusher	105-210 k gal/hr (reusable)	Same as 3a.
(3) Dust Control	60 gal/hr	Same as 3a.

Table 5.1 (Cont'd)

ACTIVITY	QUANTITY	REMARKS
4. Asphalt Plant Operations		
a. Plant	1000 gal/hr	Potable
b. 3-Car Heater	200 gal/hr	Nonpotable
5. Well Drilling Requirements		
a. Rotary Drilling (hydraulic)	3 times the volume of the hole being drilled.	Nonpotable
b. Cable-Tool Drilling	4 gal/ft of 6 in. hole 5 gal/ft of 8 in. hole	Saltwater may be used.
6. Concrete Construction	60 gal/cubic yard	Potable water preferred. Nonpotable water may be used that is acid/alkali free and has a minimum of organic materials. Seawater may be used, but strength is decreased by 20%.
7. Pipeline Testing		
a. 6-in. Pipe	16,000 gal/mile	Nonpotable acceptable. Based on initial line test and one complete flushing of line. Figure may be reduced by half if no flushing is required after testing. Saltwater may be used, but must be followed by a fresh water flushing before the system can be operational.
b. 8-in. Pipe	28,000 gal/mile	

(7) Dry compaction will not be performed.

(8) Soil is moisture-free or near moisture-free content.

(9) Range of required moisture content is 10 to 20 percent.

b. Soil Stabilization

(1) When only water is used as a stabilizing agent apply factors outlined in II, above.

(2) Bituminous stabilization is treated separately (see 1c below).

(3) Amount of water required equals 1/2 percent for each 1 percent of stabilizing agent by weight.

(4) Consumption based on a 1-mi (1.6-km) section of Class A road.

(5) Amount of stabilizing agent (lime, cement) ranges from 2 percent (best case) to 16 percent (worst case).

(6) Density of soil equals 10 lb/cu ft (160 kg/m^3).

(7) Does not include factors for compacting process.

(8) Amount listed is for one 6-in. (152-mm) stabilization effort on a 1-mi (1.6-km) road.

c. Bituminous Treatment Requirements

(1) No water required at placement site.

(2) Treated as part of the asphalt plant figure.

d. Dust Control

(1) Water will provide control for 1 hour.

(2) Requires 1 gal/sq yd (4.5 L/m^2) (worst case).

(3) Consumption based on 1-mi (1.6-km) section of Class A road.

(4) Requires 3 to 5 gal/sq yd (14 to 23 L/m^2) due to heat and zero moisture content.

(5) If coherex is used in lieu of water, application rate is approximately .33 to .67 gal/sq yd (1.5 to 3.0 L/m^2). Mix one part coherex to one to seven parts water.

(6) Other dust control agents can be used which decrease the amount of water required (penoprime, DCA 1295, etc.).

2. Construction of Airfields:

a. Compaction: Assumptions are the same as Road Construction (LA) with the exception of width and length, which are based on the criteria for a Medium Lift Support Area Airfield. Width = 60 ft (18.3 m); length = 3500 ft (1070 m).

b. Soil Stabilization: Assumptions are the same as 1b above, with the width and length changes noted in 2a, above.

c. Bituminous treatment requirements: Same as 1c, above.

d. Dust Control: Same as 1d, above, with width and length changes outlined in 2a, above.

3. Quarry Operations:

a. Based on data in FM 101-10-1 and TM 5-331C.

b. For dust control, assume 1 gal/min (0.06 L/s).

4. Asphalt Plant Operations: None.

5. Well Drilling Requirements:

a. Rotary drilling (hydraulic) data obtained from Well Drilling Manual, National Water Well Association; Water Well Technology, McGraw-Hill; and Water Well Manual, Premier Press. Planning figure listed as three times the volume of the hole being drilled.

b. Cable tool drilling data based on factors in Well Drilling Manual, National Water Well Association.

c. Figures do not include loss of water due to seepage from the settling pit into the soil. (Settling pits are considered to be lined with a membrane or impervious clay.)

6. Concrete Construction:

a. The amount of water required per cubic yard of concrete is dependent on the size of aggregates used, the water cement ratio, type of cement, concrete slump, weather conditions, and curing requirements.

b. Water figure includes only requirements to mix and finish concrete. Figures do not include cleanup of concrete mixing equipment.

c. Increase is due to higher requirements for curing and absorption by aggregates.

7. Pipeline Testing:

a. Water testing is required. (It should be noted that in emergencies fuel may be used to test the system. However, this is very dangerous and has many adverse effects.)

b. Planning figures are based on complete filling of the pipeline with water for the test and one complete flushing.

c. If fresh water is used to check pressure, flushing can be eliminated if necessary.

d. If saltwater is used to check pressure, one complete flushing of fresh water must follow testing in order to purge saltwater from the line.

CHAPTER 6 - VERTICAL CONSTRUCTION

6.1 Introduction

The use of improper building materials, building systems, construction details, or construction techniques in SWA would not only create unnecessary problems for construction workers, but would also adversely affect the working effectiveness or living comfort of the occupants because of inferior or unsatisfactory environments. This chapter considers climate, efficient use of indigenous materials for building, and appropriate methods of construction.

The Middle East covers a wide variety of geographic, climatic, and cultural regions. It is important to point out that within this region there are temperate and cool to cold areas, although the major emphasis of this report is on building in the hot climates of the Middle East.

The scenario to which this chapter responds covers an operational time period of from 0 to 12 months. This overlaps two military standards of construction: JCS Publication 3 initial construction (0 to 6 months) and JCS Publication 3 temporary construction (6 to 24 months). Current planning doctrine specifies that during the initial 6 months of an operation, troops and equipment will be housed primarily in TOE tents (may be some wood frames). However, doctrine also states that the period exceeding the initial 6 months should provide more permanent structures which exploit the indigenous methods and materials wherever and whenever possible. Therefore, this chapter will cover a period from 6 to 12 months, and will identify indigenous materials, materials growing or produced in a region or country, and the corresponding methods of construction in order to provide less expensive, habitable, and feasible building in an otherwise austere building environment.

6.2 Improving Habitability

6.2.1 *General*

Because of the austere conditions for constructing and operating a building in the desert, standard and exotic methods of heating and cooling are not possible. This means that any method requiring electricity will not be seriously considered. Evaporative cooling, which will be discussed, should only be used when there is a plentiful water supply that is easily transportable and does not present a health hazard. Electricity or water should only be used when the buildings are normally unbearable to live in because of the heat. Many steps can be taken to moderate the effects of the desert. The guidelines discussed below should be expanded upon in the field by taking advantage of soldiers' own imaginative solutions to problems and by copying successful practices of the natives.

In the desert, a building must provide protection from the sun for the people and equipment, shield them from blowing sand, and hopefully provide some relief from the high temperatures. Because the climate is so important, it will be discussed first. The factors affecting whether a person is comfortable will be examined next to see how to take advantage of the desert's extreme conditions. Techniques for passively cooling buildings will then be discussed. A brief description of non-austere mechanical systems will be given next. Finally, the main points will be summarized.

6.2.2 *Effect of Climate*

Although the Middle East climate can range from cold to very hot, only the hot regions will be considered. Temperatures can rise above 109°F (43°C). While the region is arid and generally has low humidity, some coastal regions have high humidity levels. A map of world climate zones, shown in Chapter 1, gives three climate categories covering the Middle East: hot, dry desert; intermediate hot dry desert; and humid, hot coastal desert.

The amount of humidity has a large effect on night temperatures.* In low humidity areas, the night temperatures can fall to 59°F (15°C). This wide day-to-night temperature swing helps offset the high temperatures during the day. Areas with high humidity have much lower day-to-night temperature swings. Unfortunately, this limits the number of ways to moderate the day temperature.

The sun is at a very high angle because of the low latitudes. Consequently, the roof of a structure will receive most of the solar radiation. Also, a north-south building axis receives more solar gain than a east-west building axis (Figure 6.1).

6.2.3 *Thermal Comfort*

Many factors affect whether a person feels thermal comfort. Air temperature is the most familiar; however, there are other factors: air velocity, relative humidity, interaction by radiation heat transfer with the surroundings (from the sun, outdoors, or building walls), and the conditions one is used to. To understand the goals of some of the passive building designs, it is necessary to know how each of these factors influences comfort.

Each factor's effect will be covered only briefly here since the subject is so complex. The air temperature indicates how much heat will be transferred by convection from a human body to the air surrounding it. The relative humidity is a measure of how much water vapor the air holds to how much it could possibly hold at the same temperature and pressure. The lower the humidity, the easier it is for the body to cool itself by sweating. Higher air velocities around the body increase the heat transfer by convection between the air and body, and thus the cooling which occurs with sweating. An often overlooked factor affecting comfort indoors is the wall temperature. Our bodies exchange heat by radiation with the walls, floor, and ceiling. If the walls are cool, a person may be significantly cooler in hot air than if the wall and air are hot. Obviously, being in direct sunlight can greatly influence how hot one feels. Conversely, a person who is outdoors on a hot clear night can feel the cooling effect of the cold night sky. Finally, people can adjust to hot climates that they at first think almost unbearable. The body can quickly (in a matter of days) acclimate itself to a hot environment. (See Chapter 9.)

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* B. Givoni, Desert Housing and Energy Conservation (Ben Gurion, University of the Negev).

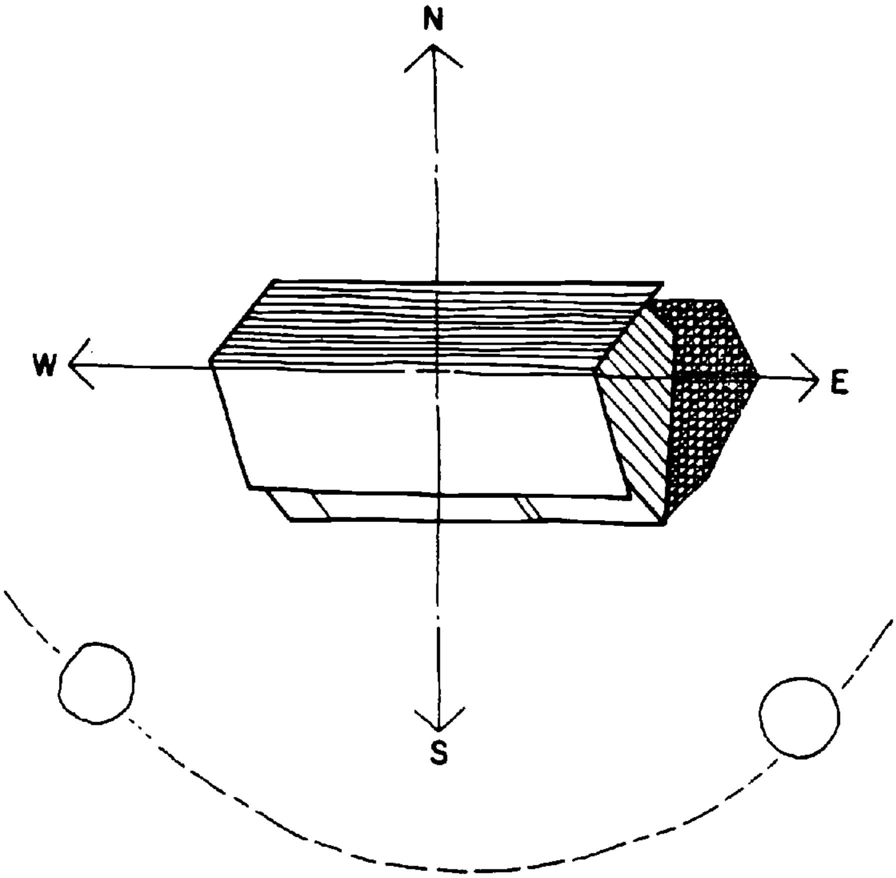

Figure 6.1. An east-west building-oriented axis.

Ordinarily, a major goal of building design is to provide a comfortable environment for the inhabitants. Under austere desert conditions, this may not be a realistic goal; instead, austere buildings must be designed to be at least livable. Nevertheless, the more comfortable people are, the more efficiently they will work and the less they will need to drink water because they are not sweating as much. Each of the factors affecting comfort can be adjusted to provide a livable, if not comfortable, building.

Desert winds and dust storms create an unbearable living environment for building occupants and also may cause problems for some structural components unless precautionary steps are taken during construction.

In windy areas, the foundations must be built deep enough to prevent erosion around the corners of the foundation system. Exterior doors and windows should be sealed as much as possible, although no attempt should be made under normal service conditions to erect a sand-tight building. Several methods for reducing dust infiltration are as follows:

1. Use nonoperable window.

2. Use inertial dust separator.

3. Use air filters.

4. Use positive building interior pressure.

5. Use high air intake louvers.

Also, roofing material must be doubly fastened and cooling systems attached securely to the supporting structure with additional fasteners.

Electrical equipment's performance can be drastically reduced by excessively high temperature. If the temperature is high enough, the machine may not work. In general, the cooling principles that apply to humans can be applied to machines.

6.2.4 *Cooling Buildings*

The purpose of any cooling system is to moderate the extreme desert heat so the inhabitants can be comfortable. Conventional cooling systems are not practical in austere desert conditions; however, other steps can be taken, as discussed below.

A person's primary shelter against the environment is his clothing. For the desert, clothing should reflect the sunlight as much as possible and allow the body to cool by evaporating sweat.

The heat sinks of electric equipment should be shielded from the sun, have a high emissivity to radiate heat, and have an air flow over them to convect the heat away.

The following passive cooling techniques take advantage of or neutralize the desert conditions:

1. Reduce solar gain by using exterior paints that are very reflective -- especially for the roof.

2. Orient the building so it has an east-west axis (Figure 6.1) to minimize the solar gain. In general, only design windows when they are necessary for adequate ventilation or daylighting.

3. Use overhangs or shutters to block sunlight from falling directly on the windows or the walls. Shading separate from the building can be used for the same effect, but it should not hinder ventilation. Movable shades and shutters may be used to maximize ventilation and minimize solar gain.

4. In order to reduce convective heating, minimize the exterior surface area by having as square a building as possible.

5. Use thick, dense walls and roof to insulate against the hot exterior air and so that the interior surface temperature will be slow to rise

during the heat of the day. This will be a cooling effect since comfort is affected by radiant interchange with the surroundings.

6. Place additional lightweight insulation on the exterior of the thick, dense walls so they will be even slower to heat up.

7. Bury the building partially or completely underground since the ground does not get as hot as the air and all that is exposed to the sun is the roof.

8. Ventilate the building. In a low-humidity region with large swings between day and night air temperature, the ventilation should be as high as possible at night so the interior walls can be cooled down to keep everyone comfortable the next day. During the day, the ventilation should be as low as possible (doors and windows closed and any air leaks blocked) so that the hot air will not get in and raise the temperature of the interior surfaces. In high-humidity regions with little change between day and night air temperatures, the interior surface temperatures will not drop very much during the night, so there will be little relief from the heat during the day. Consequently, there should always be ventilation so that the effects of sweating can be enhanced by increased air speed around the body. There is an optimum air speed for cooling by sweating; a higher speed will increase the convective heating, and a lower speed will reduce the effect of the sweating compared to the convective heating. Orient openings to take advantage of the usual direction of the wind. (Normally the wind is from the northwest or southeast.)

9. The most effective height of windows to ventilate for human comfort ranges from 18 to 60 in. (0.46 to 1.52 m) above the floor. In barracks, it is advisable to keep the sill at the height of the beds to insure an adequate airflow around this area. When higher windows are required, they should be horizontally pivoted so that the window panel deflects the airflow down into the space.

10. Minimize use of interior walls because they limit the air flow when windows are opened. Where needed, interior walls should be lightweight and light in color.

11. Whenever possible, use on-grade concrete slabs for a foundation to take advantage of the earth's insulating qualities.

12. Avoid raised foundations, whether of the point or perimeter type. Unless the floors are properly insulated, they will be exposed to the high diurnal temperature variations.

13. Use properly insulated lightweight wall and roof systems to prevent intolerable amounts of heat from being transmitted into the building.

14. External wall surfaces should be a light, nonglaring reflective color or should be painted in light, nonglaring colors to reflect solar radiation.

Some cooling techniques require manual labor. These activities can usually be done before sunup and after sundown.

1. Brush clean the exterior surface of the walls and roof so that the sand film that may form on them does not change their solar reflective properties.

2. Add extra insulation to the building exterior during the day and remove it during the night.

3. Ventilate the building by opening doors and windows when the outside air temperature is lower than the temperature inside the building.

4. Sleep outside if the building is too hot (probably in humid regions), preferably under mosquito netting.

5. Observe the techniques natives use to stay cool.

6.2.5 *Habitability of Prefabricated Temporary Buildings Without Mechanical Cooling*

A study was made to determine whether temporary, trailer-like, lightweight buildings without air conditioning would be habitable, or could be made habitable, during emergencies in hot desert environments. The study was made using the Buildings Loads Analysis and System Thermodynamics (BLAST) program.* The BLAST computer program is a detailed simulation procedure which calculates hourly heating or cooling loads, or hourly room temperatures in the absence of heating or cooling equipment, based on a detailed description of the building and on actual climate data. The climates simulated were a hot-wet climate and a hot-dry climate typical of the Middle East climate extremes. An office and two different dormitory configurations were simulated.

The baseline buildings as well as retrofit options were simulated to determine if improvements in habitability and comfort could be achieved by such techniques as adding mass to roof and walls, controlling ventilation, adding shading, reducing window area, etc. The results are summarized in Table 6.1. The results indicated that with temperatures ranging from 111°F (44°C) during the day to 87°F (31°C) at night for 1 percent design day (e.g., in Dhahran), it proved impossible to maintain the mean air temperature in the buildings to within the limits of human physiological comfort as defined by the ASHRAE Handbook of Fundamentals (Figure 6.2).**

Even the fully retrofitted office (option from Table 6.1) modeled still reached 93°F (34°C) during the 5 percent design day in the hot-dry desert regions. This showed that the prefabricated buildings studied can be extremely uninhabitable if mechanical cooling cannot be provided.

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* D. C. Hittle, The Building Loads Analysis System Thermodynamics (BLAST) Program, Version 2.0: Users Manual, Volume I, Technical Report E-153/ADA072272 (U.S. Army Construction Engineering Laboratory [CERL], 1979).

**ASHRAE Handbook 1977 Fundamentals (American Society of Heating, Refrigeration, and Air Conditioning Engineers [ASHRAE], 1977), pp 8.1-9.18.

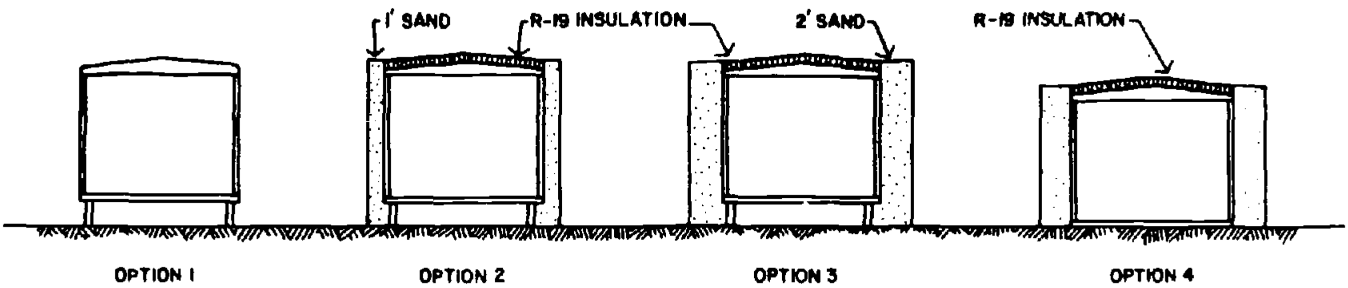
Table 6.1

Results of BLAST Analysis

Option	Hot-Wet Region (Dhahran) High Temp (°F)	Relative Humidity**	Time (Hrs)	Low Temp (°F)	Time (Hrs)	Hot-Dry Region (Riyadh) High Temp (°F)	Relative Humidity**	Time (Hrs)	Low Temp (°F)	Time (Hrs)
1 percent design day*										
Outdoor dry bulb temp	111.0	37	15	79.0	05	110.0	24	15	78.0	05
1	109.6	38	16	83.7	07	108.6	25	16	82.7	07
2	100.9	49	17	80.7	05	100.0	32	17	79.7	05
3	99.4	52	17	80.4	05	99.0	33	17	79.5	05
4	97.9	55	17	80.8	05	96.8	36	17	79.7	05
5 percent design day*										
Outdoor dry bulb temp	108.0	37	15	76.0	05	106.0	26	15	74.0	05
1	106.6	38	16	80.7	07	104.6	27	16	78.8	07
2	98.1	50	17	77.7	05	96.5	34			
3	96.6	53	17	77.4	05	95.3	35	17	75.4	05
4	95.5	55	16	77.8	05	94.3	36	16	75.9	05

* 1 percent and 5 percent design day: The high temperature of the design day is only exceeded 1 percent and 5 percent of the year.

** The relative humidity is determined using a Psychrometric chart and assuming that the specific humidity is the same indoors and outside. The actual relative humidity would probably be considerably higher due to the moisture added to the building from human perspiration.



ALL SURFACES HAVE A REFLECTIVE COATING

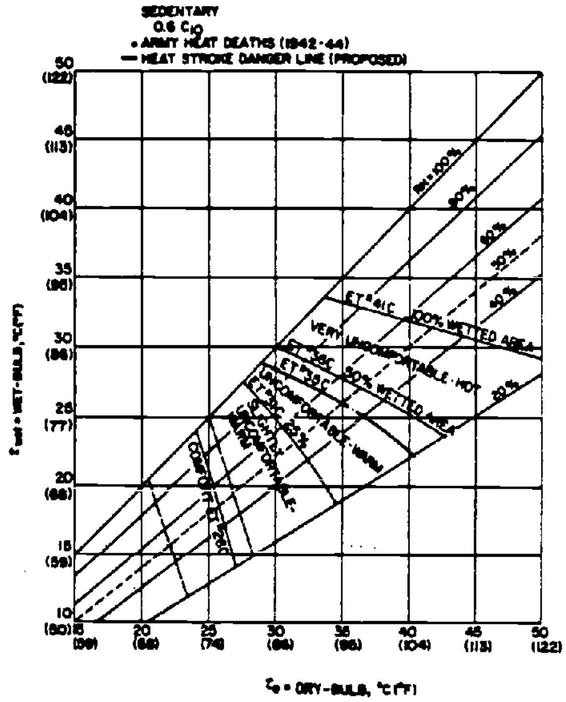


Figure 6.2. Comfort and discomfort lines, lines of equal wetted area (physiological strain). Lines for ET* at Comfort, 25 percent, 50 percent, and 100 percent wettedness also indicated. (Reprinted by permission from ASHRAE Handbook of Fundamentals, 1981.

6.2.6 *Cooling Systems*

If base camps are built up enough that austere requirements can be relaxed, several methods can cool effectively.

Evaporative cooling requires a plentiful supply of water and works well in low-humidity regions. The hot, dry air is cooled by vaporizing water. To provide cooling, air must be moved through the building either by fans (requires electricity) or naturally.

Since the water normally found in desert regions has high alkali content, the water that will be used for evaporative cooling should be treated if required. An evaporative cooler must not be used where water is at a premium. However, since evaporative cooling units are economical, they should be used as much as possible in hot, dry regions if water is available.

A traditional method of evaporative cooling can be used, as shown in Figure 6.3. This is a chimney-type structure with an opening designed to catch the prevailing dry winds, which are funnelled down a shaft in which a large porous pot full of water is suspended. The water in the porous pot slowly drips to a grid on which charcoal has been spread. The air passing over the porous pot and the charcoal absorbs the water vapor, and cooling takes place by evaporation. Both the air introduced into the interior spaces of the building and the water in the pot are cooled.

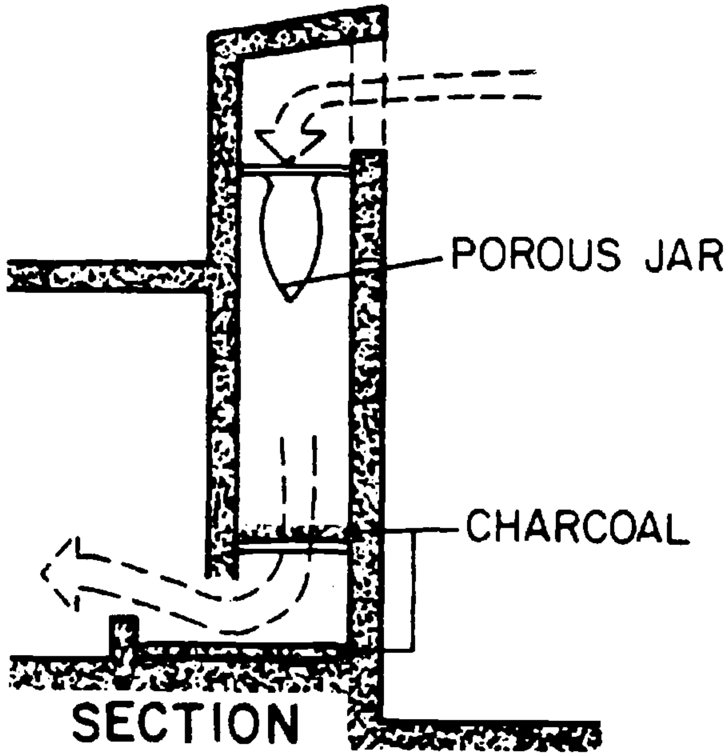


Figure 6.3 Traditional method of evaporative cooling.

Roof water ponds require a plentiful supply of water and a very strong roof. A pond of water on the roof is covered during the day to minimize heat gain and then uncovered at night to maximize cooling by the cold air, night sky, and vaporization of the water.

Conventional window air conditioners require electricity but are easily installed.

6.2.7 *Heating*

When the desert gets cold, personnel can wear warmer clothing. The passive cooling techniques can be reversed to have passive heating (e.g., ventilate during the day and not at night to keep the interior surface temperatures at a comfortable level). If fuel is not in short supply, fuel-burning heaters can be used.

6.3 Indigenous Building Methods and Materials

6.3.1 *General*

The limited range of materials for building in the Middle East is common knowledge; the area is primarily desert and inaccessible mountain ranges; vegetation is sparse, and mineral resources are difficult and expensive to exploit. Indigenous building technology is based largely on stone, clay soils, and a limited supply of wood. National development, financed by oil and gas revenues, is forcing the growth of local building materials industries, but it will be years before steel, cement, and other primary structural materials will meet regional building needs. Primary and secondary materials will need to be brought in for the foreseeable future, and thus will remain available mainly on a warehouse basis -- in the ports and centers of trade, and at the sites of development.

Designers of buildings which utilize materials and methods indigenous to the region will be faced not only with a limited choice of materials, but also by the problem of limited lengths and sizes in specific categories. In such cases, it may be necessary to overdesign in order to utilize available materials, or otherwise adapt to the local supply situation.

Climatic and environmental considerations will also affect design development. Options for building design, for example, include the possibility of burying below the ground surface -- a traditional desert technique that has been used for centuries to combat heat gain through walls. It can be demonstrated that burying a building will influence design of the superstructure in various ways: walls can be reduced in height or eliminated; traditional heavy mud roofs can be constructed more easily when the superstructure is lowered (thus increasing local material options); roof sizes can be reduced since wall shading requirements are reduced or eliminated, and opportunities for using short pieces of material are increased.

Corrosive soils containing sulfate and chloride are abundant in the region. Do not use galvanized steel in contact with ground in a corrosive area. Only zinc-coated, vinyl-covered steel should be used in such areas. Also do not use uncoated galvanized steel or aluminum in exterior applications within 5 miles of seawater or it will quickly corrode.

Conventional methods of using materials such as wood and steel, which are common knowledge among Western designers and builders, have not been considered in this chapter. Rather, this study has attempted to look for ways in which traditional local materials can be retained for their proven merits, and for opportunities to improve methods and make them easier to use by applying principles of materials science and technology.

6.3.2 *Concrete Systems*

6.3.2.1 General:

Concrete production in the Middle East has been difficult, at best, for many decades. The four major problem areas are: (1) inferior materials, (2) lack of production capabilities, (3) environment, and (4) unskilled and untrained labor forces. Reports of rapid deterioration and, in some instances, total failure of concrete structures built in the Middle East are appearing with greater frequency in engineering and construction journals.

The principal villains are the poor construction materials and the harsh environment. The general absence of both fine and coarse good-quality aggregates, which make up 85 percent of the concrete, coupled with a lack of suitable quantities of potable water for concreting operations will present a real challenge to troop construction. The very high temperatures and strong prevailing winds associated with the area will compound the problem.

Nonetheless, concrete is made and used daily in the area; this indicates that with proper training and planning, troops also could produce it.

The Engineer support associated with the size of the operation being considered in this report will not have the production equipment nor expertise needed to make anything more than occasional batches of concrete. Once made, transportation of the concrete will be difficult due to limited vehicular support and lack of suitable surfaces over which to transport it.

The following paragraphs describe the anticipated problems or areas of need for most aspects of concrete materials and concrete production. The aggregate problem will be difficult to solve, and does vary depending on site location.

6.3.2.2 Portland Cement Concrete Production:

1. Portland cement. Although there is some local cement production in the region, most cement will have to be imported. Many countries ship cement into the region. In general, there will be no control over what is received and its quality. If possible, sulfate-resistant (Type V) and low-heat cements (Type IV) should be used.

2. Aggregates. Natural sands are usually abundant, but their gradings are generally poor, and they are frequently contaminated by deleterious salts. Typical grading curves and bands of aggregates in desert areas are provided in Figures 7.2 through 7.6. Rock outcrops may be friable and porous, and contaminated with deleterious salts. These problems, in combination with extremely hot weather, are of major concern for concrete construction.

3. Water. The entire concrete operation uses large quantities of water, beginning with the processing and washing of aggregates, through mixing, curing, and equipment cleanup. In most steps, it is usually recommended that the water be potable; however, exceptions can be made, especially for the temporary construction. Water to be used for mixing mortars or concretes must not contain dissolved substances that affect the setting time unduly or retard the hardening. In general, the only impurities in natural water that are likely to be objectionable are dissolved salts; the permissible limits for these are quite wide.

Seawater or brackish water has been used for mixing concrete in many areas where potable water is difficult to obtain. It has been noted that seawater with a maximum concentration of salts on the order of 3.5 percent does not appreciably reduce the strength of concrete, although it may lead to corrosion of reinforcement. At salt concentrations beyond that, a strength reduction ranging from 8 to 15 percent can be expected. This reduction in strength may be corrected by using somewhat less mixing water and somewhat more cement. Most engineers believe that seawater should not be used for mixing reinforced concrete; however, after 4 years, no problems were reported when coral aggregate and seawater were used in military base construction in Bermuda. Therefore, seawater is acceptable for use in Portland cement concrete construction for temporary facilities.

If the quality and thickness of the concrete cover are inadequate, brackish water or seawater, when used as mixing water, may create conditions that aggravate reinforcing steel corrosion. Saline mixing water tends to cause dampness and surface efflorescence in the hardened concrete, and should not be used where surface finish is important, or where the mortar or concrete is to be covered with plastic or any decorative finish. It should also be noted that saline water must never be used for mixing high alumina cement since it has an adverse effect on the strength.

Organic impurities in water may retard setting and hardening of cement; however, these impurities do not usually occur to an objectionable extent, except in artificially contaminated waters. It is improbable that a water used for curing would attack concrete if it were the type suitable for mixing water. Staining or discoloration of the concrete by curing waters should be the principal curing water problem. Provisions should be made to retain and recycle all water, when possible, at all steps of the concrete operation (see Chapter 5).

Facilities for water storage at the site of the aggregate and/or concrete production must be provided. The mixing water storage should also include provisions for water cooling to help the problem of temperature development in fresh and new concrete.

4. Admixtures. There is a definite need for using water reducing, retarding, and superplasticizing admixtures for reduced water requirements, improved consistency, and extended working time. These will all have to be brought into the area.

5. Mix proportions. Most concrete proportioning schemes are dictated by the locally available materials which, for the problem at hand, are highly variable. The existing technology for developing concrete mixture designs is not considered applicable for proper approaches to mixture designs with materials available in the Gulf area. Suggested proportions for producing expedient concrete and mortar mix using locally available aggregates are provided in Chapter 7.

6. Placing. The very hot temperatures affect the consistency of the fresh concrete and make it very difficult to place. High temperature, winds, and direct sunlight should be avoided when placing concrete. If possible, the concrete should be placed with the temperature below 90°F (33°C). Using ice water or cool water will help lower the concrete temperature. If ice is used to chill water for mixing, the ice should be melted when it leaves the mixer. Doing concreting work at night should also be considered. The forms, reinforcement, and ground surface should be sprinkled with good-quality water, if available, just prior to placement.

7. Finishing. There will be short finishing times due to the hot temperatures and strong winds of the area. Shading and windscreens are a necessity to prolong the finishing period and reduce evaporation from the concrete surface. Concrete should be covered immediately after finishing with a temporary cover (e.g., burlap) whenever available. The quality of finishing will be marginal because the labor can be considered unskilled.

8. Curing. Troops seldom cure concrete but must do so in this area to avoid excessive and severe plastic and drying shrinkage cracking. The general lack of water suggests that either curing compounds or curing membranes be

used. These would have to be brought in. The concrete should be cured as soon as possible. The concrete should be uncovered in small sections immediately prior to applying the curing compound. Any water suitable for mixing concrete can also be used to cure it. As noted above, windscreens and shades would also be a great help.

6.3.2.3 Concrete Block Production:

1. Raw materials. Basic materials required for concrete block production are:

a. Portland cement: sulfate-resistant and low-heat cements, if available.

b. Aggregates: fines and coarse aggregates such as coral cinders, expanded shale, sand, gravel, clay, slag, and others.

c. Water.

d. Other agents which may or may not be added:

- Hydrated lime

- Pozzolans

- Other constituents, such as air-entraining agents, pigments, etc.

2. Manufacturing process. Concrete block may be manufactured with a variety of equipment. Large complex stationary block production machines, simpler mobile "egg laying" block machines, and basic hand-operated equipment may be used to produce block. In each case, relatively dry concrete is tamped in a mold which is immediately stripped off, and the procedure is repeated again and again. The basic process, in each case, is similar and is as described below and shown in Figure 6.4.

a. Prepare a well-graded mix of fine and coarse aggregates. A recommended ratio of aggregate to sand is 7 to 4 by weight. Crushed aggregates are generally better than rounded particles.

b. Make sure aggregate is clean. Wash, if necessary.

c. Mix the aggregate. Add the cement, water, and any other necessary additives; complete mixing. Mixtures for concrete block will vary with the purpose of the block. However, a possible mix ratio by weight of cement to aggregate is 1:4 or 1:5. A good water/cement ratio is about 0.3 for a 1:4 mix ratio and 0.38 for a 1:5 mix ratio.* The primary objective is to achieve adequate strength with minimum density. Depending on the type of aggregate, a standard block (8 x 8 x 16 in. [200 x 200 x 400 mm]) can weigh from 25 to 50 lb (11.4 to 22.8 kg).

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* Ronald Terrel and Mushtag Ahmed, "Mortarless Block Construction for Developing Countries," Housing Science, Vol 3, No. 5 (1979), p 327.

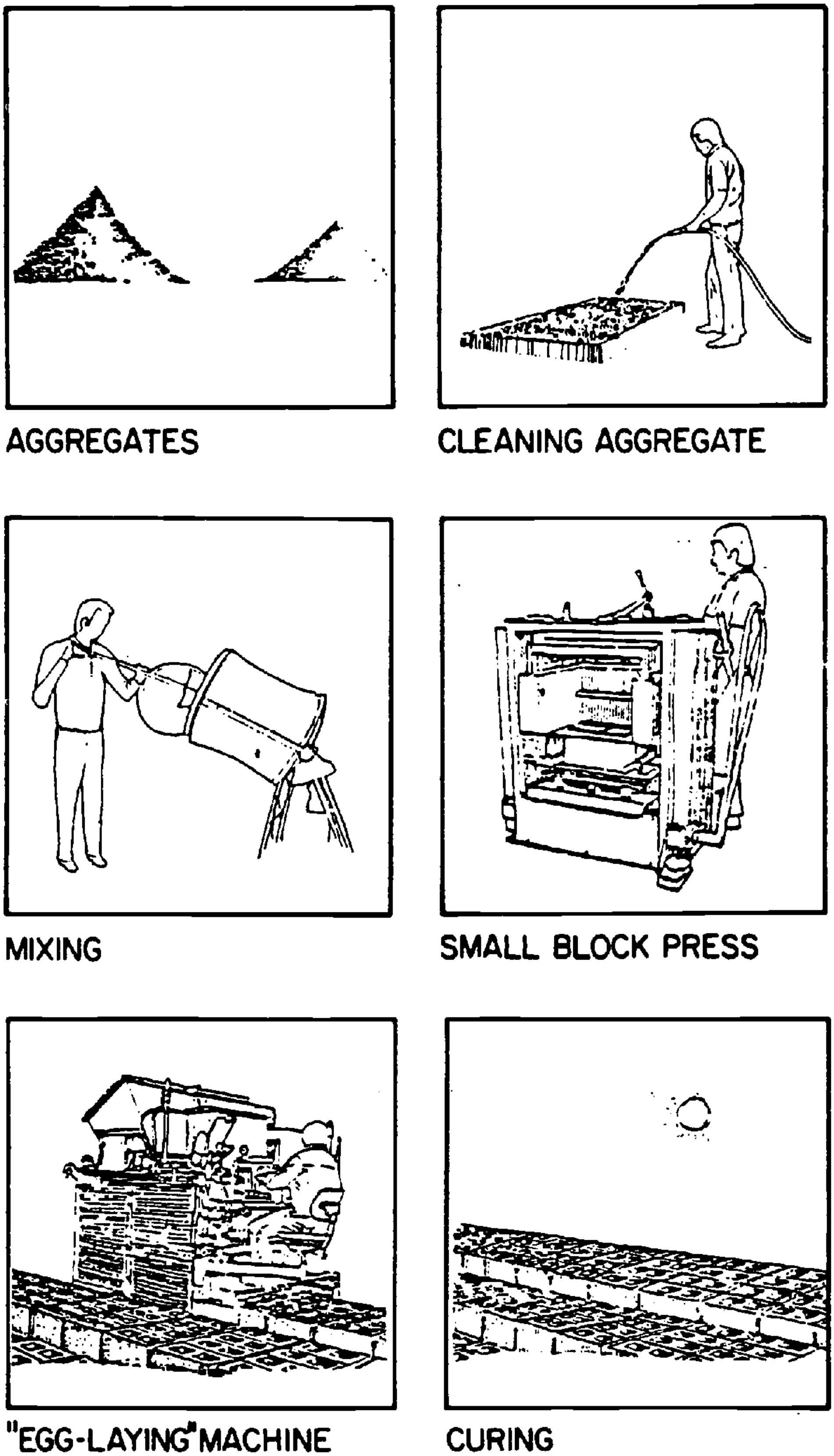


Figure 6.4. Concrete block manufacturing process.

d. Mold and compact the concrete with a block machine or by hand with metal molds.

e. Cure the block, either naturally or in steam rooms. Steam cure the block at 125°F (52°C) for a period of 15 hours or naturally by protecting from the sun and keeping it damp for 7 days. For indigenous sources, refer to the listing of some Middle East concrete block plants in Chapter 10.

3. Dimensions. Blocks can vary greatly in size from region to region, but the most common size is the 8 in. x 8 in. x 16 in. (200 mm x 200 mm x 400 mm) hollow block. However, block machines may be adjusted, by simply changing molds, to make almost any size block.

4. Labor requirement for manufacture. The labor required to manufacture concrete blocks depends on the equipment available for production. If a large-scale concrete block production plant is available, as many as 60 blocks per minute, depending on the equipment, could be produced with little labor. A smaller mobile "egg laying" block machine might produce somewhere between 24 and 48 blocks per minute, with several men required to operate the equipment. Manual production will make less than the "egg laying" equipment per unit man-hour, and will require many men to produce a significant number of blocks.

6.3.2.4 Binding Agents for Concrete Blocks:

Typically, cement mortar is used as a binding agent, but several other materials, such as sulphur, lime, and cement coatings, may be used. Extremely temporary shelters can be erected without a binding agent. However, most modern construction utilizes a portland cement mortar. Each block is bonded to the foundation with a thin joint of mortar and each successive block is bonded to the wall with a layer of mortar, until the wall is completed to the desired height, usually no more than one story tall (approximately 8 to 12 ft [2.4 to 3.6 m]). A recommended range of cement mortar -- mixes of cement to lime to sand in the proportion 1:1:6, 1:2:6, 1:3:12 by volume -- will provide adequate bonding for most situations. However, in situations where traditional block construction using cement mortar for bonding is not desirable, other types of bonding may be used.

A concrete block wall can easily be bonded with a mixture of sulphur, fibers, and plasticizer, or with a cement-based coating. First, the bottom row of blocks is bonded to a concrete foundation by pouring the molten sulphur mix or cement coating into the cavities of the hollow blocks, bonding each block to the foundation. Next, each following row of blocks is stacked up dry on top of the lower row until the desired wall height is reached. If extra strength is desired, steel reinforcement may be added by placing steel rods vertically through the cavities of the hollow blocks. Then the sulphur mix is either brushed or sprayed over the joints, or sprayed over the entire surface. The cement-based coating is sprayed over the entire surface of the wall. The sulphur mix must be applied quickly to avoid unwanted hardening due to fast cooling. Sulphur-surface bonding and cement-based coating produce a wall which is as strong as, or stronger than, a standard masonry wall.

Lime-based mortars were the most prevalent before the introduction of modern cement mortars. The lime-based mortars are a combination of burnt lime, water, and possibly pozzolanas. The pozzolana reacts with nonhydraulic lime in a water medium at ordinary temperatures to form a cement. In some areas of the Middle East this mortar is still used. It is applied with a layer of mortar between each block, producing a strong steady wall.

Fast setting of concrete and greater initial shrinkage in desert regions make the location of construction joints in concrete masonry more critical than in cooler climates. Thus to prevent any potential problems, the following steps should be taken: provide vertical control joints in the walls, reinforce horizontal joints, and provide bond beams at appropriate locations. The following table gives the appropriate spacing for concrete masonry wall joints.

Concrete Masonry Wall Joint Placement

Maximum Spacing of Control Joint*	16 ft (5.0 m) or 2 H	20 ft (6.0 m) or 2.4 H	23 ft (7.0 m) or 2.6 H	26 ft (8.0 m) or 3.2 H
Vertical Spacing of Horizontal Joint Reinforcement+	No reinf. required	24 in. (60 cm) c to c	16 in. (40 cm) c to c	8 in. (20 cm) c to c

H = Height of the wall
* = Spacing shall not exceed the smaller of the dimensions shown.
+ = Joint reinforcement shall include two or more longitudinal steel wires, minimum total area = 0.0346 sq in.

In the case of extremely temporary shelter, wide concrete blocks or slabs can be used as a foundation, and concrete blocks can be stacked on top of the foundation to form the walls. It is suggested that this type of shelter be used only in emergencies or in very temporary situations. Also, it is suggested that the height of a stacked block wall be kept as low as acceptable.

6.3.2.5 Concrete Block Construction:

1. Advantages:

a. If blocks are available in large quantities, concrete block construction can be cheap, quick, and durable.

b. Sulphur, an efficient bonding material for concrete blocks, is a byproduct in oil and natural gas refining, and is stockpiled in many refining areas of the Middle East.

c. Properly made concrete blocks have high compressive strength.

d. Blocks may be produced by manual labor or by many different mechanical means. In rural or field areas, it may be especially important to be able to produce construction material with no more than manual labor.

2. Disadvantages:

a. Cement required for the production of concrete block may not be available.

b. The time required to produce and cure concrete blocks may be prohibitive.

c. In earthquake-prone regions, standard block construction can be problematic due to its inability to withstand strong lateral forces.

d. Proper aggregates may not be available.

6.3.3 *Earth Systems*

6.3.3.1 General:

The use of earth for building construction results partly from the scarcity of wood and other construction materials. Also, earth construction is easy and has high insulation value against both heat and cold.

Earth buildings are structurally sound and durable enough for many regions. They are dry, fireproof, soundproof, cool in summer, and warm in winter. The cost of building the wall is low, the principal expense being the labor force, primarily unskilled labor. There are some kinds of mud that make stronger structures than others, and some construction techniques that apply better to some kinds of mud. Thus the type of construction method will be affected by the type of soil available.

Organic soils are the least suitable for earth construction; a combination of two types of soils is ideal: sandy clays or clayey sands. However, in very dry regions, clays are best. There are several types of construction methods for earth building: adobe, baked clay, sand shale, and stabilized soil bricks are common types. Methods of making adobe and stabilized soil bricks, as well as construction methods using these materials, are described below.

6.3.3.2 Adobe:

The raw materials for making adobe are:

1. Soils -- mix of clay, sand, and very fine silts. A recommended proportion of soils is approximately one-third each of clay, sand, and fines. However, this is only a guideline, and the proportion will vary with different types of soils. The blocks made with high sand content soils will crumble and erode easily, whereas the blocks made with very high clay content soils will shrink and crack too much. The best way to test soils is to make a test brick.

2. Agricultural materials -- crop residues are sometimes used, but are not recommended.

3. Water.

Soil suitable for making adobe bricks exists over a wide area of the Middle East. Adobe has been the chief construction material in SWA for centuries; thus, wherever there are populated regions, there should be a source of adobe nearby. However, in some remote regions, such as deserts and salt playas, no adobe dirt can be found.

The basic procedure for making adobe brick is as follows (see Figure 6.5):

1. Form a mixing pit or use a mechanical mixer such as plaster mixer or pug mill suitable to mix enough mud for the forms that will be used.

2. Place adobe dirt in the pit and mix with water and, if desired, crop residues.

3. Mix the mud thoroughly by hand or by a mechanical mixer.

4. Put the forms on level ground and place a fine layer of sand, straw, or paper under the molds to facilitate removal of dried bricks.

5. Add the adobe mixture and smooth it level with the top of the form.

6. The adobe mud should be stiff enough to keep the bricks from slumping too much, yet plastic enough to conform easily to the mold shape.

7. Pull off the forms and let dry several days before standing them on edge to complete drying, approximately 1 to 2 weeks.

8. After the bricks are completely dry, they may be immediately used, or stacked and stored. They should be stacked on edge, and no more than three or four high to minimize breakage. If the bricks are going to be stored for a long time in the open, it may be desirable to cover the bricks with a waterproof sheet of plastic or tar paper.

Before proceeding with large-scale production of bricks, several test bricks should be made to determine whether the mix proportions are satisfactory. Test bricks made should be able to withstand dropping from a couple of feet after completely drying. If the block is not satisfactory, the mixture must be adjusted by either adding clay, reducing sand content, adding crop residue, or tempering (allowing the mixture to soak overnight, for instance).

There are no specific dimensions for adobe bricks. Some suggested sizes are 14 x 10 x 4 in. (355 x 150 x 102 mm), 8 x 4 x 4 in. (200 x 100 x 100 mm), and 12 x 6 x 4 in. (300 x 150 x 100 mm). Somewhere within this range, a block size satisfactory for most situations can be found.

The properties of the block will depend on the type and amount of sand, silt, clay, and crop residue in the mixture. But mud bricks, in general, have low compressive strength, low weathering resistance, and high thermal insulation value.

Adobe brick production is a labor-intensive process, when rapid production is desired. It is an imposing, time-consuming task to manually mix enough mud for an entire building. Although, if necessary, only a few people

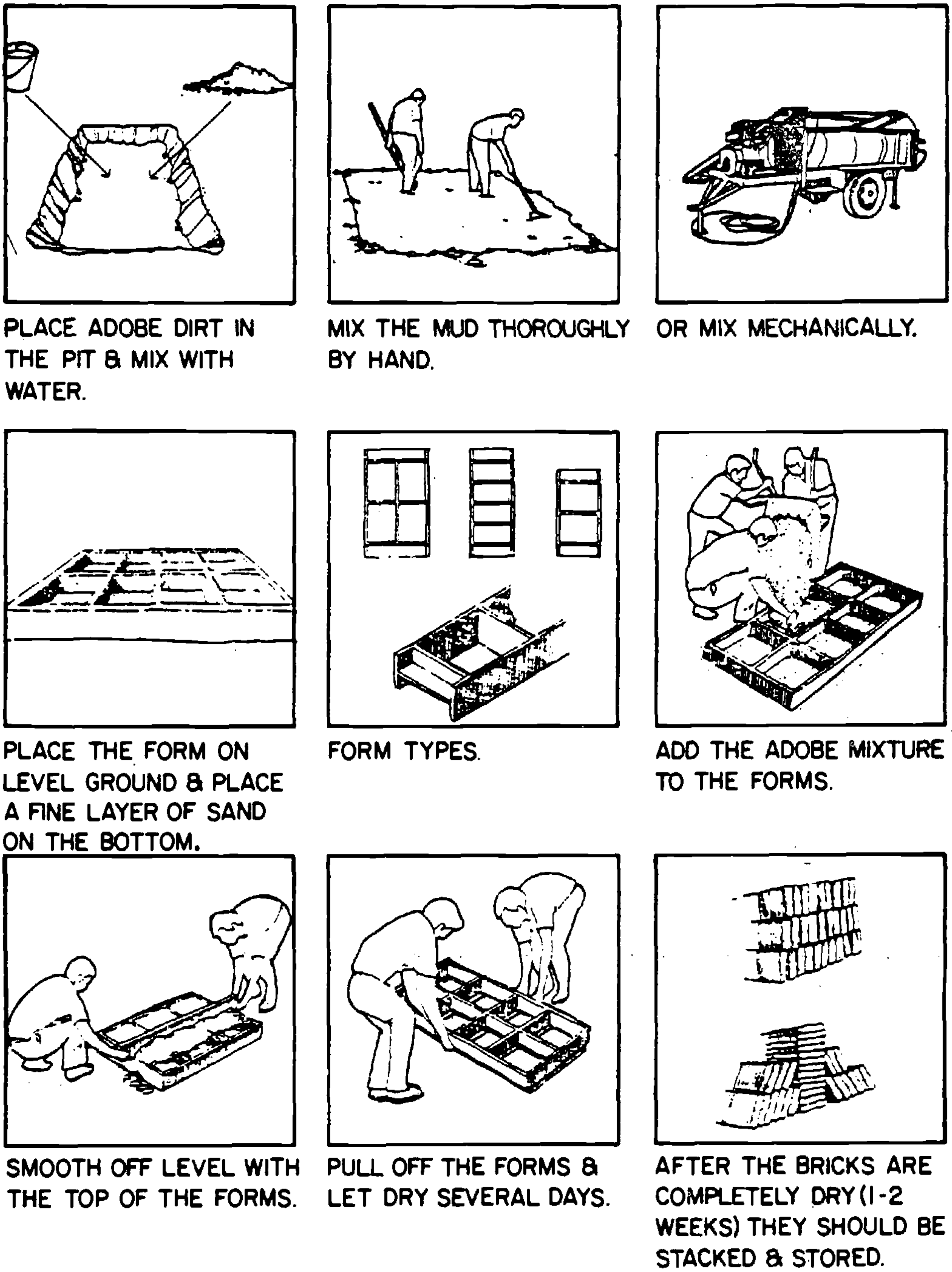


Figure 6.5. Adobe.

could complete the job in an expanded time frame. For instance, according to Little in Demonstration of Stabilized Mud Brick in Egyptian Village Housing, three people can manually produce eight bricks per minute.* Thus, the more manpower, the more rapidly the blocks can be produced, provided adequate volumes of raw material are available.

The chief use of adobe brick is as a load-bearing wall component. Adobe brick has been the major building unit in the Middle East for centuries. In fact, most rural construction in the Middle East consists of adobe brick construction. However adobe brick, as all other types of brick, may also be used in infill construction, which is covered later.

Basic adobe construction starts with the foundation. Refer to Figure 6.19 for details of the foundation, wall, and roof. A complete poured concrete slab, concrete footing, heavy concrete block, or rock may be used as a foundation. The complete poured slab will be the most stable, and the rock foundation the least stable.

In regions where freezing and thawing will occur, it is imperative to get the footing below the frost line so that heaving and buckling of the foundation will not occur. To help strengthen the foundation, steel reinforcing, if available, may be added. But in regions where there is little or no chance of freezing or thawing, such as hot desert climates, there is little need for a deep footing.

Next, a stem to raise the wall above the footing must be added in all areas where water, either surface drainage or groundwater, will be a problem. This is important since water will destroy an adobe wall. Poured concrete or concrete block filled with concrete or earth may be used to build a stem. It should be high enough above ground level to keep the adobe away from water.

If concrete block filled with earth is used as a stem, a cap of concrete should be added to the top of the stem to prevent capillary action of groundwater up through the earth in the stem. If desired, reinforcement may be added to increase the strength of the stem. If necessary, rock may be used as a stem; most early adobe buildings did use this material.

If rock is used as a stem and mud as a mortar, the rocks should be flat to prevent settlement of the foundation and stem caused by the shifting of uneven rocks when the mortar gets wet. Concrete mortar will alleviate this problem if it is available.

Finally, the adobe wall is added to the top of the stem. Traditionally, mud mortar is used as a binding agent, but cement or lime mortar can also be used (Table 6.2).

If desired, extra strength may be added to the wall by using steel, wood, or bamboo reinforcement when available. However, standard adobe construction in regions that are not earthquake prone does not require any special reinforcement -- unless, for some other reason, unusually high lateral loads are

* Arthur D. Little, Demonstration of Stabilized Mud Brick in Egyptian Village Housing (Cambridge, Massachusetts, Technical Cooperation Administration, 1961).

Table 6.2

Mortars

Cement mortar.........	1 cement, 2-1/2 to 3 sand (by volume), 1-1/2 gal asphalt emulsion per sack of cement.
Cement-line mortar....	1 cement, 1 hydrated lime, 4 sand.
Cement-soil mortar....	1 cement, 2 soil (use same soil that bricks are made from), 3 sand, 1-1/2 gal asphalt emulsion per sack of cement.
Adobe mortar..........	The same mixture as the bricks are molded from. (Slow-curing and requires working around the building, laying no more than 2 or 3 courses and allowing adequate drying time.)

anticipated. Wherever windows or openings in the walls are required, plans should be made to provide support by using lintels (beams) over the top of the openings.

When using mud as a mortar, do not lay more than about six layers of bricks on any one day in order to prevent the weight of the bricks from squeezing and compressing the mud in the joints before it sets. Adobe walls are not extremely stable, so tie-beams should be provided at the top of the walls to stabilize the structure. The thickness of exterior walls should be 12 in. (300 mm), or no less than one-tenth the wall height.

After the wall is complete, the roof must be added. Usually, roof beams or joints are wooden; however, steel, concrete, or other materials could be used if proper bearing plates are provided on the tops of the walls. Many types of roofing materials may be used. Lightweight materials, such as woods, sheet metals, corrugated asbestos cement sheets, and synthetics (plastic, composites, etc.), are recommended due to the poor compressive strength of the adobe.

The advantages of adobe are as follows:

- It is an indigenous material and is available over a wide range of areas in the Middle East.

- It is cheap and has good thermal resistance.

- It is a simple material with which to work. Native labor would be familiar with and easily adapt to any construction project involving adobe.

- It has simple production procedures.

The disadvantages are:

- It is not resistant to water. Groundwater or excessive precipitation (>30 in./yr [762 mm/yr]) can easily damage it.

- It has poor earthquake resistance unless special reinforcement is added specifically to resist lateral forces.

- Some areas of the Middle East — for instance, deserts and salt playas — do not have soil which could be used to manufacture adobe bricks.

- Adobe bricks have low compressive strength.

6.3.3.3 Stabilized Soil Bricks:

Although untreated adobe bricks have been used with varying degrees of success, depending on the weather and environment of a particular locality, adobe bricks treated with stabilizer such as asphalt (rapid-curing road oil or emulsion) have increased strength and durability, and will require very little maintenance and upkeep.* The asphalt stabilizer treatment can be included in the existing methods of manufacturing sun-dried bricks with a minimum of special equipment or skill.

Stabilized and unstabilized adobe bricks have essentially the same soil requirements and can be made from a wide variety of soils. In general, soils containing a high percentage of loam, silt, and organic matter are usually not well-suited for adobe bricks. The soluble salts and organic material are detrimental to the quality of bricks and should be avoided. Soils which consist primarily of sand and clay are usually most satisfactory for adobe construction. For stabilized brick, stabilizers such as cement, asphalt emulsion, and lime are used.

Specifications for soil to be used for stabilized adobe bricks usually call for a range of 55 to 75 percent sand and 25 to 45 percent fines (silt and clay). About 15 percent clay seems to be ideal. Sands are normally defined as material particle sizes between a No. 4 and No. 200 sieve, and fines are the material passing through a No. 200 sieve.

Soil suitable for making adobe bricks exists over a wide range of the Middle East. Sources of adobe can usually be found wherever there are populated regions. However, in some remote regions, such as deserts and salt playas, no soil usable for adobe construction can be found. Availability of stabilizers will depend on the locality; they may have to be imported.

The manufacturing of stabilized soil bricks is similar to the manufacturing of adobe brick. The only difference is in the addition of the stabilizer — asphalt emulsion, cement, or lime. Additional information about producing stabilized bricks is provided below.

* International Institute of Housing Technology, The Manufacture of Asphalt Emulsion Stabilized Soil Bricks (California State University, 1978), p 8.

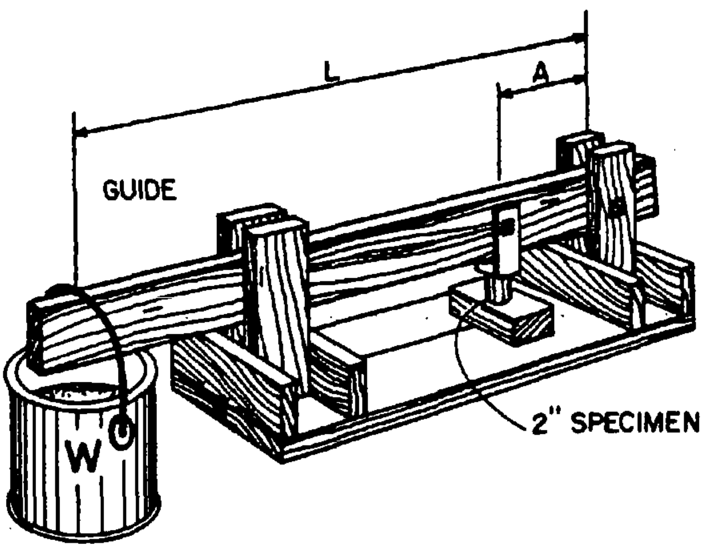
1. Asphalt stablized brick.

a. Road oil stabilizer. Rapid-curing road oil (RC-250) is preferred to medium-curing road oil (MC-70) because it permits a shorter drying period for the bricks.

b. Determining the amount of stabilizer necessary. The amount of stabilizer required for mixing can be determined by field tests. It is suggested that one mixes several batches of soil with amounts of stabilizer varying from 1 percent to 3 percent for RC-250, or 2 percent to 6 percent for emulsion. Three 2-in.-diameter x 2-in.-high (50.8 mm x 50.8 mm) and three 4-in. x 8-in. x 16-in. (101.6 mm x 203.2 mm x 406.4 mm) bricks should be made from each batch for compressive and modulus of rupture tests, which can be done by using the set-up shown in Figures 6.6 and 6.7.

If the amount of stabilizer required is greater than 3 percent for RC-250 or 5 to 6 percent for emulsion, the soil probably will not be satisfactory for brick making because of excessive cracking.

c. Mixing devices and facilities. It is suggested that a power mixer (such as a pug mill or plaster mixer) be used for making stabilized brick since it will assure a more uniform mixture consistency. If a power mixer is not available, hand tools such as hoes, rakes, and shovels may be used. A cement mixer is not suitable for mixing adobe brick mud. A mixing device having a rotating shaft with paddles attached, which may be locally produced, is best for proper blending of adobe ingredients.



TOTAL LOAD ON SPECIMEN = $\frac{W \cdot L}{A}$ + WT. OF LOAD BEAM (50# APPROX)

Figure 6.6. Compressive strength test set-up.

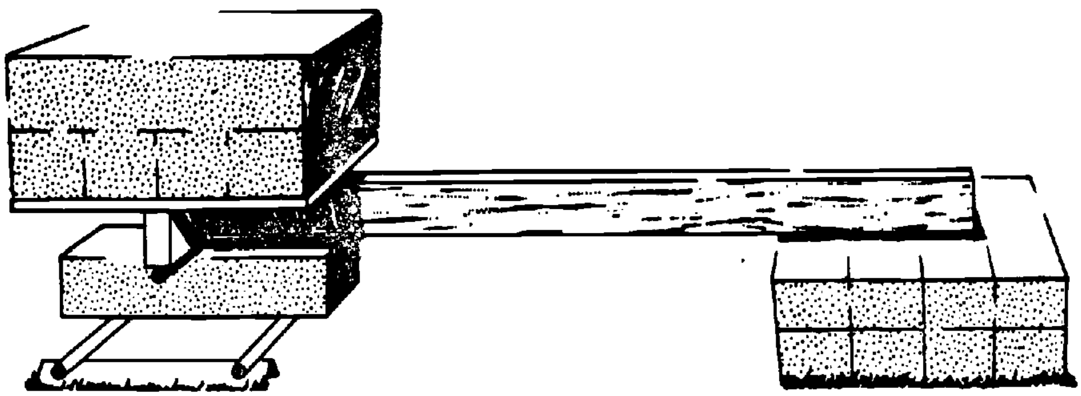


Figure 6.7. Modulus of rupture test set-up.

Adequate space must be provided for both mixing and drying. The brick drying area must be level and provide enough room for the number of adobe bricks being produced. The surface of the drying area should contain a layer of sand, straw, or paper (which is preferable) placed under the molds to facilitate removal of dried bricks.

d. Basic mixing procedures using mechanical equipment. Screened soil is placed in the mixer. Water is then gradually added to the soil while the mixing shaft is turning. While the soil is being thoroughly soaked with water, asphalt stabilizer is added to the mud and mixed until no dark streaks of asphalt are visible in the mixture. More water is added and mixed into the mud until the thoroughly wet adobe has a thick plastic consistency.

To determine the proper molding consistency, a groove can be cut in the mixed mud (small test pats about 1/2-in. [12.7 mm] thick) with a V-shaped stick. If the sides of the groove are not smooth, more water is required in the mixture. If the groove closes, the mixture is too wet and more dry soil is required. If the sides of the groove are smooth and bulge out, the mixture contains the proper amount of water and soil.

e. Hand molding. The mixed adobe mud is carefully dumped from the wheelbarrow into the compartments of the brick mold. The mud is then worked into all portions of the compartments to form smooth brick surfaces. After the top of the model has been smoothed and leveled by hand or with the straight edge of a piece of wood, the mold is carefully lifted from the brick.

f. Drying bricks. A hot, dry climate over long periods of time is most favorable for curing stabilized adobe bricks. However, on very hot, dry, or windy days, when rapid surface drying occurs, bricks may crack. Paper or straw protective covering on the wet bricks will slow down the drying process. After the bricks have dried for a few days, they will be strong enough to be turned on one edge to promote drying. Normally, it will take about 30 days to dry bricks thoroughly. However, one can determine when bricks are ready for use by selecting samples at random, breaking the bricks in half, and examining their centers for dryness.

2. Cement stabilized soil brick. The mixing of the soils for cement stabilized bricks is somewhat similar to that for asphalt bricks, but the forming of the brick is quite different. The mixing procedure begins with the selection of the proper soil, according to Table 6.3.

Once the soil is selected, it should be crumbled up and sieved through a No. 4 (5-mm) sieve. It can be mixed either manually, or mechanically in plaster mixers. Four to eight percent cement should be added to the soil. Also, enough water should be added to get the soil to about 12 percent moisture content. After thorough combining, the mixture is ready. Next, the bricks can be formed in blockmaking presses. There are two basic types of presses: constant pressure and constant volume. With constant pressure machines, reduction of the volume of soil placed in the machine will result in the reduction of the size of the block produced. However, with constant volume machines, reduction of the volume of soil placed in the machine will result in under-compacted blocks of low density. Once the block is formed it should be allowed to cure for several weeks. The resulting strength of the block is directly related to the pressure used to compact the block. Typical strengths

Table 6.3

Property Limits*

Properties	Areas of Rain Over 30 in./yr	Area of Medium or Low Rain
Distribution by weight:		
Sand	Not less than 33%	Not less than 40%
Clay	5-20%	5-30%
Ideal moisture content	10-14%	7-16%
Grain size distribution:		
Clay, loam	Not more than 30%	--
Sand, gravel	Not less than 70%	--

*Aziz Girgis and M. El-Hifnawi, Rural Low Cost Housing: Bricks and Wall Units Industry in Egypt (Cairo, General Organization for Housing Building and Planning Research), p. 43.

range from .15 ksi to 5.80 ksi (1.0 MN/m^2 to 40 MN/m^2) for stabilized soil blocks.* Once cured, the blocks are ready for use.

3. Lime-stabilized soil brick. Lime-stabilized soil brick production is quite similar to that for cement-stabilized soil bricks. Once the soil has been selected according to specifications stated in the cement-stabilized section, test bricks containing a range from 2 percent to 6 percent lime should be made. Several moisture contents in the 12 percent to 20 percent range should also be tried. Once the optimum percentages of lime and water are established, mass production should proceed with the same steps as in concrete stabilized soil bricks.

The properties of stabilized soil bricks will depend on the type and amount of soils, stabilizers, and water in the mix. Asphalt-stabilized bricks tend to be more water-resistant than cement- or lime-stabilized bricks — unless high compaction pressures, >2.32 ksi (>16 MN/m^2), are used in the production of stabilized soil bricks.

The labor required to produce asphalt-stabilized bricks is identical to that required for adobe brick production: if large volume is desired, a large amount of labor will be required. The labor required for production of cement or lime stabilized soil bricks will depend on the equipment available. If many blockmaking presses and much labor were available, large volumes of block could be produced. Approximately two to three people per blockmaking press would be required to optimize production.

The primary use of stabilized soil brick is as a load bearing wall component and as a non-load-bearing component in infill construction. The basic procedure for construction with stabilized soil brick is the same as that used for adobe construction; refer to paragraph 6.3.3.2.

Stabilized soil brick is advantageous because:

- Most of the material used is indigenous

- It is inexpensive

- It is durable

- It is more waterproof than standard adobe

- It provides good insulation.

Stabilized soil bricks have several disadvantages:

- They have poor earthquake resistance unless special reinforcement is added specifically to resist lateral forces.

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* M. G. Lunt, Stabilized Soil Blocks for Building (Garston, Watford, WD27JR, Building Research Establishment, 1980), p 11.

- Some areas of the Middle East, for instance deserts and salt playas, are totally devoid of any soil which could be used to manufacture adobe bricks.

- The time required to produce and cure stabilized bricks may be prohibitive.

- Their properties vary due to variations in types of soils.

Cement-required for the production of cement-stabilized brick may not be available.

- In earthquake-prone regions, standard block construction can be problematic due to its inability to withstand strong lateral forces.

6.3.4 *Sulphur Concrete*

Instead of using Portland cement to bind sands and aggregates to produce Portland cement concrete, sulphur can be used to produce sulphur concrete. Materials and methods for producing sulphur concrete are described below:

Elemental sulfur:	dark grade, standard bright grade, or laboratory grade
Aggregates:	Coarse Fine
Modifiers:	Dicyclopentadiene (DCPD) Dipentene (DP) Oligomers (heavier fractions from DCPD manufacturer)

Traditionally, sulphur sources are located underground in regions of past or present volcanic activity. However, today more and more sulphur is being produced as a byproduct of the desulphurization of oil, natural gas, and power plant emissions. It is estimated that by the year 2000, 85 to 90 percent of all sulphur production will come from secondary sources such as power plant scrubbers and refineries.* Thus, the Middle East region is inadvertently becoming a large producer of sulphur. Large volumes of sulphur are currently being produced and stockpiled near oil and natural gas refinery areas. In addition, several areas of the Middle East are also large mined-sulphur producers.

The availability of aggregates varies from region to region of the Middle East. In certain areas, such as salt playas and sand dunes, many types of aggregates may be nonexistent. However, sulphur concrete will allow the use of chloride- and sulphate-containing aggregates, which may be unsuitable for portland cement concrete. It is generally suggested that each aggregate system considered should be evaluated for its compatibility with sulphur and modifiers. Some aggregates may be unacceptable since they react chemically with sulphur. Also, aggregates that contain swelling clays are not suggested.

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* "U.S. Bureau of Mines Transfers Sulphur Concrete Technology to Industry," in Sulphur Research & Development, ed. J. S. Platou (Washington, D.C.: The Sulphur Institute, 1979), p 5.

In general, limestone aggregates give higher strength and better freeze-thaw resistance, and quartz aggregates give better corrosion resistance.

Modifiers are used in sulphur concrete to correct two problems: brittleness and combustibility. A commonly used modifier, dicyclopentadiene (DCPD), corrects both of these problems. Other commonly used modifiers are dipentene (DP) and oligomers, which are heavier fractions from the manufacturing of DCPD.* Since these are modern commercially produced chemicals, it may be assumed that any large quantity of modifier required in the Middle East will have to be shipped into the area.

During manufacturing, modifiers must be added to optimize the performance of sulphur concrete. However, when considering construction for short durations, it might be conceivable to use unmodified sulphur to produce sulphur concrete. According to research done by John M. Dale, elemental sulphur has reasonable structural properties of its own. The following chart is a section of a test data chart produced by Dale.**

LABORATORY TEST DATA
(Specimen Age at Test is 1 day)

Grade of Sulphur	Tensile Strength (Avg) psi (KN/m^2)	Compressive Strength (Avg) psi (KN/m^2)	Modulus of Rupture (Avg) psi (KN/m^2)
Dark	147 (1014)	3030 (20891)	275 (1896)
Standard Bright	178 (1227)	3010 (20753)	108 (745)
Laboratory	163 (1124)	3430 (23649)	113 (779)

The strengths exhibited in the above tests show that reasonably good strengths can be achieved with sulphur alone. Thus even if only sulphur were available, sound structural materials could be developed. However, unmodified sulphur does present some problems. Elemental sulphur is not fire-resistant, and it tends to be brittle. In addition, when sulphur burns it produces harmful gases such as hydrogen sulfide and sulphur dioxide.

But if modifiers and modifying equipment are not available, unmodified sulphur concrete could be the only solution. The first step in using unmodified sulphur is to acquire the raw materials. Then, melting equipment is needed. This typically consists of a standard concrete mixer with liquid or gas burners located around the drum. Liquid propane (LP) gas, natural gas, or any other fuel source can be used to heat the drum. The only problem that arises from using conventional concrete mixers is from the additional heat transferred from the hot drum to the grease in the bearings of the unit. The bearings must be closely watched and lubricated liberally if the grease starts melting.

* "U.S. Bureau of Mines Transfers Sulphur Concrete Technology to Industry," in Sulphur Research & Development, ed. J. S. Platou (Washington, D.C.: The Sulphur Institute, 1979), p 5.

**J. M. Dale, "Determination of the Mechanical Properties of Elemental Sulfur," Materials Research & Standards, Vol 1 (January 1961), p 25.

Once the proper raw materials and equipment are located, the production of unmodified sulphur concrete can proceed. The aggregate is added first to the mixer and is brought up to the desired mixing temperature range of 266 to 302°F (130 to 150°C). A mix of 25 percent sulphur and 75 percent aggregate can be used.* However, the most effective method would be to try several mixes with different sulphur and aggregate ratios.

The sulphur should be allowed to thoroughly melt and mix with the aggregates. Then the mix is ready to pour. Either poured-in-place sulphur concrete or sulphur concrete block can be formed with the mix. If sulphur concrete blocks are desired, metal molds that can be separated must be acquired. Molds that produce interlocking block or standard 8- x 8- x 16-in. (200- x 200- x 400-mm) structural block may be used. The insides of the mold should be lightly oiled before adding the sulphur concrete. The sulphur concrete blocks will achieve full strength in about 1 hour; however, they can be removed from the molds in as few as 10 minutes after casting.** Thus, with only a few molds, fairly rapid production can be achieved.

Poured-in-place sulphur concrete is placed like ordinary concrete, but due to the quick hardening of the sulphur, the mixture must be quickly worked into place. In approximately 1 hour the sulphur concrete will reach full strength. Poured-in-place sulphur concrete is excellent for foundations, footings, slabs, and other structural materials.

If modifiers such as DCPD are available, it would be extremely beneficial to incorporate them into the sulphur concrete mix. When modifiers such as DCPD are added in adequate quantities, the sulphur concrete becomes fire-resistant and flexible. The addition of 2 percent to 5 percent DCPD modifier is a reasonably complex chemical reaction which requires that the temperature not exceed 284°F (140°C). If the temperature exceeds 284°F (140°C), the mix may become stiff and rubbery. The advantages of using modified sulphur cement are exemplified in the properties given in the chart below.+

Sulphur concrete can be poured in place like ordinary portland concrete, or any size block can be formed if the proper mold is available. Labor required to pour sulphur concrete would be similar to that for portland cement concrete. If mixing equipment is available, men will be needed to load and operate the equipment and to transfer the sulphur cement to the work site. Also, men will be needed to work the cement into place. If sulphur cement blocks are going to be produced, the labor required will vary depending on the production volume desired.

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* Alvaro Ortega, "Sulphur Concretes in the Arabian Desert," in Sulphur Research & Development, ed. J. S. Platou (Washington, D.C.: The Sulphur Institute, 1979), p 14.

**Alvaro Ortega, "Sulphur Concretes in the Arabian Desert," in Sulphur Research & Development, ed. J. S. Platou (Washington, D.C.: The Sulphur Institute, 1979), p 14.

\+ From William C. McBee and Thomas A. Sullivan, Development of Specialized Sulfur Concretes, Bureau of Mines Report of Investigations 8346 (Washington, D.C., U.S. Department of the Interior, 1979), p 12.

Properties of Sulphur Concrete Materials

Aggregate	Sulphur (pct)	Strength, psi Compressive	Strength, psi Flexural	Tensile	Specific Gravity
Silica	24	5075	845	730	2.3409
Silica	26	7280	905	830	2.4012
Silica	$22M^1$*	5310	1220	775	2.2132
Silica	$24M^1$	6120	1335	760	2.2306
Limestone	22	6740	700	795	2.4762
Limestone	24	6855	810	760	2.4974
Limestone	$21M^1$	7990	1235	815	2.4364
Limestone	$23M^1$	9020	1330	895	2.4281

*M^1 designates sulphur that has been reacted with 5 percent dicyclopentadiene.

Sulphur concrete can be used to form block or poured-in-place structures. Sulphur concrete block may be used as a load bearing wall component or as a non-load bearing component in infill construction.

The basic procedure for construction with hollow 8- x 8- x 16-in. (200- x 200- x 400-mm) sulphur concrete block is the same procedure used in concrete block construction. Cement mortar, lime mortar, or sulphur bonding may be used to join the block. If interlocking block is used, little or no bonding may be required.

The procedure for sulphur concrete poured-in-place construction is identical to the procedure for portland cement construction, except quick cooling of the sulphur concrete will create some problems. Therefore, special consideration will have to be given since sulphur concrete will cool quickly and thus set up before being worked into place.

The advantages of sulphur concrete are as follows:

- Sources of sulphur are plentiful in the Middle East
- The blocks have good compressive strength
- Only sulphur and aggregate are needed to produce blocks
- The blocks are waterproof
- Sulphur can be stored outdoors with no loss of value

- Sulphur concrete can easily be recycled by simply reheating.

The disadvantages of sulphur concrete are as follows:

- Unmodified sulphur concrete can burn and produce noxious gases

- Modified sulphur concrete can melt and therefore is unsatisfactory for any structure which would normally experience temperatures above approximately 234°F (113°C)

- Conventional cement and asphalt equipment can be used but must be adapted to sulphur concrete

- Separable ceramic or metal molds are required to produce blocks

- Modifiers are required to produce a sulphur concrete which will not burn or fail in a brittle manner

- Modifiers will probably not be available unless they are shipped and brought to the area where they will be used.

6.3.5 *Other Local Construction Materials*

6.3.5.1 Sand-Lime Brick:

Sand-lime brick can be found in some parts of the Middle East, such as Kuwait and Qatar. It is made of silica sand, quick lime, and water. Blocks vary greatly in size from region to region, but several common sizes are 222 x 108 x 66.7 mm, 250 x 130 x 60 mm, and 222 x 108 x 139 mm. The chief uses of sand-lime (calcium silicate) brick in the Middle East are as both non-load-bearing and load-bearing wall components. However, in load-bearing applications, the structure is usually not over one story tall. Sand-lime brick may also be used in infill construction.

6.3.5.2 Stone Block:

Many different types of stone can be found throughout the Middle East. Limestones are common in Israel and Egypt. Sandstones also are common in Israel. Many types of stones, such as limestone, sandstone, dolomite, and marble, are presently mined in many areas. Thus, in addition to untapped natural stone sources, there are operating quarries throughout the area. Stone block may be used for many purposes, but mainly stone blocks are used as load-bearing wall components. Stone blocks may also be used in infill construction as wall fillers. The basic procedure for constructing a stone block building is similar to the procedure used in adobe construction.

6.3.5.3 Wood:

In general, it is safe to assume that no wood will be available for major construction projects in the Middle East. In fact, however, some woods may be available in some parts of the Middle East. The natural habitats of deciduous and coniferous trees suitable for sawn timber are located in the mountains and highland plains of Afghanistan, Pakistan, Iran, and Turkey. International trade statistics* and individual country surveys** show that forestry and wood conversion industries exist in these countries, although it cannot be assumed that supplies of sawn timber are necessarily available. Pakistan is attempting reforestation, although some earlier plantations have been destroyed for firewood.

The coastal and low-lying areas of the region are sources of roundwood from palm trees of various species. These areas support the growth of coconut, oil, and especially date palms -- the basis of a diversifying agricultural industry. Although unsuitable for sawn timber, palm tree trunks have always been a traditional building material, used for columns and as floor and roof beams.

Small roundwoods, called "bally poles" in Iran, varying in diameter from about 2 to 6 in. (51 to 152 mm), are used traditionally for rafters, purlins, and posts. They come from a local poplar-like tree, and thus are generally straight and suitable for these purposes.

Wood is not normally recommended in hot, dry regions of SWA because it is unavailable locally and much would be wasted due to the combination of high solar radiation and low humidity. However, if lumber is imported for constructing some of the required buildings, such as AFCS facilities, certain steps may be taken to minimize the problem. These steps are given below:

1. Utmost care must be taken to limit waste due to cutting, etc. For instance, a centralized cutting yard may be used.

2. If wood is used, the studs must be used as soon as the bands around the stud package are broken to reduce wood stud loss caused by warping. (Do not untie the bands until the studs are ready to be used.)

3. The frame must be wrapped immediately with some material to shield it from the sun's direct rays to prevent warping and cracking.

4. Sidings should be installed as soon as wall framings are completed.

5. A raised foundation which requires wood normally is not recommended.

6.3.5.4 Pole Construction: Figure 6.8 illustrates the construction of the main frame of a building utilizing roundwood poles embedded in the ground. The advantage of pole construction is that the cantilevered poles reduce the need for bracing, which is important when the building contains no internal walls. Spacing of the poles will be determined by the enclosing wall system selected.

6.3.5.5 Roundwood Roof Timbers: The use of tree trunks and large poles is a traditional form of floor and roof support in the Middle East. Figure 6.9 illustrates a cantilevered timber floor in an urban house in Iraq. Roof

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* Foreign Trade Statistics of Asia and Pacific (United Nations, 1978).

**The Middle East and North Africa 1981-82: A Survey and Directory (London, Europa Publications Ltd., 1981).

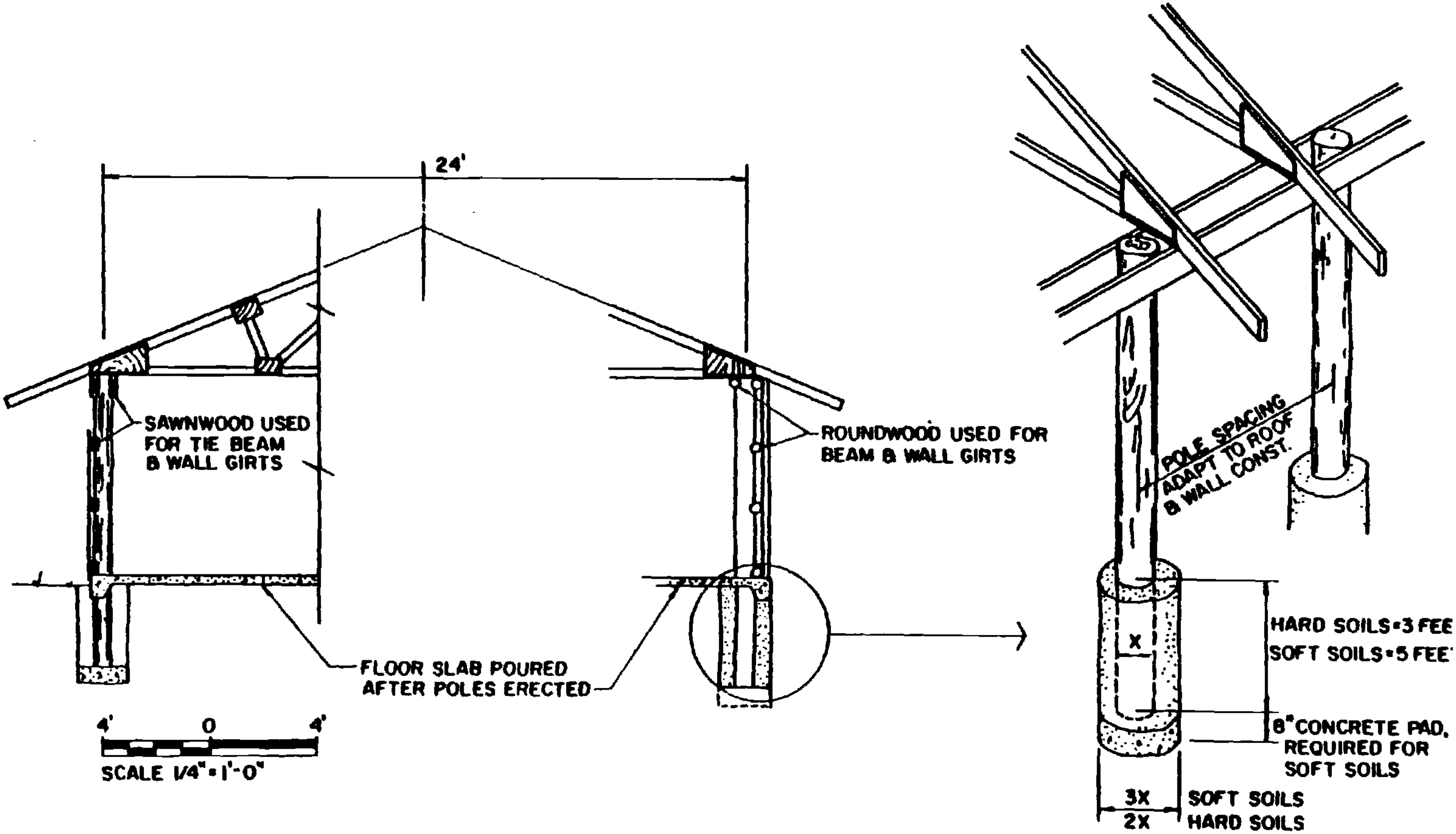


Figure 6.8. Roundwood poles.

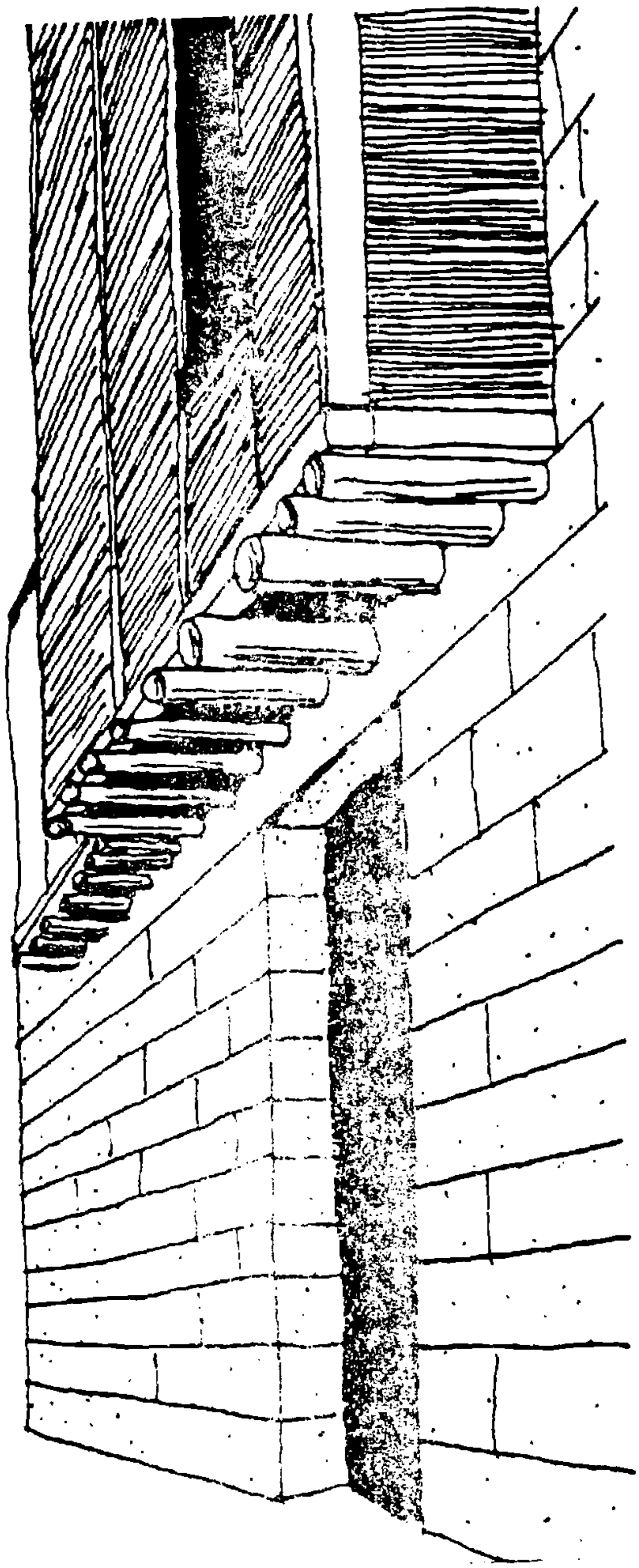


Figure 6.9. Traditional floor construction (Iraq).

construction by this method will require heavy external supporting walls, particularly if the traditional method is carried out to the extent of using packed earth, on bearers, for the roof itself. This method can be used with masonry or thick adobe wall materials, or if the building is buried to some extent.

6.3.5.6 Cement-Asbestos Panels:

These can be used in conventional ways and as roof coverings. They are more suitable than metal panels in the desert since there is less heat gain in the material itself, and because they do not corrode. If used, they should be insulated or shaded, depending on the application. Figure 6.10 shows an application of cement-asbestos panels in which they are buried about 3 ft (1 m) in the ground to form cantilevered walls.

6.4 Prefabricated Structural Systems

Prefabrication is production of buildings or parts of buildings before their installation on the site. Prefabrication may be used for expediency, efficiency, or convenience when applicable. Prefabrication can take place in highly mechanized factories but also at temporary locations with minimal equipment and protection, as circumstances dictate.

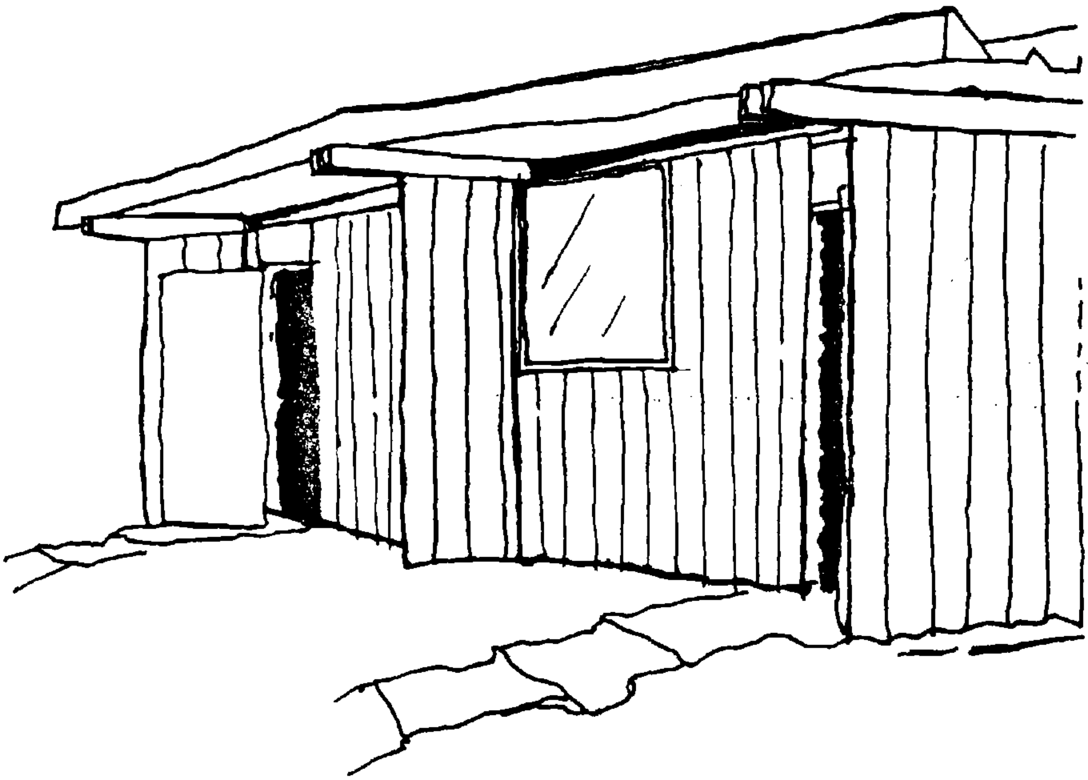


Figure 6.10. Cement-asbestos panels.

In some countries of the Middle East, there is considerable experience with prefabrication, including Israel, Turkey, Kuwait, and Saudi Arabia; new prefabricating plants are constantly being established at industrial centers and construction sites throughout the region as the market demands. Prefabrication in certain Middle East locations is as common as on-site or "conventional" construction. Therefore, locally produced prefabricated buildings should be investigated for possible use in a base development.

Another problem common to lightweight structures is the desert wind which can reach almost hurricane force in some regions. It is essential to anchor buildings securely to the ground with cables and ground anchors.

Caution must be used, however. Although prefabricated relocatable buildings used for offices or barracks generally are lightweight, and their walls, roof, and floor systems are adequately insulated, they will function well and provide comfortable working or living quarters only if they are cooled mechanically. Without mechanical cooling, the interior temperatures will rise above the outside air temperature and become intolerable during some parts of the day due to high solar radiation and heat generated by the occupants (see paragraph 6.2.5).

6.5 Tents

6.5.1 *General*

Tent, General-Purpose, Medium, and Tent, General-Purpose, Large are two of the tents procured and available from depots for rapid issue. Tent, Extendable, Modular, Personnel (TEMPER tent) is being developed and ultimately will replace the medium and large general-purpose tents. Although the TEMPER tent has greater flexibility for use in different environments, the information detailed here covers expedient modifications to improve the use and habitability of the general-purpose tents in a desert environment. Information on the TEMPER tent is also provided.

Tents can be very undesirable quarters in the desert because of high solar radiation, desert winds, and insects. However, tents are required for the initial stage of military operations. To make tents more habitable, double roofs should be used, and the outer roof should be painted in light color, such as sand color when possible. Concrete floors under the tents can also make them more comfortable.

6.5.2 *Expedient Modifications of General-Purpose Tents*

The modifications detailed here can be procured and stocked as a kit, and can be applied to the tent issued from depot stocks. The kit will consist of a multicolored fly, 14 extenders, and a lightweight ground cloth or floor. A liner must be used with the proposed kit to produce a more effective tent, and must be requisitioned on a one-to-one basis for the tent. Figure 6.11 shows the basic tent with the liner, extenders, and fly in position.

1. Multicolored fly. The fly must be made of a lightweight, vinyl-coated fabric. One side is to be sand-colored for use when the temperatures

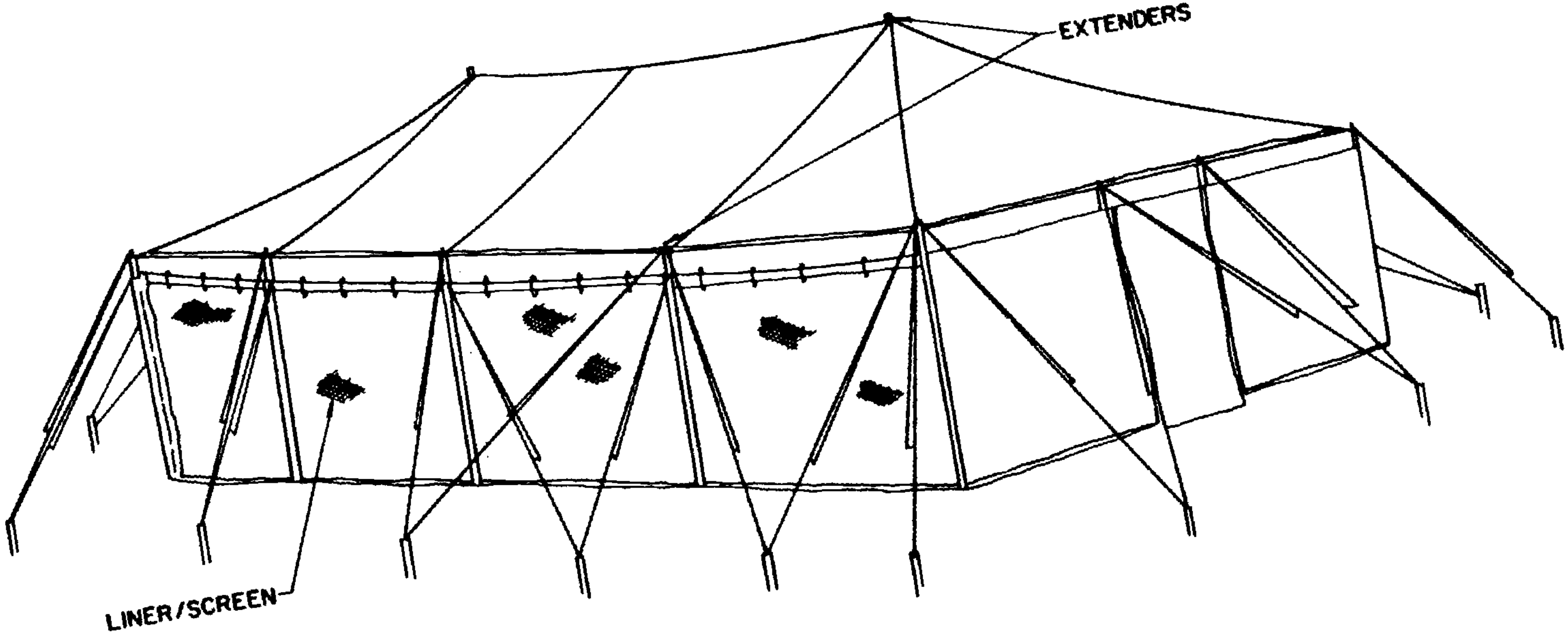


Figure 6.11. Tent, general-purpose, medium, with kit and liner.

will be in the normal desert range. The other side must be white to be used in desert extremes. The configuration of the fly is shown in Figure 6.12.

2. Extender. The kit includes 14 extenders, which are to be used with the fly to form an insulating air space between the fly and the tent roof top. The extenders are used with the eave and door poles, as shown in Figure 6.11. The basic concept of the extender is shown in Figure 6.13.

3. Ground cloth or floor. The kit includes a ground cloth which is to be used primarily for protection against crawling insects and small animals. The item must be made of a 12-oz (0.34-kg) forest-green, coated fabric. The dimensions and configuration of the ground cloth or floor must fit the interior of the tent. Instead of using ground cloth, a concrete floor under the tents can make the occupants more comfortable.

4. Use in desert environment. The tent, to be effective in a desert environment, must make maximum use of the screens in the liner and in the doors at each end. The fabric on each of the sidewalls must be separated at the ends, rolled back, and tied in place at the eaves with the ties provided. The screens in each of the ends must be unrolled and positioned over the door openings. The screens and fly will lower the temperature of the air in the tent. See Figure 6.14 for an example of tents used by the Egyptian Army in a desert environment.

5. On-site fabrication of kit. The fly, ground cloth, or floor, and extender can be made on-site by maintenance personnel if the required basic materials and equipment are provided. This may be a little difficult for the fly, since the multicolored, vinyl-coated fabric must be rolled and stitched to form the detailed shape and size. Grommets can be used at designated locations and tie ropes added. A machine shop is necessary to fabricate the extenders. The tube must be cut to the proper length and the ends drilled to accept the rod at one end and the pins on the poles at the other end. Welding equipment is required to weld the pin to one end of the tube.

6.5.3 *Tent, Extendible, Modular, Personnel*

The TEMPER tent can be used without modification in a desert environment. This tent has two types of covers. The tropical/desert type has windows and screens on each side and on both sides of the roof. For example, a 24-ft-long (7.32-m) tent has 12 side and roof openings. Sidewall windows are complete with screens, glass, and blackout flaps. Roof openings are provided with roll-up weather flaps. Each end of the tent has two windows with screens and glass, plus a door with a screen. A fly is also available in a basic 16-ft (4.88-m) length; additional fly sections are each 8 ft (2.4 m) long. Extenders are available for positioning the fly over the tent roof top. A ground cloth or floor is available in either a single layer or an insulated floor with a foam encased between two sheets of coated fabric. A liner with door or window openings is available. Another feature of the TEMPER tent is the transition section. This makes it possible to develop a complete shelter which does not require personnel to go outside. A single-layer ground cloth or floor, plus the insulated floor and a frame-supported system are available for the transition section. Also included is a flexible door for the open end of the transition section when it is not used for connecting two tents.

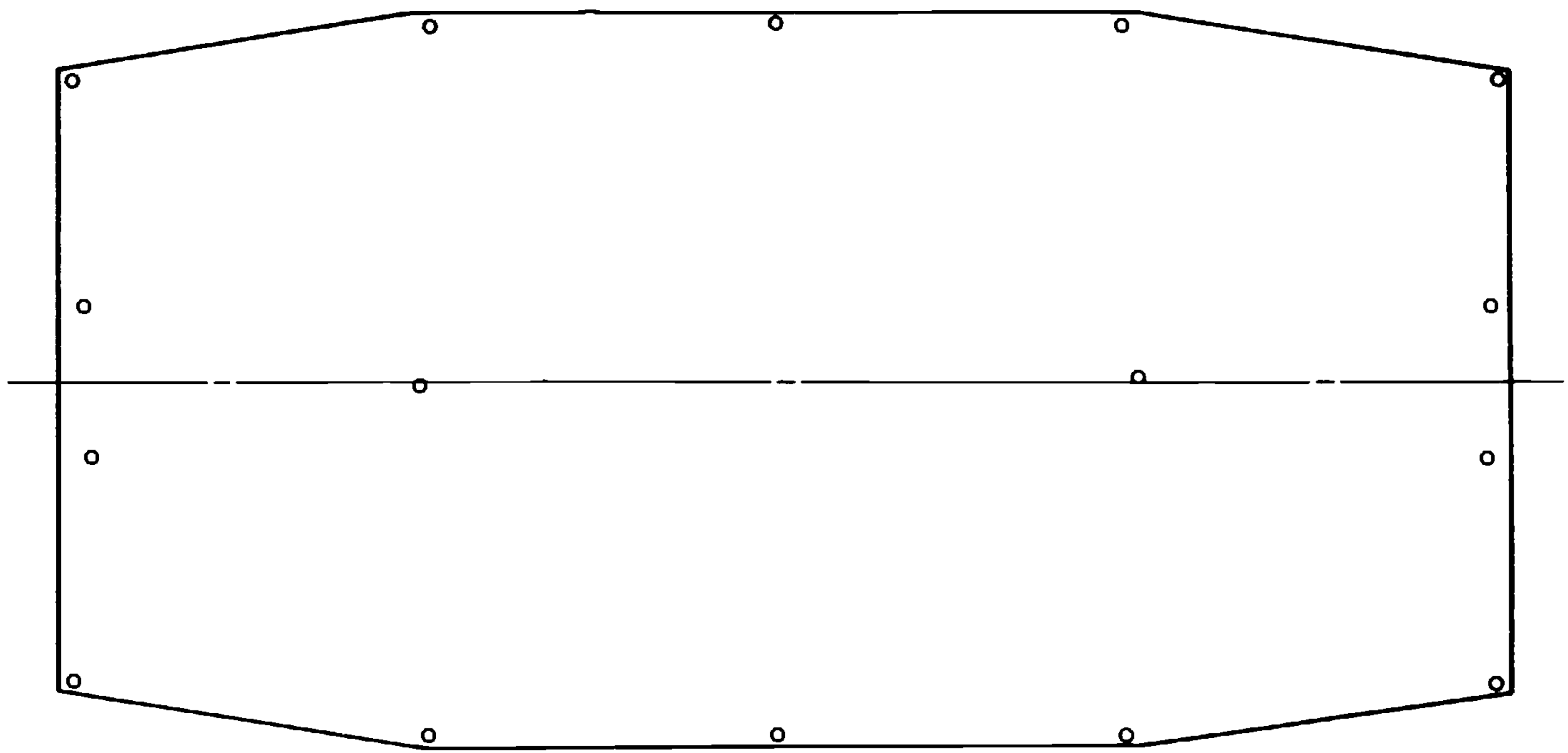


Figure 6.12. Fly configuration for tent, general-purpose, medium.

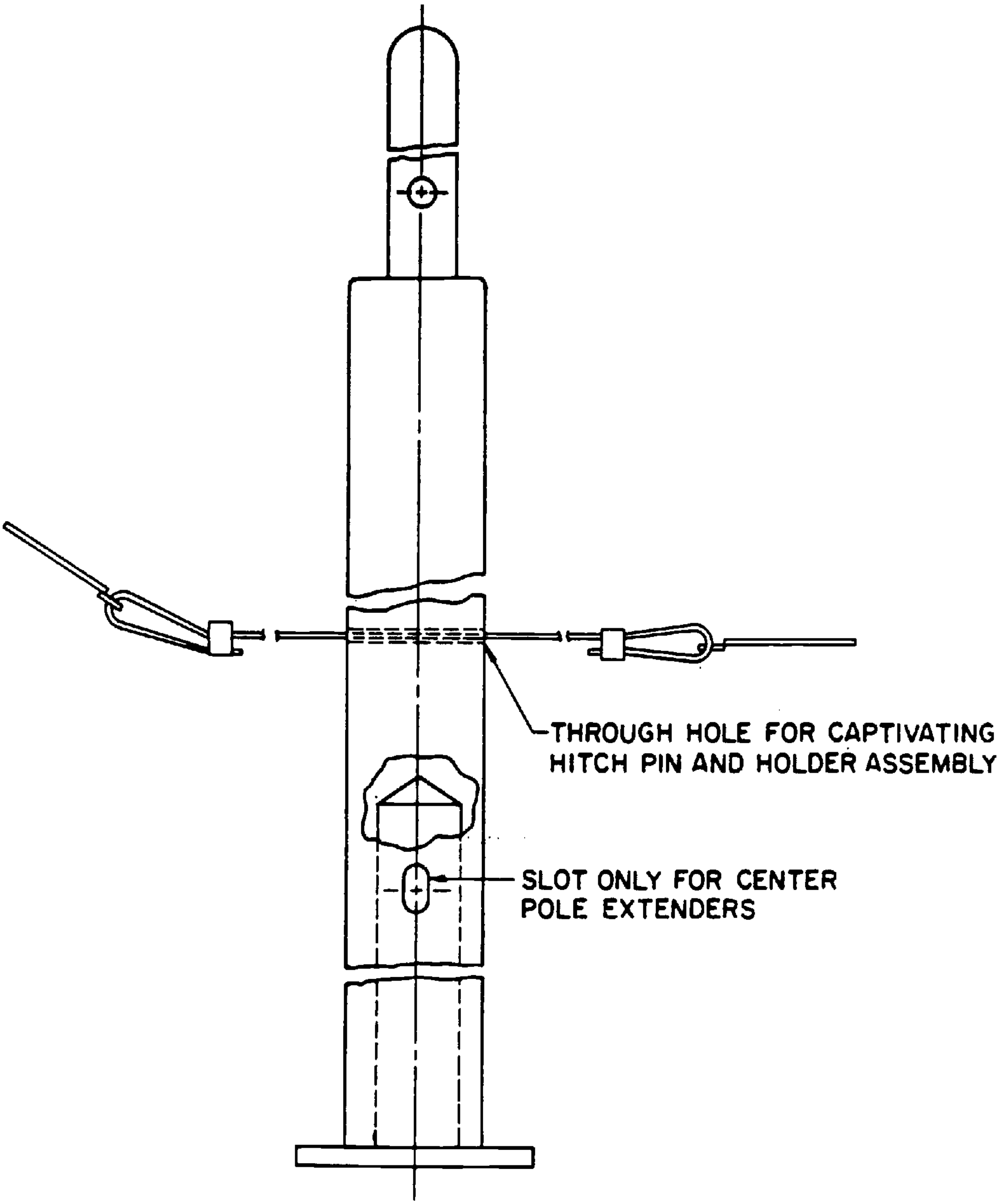


Figure 6.13. Extender concept for tent, general-purpose, large and medium.

Figure 6.14. Egyptian Army tents.

Figure 6.15 shows the TEMPER tent complete with a transition section. Figure 6.16 shows this tent configured for a complete field feeding system.

6.5.4 *Ground Anchors for Tents*

Sandy and rocky ground combined with high winds in the desert can cause problems with pitching tents. Possible solutions to the problem are:

1. Use of the deadman anchor for cohesionless soil such as sand or loose, silty soils. A deadman anchor consists of a steel rod or cable attached to a mass such as steel plates, steel I-beam, pipe, concrete blocks, etc., buried in the ground (Figure 6.17).

2. Use of corkscrew anchors if the required resistance force is not large (the corkscrew anchor is more suitable for clay-like soil).

3. To provide anchorage in rock or rock-like soil, it is necessary to bore holes in the rock and grout in anchor bolts.

4. Explosive charges can also be used to break up the rocks or hard soils to install anchoring devices.

5. A wedge anchor embedded in an augered hole can also be used for rocky conditions.

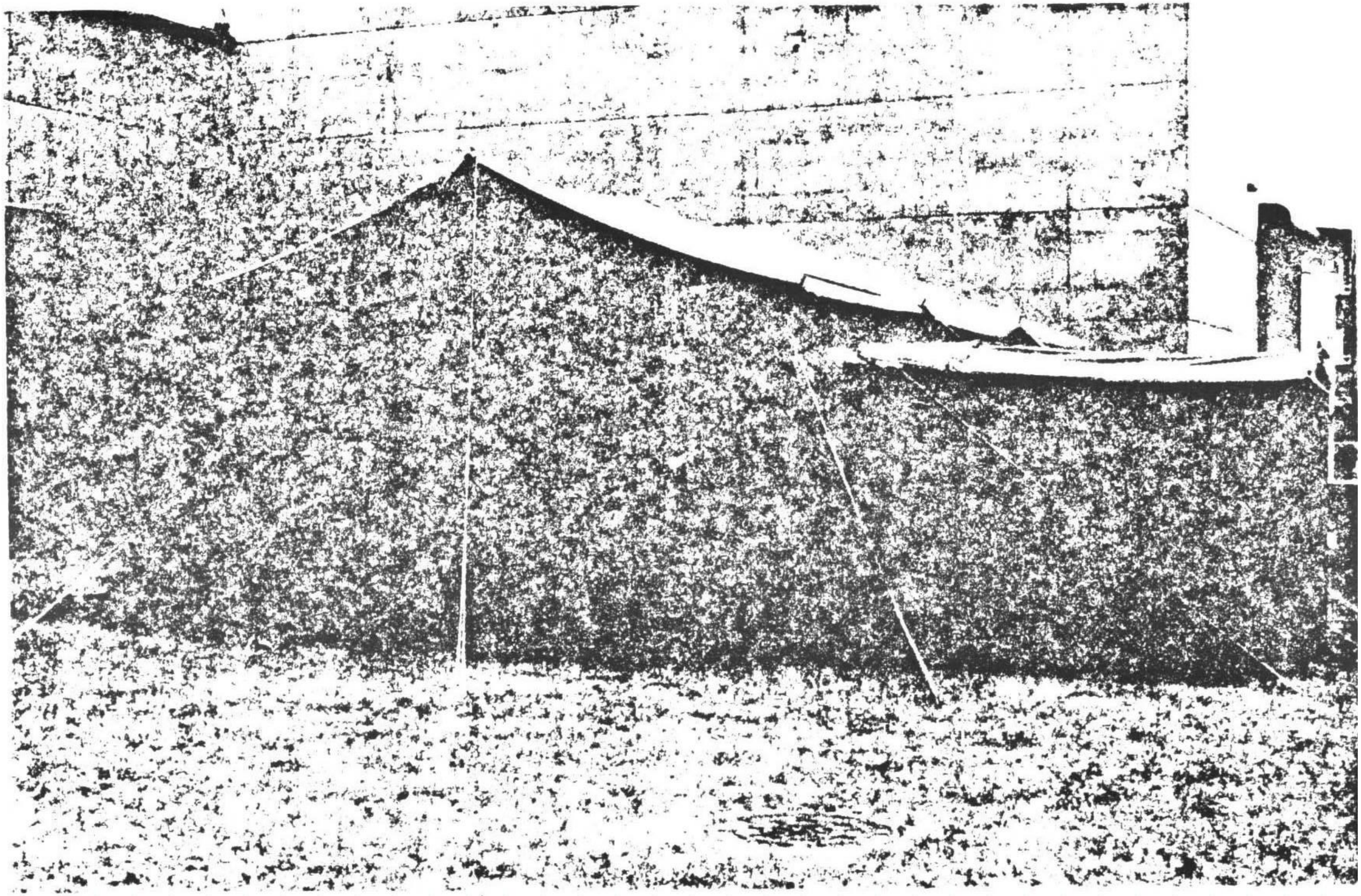


Figure 6.15. TEMPER tent with transition.

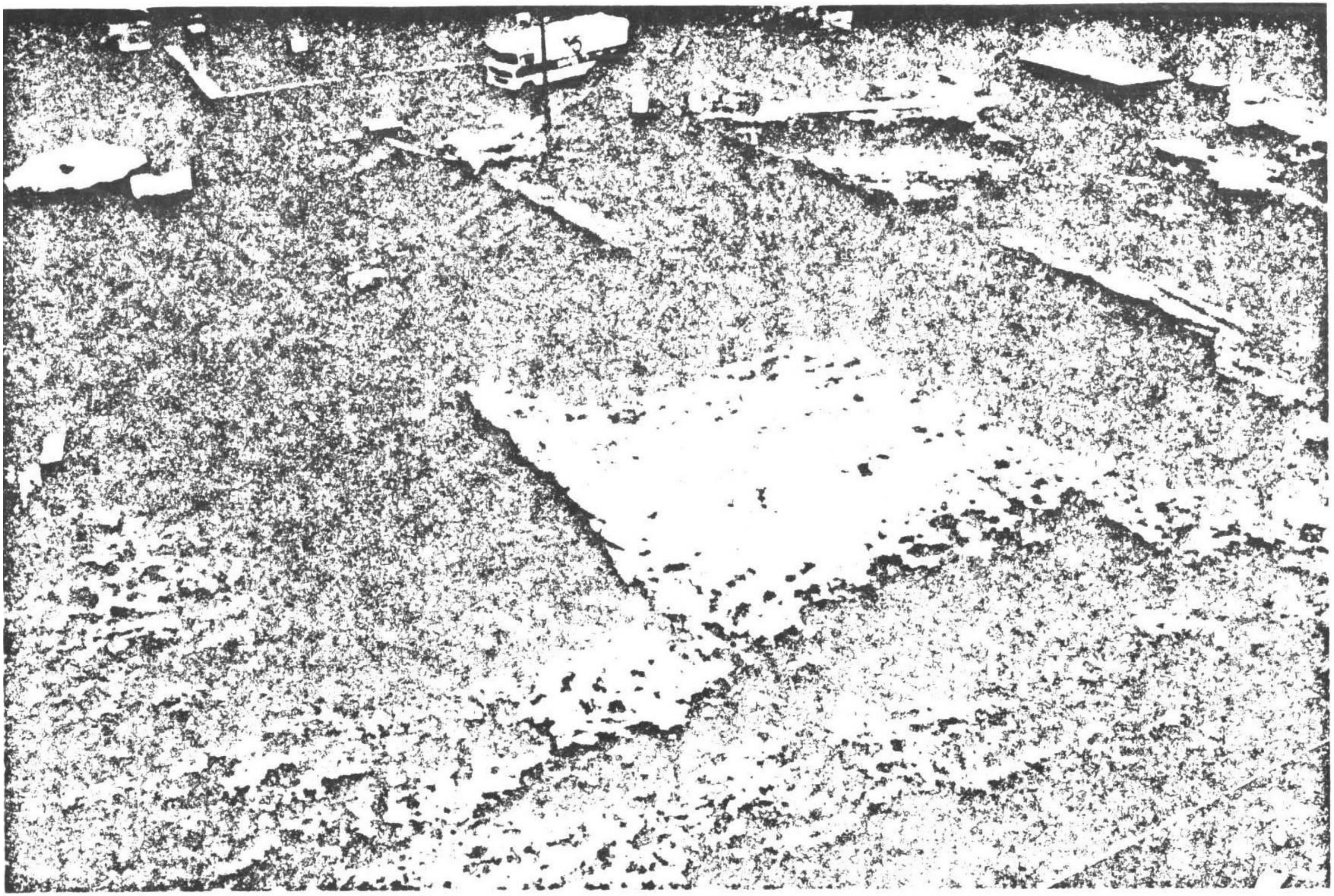


Figure 6.16. A complete TEMPER tent system.

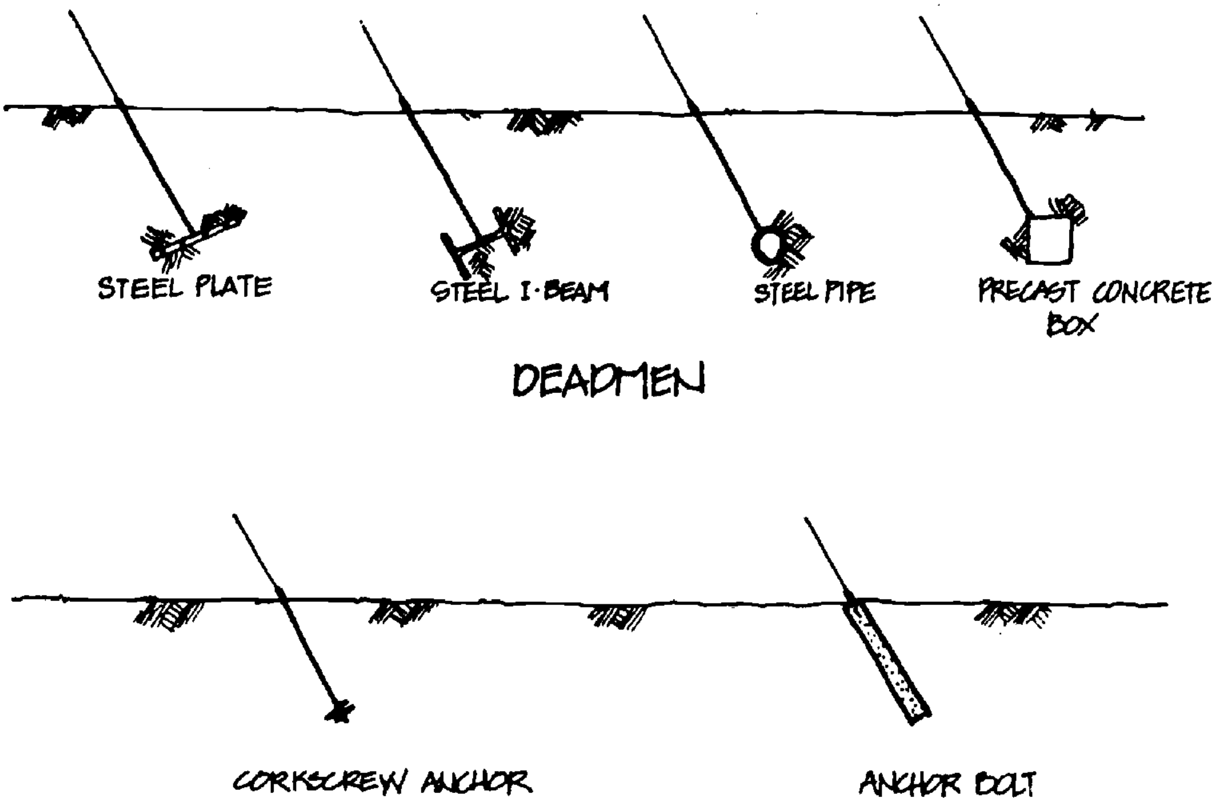


Figure 6.17. Ground anchors.

6.6 Facility Design Drawings

Plans, elevations, sections, and selected details of a typical 24-ft (7.3-m) building are provided as an example for the block system construction (Figures 6.18 through 6.20).

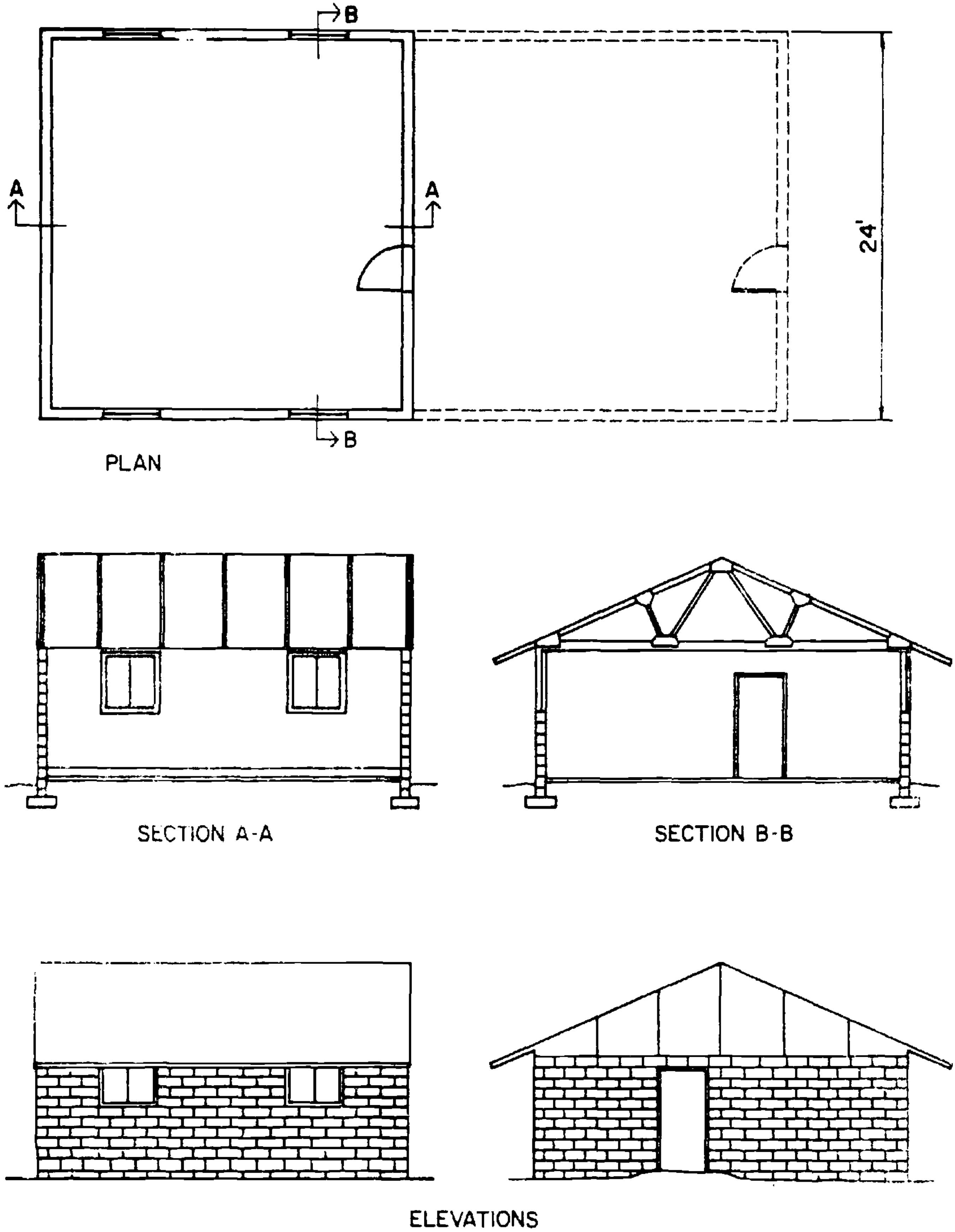


Figure 6.18. Typical 24-ft-wide (7.3-m) building.

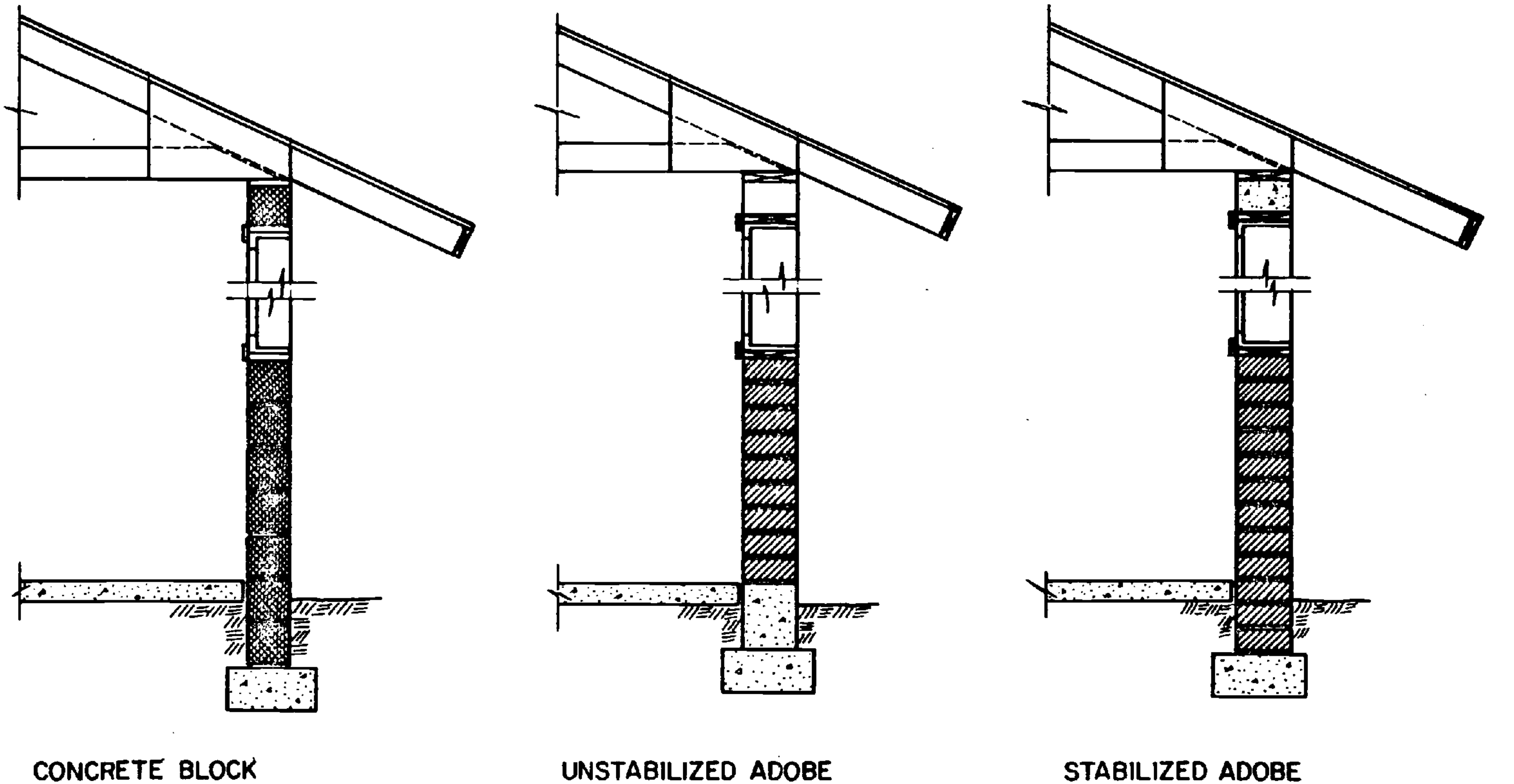


Figure 6.19. Wall sections.

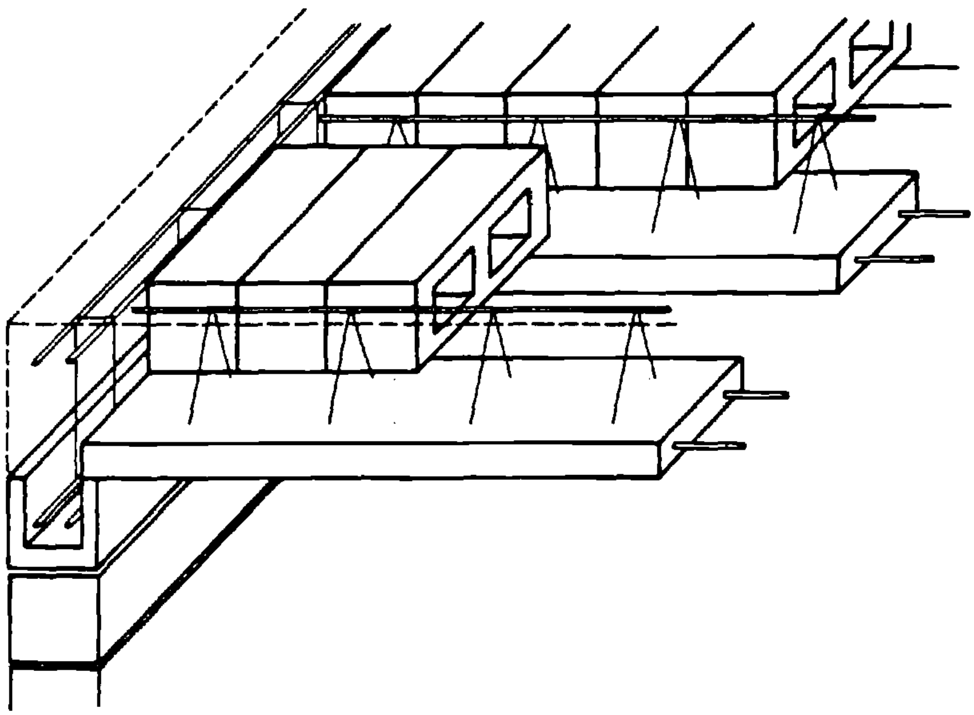


Figure 6-20. Concrete block, precast concrete, and poured-in-place concrete roof system.

CHAPTER 7 - HORIZONTAL CONSTRUCTION

7.1 General

Historically, TO construction has played a paramount role in providing the logistical support needed by U.S. combat units. Movement of these units and support units within a theater depends on lines of communications (LOC). Because of the limited number of existing roads and the difficulty of off-road mobility in some desert areas, considerable effort may be required to construct and maintain roads forward to maneuver units (FM 90-3, p 4-21). New or rehabilitated roads and airfields are key elements in the mobility system (see TM 5-330 and TM 5-337 [C1]). In addition, engineer capabilities in horizontal construction will be employed in excavation and construction of revetments for ammunition and petroleum-oil-lubricants (POL) storage, and in the repair of bomb-damaged or sabotaged airfields.

The harsh Mid-East environment presents critical horizontal construction problems related to lack of water, temperature extremes, dust, lack of construction materials, and soil conditions. Fine aggregate is generally abundant; however, natural coarse aggregate is characteristic of the alluvial fan and watercourse (wadi) areas. A positive note is that very little bridging, culvert, and roadway drainage construction is required for LOC. Emphasis is on getting the maximum use out of existing facilities.

To do this, it is necessary to have the capabilities to (1) repair bomb-damaged or sabotaged runways, (2) build or rebuild adequate all-weather traffic surfaces without bringing in large amounts of construction materials, (3) control dust, (4) estimate the future effects of heavy and sustained military traffic on road networks, (5) provide C-130 airstrips and heliports with minimum essential construction efforts, and (6) build a limited number of bridges (in some scenarios, perhaps none at all). In general, horizontal construction requires mat and membrane (see Table 7.1) as well as asphalt products, water (seawater will suffice for most requirements), and construction equipment in quantity. A total base development would be extremely difficult using only indigenous materials.

7.2 Existing Construction

Existing paved roads in developed areas will generally be structured for wheeled-vehicle traffic. The dominant characteristic of the area affecting horizontal construction is the absence of existing roadways. Because some areas are sparsely populated, few roads exist. This factor, coupled with poor off-road mobility in sand areas, increases the size of the road construction workload. Population centers (cities and large towns) are usually connected by paved roads that are fairly modern and adequate for heavy traffic. In undeveloped areas, roads will be narrow (16 ft [5 m] wide or less) and have thin pavements that will not stand up under use by tracked or heavy wheeled vehicles. Consideration should be given to widening the shoulders of such roads and using the shoulders for tracked-vehicle operations.

Table 7.1

Engineer Materials for Horizontal Construction
(Available from Depot Sources.)

Item	Length and Weight (lbs/sq ft)	Width (Inches)	Depth (Inches)	FSN	Unit of Issue	Unit of Issue
M19 medium duty landing mat	4.3	50.2, 49.5	1.5	5680-00-930-1524	M-19	Bundle 32 panels
XM18 medium duty landing mat	4.9	144, 12	1.5	5680-00-089-7661	XM-18	Bundle 18 panels
M8A1 light duty landing mat	7.5	141.75, 19.5	1.1	5680-00-782-5577	M8A1	Bundle 14 panels
AM2 medium duty landing mat	6.3	144, 12	1.5	5680-NAEL-613370-1	AM2	Bundle 18 panels
T17 membrane	0.31	100 ft, 66 ft or	0.08	5680-00-921-5809	T-17	Roll
		100 ft, 36 ft		5680-00-921-5810		Roll

7.3 Soils and Aggregates

Fookes* concisely describes engineering properties of various geographic units found in desert areas in Figure 7.1 and Table 7.2. Figure 7.1 shows the four geographic zones into which most desert regions can be subdivided: Zone I, mountain slopes; Zones II, the apron fan or bajada; Zones III, the alluvial plain; and Zone IV, the base plain, which includes sabkhas, playas, salt playas, salinas, and sand-dune areas. Table 7.2 shows percentages of various types of terrain in several desert regions.

The playas, which usually have a deep water table, have cemented surfaces that are structurally satisfactory for most vehicle and aircraft loads. Because the soils are primarily silts, dust problems are severe. The sabkhas (coastal flats that are inundated by seawater at very high tide) and salinas usually have cemented surface crusts and water at shallow depths. While each has a cemented crust, its usefulness under heavy loads depends on the depth to water because the material below the water table is usually quite weak.

The sandy areas consist of so-called desert flats and sand dunes. Together they account for 20 to 40 percent of desert regions. Windblown sand (0.06- to 0.6-mm grain size) can present a significant maintenance problem on roadways and airfields, and in base areas. It also impedes off-road mobility of wheeled vehicles.

Based on these geographic zones, the aggregates in the Mid-East have been classified into eight major categories: beach sand, dune sand, sand Zone II,

* P. G. Fookes, "Road Geotechnics in Hot Deserts," The Highway Engineer, Journal of the Institution of Highway Engineers, Vol XXIII, No. 10 (October 1976), pp 11-23.

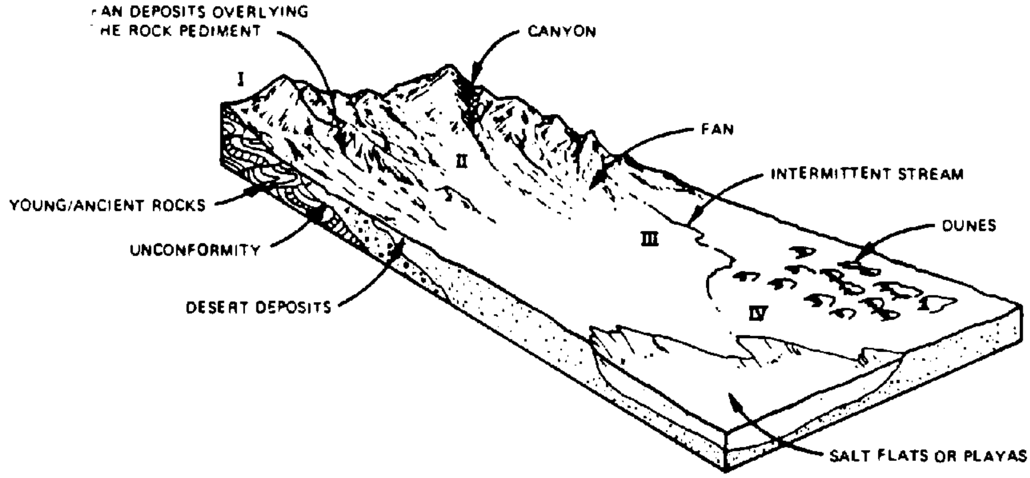


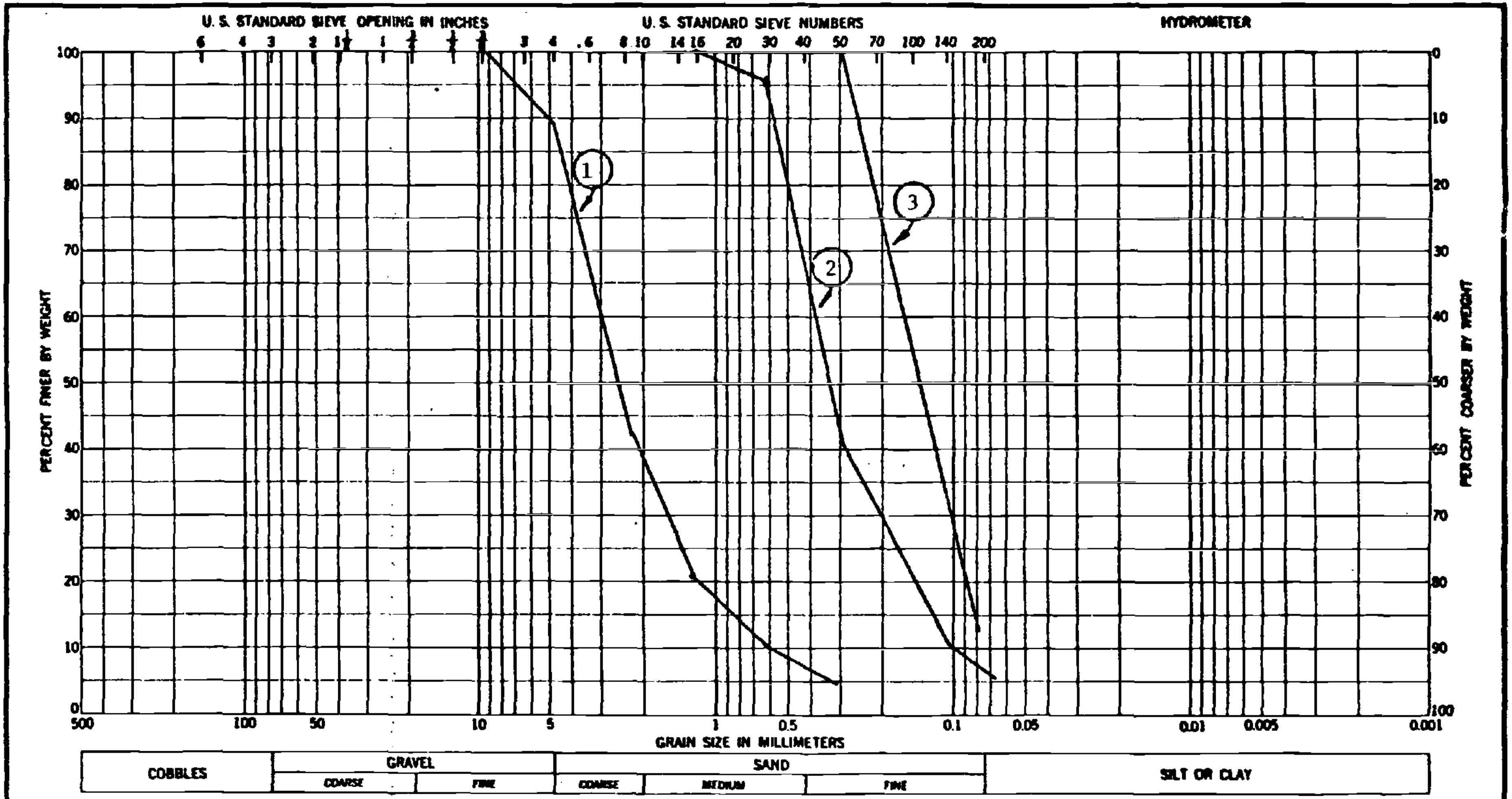
Figure 7.1. Block diagram of hot desert mount and plain terrain showing the four engineering zones (adapted from P. G. Fookes, "Road Geotechnics in Hot Deserts," The Highway Engineer, Journal of the Institution of Highway Engineers, Vol XXIII, No. 10 [October 1976], pp 11-23).

desert fill Zone IV, silty stone Zone III, fan gravel Zone II, sandy stone Zone III, and stone pavement Zone IV. Typical gradations of various sands and aggregates found in these areas are shown in Figures 7.2 through 7.6. These soil gradation data are provided for general guidance and are not intended as a substitute for on-site investigations. Since laboratory equipment probably will not be available, field classification will be required.

It is also important to be alert to sources of man-made and other materials to serve as aggregate for horizontal construction. These include cinder block, baked and adobe bricks, and tailing from quarry operations. Such materials may be crushed into smaller sizes by trafficking with heavy tracked vehicles such as tanks and dozers.

7.4 Horizontal Construction Techniques

Certain techniques and guidance on design mixes for asphalt and portland cement materials that are peculiar to expedient construction in arid regions are described as follows. These general guidelines are not intended to take the place of field experimentation and application of engineering judgment in individual situations, but are mainly presented to provide general information. In situations where suitable materials, aggregate, binder, and water are available and time and equipment permit, then conventional construction procedures should be followed and the appropriate field manual or technical manual consulted. For situations involving expedient construction, it may be advantageous to observe and evaluate local construction methods in the operational area. In some of the more undeveloped areas, what may appear to be somewhat crude construction techniques compared to conventional advanced methodology may serve well in expedient situations. Thus, it may be possible to duplicate what appears to be the standard practice in the local area to



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1		Beach sand - upper limit				
2		Dune sand - upper limit				
3		Beach and dune sand - lower limit				

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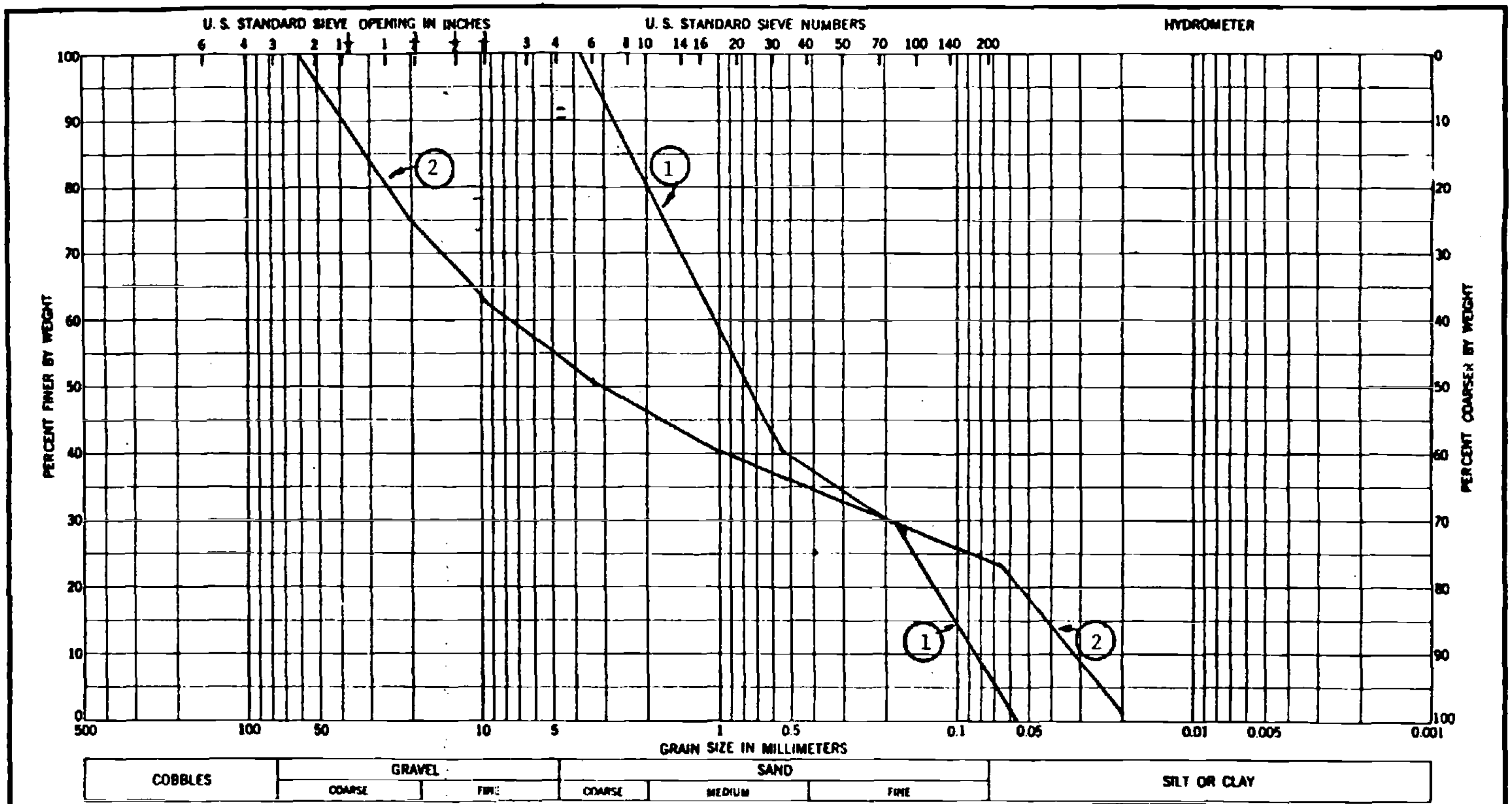
GRADATION CURVES

Figure 7.2. Gradations of sands and aggregates.



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1		Sand Zone II				
2		Desert fill Zone IV				

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GRADATION CURVES

Figure 7.3. Sand zone II.

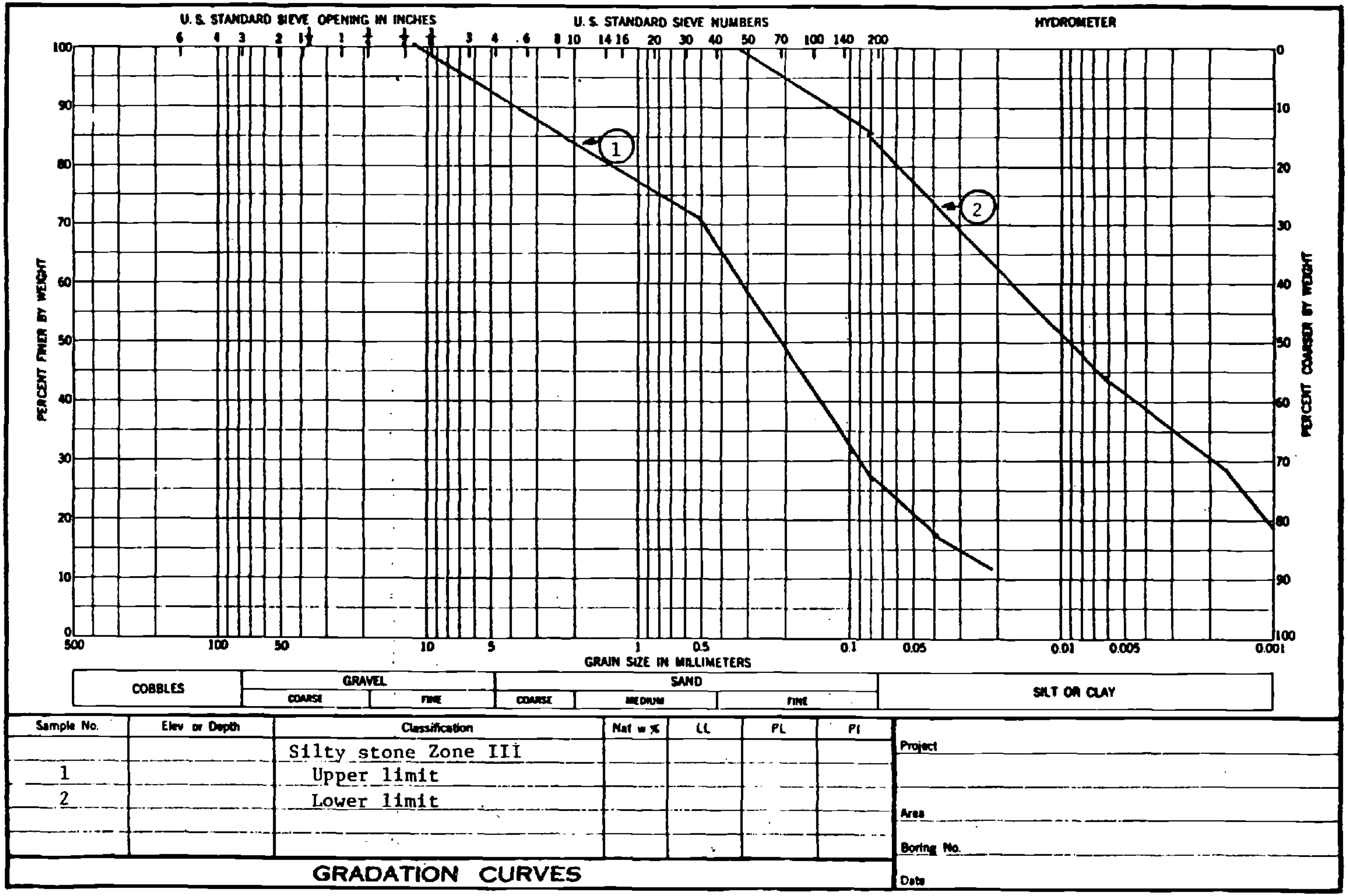


Figure 7.4. Silty stone.

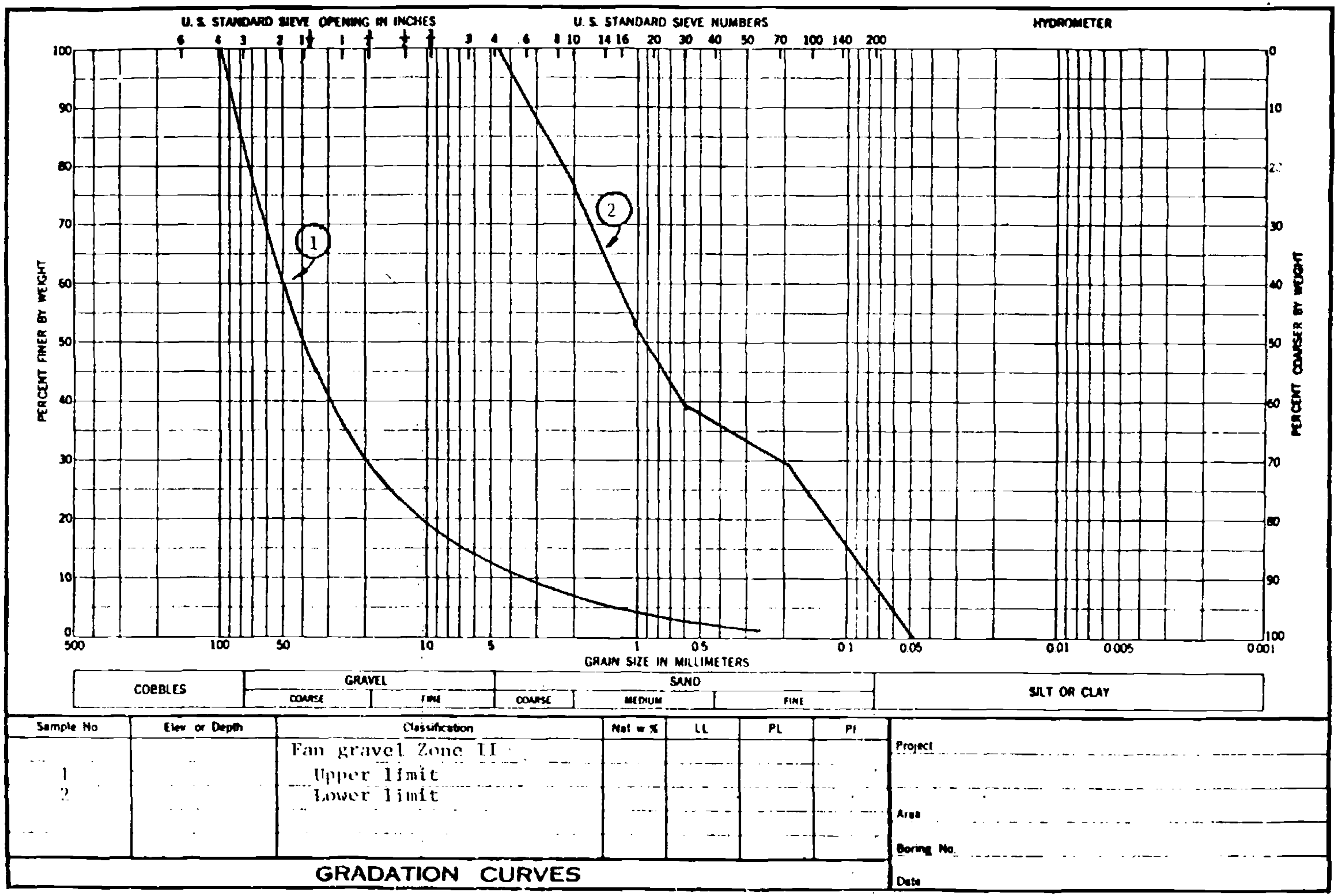
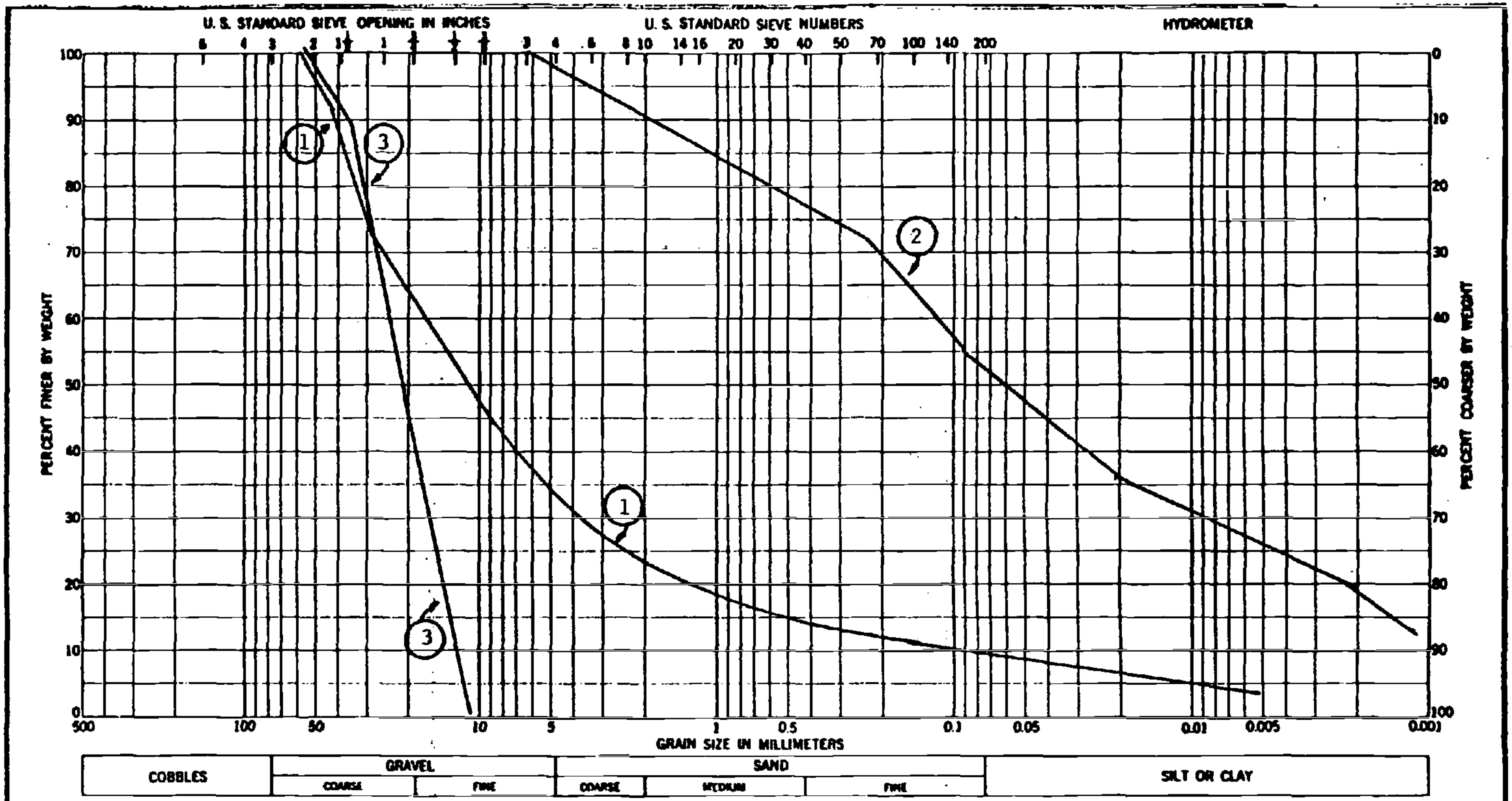


Figure 7.5. Fan gravel.



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		Sandy stone Zone III				
1		Upper limit				
2		Lower limit				
3		Stone pavement Zone IV				

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GRADATION CURVES

Figure 7.6. Sandy stone.

Table 7.2

Comparison of Desert Surface Types by Plan Area
(Reprinted from P. G. Fookes, "Road Geotechnics in Hot Deserts,"
The Highway Engineer, Journal of the Institution of Highway
Engineer, Vol XXIII, No. 10 [October 1976], pp 11-23.
Reproduced by permission of the Institution of Highway Engineers.)

Geographical Zone	Likely Occurrence Commonest in Engineering Zone	Sahara	Libyan Desert	Saudi Arabia	Southwestern U.S.
Desert Mountains	I	43%	39%	47%	38.1%
Volcanic Cones and Fields	I	3	1	2	0.2
Badlands and Subdued Badlands	I/II	2	8	1	2.6
Wadis	I/II/III	1	1	1	3.6
Fans	II	1	1	4	31.4
Bedrock Pavements	II/III	10	6	1	0.7
Regions Bordering Throughflowing Rivers	II/III/IV	1	3	1	1.2
Desert Flats	III/IV	10	18	16	20.5
Playas and Salinas	IV	1	1	1	1.1
Sand Dunes	IV	28	22	26	0.6
		100	100	100	100.0

advantage since such practices are often dictated by availability of engineering materials.

7.4.1 *Compaction of Dry Soils*

Compaction of dry soils is generally best accomplished by vibratory methods. Soils most suitable for vibratory compaction are sands and gravels which are susceptible to consolidation under vibratory motion. Very fine sands and silty and clayey sands may be compacted to some degree but not as successfully as the more granular materials. The most desirable equipment for compaction is a vibratory roller, either driven or self-propelled. Tracked vehicles such as tanks and crawler tractors may also be used for compacting dry granular materials since such vehicles are heavy and impact vibratory motion to the underlying soil. Although vibratory compaction is most desirable, dry materials may also be densified using heavy pneumatic-tired equipment having low tire inflation pressure. This method relies primarily on weight alone to force the soil grains into a closer configuration while the lower tire contact pressure prevents surface rutting. Although fairly high soil strengths may be obtained in some soils that are compacted dry, maintenance of unsurfaced roads and parking areas may be a problem. Since dry sands depend on confinement to maintain strength, unsurfaced roads, airfields, and parking areas subject to traffic with high-pressure tires will tend to deteriorate and will require close attention to maintenance. In areas used frequently by heavy tracked vehicles, the soil will generally remain compacted to some depth as a result of traffic; however, tank traffic will also tend to deteriorate surface conditions. Therefore, maintenance of the surface layer will be required.

7.4.1.1 Soil Types:

The primary soil types that can be compacted successfully at or near zero water content are the gravels, sands, and gravelly and sandy materials. These materials include the following soils classified according to the Unified Soil Classification System: GW, GP, GM, GC, GM-GC, SW, SP, SM, SC, and SM-SC. Generally, the fines content should not exceed about 40 percent of the total soil weight. Extremely dry, powdery, and pulverized soils that are easily windblown and that are characterized by the formation of trails of dust clouds when exposed to vehicular traffic are extremely difficult to densify from a practical standpoint. Generally, these soils are characterized as surface material with the underlying soil being depended on to offer structural support. These materials generally classify as the silts and clays: CL, CH, ML, MH, and ML-CL.

7.4.1.2 Equipment:

Vibratory rollers: Vibratory rollers are best suited for compaction of dry soils. Examples of typical equipment used in vibratory compaction are the single-drum, 5-ton (4.5 tonnes) towed vibratory roller and the single-drum, 10-ton (9.1 tonnes) self-propelled vibratory roller.

Tracked vehicles: Heavy tracked equipment such as crawler tractors, dozers, and tanks can also be used to compact dry soils since such equipment naturally induces vibratory motion into the underlying soils during normal operations.

Pneumatic-tired rollers: Heavily loaded pneumatic-tired rollers may also be used to compact dry soils although generally not as successfully as vibratory equipment. The most suitable pneumatic-tired roller is the drawn four-tired roller ballasted to a weight of 25 tons (22.7 tonnes) and with the tire pressure lowered to about 45 psi (310.3 KN/m^2). It is doubtful that any large-scale compaction can be accomplished with smaller pneumatic-tired rollers, although they may be used for smaller compaction projects. Pneumatic-tired rollers such as the 9-ton (8.2 tonnes) self-propelled or towed rollers should be loaded to maximum capacity with tire inflation pressure of about 40 psi (275.6 KN/m^2).

Trucks and construction equipment: Heavy trucks and construction equipment such as front-end loaders may also be used to a limited extent for compaction of dry materials using principles similar to those for standard pneumatic-tired compaction equipment. Such vehicles should be loaded as heavily as possible and have tire inflation pressures in the range of 25 to 30 psi (172.3 to 206.7 KN/m^2). Care should be taken to prevent tire damage.

7.4.1.3 Construction Procedures:

Construction procedures for compaction of dry soils differ in one significant aspect from normal compaction techniques. In dry compaction and in the expedient construction situation, the assumption is made that the soil is at or near zero water content condition and that no adjustment in water content can be made. Also, in expedient construction, equipment may not be available to check soil water content or in-place density; therefore, the engineer may have to rely on judgment to determine whether acceptable densification has been achieved. An airfield penetrometer or standard cone penetrometer may be useful in evaluating the effectiveness of compaction procedures.

When vibratory equipment or tracked vehicles are used, dry sands may be compacted in lifts up to 12 in. (304.8 mm) thick, while lift thickness for fine-grained soils should be kept to about 9 in. (228.6 mm) in thickness. In any event, it will probably be necessary to construct small test sections of various lift thicknesses to determine the optimum lift thickness. Vehicle or roller speed should range from 1 to 3 mph (1.6 to 4.8 km/hr). The number of passes required to develop adequate thickness will depend on soil type and should be determined in the field on test sections.

Compaction of dry soils with pneumatic-tired rollers generally requires thinner lift thickness of about 4 to 6 in. (101.6 to 152.4 mm), depending on the roller or vehicle weight and soil type. Again, experimentation in the field using test sections of various thicknesses will be required to determine optimum thickness and number of vehicle passes. Vehicle or roller speed will generally be determined by the resistance the soil being compacted offers to the vehicle.

7.4.1.4 Maintenance:

Unsurfaced compacted dry soils will tend to deteriorate under traffic of vehicles or aircraft having high-pressure pneumatic tires. In order to maintain or restore stability to the soil, it will be necessary to apply repeated passes of a compactor or, preferably, a tracked vehicle. Timely maintenance is required to prevent progressively deepening deterioration. If subject to considerable tracked vehicle traffic, surface deterioration will not be as severe; however, channelized traffic or traffic in the same track paths will tend to cause rutting. Therefore, continual recompaction of the surface will be necessary. Dust palliatives may be used to alleviate dust problems, but they will provide little or no structural stabilization.

7.4.2 *Expedient Asphalt Mix*

A number of naturally occurring aggregates are available in the Mid-East region, some of which can be used for construction of bituminous pavements. The following guidelines for use and expected performance of each of the eight aggregate types likely to be found in the Mid-East are useful for planning purposes. Further analysis such as mixture design is needed before using these aggregates in pavement mixtures.

7.4.2.1 Asphalts:

Three types of asphalt materials are generally available for pavement construction: asphalt cement, asphalt emulsion, and cutback asphalt. Although all three of these materials can be used in the production of asphalt mixes, asphalt emulsions and cutback asphalts are primarily used when the materials are mixed in place; asphalt cements are primarily used when materials are mixed at a central point. Since water is in short supply in the Mid-East, it is doubtful that a significant amount of asphalt emulsions will be used. Hence, it is anticipated that the two types of asphalt materials available for construction will be asphalt cement and cutback asphalt.

7.4.2.2 Aggregate:

Since aggregate makes up over 90 percent of the asphalt concrete mixture, the performance of the mixture depends a great deal on the quality and gradation of the aggregate. It is desirable to use crushed aggregates, well-graded from coarse to fine, for best performance of bituminous mixtures. Generally, it is desirable that the bituminous mixture consist of 30 to 40 percent coarse aggregate (+ No. 4 material), 55 to 65 percent fine aggregate (No. 4 to No. 200 material), and approximately 5 percent filler (material passing the No. 200 sieve). Uncrushed aggregates can be used for pavement construction at a reduced cost and for expediency, but the performance anticipated is less than that for bituminous pavements composed of crushed aggregates.

7.4.2.3 Bituminous Mixtures:

The bituminous mixture should be designed and constructed so that a stable, durable pavement is obtained. The pavement surface must possess satisfactory friction properties to carry the intended traffic safely at the anticipated speeds. All of these items must be considered in the design and construction of a bituminous mixture. Dense-graded bituminous mixtures are normally used to provide a tight, stable, durable surface. Often uniformly graded (one size) aggregates are used in the production of porous friction courses or bituminous surface treatments to improve surface friction properties. Dense and uniformly graded aggregates have applications in the construction of bituminous pavements in the Mid-East. Dense-graded bituminous mixtures are designed to have 3 to 5 percent air voids in the laboratory-compacted mixtures, resulting in 3 to 7 percent air voids in the field-compacted mixture. The low voids (3 to 7 percent) and high density (98 to 100 percent of laboratory density) result in a durable, stable pavement with tight surface texture. The quality of the aggregate is important for dense-graded mixtures; crushed aggregate, well-graded from coarse to fine, is desired. Because asphalt binder tends to bond better to crushed than uncrushed aggregate, less raveling occurs in mixtures with crushed aggregate. In a well-graded mixture, particle interlock is greater with crushed aggregate, than with uncrushed aggregate resulting in a more stable mixture. The quality of dense-graded mixture is sensitive to a change in the amount of -200 material. Adding or reducing the amount of -200 material generally changes optimum asphalt content and stability. An increase in the amount of -200 material normally decreases the optimum asphalt content and increases the stability. This is because the -200 material fills the voids in the mineral aggregates, resulting in fewer voids to be filled with asphalt and a stiffer asphalt-filler matrix. In a well-graded mixture, stability and optimum asphalt content are also functions of the maximum aggregate size. Generally, mixtures with larger aggregate sizes result in higher stabilities at lower optimum asphalt contents. The asphalt type plays an important part in the performance of a bituminous mixture. The higher viscosity asphalts (lower penetration) produce mixes having higher stability but more susceptibility to cracking at lower temperatures. The lower viscosity asphalts (higher penetration) produce mixes having low stability at higher temperatures but less susceptibility to cracking at lower temperatures.

7.4.2.4 Gradations and Recommended Uses of Aggregates Found in the Mid-East:

Based on the eight major categories of aggregates found in the Mid-East, asphalt mix designs have been developed. The predicted stability, asphalt content, and performance for each of these gradations is shown in Table 7.3. In addition, design mixes for midband gradings are also presented for beach sand, fan gravel (Zone II), and sandy stone (Zone III). These values are for guidance only and should not be substituted for further analysis when needed. For this report, poor performance describes mixtures which will perform satisfactorily less than 1 year, fair performance describes mixtures which will perform satisfactorily for at least 1 year, and good performance describes mixtures that should provide satisfactory performance for 2 or more years.

Beach sand: A wide range of gradations may be found for beach sand; therefore, this aggregate type was evaluated for the upper-bound gradation, lower-bound gradation, and midband gradation (Figure 7.2). Sand mixtures usually provide tight surfaces but are often unstable under traffic and may not be suitable for tracked vehicles. These mixtures can be expected to perform satisfactorily in cooler weather, but traffic during the hot summer months may cause excessive rutting, resulting in shear failure and subsequent deterioration of the pavement. When sand mixtures are to be subjected to traffic during summer, a higher viscosity (lower penetration) asphalt cement may be selected to provide some additional stability; however, this may result in an increase in deterioration in the winter months. Blending of aggregates is desirable to optimize the aggregate gradation to improve mixture properties. For instance, coarse aggregate can be blended with the beach sand to improve the overall aggregate gradation, resulting in better mixture properties. The beach sand mixture requires a large amount of asphalt to properly coat the aggregate particles. The stability of mixtures prepared with aggregate meeting the lower-bound, midband, and upper-bound gradations will generally be between 100 and 500 lb (45.4 to 226.8 kg). The upper-bound gradation requires the most asphalt (9 to 11 percent) while the lower-bound gradation requires the least asphalt (6 to 8 percent). The midband gradation will probably result in the best mixture, with probable poor to fair performance. The lower-bound and upper-bound gradations would probably result in poor performance. Sand mixes that have a small amount of -200 material, such as beach sand, are easy to mix, place, and compact. Beach sand can be readily mixed in place or at a central plant. The upper-bound gradation may present some mixing problems since the gradation is very fine (100 percent of the material passes the No. 50 sieve).

Dune sand: Mixtures prepared with dune sand (Figure 7.2) should perform similarly to mixtures prepared with beach sand.

Table 7.3

Expected Performance of Bituminous Mixtures Prepared From Aggregates Found in the Mid-East

Material	Approximate Asphalt Content, %	Approximate Stability, lb	Expected Performance
Beach Sand			
Upper Bound	9-11	100-500	Poor
Mid Band	7-9	100-500	Poor-Fair
Lower Bound	6-8	100-500	Poor
Dune Sand			
Upper Bound	9-11	100-500	Poor
Lower Bound	8-10	100-500	Poor
Sand Zone II	7-9	100-500	Poor-Fair
Desert Fill Zone IV	6-8	1000-1500	Good
Silty Stone Zone III			
Upper Bound		U N S A T I S F A C T O R Y	
Lower Bound	7-9	1000-1500	Fair
Fan Gravel Zone II			
Upper Bound	5-7	500-1000	Fair
Mid Band	5-7	1000-1500	Good
Lower Bound	5-7	Not Applicable	Fair
Sandy Stone Zone III			
Upper Bound		U N S A T I S F A C T O R Y	
Mid Band	5-7	1000-1500	Good
Lower Bound	5-7	500-1000	Fair
Stone Pavement Zone IV	5-7	Not Applicable	Fair

Sand Zone II: Mixtures prepared with Sand Zone II (Figure 7.3) should perform similarly to mixtures prepared with the beach sand of midband gradation.

Desert Fill Zone IV. Mixtures prepared with aggregate having a gradation similar to that of desert fill Zone IV (Figure 7.3) should provide very tough, tight surfaces. These mixtures should support traffic during the hot summer months with a minimum of distress. The asphalt required for this mixture is 6 to 8 percent, and the resulting stability should be 100 to 1500 pounds (45.4 to 680.4 kg). The performance of this mixture should be good, with raveling and cracking the most likely problems. These problems should occur over a period of time, however, and thus not cause early failure. It will be difficult to obtain a well-coated mixture because the amount of -200 material is high (22 percent). It is recommended that this type of mixture be mixed in a central plant so that mixing can be better controlled. Placing and compacting this mixture may also present problems. When lifts 2 in. (50.8 mm) or less are placed, the coarse aggregate will tend to tear the mat, resulting in an uneven surface that is difficult to compact. To insure good performance with this mixture, steps must be taken to make sure mixing, placing, and compacting are done properly.

<u>Silty Stone Zone III</u>: The silty stone material has a large amount of -200 material (Figure 7.4) and is generally not acceptable in asphalt mixtures. The material represented by the upper-bound curve can be used as a mineral filler in asphalt mixtures but is not acceptable as the only aggregate in an asphalt mixture. The material represented by the lower-bound curve can be used satisfactorily; however, the amount of -200 material is on the upper limit of that which can be properly mixed and compacted. When the amount of -200 material exceeds 30 percent in the blend of aggregate to be used in a bituminous mixture, the aggregate should be considered unsatisfactory. When the amount of -200 material is high, additional mixing time will be necessary. Mixtures prepared with the aggregate represented by the lower-bound curve should require 7 to 9 percent asphalt and have stability values in the range of 1000 to 1500 pounds (453.6 to 680.4 kg). The performance of such a mixture is no better than fair -- even though the stability is high -- because the amount of -200 material is high and very little of the aggregate is larger than a No. 4 sieve. This mixture will be difficult to mix sufficiently to obtain a homogeneous mixture. Since there is little coarse aggregate, little difficulty in placement of the mixture would be expected. Compaction of lifts up to 1-1/2 in. (38.1 mm) should not be difficult, but thicker layers may present compaction problems such as lateral movement of the mixture during rolling and ruts that cannot be removed with the finish roller.

<u>Fan Gravel Zone II</u>: The gradation of the aggregate found in fan gravel deposits varies considerably. The aggregate represented by the upper-bound and midband gradation curves (Figure 7.5) can produce fair to good dense-graded bituminous mixtures. However, the aggregate represented by the lower-bound curve should be used to produce an open-graded mixture since very few fines are available, or it should be crushed to produce a dense-graded mixture. The upper-bound material should require 5 to 7 percent asphalt and produce a stability of 500 to 1000 pounds (226.8 to 453.6 kg). It should be mixed, placed, and compacted with standard procedures, and should provide fair performance. The most likely problem with this mixture is rutting during hot weather.

The aggregate represented by the midband gradation is very similar in size to that used for dense-graded mixtures for airfields. It is well-graded and should produce a tight, stable mixture. The estimated asphalt content for this mixture is 5 to 7 percent, which should result in an estimated stability of 1000 to 1500 pounds (453.6 to 680.4 kg). The estimated performance is good. No major problems are anticipated in mixing, placing, and compacting.

The aggregate represented by the lower-bound gradation curve is not generally recommended for use in bituminous mixtures. Ideally, this aggregate should be crushed to produce an aggregate that could be used to produce a bituminous mixture that would provide excellent performance. If this aggregate is not crushed and is used to produce a bituminous mixture, 5 to 7 percent asphalt should generally be used. The mixture should be easy to mix but difficult to place and compact. Compaction for this mixture would primarily be to seat the aggregate so that it bonds to the layer underneath and to the adjacent aggregates. The stability test is not applicable to mixtures having aggregate this large. Performance should be fair with raveling being the most likely problem.

Sandy Stone Zone III: The aggregate represented by the upper-bound gradation (Figure 7.6) is not acceptable for bituminous mixtures. The amount of -200 material should not exceed 30 percent. Material with gradation similar to the upper bound can be used as a filler in bituminous mixtures but must be blended with other aggregates to produce an acceptable gradation. The midband gradation is the upper limit of aggregates that should be used in bituminous mixtures. This gradation will produce a tight, stable mixture requiring a 5 to 7 percent asphalt binder and having a stability of 1000 to 1500 pounds (453.6 to 680.4 kg). Bituminous mixtures produced with this type of aggregate should provide good performance (Figure 7.6). Mixing and compaction may be difficult because of the large amount of -200 material, but spreading should present no major problem.

Aggregate represented by the lower-bound gradation curve should produce a stable mixture. The estimated asphalt content for this mixture is 5 to 7 percent, which should produce a stability of 500 to 1000 pounds (226.8 to 453.6 kg). Bituminous mixtures produced with this aggregate should provide fair performance. There should be no problem in mixing this mixture, but spreading and compaction may be difficult because of the coarse aggregate.

Stone Pavement Zone IV: The performance of this aggregate (Figure 7.6) in bituminous mixtures should be similar to that for the lower-bound gradation of the fan gravel Zone II aggregate.

7.4.3 *Expedient Concrete and Mortar Mix*

An arid climate is one where evaporation exceeds precipitation, as in the hot, arid areas of the Middle East. Extreme temperatures present special problems in concrete production. High temperatures increase the hardening of concrete. The length of time within which the concrete is handled is more critical, making it more difficult to place. High range water reducers, commonly known as "super plasticizers," have proven beneficial in improving the handling characteristics of concrete without using additional water. The climate also increases mixing water demand that promotes bleeding. The time in which protective measures are applied is critical because difficulties in retaining uniform temperature conditions adversely affect concrete strength.

The harmful effects of hot weather on concrete may be minimized by a number of practical procedures. The degree to which their application is justified depends on circumstances. One or more of the ingredients may be cooled to keep the temperature of the concrete from being excessive at the time of placement. Storing aggregate in the shade may help maintain lower temperature. Because of the heat of hydration, cement content should be maintained at the minimum permitted. Concrete in place may be protected to minimize drying and absorption of heat. Difficulties resulting from high temperatures, such as plastic shrinkage cracking, can only be controlled by last-minute improvisations. Night construction may alleviate some of the heat and temperature problems encountered during daytime construction.

Portland cement: Although there is some local cement production in the region, most cement will have to be imported. Numerous countries ship cement into the region, and it varies in quality from bad to good. In general, there will be no control over what is received and its quality. If possible, sulfate-resistant (Type V) and low-heat (Type IV) cements should be used. These are the main types being imported. Unless bulk handling capabilities are available locally, the troops will not be able to handle and transport large quantities of cement with their equipment. Bag handling of cement is very slow, labor intensive, and not recommended except as a last resort. If none exists locally, airtight storage will have to be provided for the cement in all coastal areas. This is best accomplished by rubberized bulk bags. Any prolonged storage of cement at the high temperatures of the region will result in a degradation of the cement.

Aggregates: Typical grading curves and bands for desert areas are illustrated in Figures 7.2 to 7.6. Natural sands are usually abundant, but their gradings are generally poor and they are frequently contaminated by deleterious salts. Rock outcrops may be of a friable and porous nature and may also be contaminated with deleterious salts. These problems and the climatic condition are of major concern in horizontal and vertical construction.

Mix proportions: Mixture proportions are given in Table 7.4 for each of the sand and composite material gradation curves given in Figures 7.2 through 7.6. When only sand is available in a given location, it is assumed that 1-1/2-in. (38 mm) maximum-size aggregate available from other sources will be added in the quantities noted to produce the concrete. When the indigenous material is already a composite material of sand and rock, it can be used in its already-combined condition. Adjustments in the amount of fine material (sand) and water may be necessary to achieve the workability needed to place the material.

7.4.4 *Miscellaneous Construction Techniques*

Horizontal construction on bases or between bases will require innovative construction techniques to offset the additional time required by harsh environment.

1. Use seawater (see Section 5.7, pp 5-60 to 5-67), crude oil, or waste oil for compaction and stabilization. Portland cement may also be used if available.

2. Blend available on-site soils for road-base materials.

3. Increase priority on transportation of replacement and repair parts due to increased maintenance.

4. Shoulders of existing roadways, or expedient roadways constructed parallel to the existing pavement, may be used for tank traffic, thereby extending the life of the existing pavement.

Table 7.4

Proportioning Guidelines and Expected Performance for Concrete Made With Aggregates Found in the Mid-East

Part A. Naturally Occurring Sands to Which Coarse Aggregate (Rock) Must Be Added

	Approximate Weights in Pounds per Cubic Yard of Concrete			Approx. Batch Water (gallons)	Estimated Slump (inches)	28-day Strength of Concrete
	Cement	Sand	Rock			
Beach Sand						
Upper Bound	700-750	1350-1450	1650-1750	33-39	1	Good
Midband	550-600	1300-1400	1850-1950	33-39	2	Good
Lower Bound	400-450	1230-1300	2030-2130	33-39	3	Fair
Dune Sand						
Upper Bound	440-490	1230-1300	2030-2130	32-38	3	Fair
Lower Bound	400-450	1230-1300	2030-2130	33-39	3	Fair
Sand, Zone II	550-600	1300-1400	1850-1950	33-39	2	Good
Silty Stone, Zone III						
Upper Bound	Unsatisfactory					
Lower Bound	440-490	1230-1300	2030-2130	33-39	3	Fair
Fan Gravel						
Lower Bound	550-600	1300-1400	1850-1950	33-39	2	Good

Part B. Naturally Occurring Blends (Composites) of Sand and Rock

	Approximate Weights in pounds per cubic yard of Concrete		Approx. Batch Water (gallons)	Estimated Slump (inches)	28-day Strength of Concrete
	Cement	Composite Materials			
Desert Fill, Zone IV	700-750	3000-3200	35-41	2	Fair
Fan Gravel,					
Mid Bound	450-500	3200-3400	33-39	3	Good
Upper Bound	550-600	3150-3350	33-39	2	Good
Sandy Stone, Zone III					
Upper Bound	Unsatisfactory				
Midband	550-600	3150-3350	35-41	2	Fair
Lower Bound	700-750	3000-3200	35-41	2	Fair
Stone Pavement, Zone IV	900-1000	2330-2550 (No Sand)	54-60	2	Good

5. Clays may be blended with sands in low rainfall areas to provide a riding surface.

6. Hard crusty sections may require no construction effort if left undisturbed.

7. A general-purpose, lightweight, low-cost matting could be developed for road and other uses over sands.

8. Membrane encapsulated soil layers, sand grids, and soil reinforcement would enhance road construction by conventional methods.

9. Increase use of locally available cutback and emulsified petroleum products.

10. Do not expect road construction equipment to be used without modifications (i.e., cooling fans may have to be side-mounted instead of front-mounted to prevent abrasive action of sand).

11. Do not expect timber to be available for culverts and trusses.

12. Rippers may be required on large tractors for removal of hardpan.

13. Tires will deteriorate more quickly due to extreme heat.

14. Equipment life and performance may be severely hampered in harsh environments.

7.5 Roads Over Loose Sand

Over-the-shore transportation of supplies in loose sand is very difficult without treatment of the sand. Supply roads and storage areas over loose sand will be required.

7.5.1 *Possible Solutions*

1. Use lighter traffic loads and reduce tire pressures. A general rule of thumb is to lower tire pressure so that tire deflection is increased by 50 percent.

2. Sand stabilization using portland cement is a well-established method for constructing pavement base layers. See TM 5-330, "Portland Cement Stabilization."

3. Mix available local gravel or soils with the sand to improve trafficability.

4. If a firmer material lies at shallow depths, keep blading loose sands off the roadway.

5. Bury membrane (T-17) filter fabric, netting, or other materials 3 to 4 in. (76 to 102 mm) in the sand. Tests have shown best performance over buried membrane occurs when traffic stays in the same ruts.

6. Any of the airfield landing mats in inventory can be used on a smoothed surface to provide a roadway for over-the-beach truck traffic (see Table 7.1).

7. Place building rubble in the ruts.

8. Use crude oil, if available, for stabilizing the sand.

7.5.2 *Don't*

Do not place membranes, even if anchored, on the surface of the loose sands for improving trafficability. Tests have shown that best performance results when the membrane is buried 3 to 4 in. (76 to 102 mm).

7.5.3 *Special Considerations*

Blowing sands may cause operation problems with the construction equipment and high maintenance for the roadway or storage facility. Almost anything mixed with a loose sand will improve its trafficability.

7.6 Intermittent Stream Crossing

Build a ford instead of a bridge to make the roadway unusable during and for a few hours after an unusual storm. If such a storm does occur, a bulldozer, a front-end loader, and some dump trucks should be able to restore operation in a few hours after the water subsides by removing boulders washed onto the roadway and filling areas eroded by the stream. Concrete fords are very successful and allow almost immediate return to operation after rainfall.

7.7 Control of Drifting Sand

Obviously loose sand and dune areas are best avoided. However, if small dunes must be crossed, several methods are available for controlling them or at least minimizing their effects.

1. Align routes or airfields upwind from existing dune areas or sand-source areas.

2. Oil the surface of windblown sands with high-gravity crude oil for temporary dust control.

3. Erect porous barriers (i.e., snow-type fences or spaced nonporous barriers).

4. Build roadways on an embankment above normal surface elevation.

5. Dig trenches to destroy the symmetry of a dune and thus accelerate its destruction by wind. Trenching on the windward side of the works to be protected and using the excavated material as a second barrier or mound between the trench and the item to be protected can control sand temporarily.

Further guidance provided by Fookes* may also be useful:

> A level road will receive a layer of sand over the leeward side during normal wind conditions. The layer will be thin and will probably not impede vehicles even if they are equipped with high pressure tyres. When wind of the opposite direction occurs, the thin layer of sand will shift to the other side of the road. A crown to the road will aggravate the down-wind side accumulations, and for this reason the crown should be kept to a minimum. Ideally for dune areas flat roads are to be preferred, but the embankment should be greatly rounded at the shoulder break point.
>
> Unbanked, single-line roads on elevated grades are generally self-cleaning and do not usually present a serious problem by drifting sand. They are, however, vulnerable to migrating dune masses. Banked horizontal curves are troublesome and vulnerable to drifting sand, if the wind first impinges on the high side of the bank. The high windward side will remain exposed, but the lower leeward side will receive a deposit of sand, the depth of which depends on the amount of super-elevation of the windward side. Curves should, therefore, have as long a radius as possible and banking should be held to a minimum.
>
> Cuts can be serious problems and probably the best remedy is to build impounding fences up-wind from the cut, stabilize the sand between the cut and the fence...and then increase the height of the fence whenever it loses its trapping efficiency.
>
> It is important to remove all obstructions upwind from the road. Any obstruction will cause a drift stream to develop downwind. It is not uncommon for these drifts to be 20 times the height of the obstruction. A large bush a metre high may send out a streamer 35 metres long. A hummock of earth or a rock a few centimetres high at the edge of the road can send a drift across the entire road. The up-wind side of the road should therefore be cleaned off and smoothed with a drag for a width of at least 20 metres or even wider if large bushes or hummocks are present.
>
> Migrating dunes that are approaching the road are another serious hazard. Destruction or immobilization of the dunes can be accomplished if it is carried out while the dune is over 20 times its height away from the road. If the dune is allowed to approach closer

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* P. G. Fookes, "Road Geotechnics in Hot Deserts," The Highway Engineer, Journal of the Institution of Highway Engineers, Vol XXIII, No. 10 (October 1976), p 11-23.

than this distance, it will probably have to be immobilised by oil stabilisation and then restricted against further growth by building an impounding fence up-wind from it. This would cut off new supplies of sand that would otherwise cause it to become elongated down-wind.

To prevent erosion of embankments built with dune sand choose low slope angles (1:4) and protect the slope with a stabilising material.

During construction vehicles should be discouraged from running wild over the existing desert surface up-wind of the road as it could destory an existing natural thin crust or sparse binding vegetation which in turn could lead to sand near the road being mobilised by the wind.

7.8 Dust Control

Dust control will be necessary to prevent increased engine maintenance and reduced propeller-blade life, and to lessen battlefield signature location.

7.8.1 *Possible Solutions*

1. Define technology currently being used by contractors operating in the area.

2. Use an asphalt distributor for application of dust-control agents. Recommended materials for dust control include peneprime types, DCA 1295, crude oil, and saltwater.

3. Install grease fittings on the asphalt distributor pump to allow manual lubrication when spraying DCA 1295, a low-viscosity dust-control agent.

4. Use a fiberglass scrim with DCA 1295 reinforcement, especially for trafficked areas.

5. Mechanical means of dust control, such as plywood or membranes, may be used temporarily.

6. Use asphalt-based crude oil (will require heating before spraying).

7. If available, other dust palliatives such as resin emulsions (e.g., Coherox), magnesium chloride, liquid products, etc., may be used.

7.8.2 *Don'ts*

1. Do not use experimental or unproven chemicals for dust control.

2. Do not expect water or light oil applications to control dust for a long time.

7.8.3 *Special Considerations*

1. Highly porous materials require dust control.

2. In trafficked areas, sand will rut, causing deterioration of dust control preparations.

3. Seawater may be used for the prewetting recommended in DA PAM 525-5.

4. The minimum flash point of peneprime and cutback asphalt is about 80°F (26.6°C).

5. Asphalt products will have a tacky surface above 100°F (37.8°C).

7.9 Construction of C-130 Airstrips

Many areas in the arid flat regions such as the playas and desert pavements may allow operation of C-130 aircraft with minimal construction effort, while areas of large active sand dunes may present considerable problems in constructing and maintaining a suitable airstrip surface. Some important considerations that must be addressed in constructing C-130 airstrips include soil strength, runway length, surface roughness and obstacles, and lateral and approach zone clearances. The expedient runway must have enough strength to maintain the desired number of aircraft operations. It must also meet certain criteria of length and grade, have safe lateral and approach zone clearances, and be reasonably free of surface obstacles and unsafe ground irregularities. Detailed information on construction of expedient C-130 runways is in TM 5-330/AFM 86-3, Vol II, "Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations."

7.9.1 *Strength Requirements*

Strength requirements for C-130 airstrips without surfacing and with membrane and light- and medium-duty landing mat surfacing are shown in Figure 7.7. These criteria indicate the number of cycles of aircraft traffic allowed for different gross aircraft weights in kips and different soil strengths in terms of airfield index (A.I.). One cycle is equal to one takeoff and one landing.

7.9.1.1 Airfield Index:

Airfield index is a soil strength measurement normally obtained using an airfield penetrometer. Therefore, the engineer should ensure that an airfield penetrometer is included as part of his equipment for initial engineer reconnaissance.

If no airfield penetrometer is available, the standard trafficability cone penetrometer may be used and the readings converted to A.I. Two types of cones are used with the trafficability penetrometer: one having a base area of 0.2 sq in. and another having a base area of 0.5 sq in. To determine values of A.I., readings taken with the 0.2 sq in. and 0.5 sq in. must be divided by 20 and 50, respectively. These converted readings may then be used with Figure 7-7.

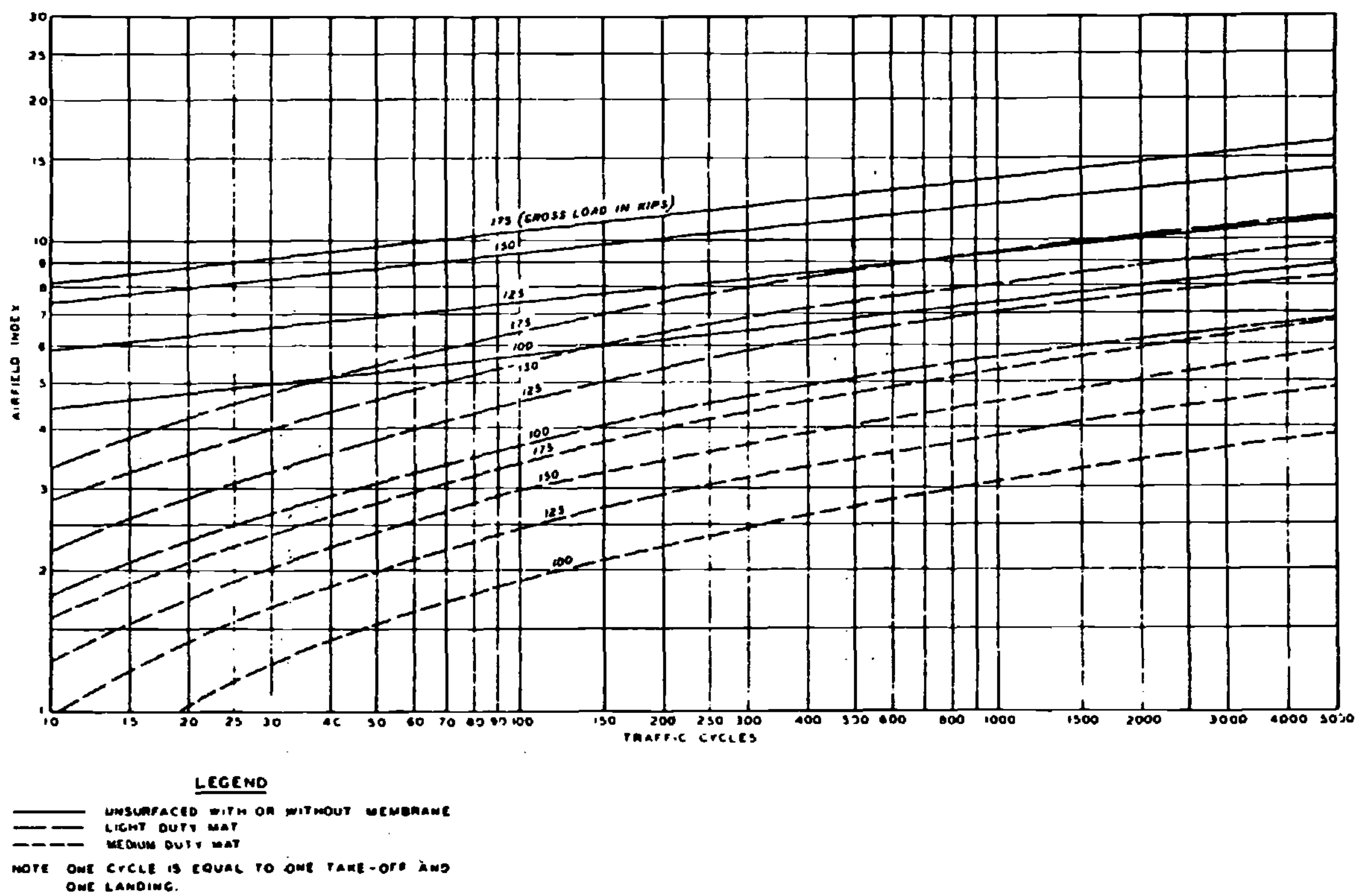


Figure 7.7. Subgrade strength requirements, C-130 aircraft.

7.9.1.2 Use of Penetrometers:

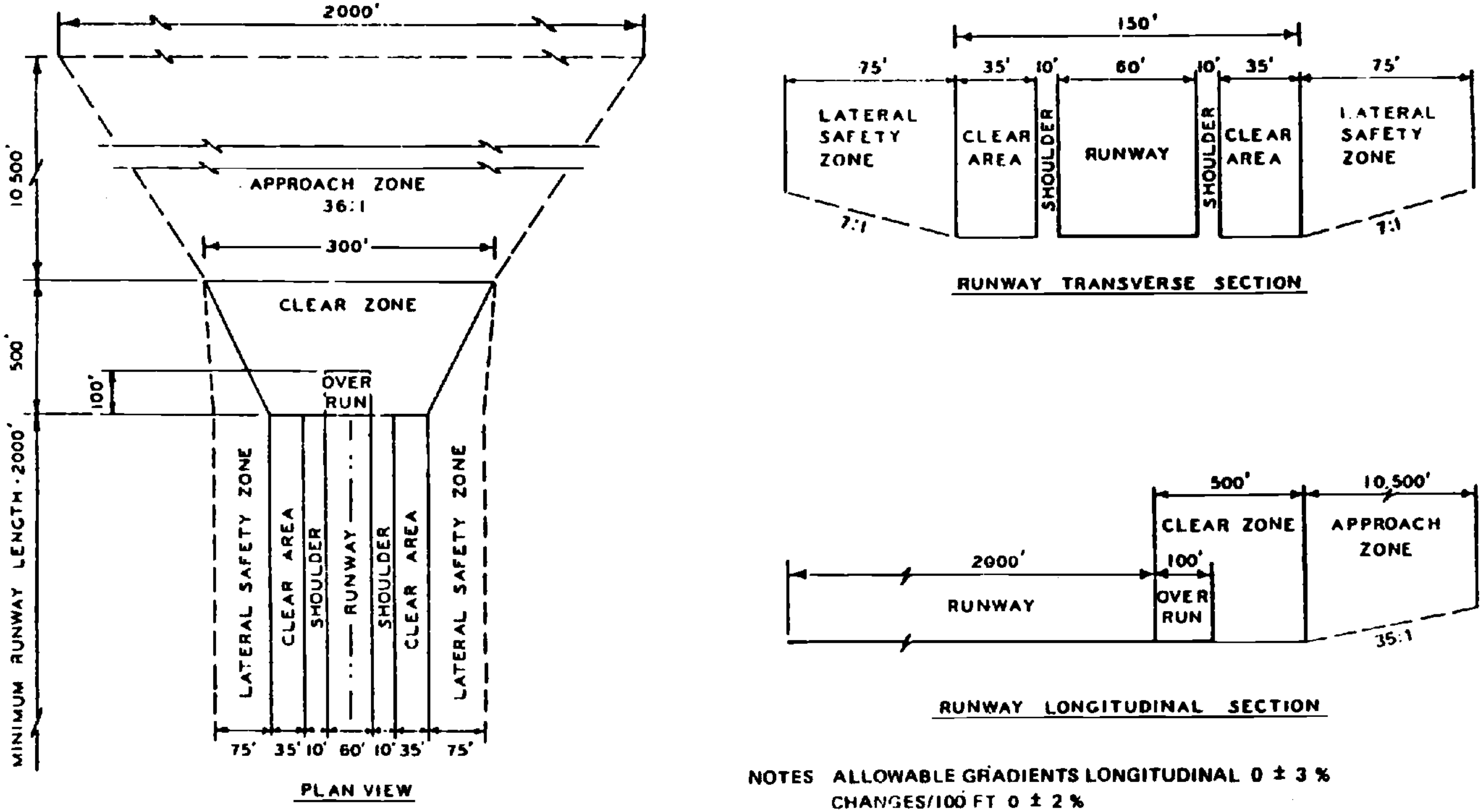
Penetrometers are crude field-expedient methods of evaluating soil strength. Their use must be tempered with an understanding of soil behavior. If a site consists of dry, clean sands (sands with no fines or material passing the No. 200 sieve), the confining effect of the large C-130 tire generally will allow the aircraft to operate regardless of the measured or converted airfield index. Windblown beach and desert sands are examples of this type of material. The airfield index is a fairly reliable indicator of the strength of many clays, but there are exceptions. Certain clay soils can lose over 90 percent of their strength when remolded and turn into thick, viscous liquids. Some residual clay soils formed in tropical and subtropical areas and known as laterites have good bearing capacity when they are undisturbed, but if reworked with heavy equipment in the present of moisture, they become a plastic, low-strength material. It is impossible to predict behavior of such soils on the basis of *in situ* penetrometer readings alone. The engineer must also consider the effects of moisture on soils when evaluating a site. Some soils (clays and silts) can have large reductions in strength when they become wet. Consequently, rain can make these soils unusable, and they should be avoided if an unsurfaced soil is needed for operations in wet weather. Aircraft will behave differently in different types of soil. If an aircraft is braking or turning in a cohesionless soil (particularly clean sand), the soil will rut very easily and the aircraft may bog down. However, simply shoveling the sand from in front of the wheels will often allow the C-130 to taxi out of the rut without assistance. The pilot can also help prevent delay of takeoff by cyclic braking. Plastic soils, particularly CH clays, will allow braking and turning with less rutting when dry, but a light rain will make their surfaces very slick and hazardous.

7.9.2 *Clearance Requirements*

Minimum runway and clearance criteria for the C-130 are given in TM 5-330 (Department of the Army, 1968); these criteria are summarized in Figure 7.8. However, the actual clearance criteria and runway length used in the mission must be established by the aircraft commander to reflect factors such as load, altitude, temperature, and aircraft model. Operation on runways meeting these criteria will still be hazardous, inefficient, and limited to good weather. Close cooperation between the engineers and aircraft commanders is vitally important in selecting a usable expedient runway and cannot be overemphasized.

7.9.3 *Surface Roughness and Obstacles*

TM 5-330 provides allowable limits for runway roughness and obstacles. These are summarized in Table 7.5. If the landing strip is used by more than one aircraft at a time, the engineer must plan and build parking areas adjacent to the strip. TM 5-330 provides guidance on parking requirements for forward area fields, which would be applicable under these conditions. If only one aircraft will use the landing strip at a time, the engineer must plan adequate space for the aircraft to turn around at the end of the strip. Normally, a C-130 can turn around within the 60-ft (18-m) wide strip with 10-ft (3-m) shoulders, but requirements for the turnaround area should be planned ahead of time with the aircraft commander.



NOTES ALLOWABLE GRADIENTS LONGITUDINAL 0 ± 3 %
CHANGES/100 FT 0 ± 2 %
TRANSVERSE 0.5 - 3 %

Figure 7.8. Minimum runway requirements for a C-130.

Table 7.5

Minimum Runway Requirements for C-130

a. Anticipated life	3 days
b. Runways:	
(1) Length	2000 ft*
(2) Width	60 ft
(3) Gradients:	
(a) Longitudinal	0± 3 percent
(b) Changes/100 ft	0± 2 percent
(c) Transverse	0.5-3 percent
(4) Shoulders:	
(a) Width	10 ft
(b) Transverse grade	1.5-5 percent
(5) Clear areas:	
(a) Width	35 ft
(b) Maximum transverse grade	5 percent
(6) Overruns:	
(a) Length	100 ft
(b) Width	60 ft
(7) Lateral safety zones:	
(a) Slope	7:1
(b) Width	75 ft
c. Runway end clear zone:	
(1) Length	500 ft
(2) Width:	
(a) Inner	150 ft
(b) Outer	300 ft
(3) Grade, maximum	5 percent
d. Runway approach zones:	
(1) Length	10,500 ft
(2) Width:	
(a) Inner	300 ft
(b) Outer	2000 ft
(3) Glide slope	35:1

*Runway length is computed for conditions of sea level and 59°F. Increase in elevation and temperature will require adjustments in runway lengths and/or aircraft load. Such determination should be made in coordination with the aircraft commander.
Metric conversion factor: 1 ft = 0.3048 m.

7.9.4 *Use of Existing Roads*

Operating aircraft from an existing road is an attractive concept since paved roads are widely available, and the problems associated with repairing a badly damaged runway can be avoided. However, the runway length and the width requirements and the necessary clear areas around the landing strip are so restrictive that only a four-lane highway with shoulders and without a median would come close to meeting the landing strip width requirements. In addition to widening the road to support C-130 aircraft, the engineers will also have to clear trees, buildings, and power lines around the road to provide required lateral and approach clearances. Figure 7.9 shows the requirements for widening a typical two-lane road having a width of 22 ft (6.7 m). Depending on the natural ground contours, cut or fill may be required. Drainage ditches on either side of the road must be filled. If the drainage ditch cross sections from TM 5-330 are considered typical, 2000 cu yd (1529.1 m^3) of fill will be required to fill these ditches for a 2000-ft (610-m) long landing strip. Even under favorable conditions, filling the ditches will require about 6 hr for a light dozer (D-6). Additional time will be needed for grading and compacting. If the surrounding topography requires much cut and fill, widening of the road may become a massive earthmoving operation; therefore, site selection is an extremely important aspect of this type of operation.

7.10 Runway Bomb Damage Repair

Existing runway pavements cratered as a result of bomb damage and rocket and cannon fire must be repaired quickly to allow operations of cargo, fighter, or other aircraft. The effort required to repair a crater will depend on the extent of damage and crater size. Pavement damage will range from spalls and scabs less than 5 ft (1.5 m) in diameter to large craters over 15 ft (4.6 m) in diameter. In repairing craters, consideration must be given to the structural adequacy of the repair to carry aircraft loadings, surface roughness of the finished repair with impacts on aircraft performance, and cleanup of surface debris to minimize foreign object damage (FOD) potential.

7.10.1 *Clearing and Backfilling*

The area around the crater should be cleared of surface debris as soon as possible. Broken pieces of pavement around the edge of the crater should be removed to provide a level surface depending on the desired quality of repair. Some of the ejected debris and broken pavement pieces may be pushed into the bottom of the crater to provide fill material. The remainder should be cleared from the runway. The fill should be compacted as much as possible. If the fill material and crater bottom are saturated from rain water or ground water, compaction may not be possible. It may be necessary to place large aggregate, 3 to 5 in. (76 to 127 mm) in diameter, in the crater bottom to provide stability. The crater may be backfilled with compacted debris or large aggregate to within 24 in. (610 mm) of the surface. Above this fill, well-graded crushed aggregate should be used. If crushed aggregate is not available, it may be necessary to use aggregate or gravel obtained from natural deposits; however, the stability of such fill material will depend on its natural gradation and the angularity of the aggregate particles. Placement of a membrane layer, such as T-17, between the upper and lower fill materials will also add stability. The aggregate fill must be well compacted. A

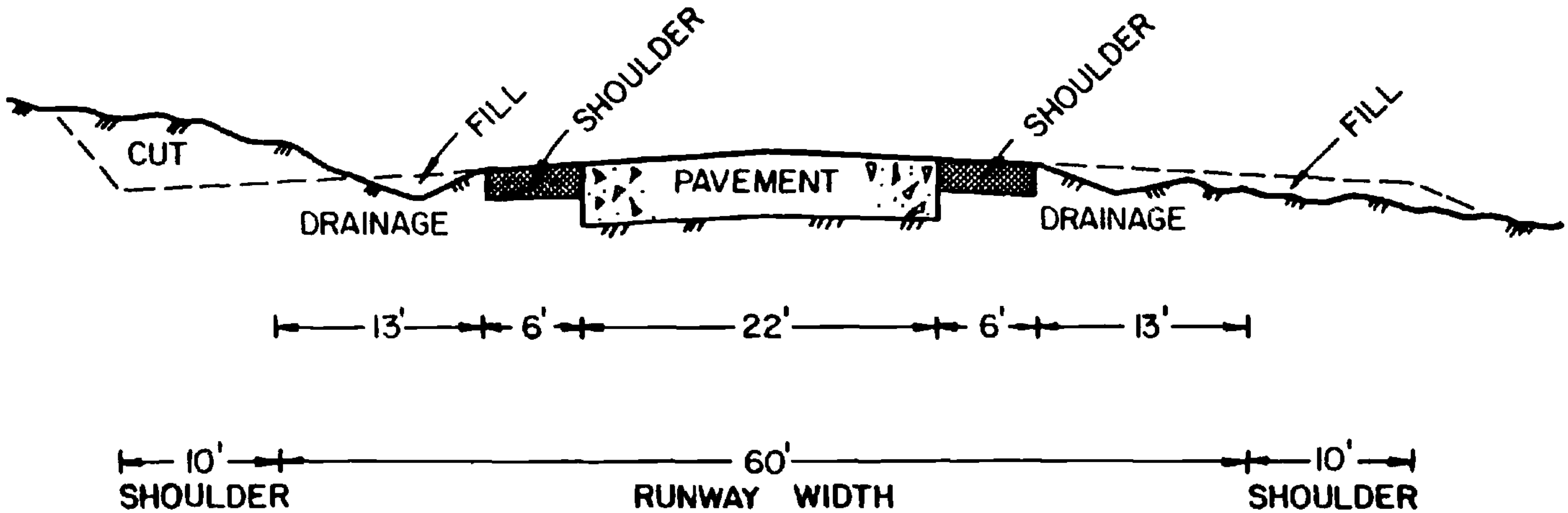


Figure 7.9. Widening a two-way road.

vibratory roller will normally be required; however, a heavy tracked vehicle such as a crawler tractor or tank may also be used. As indicated, a minimum depth of 24 in. (610 mm) of crushed aggregate below the crater surface is required. Thus, for small craters having a total depth of backfill only slightly over 54 in. (1372 mm), it may be more convenient to fill the entire crater with crushed aggregate.

7.10.2 *Crater Repair Surface*

The use of AM-2 landing mat as a surface cap has been the standard procedure, as outlined in AF Regulation 93-2 and Army Field Reference Document Airfield Damage Repair, Office, Chief of Engineers. This solution requires prepositioning of the mat kit or having the kits air dropped. Use of the AM-2 kits requires additional logistical support. Ideally, the surface of the finished repair should be flush with the surface of the surrounding pavement. If time and materials are available, a portland cement concrete cap may be placed to cover and fill the top surface of the crater. Such a cap should have a minimum thickness of 6 in. (152 mm). The cap material may be batched using portland cement aggregate, sand, and water. To accelerate the setting time, calcium chloride may be added to the grout at a rate of 1 percent by weight of cement. The concrete should have sufficient slump to facilitate screeding of the repair surface flush with the surrounding pavement. A concrete cap with accelerated curing will require 10 to 15 hours to achieve adequate strength. Another surfacing alternative which has been satisfactorily tested by the Navy is the use of a fiberglass reinforced polyester (FRP) cover. The FRP cover offers little structural support but is intended primarily for protection against FOD. Fabrication and placement instructions are given in "Rapid Runway Repair Interim Planning Guide (RRRIPG)." The finished surface profile requirements will depend on the type aircraft using the facility. Criteria are specified in the RRRIPG and AFR 93-2 in terms of surface roughness criteria. Surface roughness is critical to both cargo and fighter aircraft.

7.10.3 *FOD Protection*

As indicated, the FRP cover is used primarily to provide FOD protection at the crater repair site. Hard surfacing materials such as AM-2 or a grout cap also minimize FOD potential from the underlying fill material. All loose material generally should be cleared from the runway site; however, in special cases it may be necessary to operate aircraft with no FOD protection on the crater surface. Thus, there will be FOD potential from the exposed aggregate fill material. In such cases, the decision to operate aircraft without FOD protection on the crater repair will be at the discretion of the aircraft, squadron, or wing commander as appropriate.

7.11 Foundation Pads

In areas where drifting sand and dry dusty soil present a problem, stabilized pads may be constructed to provide firm foundations for small foot traffic areas, placement of equipment, and possibly tent foundations. Thickness requirements for cement stabilized pads and asphalt stabilized pads are presented in Tables 7.6 and 7.7, respectively. Pad designs are divided into

Table 7.6

Thickness Requirements for Cement Stabilized Foundation Pads

Category	Weight Classification, lb	Thickness (in.) for CBR Indicated		
		4	8	15*
Light duty	1000	3.0	2.5	2.5
	2500	3.0	2.5	2.5
	5000	4.5	3.0	2.5
Medium duty	10,000	6.0	4.5	3.0
	15,000	8.0	5.0	3.0
	20,000	9.0	6.0	3.5
	25,000	10.0	7.0	4.5
Heavy duty	35,000	12.5	9.0	6.0
	45,000	14.0	10.0	7.0
	55,000	16.0	10.5	7.5
	65,000	17.0	11.5	8.0
	75,000	18.0	12.5	9.0

*Use this column for sandy soils and silty soils for which no appreciable settlement is anticipated.
Metric convertion factors:
1 lb = 0.373 kg
1 in. = 25.4 mm

three general categories: light, medium, and heavy duty. Within each category, pads are further classified according to specific weight limits. Light duty pads include those to be used for foot traffic or foot loadings, light vehicles or equipment, and small storage areas; medium duty pads are those to be used for passenger vehicles, light- to medium-weight trucks, storage areas for heavy stock items, and small shop equipment. Heavy duty pads approach the structural characteristics of pavements and include foundations for heavy equipment storage areas, placement areas for large shop equipment, and possibly parking areas for some large construction equipment. In each class of pads, thickness designs are given based on the strength of the underlying soil in terms of CBR. If natural soil strengths are not adequate, the soil should be compacted to increase the strength to the desired level.

Table 7.7

Thickness Requirements for Asphalt Stabilized Foundation Pads

Category	Weight Classification lb	Thickness (in.) for CBR Indicated 4	8	15*
Light duty	1000	2.0	2.0	2.0
	2500	2.5	2.0	2.0
	5000	4.0	2.5	2.0
Medium duty	10,000	5.0	4.0	2.5
	15,000	7.0	4.5	2.5
	20,000	8.0	5.0	3.0
	25,000	9.0	6.0	4.0
Heavy duty	35,000	11.0	8.0	5.0
	45,000	12.0	8.5	6.0
	55,000	14.0	9.0	6.5
	65,000	15.0	10.0	7.0
	75,000	16.0	10.0	8.0

*Use this column for sandy soils and silty soils for which no appreciable settlement is anticipated.
Metric conversion factors:
1 lb = 0.373 kg
1 in. = 35.4 mm

For pads resting on cohesionless soils, e.g., primary sandy soils, as on silty soils on which no appreciable settlement is anticipated, thickness criteria indicated under the columns for 15 CBR should be used.

7.12 Field Identification of Soils

7.12.1 *Introduction*

Lack of time and facilities often make laboratory soil testing impossible in military construction. Even where laboratory tests are to follow, field identification tests must be made during the soil exploration to distinguish between the different soil types encountered so that duplication of samples for laboratory testing will be held to a minimum. Several simple tests that can be used in field identification are described in this report. Each test can be performed with a minimum of time and equipment, although seldom will all of them be required to identify any given sample. The number of tests employed will depend on the type of soil, and on the experience of the individual performing them. Using these tests, the soil properties can be estimated and the materials classified. Such classification should be recognized as an approximation, since even experienced personnel have difficulty estimating detailed soil properties with a high degree of accuracy. The material which follows is intended to aid in the identification and classification of soils according to the Unified Soil Classification System.

7.12.2 *General Procedures*

7.12.2.1 Coarse-Grained Soils:

An approximate identification of a coarse-grained soil can be made by spreading a dry sample on a flat surface and examining it, paying particular attention to grain size, gradation, grain shape, and hardness of particles. All lumps in the sample must be thoroughly pulverized to expose the individual grains and to obtain a uniform mixture when water is added to the fine-grained portion. The use of a rubber-faced or wooden pestle and a mixing bowl is recommended for this purpose. The material also may be pulverized by placing a portion of the sample on a firm, smooth surface and mashing it with the feet. The use of an iron pestle for pulverizing will break up the mineral grains and change the character of the soil.

7.12.2.2 Fine-Grained Soils:

Tests for identification of the fine-grained portion of any soil are performed on the portion of the material which passes a No. 40 sieve. This is the same soil fraction used in the laboratory for Atterberg limits tests, such as plasticity. If this sieve is not available, a rough separation can be made by spreading the material on a flat surface and removing the gravel and larger sand particles. Fine-grained soils are examined primarily for characteristics related to plasticity.

7.12.3 *Equipment Required*

Practically all the tests described can be performed with no equipment or accessories other than a small amount of water. However, the accuracy and uniformity of results will be greatly increased by the proper use of certain items of equipment. The following items of equipment, which will meet most requirements, are available in nearly all engineer units or may be improvised, and are easily transported:

7.12.3.1 Sieves:

A No. 40 U.S. standard sieve is perhaps the most useful item of equipment. Any screen with about 40 openings per lineal inch could be used, or an approximate separation may be made by sorting the materials by hand. No. 4 and No. 200 sieves are useful for separating gravel, sand, and fines.

7.12.3.2 Pioneer Tools:

A pick and shovel or a set of entrenching tools is used in obtaining samples. A hand earth auger is useful if samples are desired from depths more than a few feet below the surface.

7.12.3.3 Stirrer:

The spoon issued as part of mess equipment serves in mixing materials with water to desired consistency. It also will aid in obtaining samples.

7.12.3.4 Knife:

A combat knife, or engineer pocket knife, is useful in obtaining samples and trimming them to the desired size.

7.12.3.5 Mixing Bowl:

A small bowl with a rubber faced pestle is used in pulverizing the fine-grained portion of the soil. Both may be improvised, such as by using canteen cup and wood pestle.

7.12.3.6 Paper:

Several sheets of heavy paper are needed for rolling samples.

7.12.3.7 Heating Samples:

A pan and heating element are used for drying samples.

7.12.3.8 Scales:

Balances or scales are used in weighing samples.

7.12.4 *Factors Considered in Identification of Soils*

The soil properties which form the basis for the Unified Soil Classification System are: the percentages of gravel, sand, and fines; shape of the grain-size distribution curve; and plasticity. These same properties are, therefore, the primary ones to be considered in field identification, but other characteristics observed should be included in describing the soil, whether the identification is made by field or laboratory methods.

7.12.4.1 Soil Description:

Properties normally included in a description of a soil are as follows:

1. Color.

2. Grain size.

a. Estimated maximum grain size.

b. Estimated percent by weight of fines (material passing No. 200 sieve).

3. Gradation.

4. Grain shape.

5. Plasticity.

6. Predominant soil type.

7. Secondary components of soil.

8. Classification symbol.

9. Other remarks such as --

a. Organic, chemical, or metallic content.

b. Compactness.

c. Consistency.

d. Cohesiveness near plastic limit.

e. Dry strength.

f. Source -- residual, or transported (aeolian, waterborne, glacial deposit, etc.).

7.12.4.2 Example of Soil Description:

An example of a soil description using the sequence and considering the properties referred to above, might be as follows:

1. Dark brown to white.

2. Coarse-grained soil, maximum particle size 2-3/4 in. (69.9 mm), estimated 60 percent gravel, 36 percent sand, and 4 percent passing No. 200 sieve.

3. Poorly graded (insufficient fine gravel, gap-graded).

4. Gravel particles subrounded to rounded.

5. Nonplastic.

6. Predominantly gravel.

7. With considerable sand and small amount of nonplastic fines (silt).

8. GP.

9. Slightly calcareous, no dry strength, dense in the undisturbed state.

7.12.4.3 Importance of Descriptions:

A complete description with the proper classification symbol obviously conveys much more to the reader than the symbol or any other portion of the description used alone.

7.12.5 *Visual Examination*

By visual examination, it is possible to determine the color, grain size, and grain shape of the coarse-grained portion of a soil, and estimate the grain-size distribution. To observe these properties, a sample of the material is first dried and then spread on a flat surface.

7.12.5.1 Color:

In field soil surveys, color is often helpful in distinguishing between various soil strata, and with enough preliminary experience with local soils, color also may be useful for identifying soil types. Since the color of a soil often varies with its moisture content, the condition of the soil when color is determined must always be recorded. There is generally more contrast in these colors when the soil is moist, with all the colors becoming lighter as the moisture contents are reduced. In fine-graded soils, certain dark or drab shades of gray or brown, including almost black colors, indicate organic colloidal matter (OL, OH). In contract, clean and bright looking colors, including medium and light gray, olive green, brown, red, yellow, and white generally are associated with inorganic soils. Soil color also may indicate the presence of certain chemicals. Red, yellow, and yellowish brown soil colors may result from the presence of iron oxides. White to pinkish colors may indicate considerable silica, calcium carbonate, or aluminum compounds in some cases. Grayish blue, and gray and yellow mottled colors frequently indicate poor drainage.

7.12.5.2 Grain Size:

The maximum particle size should always be estimated for each sample considered, thereby establishing the upper limit of the grain-size distribution curve for that sample. To help determine the lower limit of the grain size distribution, it is useful to know the naked eye can normally distinguish the individual grains of soil down to about 0.07 mm. This means that all of the particles in the gravel and sand ranges are visible to the naked eye. All of the silt particles and all of the clay particles are smaller than this size and are therefore invisible to the naked eye. Material smaller than 0.07 mm will pass the No. 200 sieve.

7.12.5.3 Approximate Grain-Size Distribution:

The laboratory mechanical analysis must be performed whenever the grain-size distribution of a soil sample must be determined accurately. However, the grain-size distribution can be approximated by visual inspection. The best method of observing a material for such a determination without using laboratory equipment is to spread a portion of the dry sample on a flat surface; then, using the hands or a piece of paper, attempt to separate the material into its various grain-size components. By this method, the gravel particles and some of the sand particles can be separated from the remainder. This will at least give the observer an opportunity to estimate whether the total sample is to be considered coarse-grained or fine-grained, depending on whether or not more than 50 percent of the material would pass the No. 200 sieve. Percentage values refer to the dry weight of the soil fractions indicated as compared to the dry weight of the original sample.

Coarse-Grained Soil: If the material is believed to be coarse-grained, then there are two other criteria to consider. First, is less than 5 percent passing the No. 200 sieve; and second, are the fines nonplastic? If both these criteria can be satisfied and there appears to be a good representation of all grain sizes from largest to smallest, without an excessive amount or a deficiency of any one size, the material may be said to be well graded (GW or SW). If any intermediate sizes appear to be missing, or if there is too much of any one size, then the material is poorly graded (GP or SP). In some cases, it may be possible to take a few of the standard sieves into the field. When such is the case, the No. 4, No. 40, and No. 200 sieves should be included. Using the No. 4 and No. 200 sieves, the sample may be separated into the three main fractions -- gravel, sand, and fines. However, if there is a considerable quantity of fines, particularly clay particles, the fines can only be readily separated by washing them through the No. 200 sieve. In such cases, a determination of the percentage of fines is made by comparing the dry weight of the original sample with that retained on the No. 200 sieve after washing. The difference between these two is the weight of the fines lost in the washing process. For determination of plasticity, only that portion of the soil which will pass through a No. 40 sieve should be used.

Fine-Grained Soil: Estimating the grain-size distribution of a sample using no equipment at all is probably the most difficult part of field identification and obviously places great importance on the experience of the individual making the estimate. A better approximation of the relative proportions of the components of the finer soil fraction may sometimes be obtained by shaking a portion of this sample into a jar of water and then allowing the material to settle to the bottom. The material will settle in layers, with the gravel and coarse sand particles settling out almost immediately, the fine sand particles within a minute, the silt particles requiring as much as an hour, and the clay particles remaining in suspension indefinitely, or until the water is clear. In using this method, it should be kept in mind that the gravel and sand will settle into a much more dense formation than will either the silt or clay.

7.12.5.4 Grain Shape:

The grain shape of the sand and gravel particles can be determined by close examination of the individual grains. The grain shape affects the stability of the soil because of the increased resistance to displacement that is found in the more irregular particles. A material whose grains are rounded has only the friction between the surfaces of the particles to help hold them in place. An angular material has this same friction, which is increased by the roughness of the surface and the area of contact. In action, an interlocking action is developed between the angular particles; this gives a much greater stability than friction alone.

7.12.5.5 Undisturbed Soil Properties:

A complete description of a soil should include prominent characteristics of the undisturbed materials. The aggregate properties of sand and gravel are described qualitatively by the terms "loose," "medium," and "dense," while those of clays are described by "hard," "stiff," "medium," and "soft." These characteristics usually are evaluated on the basis of several factors, including the relative ease or difficulty of advancing the drilling and sampling tools and the consistency of the samples. In soils that are described as "soft," it should also be indicated whether the material is loose and compressible, as in an area under cultivation, or spongy or elastic, as in highly organic soils. (Moisture conditions will influence these characteristics and should be included in the report.)

7.12.6 *Breaking or Dry Strength Test*

7.12.6.1 Preparation of Sample:

The breaking test is performed only on the material passing the No. 40 sieve. This test, as well as the roll test and the ribbon test, is used to measure the cohesive and plastic characteristics of the soil. The test normally is made on a small pat of soil about 1/2 in. thick and about 1-1/2 in. in diameter. The pat is prepared by molding a portion of the soil in the wet plastic state into the size and shape desired and then allowing the pat to dry completely. Samples may be tested for dry strength in their natural condition as they are found in the field, but too much reliance must not be given to such tests because of the variations that exist in the drying conditions under field circumstances. Such a test may be used in an approximation, however, and verified later by a carefully prepared sample.

7.12.6.2 Breaking the Sample:

After the prepared sample is thoroughly dry, attempt to break it using the thumb and forefingers of both hands (Figure 7.10). If it can be broken, try to powder it by rubbing it with the thumb and fingers of one hand.

7.12.6.3 Typical Reactions:

Typical reactions obtained in this test for various types of soil are described below.

Figure 7.10. Breaking or dry strength test.

Very Highly Plastic Soils (CH): Very high dry strength. Samples cannot be broken or powdered by use of finger pressure.

Highly Plastic Soils (CH): High dry strength. Samples can be broken with great effort, but cannot be powdered.

Medium Plastic Soils (CL): Medium dry strength. Samples can be broken and powdered with some effort.

Slightly Plastic Soils (ML, MH, or CL): Low dry strength. Samples can be broken quite easily and powdered readily.

Nonplastic Soils (ML or MH): Very little or no dry strength. Samples crumble and powder on being picked up in the hands.

7.12.6.4 Precautions:

The test described above is one of the best for distinguishing between plastic clays and nonplastic silts or fine sands. However, a word of caution is appropriate. Dry pats of highly plastic clays quite often display shrinkage cracks. To break the sample along such a crack will indicate only a very small part of the true dry strength of the soil. 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.

7.12.7 *Roll or Thread Test*

7.12.7.1 Sample:

The roll or thread test is done only on the material passing the No. 4 sieve. The soil sample used in this test is prepared by adding water until the moisture content is such that the sample may be easily remolded without sticking to the fingers. This is sometimes referred to as being just below the "sticky limit." Using a nonabsorbent surface, such as glass, this sample is rolled rather rapidly into a thread approximately 1/8 in. (3.18 mm) in diameter (Figure 7.11).

7.12.7.2 Rolling:

If a moist soil can be rolled into such a thread at some moisture content, it is said to have some plasticity. Materials which cannot be rolled in this manner are nonplastic, or have very low plasticity.

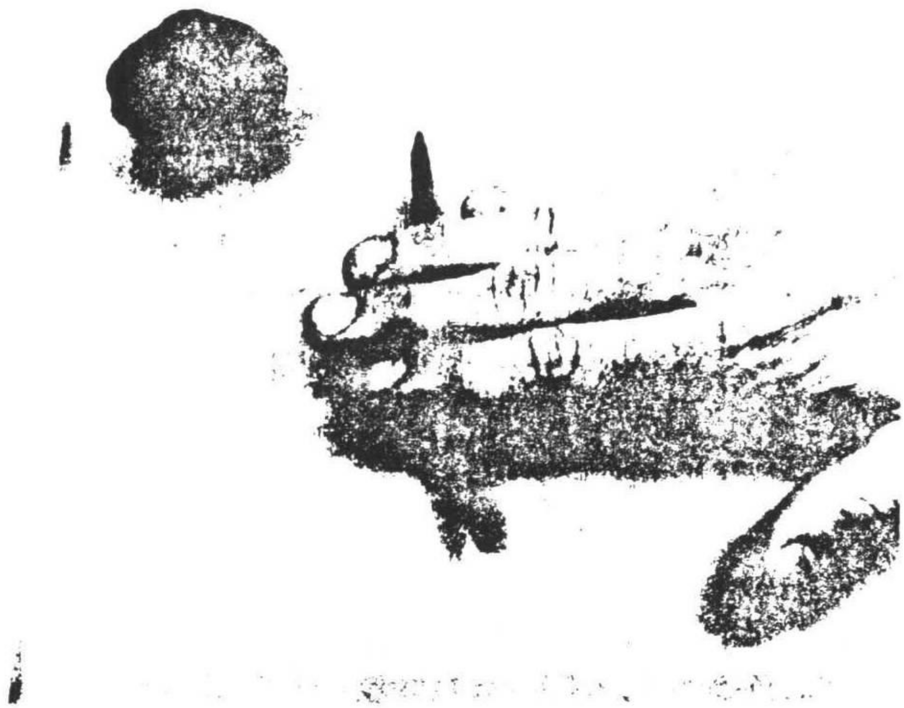


Figure 7.11. Roll or thread test.

7.12.7.3 Typical reactions:

After reaching the plastic limit, the degree of plasticity may be described as follows:

High Plasticity (CH): The soil may be remolded into a ball and the ball deformed under extreme pressure by the fingers without cracking or crumbling.

Medium Plasticity (CL): The soil may be remolded into a ball, but the ball will crack and easily crumble under pressure of the fingers.

Low Plasticity (CL, ML, or MH): The soil cannot be lumped into a ball without completely breaking up.

Organic Materials (OL or HO): Soils containing organic materials on mica particles will form soft spongy threads or balls when remolded.

Nonplastic Soils (ML or MH): These cannot be rolled into a thread at any moisture content.

7.12.7.4 Description of Cohesiveness:

From this test, the cohesiveness of the material near the plastic limit may also be described as weak, firm, or tough. The higher the position of a soil on the plasticity chart, the stiffer are the threads as they dry out and the tougher are the lumps if the soil is remolded after rolling.

7.12.8 *Ribbon Test*

The ribbon test is performed only on the material passing the No. 40 sieve. The sample prepared for use in this test should have a moisture content that is slightly below the "sticky limit." The "sticky limit" is the lowest water content at which the soil will adhere to a metal tool. Using this material, form a roll of soil about 1/2 to 3/4 in. (12.7 to 19.05 mm) diameter and about 3 to 5 in. (76.2 to 127 mm) long. Place the material in the palm of the hand and, starting with one end, flatten the roll, forming a ribbon 1/8 to 1/4 in. (3.18 to 6.35 mm) thick by squeezing it between the thumb and forefinger (Figure 7.12). The sample should be handled carefully to form the maximum length of ribbon that can be supported by the cohesive properties of the material. If the soil sample holds together for a length of 8 to 10 in. (203 to 254 mm) without breaking, the material is then considered to be both highly plastic and highly compressive (CH). If the soil cannot be ribboned, it is nonplastic (ML or MH). If it can be ribboned only with difficulty into short lengths, the soil is considered to have low plasticity (CL). The roll test and the ribbon test complement each other in giving a clearer picture of the degree of plasticity of soil.

7.12.9 *Wet Shaking Test*

7.12.9.1 Sample Preparation:

The wet shaking test is performed only on the material passing the No. 40 sieve. For this test, enough material to form a ball about 3/4 in. (19.05 mm) in diameter is moistened with water. This sample should be just wet enough

Figure 7.12. Ribbon test.

that the soil will not stick to the fingers upon remolding or just below the "sticky limit."

7.12.9.2 Testing:

The sample is then placed in the palm of the hand and shaken vigorously. This is usually done by jarring the hand on the table or some other firm object, or by jarring it against the other hand. The soil is said to have given a reaction to this test when, on shaking, water comes to the surface of the sample producing a smooth, shiny appearance. This appearance is frequently described as "livery" (Figures 7.13a and 7.13b). Then, upon sqeezing the sample between the thumb and forefinger of the other hand, this surface water will quickly disappear; the surface will become dull (Figure 7.13c); the material will become firm, resisting deformation; and cracks will occur as pressure is continued, with the sample finally crumbling like a brittle material (Figure 7.13d). The vibration caused by the shaking of the soil sample tends to reorient the soil grains, decrease the voids, and force water, which had been within these voids, to the surface. Pressing the sample between the fingers tends to disarrange the soil grains and increase the voids space; and the water is drawn into the soil. If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together, and the complete cycle may be repeated. This process can occur only when the soil grains are bulky in shape and noncohesive in character.

7.12.9.3 Typical Reactions:

Very fine sands and silts fall into this category and are readily identified by the wet shaking test. Since it is rare that sands and silts occur without some clay mixed with them, there are varying degrees of reaction to this test. Even a small amount of clay will tend to greatly retard this reaction. Some of the descriptive terms applied to the different rates of reaction to this test are as follows:

Sudden or Rapid: A rapid reaction to the shaking test is typical of nonplastic, fine sands and silts (Figure 7.13b).

Sluggish or Slow: A sluggish reaction indicates slight plasticity such as might be found from a test of some organic silts, or silts containing a small amount of clay.

No Reaction: Obtaining no reaction at all to this test does not indicate a complete absence of silt or fine sand.

7.12.10 *Odor Test*

Organic soils of the OL and OH groups usually have a distinctive, musty, slightly offensive odor which, with experience, can be used to aid their identification. This odor is especially apparent from fresh samples. It is gradually reduced by exposure to air, but can again to made more pronounced by heating a wet sample. Organic soils are undesirable as foundation or base course material and usually are removed from the construction site and wasted.

7.12.11 *Bite or Grit Test*

The bite and grit test is a quick and useful method of identifying sand, silt, or clay. In this test, a small pinch of the soil material is ground lightly between the teeth and the soils are identified as follows:

7.12.11.1 Sandy Soils:

The sharp, hard particles of sand will grate very harshly between the teeth and will be highly objectionable. This is true even of the fine sand.

7.12.11.2 Silty Soils:

The silt grains are so much smaller than sand grains that they do not feel nearly so harsh between the teeth, and are not particularly gritty although their presence is still easily detected.

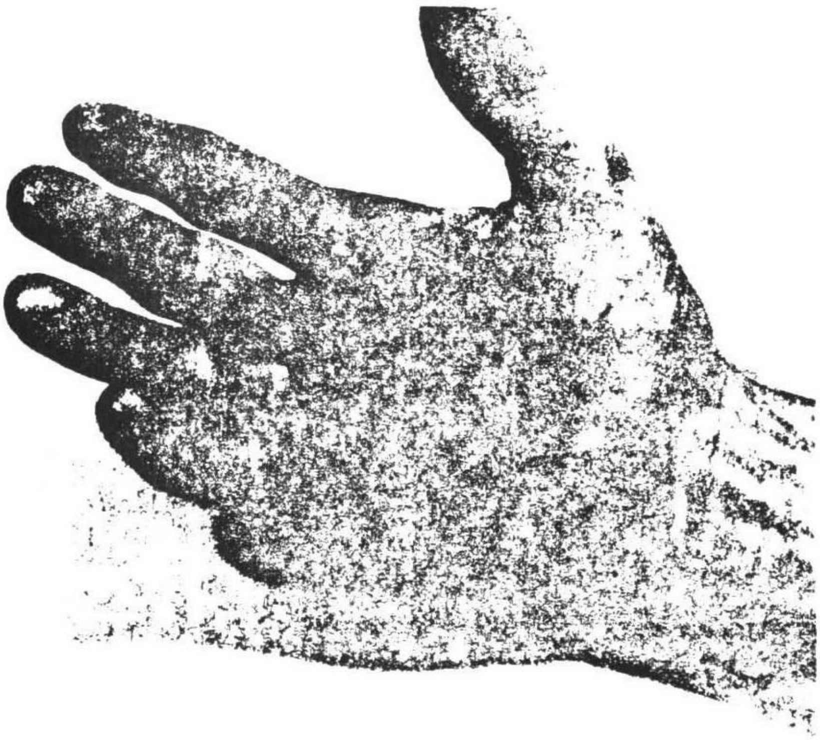


Figure 13a. Wet shaking test (initial sample).

Figure 13b. Wet shaking test (livery appearance).

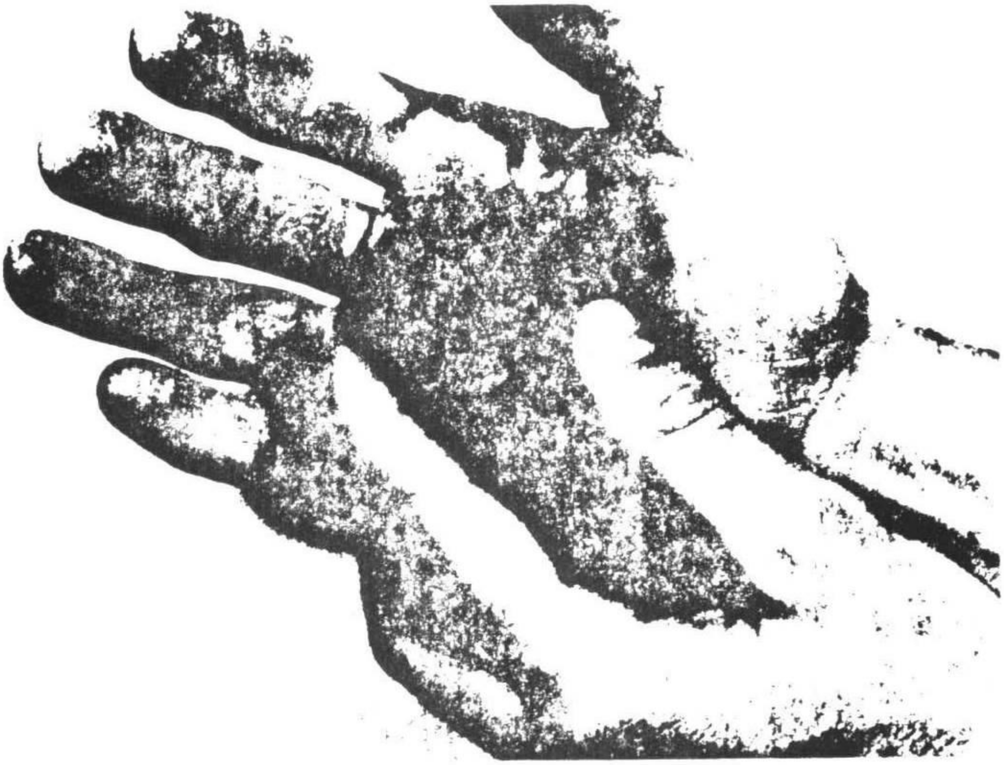


Figure 7.13c. Wet shaking test (crumbling the sample).

Figure 7.13d. Wet shaking test (squeezing the sample).

7.12.11.3 Clayey Soils:

The clay grains are not at all gritty, but feel smooth and powdery like flour between the teeth. Dry lumps on clayey soils will stick when lightly touched with the tongue.

7.12.12 *Slaking Test*

The slaking test is used to assist in determining the quality of certain soft shales and other soft "rocklike" materials. The test is performed by placing the soil in the sun or in an oven to dry, and then allowing it to soak in water for at least 24 hours. The strength of the soil is then examined. Certain types of shale will completely disintegrate, losing all strength.

7.12.13 *Acid Test*

The acid test is used to determine the presence of calcium carbonate and is done by placing a few drops of hydrochloric acid on a piece of the soil. A fixing reaction (effervescence) to this test indicates the presence of calcium carbonate, and the degree of reaction gives an indication of the concentration. Calcium carbonate normally is desirable in a soil because of the cementing action it provides to add to the stability. (In some very dry noncalcareous soils, the absorption of the acid creates the illusion of effervescence. This effect can be eliminated in all dry soils by moistening the soil before applying the acid.) Since this cementation normally is developed only after a considerable curing period, it cannot be counted upon for strength in most military construction. The primary use for this test is, therefore, to permit better understanding of what appear to be abnormally high strength values on fine-grained soils which are tested in place, where this property may exert considerable influence.

7.12.14 *Shine Test*

The shine test is another means of measuring the plasticity characteristics of clays. A slightly moist or dry piece of highly plastic clay will give a definite shine when rubbed with a fingernail, a pocket knife blade, or any smooth metal surface. A piece of lean clay will remain dull.

7.12.15 *Feel Test*

The feel is a general purpose test that requires considerable experience and practice to obtain reliable results. The extent of its use will grow with increasing familiarity with soils. Some of the following characteristics can be readily estimated by proper use of this test.

7.12.15.1 Moisture Content:

The natural moisture content of a soil is of value as an indicator of the drainage characteristics, nearness to water table, or other factors which may affect this property. A piece of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency. The consistency is described by such terms as "hard," "stiff," "brittle," "friable," "sticky," "plastic," or "soft." The soil is then remolded by working it in the hands, and changes are observed. This test indicates the natural water content relative to the liquid or plastic limit of the soil. Clays which turn almost liquid on remolding are probably near or above the liquid limit. If the clay remains stiff, and crumbles upon being remolded, the natural water content is below the plastic limit.

7.12.15.2 <u>Texture</u>:

"Texture," as applied to the fine-grained portion of a soil, refers to the degree of fineness and uniformity. It is described by such expressions as "floury," "smooth," "gritty," or "sharp," depending on the sensation produced by rubbing the soil between the fingers. Sensitivity to this sensation may be increased by rubbing some of the material on a more tender skin area such as the wrist. Fine sand will feel gritty. Typical dry silts will dust readily, and feel relatively soft and silky to the touch. Clay soils are powdered only with difficulty but become smooth and gritless like flour.

7.12.16 *Hasty Method*

With the standard methods of field identification supplemented with a few simplified field tests, an approximate and hasty classification can be obtained for almost any soil. The three simple or hasty tests outlined below will, for the most part, eliminate the need for specialized equipment such as sieves. The results of these tests, when used or supplemented with the results of the tests described in the previous paragraphs, will give at least a tentative classification to almost any soil. The schematic diagram (Figure 7.14) may be used as a guide to the testing sequence in the process of assigning a symbol to a sample of soil.

7.12.16.1 <u>Sedimentation Test</u>:

From the visual observation test described above, it is relatively simple to approximate the comparative proportions of sand and gravel in a sample of soil by spreading a dry sample out on a flat surface, and separating the gravel particles by hand. Separating the fines from the sand particles is more difficult although just as important. Small particles will settle through water at a slower rate than large particles. By placing a small, representative amount of soil (such as a heaping tablespoon measure) in a transparent cup or jar, covering with about 5 in. (127 mm) of water, and agitating by stirring or shaking, the soil will be completely suspended in the water. With most cohesive soil it will be necessary to break up the lumps of soil before adding the water. This can be done by grinding the soil in a canteen cup with an improvised wood pestle. After the soil particles have been thoroughly dispersed in the water and then left, they will start to settle out, beginning with the larger size particles, in time periods approximately as indicated in Table 7.8.

1. The most important use of the sedimentation test is to differentiate the coarse (0.072 mm) fraction from the fine fraction of a soil. Since all of the particles of soil larger than 0.072 mm 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. If the water containing the suspended fines is carefully poured into another container 30 seconds after agitation, if more water is added to the cup or jar containing the coarse fraction, and if the procedure is repeated until the water-soil mixture

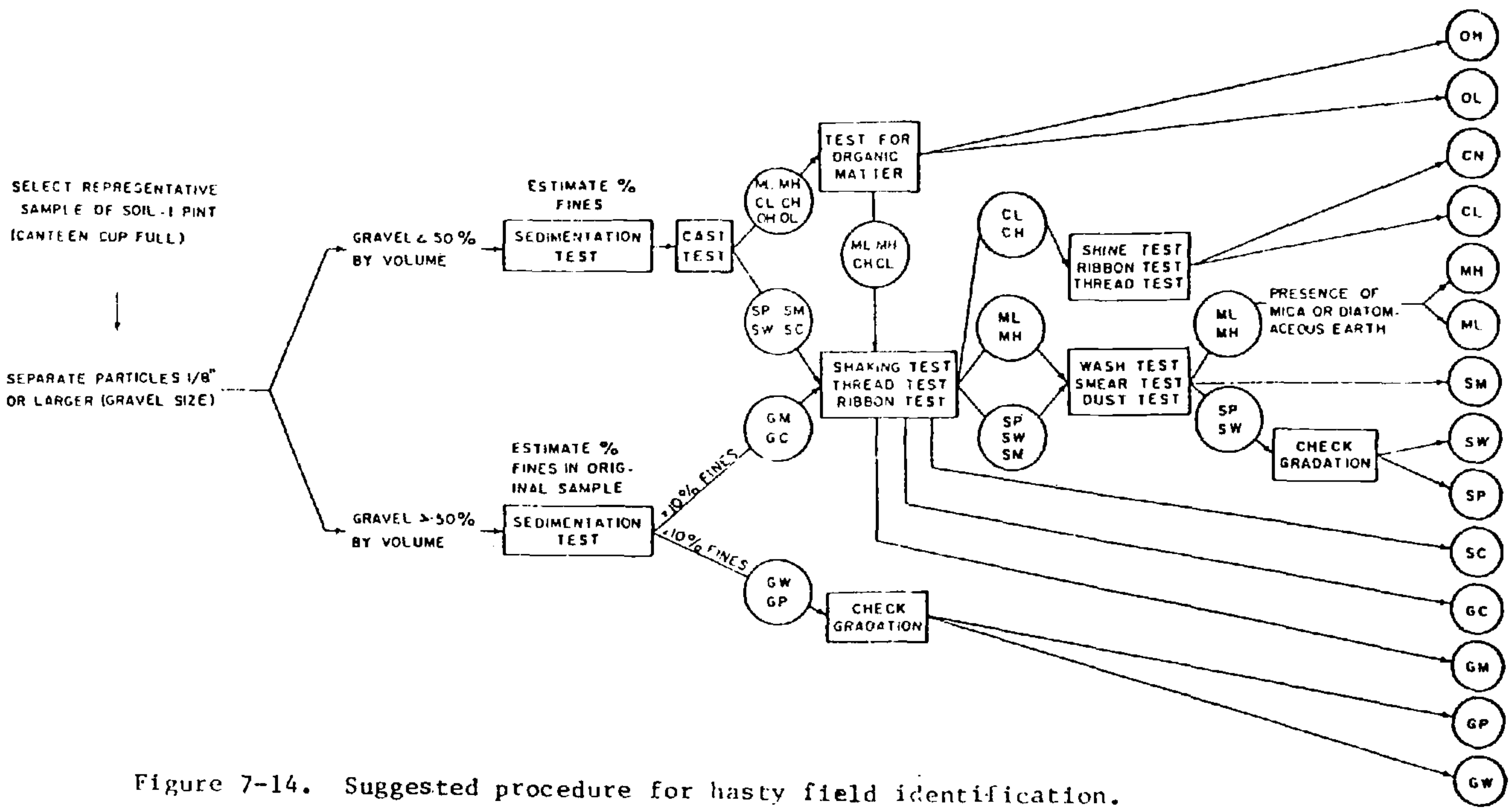


Figure 7-14. Suggested procedure for hasty field identification.

Table 7.8. Settling Times for Small Particles

Approximate Time of Settlement Through 5 in. (127 mm) of Water	Grain Diameter	Differentiates
2 seconds	0.4 mm	Coarse sand—fine sand
30 seconds	0.072	Sand—fines
10 minutes	0.03	Coarse silt--fine silt
1 hour	0.01	Silt--clay

becomes clear 30 seconds after mixing, then the cup or jar will contain the coarse fraction of soil and the pan containing the suspension will hold the fines. If the water can be wicked or evaporated off, the relative amounts of fines and sand can be determined fairly accurately. Otherwise a direct measurement of the settled out fines can be obtained as a guide. Thus, in a sense, the test acts like a No. 200 sieve.

2. Most field identification tests are done on the No. 40 sieve soil fraction (fines and fine sand portion). This fraction can be separated by using a procedure similar to that outlined above, except that the water is poured off within 1 to 2 seconds after completion of agitation. The suspended portion will then include the particles of the fine sand range.

3. A difficulty encountered with many clay soils is that the clay particles will often form small lumps (flocculate) that will not break up in water. Usually this condition can be detected by examining the coarse fraction of the soil after several repetitions of the test. If substantial amounts of clay are still present, the sand will have a somewhat slippery feel, and further mixing and grinding with a wood stick will be necessary to help break up these lumps.

7.12.16.2 Cast Test:

The cast test refers to the strength of a moist soil sample when squeezed in the hand. It is used to indicate the approximate type and quantity of fines in the sample. The correct amount of water to add to the soil must be estimated by trial and error, although maximum cohesion or attraction between the individual soil particles generally will occur when the soil is damp but not sticky. The test consists of compressing a handful of the moist soil into a ball or cigar-shaped cast and observing its capability to withstand handling without crumbling. While experience is desirable in making predictions based upon this test, Table 7.9 may serve as a general guide of the behavior of different soil types when formed into a cast and tested.

7.12.16.3 Wash, Dust, and Smear Tests:

A small amount of silt (less than 5 percent), when intermixed with a coarse-grained soil, normally will not lessen the value of the soil as a construction material. However, increasing quantities of silt will sharply

Table 7.9 Cast Test Reactions

Soil Type	Reaction to Handling
GP, SP, SW, GW	Cast crumbles when touched
SM, SC	Cast withstands careful handling
ML, MH	Cast can be handled freely
CL, CH	Cast withstands rough handling

reduce the strength and interfere with the free drainage characteristics of the coarse-grained soil, thus making it less desirable as a road or airfield construction material. To decide what constitutes a harmful concentration of silt by the field identification methods generally requires extensive field experience. If the dust, wash, and smear tests are first practiced on soils of known silt contents, they can be used to produce a fairly accurate result. In the dust test, when a completely dry sample of soil (with the gravel portion removed) is dropped from a height of 1 or 2 ft (0.3 or 0.6 m) onto a solid surface, a silt content higher than 10 percent will generally cause a fairly large amount of dust to be produced. In the wash test, an identical soil sample, as above, is placed in the palm of a hand, and covered with about 1/8 in. (3.18 mm) of water. If the water becomes completely discolored and hides the sand grains, this indicates that the soil sample contains a silt content higher than 5 percent. In the smear test, a sample of soil, again with the gravel portion removed, is moistened to just below the "sticky limit," and then smeared between the thumb and forefinger. When it produces a gritty, harsh feel, this indicates that it contains a silt content of less than 10 percent. A rough, less harsh feel, however, indicates that the sample contains more than 10 percent silt. It should be emphasized that all of the above tests require the testing engineer to have some experience in their use before they can be considered reliable indicators of the silt contents.

CHAPTER 8 - PORT CONSTRUCTION

8.1 Introduction

Certain geographic areas of operation may require use of beach sites for extended periods of time beasue there are few--or no--facilities for handling containers in most ports in the Middle East at present, and container terminals are only in the planning stage. Wooden and concrete jetties are used throughout for shipping crude and refined oil for local consumption and for exporting oil products. It appears that currently designated U.S. Army Port Construction Companies (one regular Army, two reserves) require new equipment and training to become familiar with the best methods of performing container port construction. Because of construction limitations caused by the equipment presently authorized the Engineer Combat Battalion Heavy, time restrictions preclude any extensive repairs on heavily damaged ports. Characteristics of selected "major" ports in the Middle East reveal two common problems: (1) most ports in the region are not equipped to handle heavy cargo or container lifts, and (2) some have less than 40-ft (12-m) draft available in the channel or at dockside. A typical small port involved in coastal trade is shown in Figure 8.1.

8.2 Dredging of Channels

Rapid dredging of channels with depths of a least 40 ft (12 m) is needed to accommodate container ships. There are no expedient solutions to this problem. Hopper dredges and sidecasting dredges are the only ones that are seagoing. The cutterhead dredge is the most functional of all dredges because it can operate in materials up to a consistency of soft rock. The dredge works most efficiently when making a deep cut in relatively calm waters. Its use is very limited in waters subject to waves over 2 to 3 ft (0.6 to 0.9 m). It takes a significant amount of time to move equipment such as dredges from secured areas to occupied areas. In fact, the equipment would not arrive for more than 48 hours unless it were pre-positioned so that it could be sent at a moment's notice. Identifying items that are difficult to move is imperative for the completion of large-scale missions such as port rehabilitation.

8.3 Training of Personnel in Operation and Maintenance of Local Materials-Handling Equipment

Personnel who will operate a port may be unfamiliar with the operation and maintenance of civilian material-handling equipment left in an operational status by departed host nation personnel. One solution may be familiarization schooling for personnel assigned to rapid deployment forces. Other approaches could be the importation of allied civilian workers skilled in operation of such equipment or on-the-job orientation for untrained military personnel.

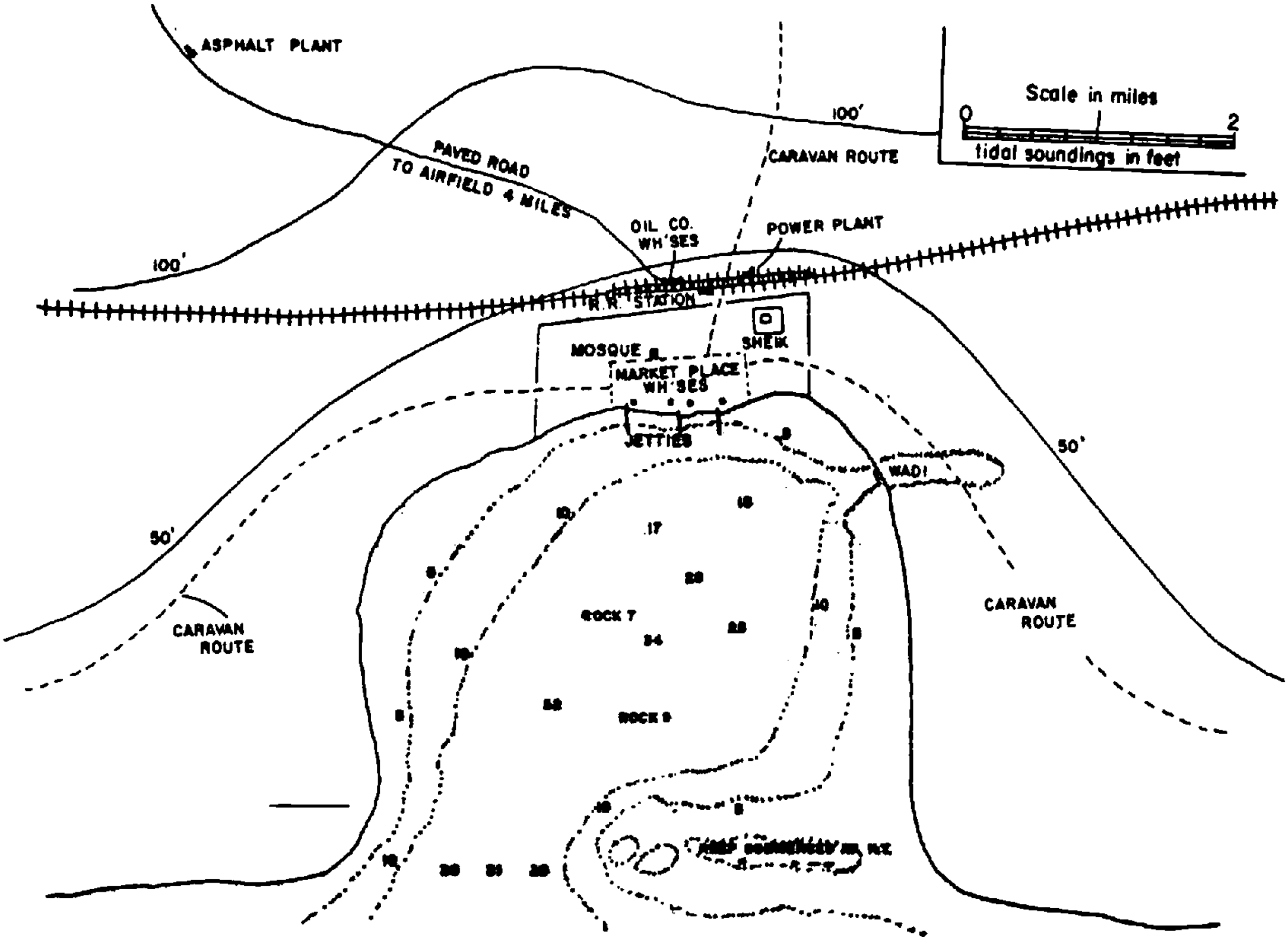


Figure 8.1. Typical facilities in a small port in the Middle East. (From Tropical Engineering, NAVDOCKS P-39 [Navy Department, 1951].)

To enhance operation capabilities, detailed information should be gathered concerning the type and quantity of equipment available at the Persian Gulf ports so that familiarization schooling can be done. On-the-job training is not recommended as the best solution; learning accidents can be costly in a operation for which time is minimal.

8.4 POL Terminal Facilities

Construction, rehabilitation, and/or improvement of POL terminal facilities are needed to achieve an early capability for unloading POL tankers. Tactical marine terminals consisting of two functional portions, an offshore and an onshore portion, will bring ashore, store, and issue bulk petroleum products where no facilities exist for doing so. The storage capacity of the terminal should accommodate large ocean-going tankers. Holds of ships not being used for other purposes can provide a temporary oil reservoir. If the ship is floating, it can be towed to larger tankers, have the hold filled, and then be towed to a storage site. Collapsible tanks are vulnerable to puncture from standard materials-handling equipment and, due to their weight and bulk, require considerable manpower for positioning. This solution is susceptible to enemy attack since any ship must be exposed in the water. Also, disabled ships or unpowered barges require powered vessels to get to and from tankers. Collapsible POL tanks can be inserted in below-ground pits or underwater to reduce vulnerability and exposure to weapons fire.

8.5 Lack of Container-Handling Facilities

Capability is required for the rapid construction of expedient container ports to meet rapid deployment force requirements. However, there are no quick and easy solutions to this problem. It should be recognized that plans for future uses of expedient military ports must be especially adaptable for container-handling operations and must employ the latest innovative commercial applications for reducing off-loading and turnaround times of container ships. Pre-positioning of critical equipment for off-loading operations may provide flexibility to react in undeveloped port areas.

8.6 Rapid Removal of Debris

Removal of horizontal and vertical structures that are damaged beyond repair and are interfering with completion of the port operation mission may be required. Material that has been reduced to rubble, such as broken concrete, can be turned into fill material within the port area to act as foundation for extensions of piers breakwaters, and construction of new piers, or to fill craters. Blasting techniques have been effective in reducing structures to rubble. However, blasting and the handling of explosives should be done only by trained personnel. To facilitate debris removal the addition of adding a dump truck company could make it easier to handle large quantities of earth, rubble, or damaged construction material. Also, subassemblies salvaged from a destoryed structure could serve as structural membranes in other facilities; e.g., salvageable wood could be used for expedient roadway surfacing in areas of weak soil.

8.7 Lack of Adequate Road Networks

Lack of adequate road networks from port to inland areas may hinder transportation. Expedient construction techniques may be used with minimum quantities of hauled-in materials to provide binder for in-place, sandy materials. Use sea-water to obtain compaction with heavy construction equipment and dump trucks. The minimum length and width of one-way roads should be constructed until semipermanent and/or permanent inland road nets are reached. If proper consolidation and compaction of sandy soils cannot be completed in the allotted time, re-outfitting trucks with tires that perform well in loose sand may prevent having to extract vehicles that have become trapped in the sand. A minimum stand-by force of water trucks and dozers is required to smooth the road surface as ruts occur from vehicle traffice.

8.8 Temporary Methods of Through-Put Operations

During the rehabilitation of ports, the off-loading of supply ships will be hindered until wharves and quays can be reconstructed. On possible solution is lighterage operations from ships anchored within the harbor to barges for transfer to shore. Other solutions could include: lighterage from lighter aboard ship (LASH) or SEABEE ships for over-the-beach discharge of cargo; use of heavy-lift helicopters to off-load break-bulk or container cargoes; or use of causeway barges to ferry containers from ship to shore (in calm seas). There are certain considerations to be observed. For example:

- Ligherage from ships that do not have self-sustaining capability would require the use of a floating crane or use of helicopters.

- Lighterage operations cannot be conducted in heavy seas.

- Discharge or roll-on/roll-off (RO/RO) ships is only possible through the Army's Beach Discharge Light (BDL), of which there is only one.

- Use of helicopters restricts cargo weight to useful limits of the helicopter. Nominal loads of up ot 18,200 lb (16 380 mt) can be carried by CH-47C helicopters.

- It should noted that all of the foregoing methods are time consuming and should only be used until docking facilities are available. In addition, movement of barges will require powered vessels.

8.9 Lack of Materials for Construction and Repair of Port Facilities

Local timber is generally not available for piling or wharf superstructures. During World War II port development in the Persian Gulf, timber for piling was imported from India. TM 5-258, Pile Construction, describes a number of species of trees in that area which make excellent piling. Salvaged materials, such as structural steel or telephone poles, can be used for expedient piling. During demolition and debris removal, the normal tendency is to cut such members into short, easily handled pieces. If general cargo pier reconstruction is required, a premium should be placed on salvaging large pieces intact. Since timing of the operations makes fabrication of piling unrealistic , materials must either be scavenged or imported.

CHAPTER 9 - FACTORS AFFECTING ENGINEER WORK FORCE

9.1 Introduction

Working conditions in the desert can be extremely harsh. High solar radiation, temperature, lack of water supply, and sand storms all contribute to the difficult environment. This chapter describes how the environment affects personnel and equipment, and how the impacts can be minimized. Generally, all movements should be as deliberate and unhurried as possible; this reduces the body's heat production and use of energy and water.

9.2 Health and Operational Effectiveness

9.2.1 *Effect of Heat on Efficiency*

Desert is characterized by high solar radiation and temperature. Solar radiation beats down on desert regions with great intensity. The air temperature in the summer can range up to 131°F (55°C). Without precautionary measures, the heat not only will reduce the efficiency of workers, but also will create health problems.

The reduction in the efficiency of workers caused by high daytime temperatures can be considerable. Therefore, one needs to consider letting personnel work at night to take advantage of the cooler temperatures. However, the problem with this is that workers must sleep in excessive daytime temperatures.

High solar radiation and temperature may cause heat cramps and heat exhaustion. The following preventive measures should be taken:

1. Water and salt intake by individuals must be adequate. However, excess intake of salt should be avoided since it may cause increased thirst and incapacitating nausea. Unless workers are sweating continuously or repeatedly, they do not need saline fluids or salt tablets. Extra salt in food and on the table, coupled with sound training, will meet most requirements. When water supplies are restricted, salt in excess of that normally present in food should not be taken. Consult TB MED 507 for information on salt tablets.

2. Whenever practical, work should be performed in the shade or in the early morning, evening, or night. If shade over a work area is not possible, some sort of shady shelter should be provided at the job site.

3. When it is very hot, the men should work in shifts, and strenuous labor should be reduced.

4. Clothing must be loose enough to permit ventilation of the body.

5. Dress as the natives do. Wear light colored clothing.

6. The body, especially the head, should not be unnecessarily exposed to the sun.

It is well understood that a sudden onset of hot weather impairs ability of personnel to perform work that is easily done in cool environments. However, one can get acclimated if the heat wave lasts several days. Nevertheless, it should be pointed out that the ability to perform as much work as possible in the heat must be attained by progressively increasing the daily workload. Strenuous exertion on first exposure may result in disability that will impair performance for several days.* Therefore, gradual workload increases are suggested so that fresh troops perform lighter work for a short time before being assigned heavier workloads. Personnel can become acclimated with short, intermittent work periods of 2 to 4 hours daily for 4 to 7 days.** Drinking water must not be restricted during this time since inadequate water and salt replacement can delay acclimatization. Nevertheless, salt intakes should not be excessive, as noted earlier. A suggested schedule of work during acclimatizing period is given in Table 9.1.

9.2.2 *Protective Equipment*

In desert regions, the night vision of personnel may be impaired by prolonged exposure of the eyes to intense sunlight and reflected light from the earth. These problems can be corrected by taking the following steps:

1. Providing caps or hats with wide brims or bills to shade the eyes.

2. Prohibiting personnel from working in the direct sunlight without having their heads covered and eyes shaded.

3. Providing sunglasses to all personnel and requiring that they wear them when they are outside in the daytime. If sunglasses are not available, under extreme conditions personnel can take a piece of cardboard or paper and cut small slits or holes in it that will align with each eye. The paper or cardboard can be kept in place with rubber bands, tape, or wire positioning a hole or slit directly in front of each eye. This will reduce the amount of light entering the pupil of the eye, but will still provide limited vision.

Any metallic object, such as a tool or equipment, will become too hot for handling if left in the sun. Therefore, workers need gloves for protection against burns. To prevent tools from becoming too hot, they must be stored in the shade whenever possible. Soft, "spongy" handle covers would also make tools easier to use in the heat.

In addition to the problems caused by intense sunlight, dust or sand storm will also cause considerable difficulty for workers. All personnel will need goggles, chapsticks, and skin and eye ointments. Sometimes it is better to just stop working than to try to keep going when there are bad dust storms.

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* D. E. Bass, "Thermoregulatory and Circulatory Adjustments during Acclimatization to Heat in Man," in James P. Hardy, ed., Temperature: Its Measurement and Control in Science and Industry, Vol 3, part 3, Biology and Medicine (Van Nostrand Reinhold Company, 1963), pp 299-305.

**Ibid.

9.2.3 *Water Intake Requirements*

Table 9.2 may be used as a guide to estimate the drinking water requirements for personnel exposed to heat.*

Occasionally, drinking water must be restricted. The restricted drinking water supply will reduce operational effectiveness and increase health hazards. Therefore, the number of working hours should be reduced, the work should be made less strenuous, and the men should not be allowed to work in the sun. Never reduce the amount of drinking water as a "hardening" measure or "toughening" process for personnel. This is a dangerous practice -- it only produces dehydration. When water is in short supply, significant water economy can be achieved only be reducing physical activity or limiting it to early morning or night hours when there is less heat and workers do not sweat as much. Any attempt at water economy by restricting water intake must be paid for in reduced work capability, reduced efficiency, and increased risk of heat innjury.

It is common for "chemical diarrhea" to be caused just by changing sources of water supply. Often, even treated water contains certain laxatives to which one must become acclimated. If one is forced to constantly drink water from different sources, one's system does not have an opportunity to adjust to the new supply. This problem will be more common with freshwater sources which have been treated with an ERDLater rather than a desalination unit; ERDLater-type devices are not designed to remove from water substances which act as laxatives. Local water may also contain relatively high levels of magnesium sulfate or sodium sulfate (500 ppm). It may also have high pH (above 9). Therefore, local water supplies must be avoided unless qualities personnel have tested and approved the water. In addition, the unit commander must try to keep changes in sources of water supply to a minimum.

9.2.4 *Sanitation Considerations*

Many species of flies are annoyances in all countries of SWA. Many other types of insects -- such as mosquitoes and fleas -- are also found in the region. Insecticides provided by the Quartermaster Corps may be used. However, it probably will be more effective to use screens in the work areas to stop the flies and mosquitoes. Deodorant, hair spray, and cologne should not be used since they will attract insects.

9.2.5 *Use of Local Labor Force*

Every effort should be made to use native personnel whenever practical since they know the country, in many instances have considerable practical knowledge of construction problems in the immediate area, and furnish a ready labor force which can be called upon. It should be cautioned, however, that native laborers are more efficient when working with familiar materials and tools. For instance, local or native workmen are far more experienced in masonry than in carpentry. Local laborers should not be forced to use modern tools unless the training can be done easily.

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* TB-MED-507, Occupational and Environmental Health (Headquarters, Department of the Army, Navy and Air Force, July 1980).

Table 9.1

Schedules of Work, If Necessary, During Acclimatizing Period
(This table is based on TB-MED-507, Occupational and Environmental Health Headquarters [Departments of the Army, Navy, and Air Force, July 1980].)

Moderate Conditions, WBGT or WD Less Than 80°*

	Hours of Work**	
	Morning	Afternoon
First day	1	1
Second day	1-1/2	1-1/2
Third day	2	2
Fourth day	3	3
Fifth day	Regular duty	

Severe Conditions, WBGT or WD Greater Than 80°

	Hours of Work**	
	Morning	Afternoon
First day	1	1
Second day	1-1/2	1-1/2
Third day	2	2
Fourth day	2-1/2	2-1/2
Fifth day	3	3
Sixth day	Regular duty	

*80° wet-bulb-globe-temperature (WBGT), or WD index, is approximately equivalent to a dry bulb (DB) temperature of 85° in a jungle or 105° in a desert environment (WD = 0.85 WB + 0.15 DB).

**Recommended for men in fair or worse physical condition; with some care, very fit individuals should do double this schedule and be able to perform regular duty on third or fourth day.

Table 9.2

Water Requirements

		Quarts per Man per Day for Drinking Purposes (a Guide for Planning Only) WBGT or WD Index*	
Activity	Illustrative Duties	Less than 80°	Greater than 80°
Light	Desk work	5	6
Moderate	Route march	7	9
Heavy	Forced marches; stevedoring; entrenching; or route marches with heavy loads or in CBR protective clothing.	9	13

*80° wet-bulb-globe-temperature (WBGT) or WD index is approximately equivalent to a dry bulb temperature of 85° in a jungle or 105° in a desert environment (WD = 0.85 WB + 0.15 DB).

Dealing with local laborers may create problems because of the language barrier and the customs of natives. The following approaches are suggested.

1. Use of native labor leaders is the most satisfactory method of dealing with native labor.

2. Discussions with local authorities should always precede any use of native labor.

3. Existing rules and local customs should be carefully observed.

The experience of the Persian Gulf Command during World War II indicated that American Engineer units got the best available labor without upsetting the local wage scales by issuing ration coupons.* To make efficient use of the local workers, foremen were drawn from the workers and given proper training. Supervisors on-site then directed foremen, who in turn directed the laborers. Proper security must be provided in the storage areas to keep local residents from stealing construction materials.

9.3 Construction and Engineering Equipment Maintenance

9.3.1 *Maintenance Facilities and Operations*

Working areas must be on bare ground or concrete, if possible; sand must be swept from the location. The repair area must not be established beside a road. If there is a patch of fine, loose sand, the work space should be located so that it will not be dusted by every breeze.

When machinery must be opened up for servicing, workers should try to get a canvas lean-to or a half tent. The whole working area must be kept cleared of dust. If water is available, workers could dampen the sand, or better still, sprinkle it with used engine oil and cover it with rock to bind it down. Tools must be kept clean at all times. When there are bad sand or dust storms, work should be stopped.

Parking spaces should be arranged so that vehicles can leave without having to circle around others. Although it is not practical to have equipment so widely separated that there is no danger from dust, care should be taken to park the machines so that turning and travel are done outside the area and on the side away from prevailing winds.

9.3.2 *Fuel and Refueling Operations*

A serious problem that has occurred in Saudi Arabia and other desert areas is clogging of fuel lines due to sand and dust in the fuel tank. The fuel filters usually prevent sand and dust from getting into the carburetor, but the fuel pump, fuel lines, or tank screens can become clogged. The problem results from careless refueling operations and refueling during sand or dust storms. The following solutions are suggested:

* T. H. Vail Motter, The Persian Corridor and Aid to Russia (Washington, Office of the Chief of Military History, 1952), p 103.

1. The first, most obvious, solution is to avoid refueling during storms if possible.

2. Before the fuel tank cap is taken off, care should be taken to make sure that sand or dust which might enter the tank has been removed.

3. If it is necessary to refuel during a storm, then certain precautions should be taken:

a. If a funnel is to be used, then it should be a filtered funnel and should fit tightly into the fuel tank opening. If possible, the funnel should screw on the opening or fit the tank opening snugly. If necessary, solder a small vent pipe down the inside of the funnel to allow air to escape while pouring the fuel.

b. If a "screw-on" funnel is not available, then a rag should be wrapped around the funnel base and fuel tank opening to prevent sand/dust entry.

c. The "rag wrap" procedure may be used with hose/nozzle filling approaches also.

d. Be sure to wipe the tank clean for several inches around the opening before taking off the filler cap. Remember, a few grains of sharp, cutting sand can completely ruin a diesel fuel engine or pump.

e. Fuel filters must be cleaned more frequently.

The high diurnal temperature is another problem for fueling operations in hot desert region. If fuel tanks are filled to the brim at night, they will overflow at mid-day. Therefore, fuel tanks must be filled to their correct capacity.

9.3.3 *Lubrication*

Lubricant must be the correct viscosity for the temperature, and must be kept to the absolute minimum on exposed or semi-exposed moving parts. Lube fittings must be checked frequently. If they are missing, sand will enter the housing and cause bearing failure. Teflon bearings require constant inspection to ensure that the coating is not being removed.

Lightweight oils are not suitable in hot climates. Their use can reduce engine life; therefore, oil of the proper weight must be used. Engine oil must be changed more often than in temperate climates, and oil filters have to be replaced more frequently than usual.

9.3.4 *Air Filters*

Improper servicing -- such as cleaning an air filter by beating it to remove dust particles -- can damage the element. In addition, filters are sometimes installed slightly ajar, and punctured elements are occasionally put back on the engine because there is no replacement filter. Other improper maintenance includes servicing air filters at incorrect intervals. If sand/dust leaks through damaged elements, the engine's life span will be cut significantly.

Air cleaners of every type must be inspected at least daily, or more frequently if operating conditions require. Use compressed air for cleaning. A redundant air filtering system with two elements in series may be used. A proper quantity of replacement elements must be provided.

9.3.5 *Engine Overheating*

All types of engines are apt to overheat to some degree. This will happen more frequently in the high-temperature desert region, and will lead to excessive wear and ultimately to leaking oil seals in the power packs. The following solutions are suggested:

1. Be aware of which vehicle types tend to overheat often, and ensure that they are maintained with extra care.

2. Check oil level frequently.

3. Check seals frequently to make sure they are not leaking and that oil consumption is not higher than normal.

4. Radiators and air-flow areas around engines must be kept clean and free of debris and other obstructions.

5. Water-cooled engines should be fitted with condensors to avoid waste as steam through the overflow pipe.

6. Cooling hoses must be kept tight.

7. Operators should not remove hood side panels from engine compartments while the engine is running because this will cause turbulence, leading to ineffective cooling.

9.3.6 *Battery Maintenance*

Batteries do not hold their charge efficiently in intense heat. To minimize the problems, the following solutions are suggested:

1. Change the battery's specific gravity to adjust to desert environment; adjust the battery's electrolyte to 1.200 to 1.225 specific gravity or obtain sulfuric acid, electrolyte FSN 904-9372 with a specific gravity of 1.2085 to 1.2185.

2. It may also be necessary to adjust the battery's specific gravity to compensate for cold nights (see TM 9-6140-100-12).

3. Batteries must be kept full, but not overfilled, and a reserve of distilled water should be carried.

4. Air vents must be kept clean or vapors may build up pressures and cause the battery to explode.

5. Voltage regulators should be set as low as practical.

6. Dry battery supplies must be increased to offset high attrition rates caused by heat exposure.

9.3.7 *Tire Pressures*

High diurnal temperatures may cause problems for tires. For instance, if tires are inflated to the correct pressure during the cool night, they may burst during the heat of the day. Therefore, one must try to find the proper air pressure when the equipment is operating at efficient working temperature and maintain it. Service of these items during heat of the day will result in under-pressures and overheating of tires.

9.3.8 *Critical Fuel and Equipment Temperatures*

Gasolines deteriorate largely through formation of gum, which causes filter clogging and lowering of octane number. Although the initial gum content and the rate of gum formation differ widely, the effect of varying temperature on this rate is quite similar for all gasolines. The rate approximately quadruples for each 20°F (11°C) rise in temperature.

A map can be prepared from effective gasoline storage temperatures weighted so that they represent -- in gum-degradation effect -- the whole series of cycling temperatures during a field storage season for gasoline in 55-gal (208-L) drums at various places on the map. Figure 9.1 is such a map; effective gasoline storage temperatures have been coverted to storage life.

For a typical gasoline with inhibitors added, 5 mg of gum per 100 ml of gasoline might form in 12 months at 100°F (38°C) gasoline temperature. Since this is enough gum to cause rejection (if some gum were already present), 12 months becomes the storage life for this particular gasoline.

Figure 9.1 (computed from data for the six hottest months) shows comparitive gasoline storage life at various points in SWA, assuming that the gasoline would be acceptable for 12 months at 100°F (38°C). It should be emphasized that other gasolines with other inhibitors might differ in basic gum-forming rates, but that proportionality between rates at various places on the map will be the same for almost all gasolines.

For example, if a sensitive gasoline were acceptable for only 4 months at 100°F (38°C), storage times for this gasoline could be obtained from the map by dividing the plotted storage time by three. Conversely, predictions for a gasoline stable for 2 years at 100°F (38°C) could be obtained by multiplying by two the time shown.

Some equipment may fail when it operates above a critical temperature, but may be completely effective when the temperature drops to acceptable levels. For such equipment, a map showing frequency of occurrence of critical temperatures becomes an indicator of the probability of equipment difficulty. For example, the rough terrain fork lift truck is designed for temperatures below 110°F (43°C) and becomes less effective above that temperature.

Figure 9.2 shows where temperatures above 110°F (43°C) are common in July and, therefore, where the equipment mentioned above may give difficulty. Although the map is based on percentage of total hours above 110°F (43°C) (and

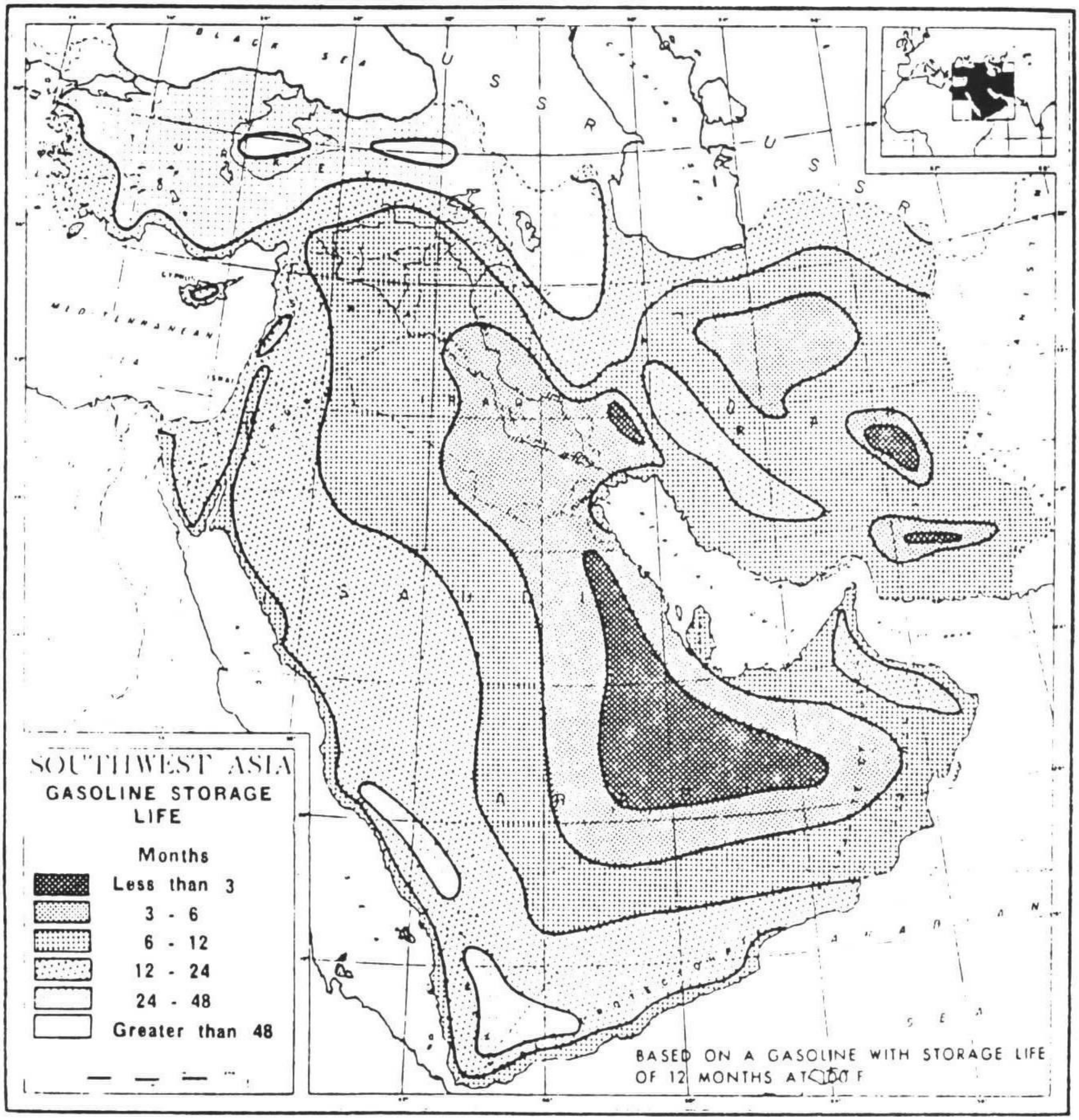
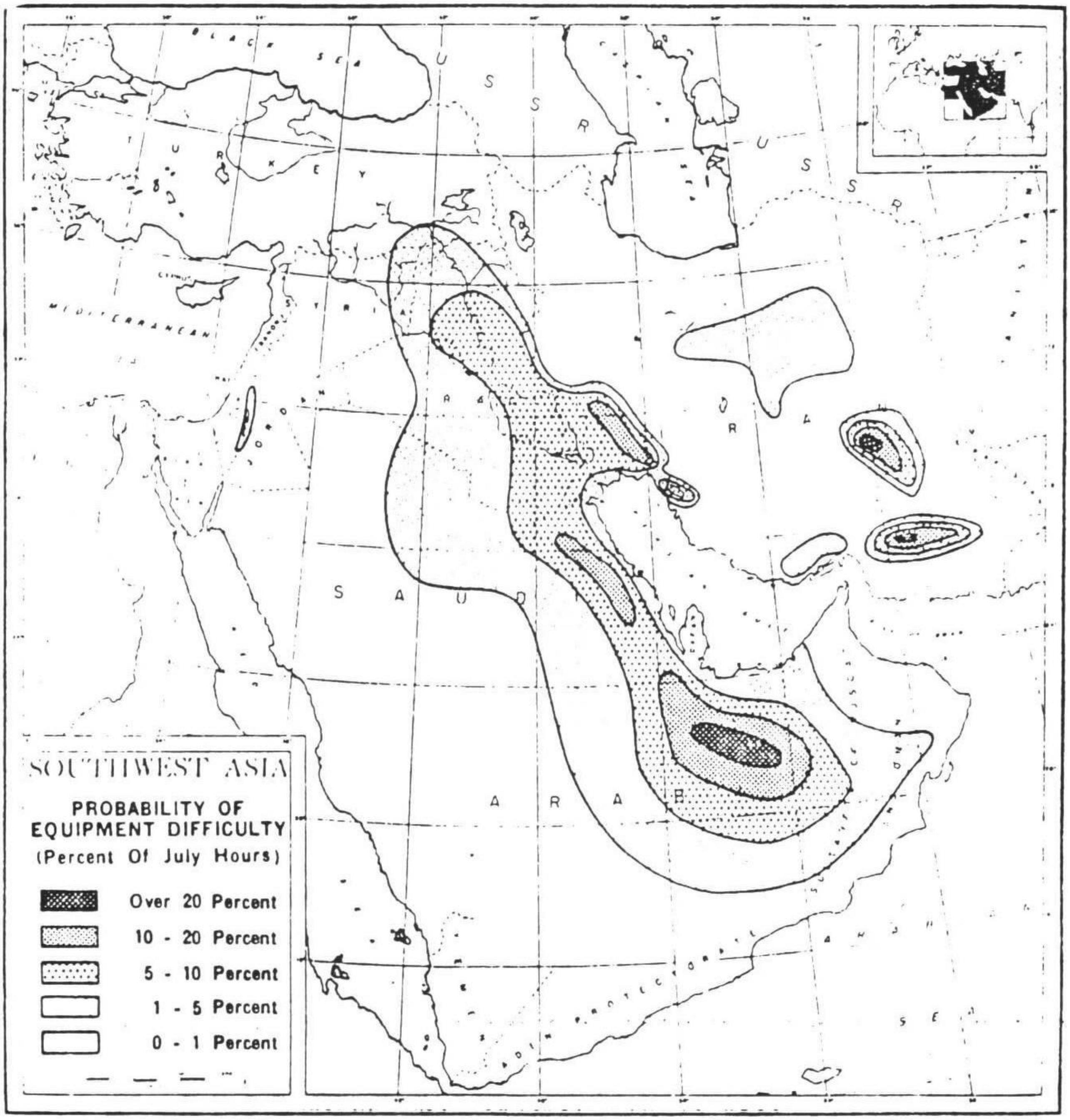


Figure 9.1. Gasoline storage life based on a gasoline with storage life of 12 months at 100°F. (Reprinted from SW Asia: Environment and Its Relationship to Military Activities [Quartermaster Research and Engineering Center, July 1959].)



This map shows the percentage of July hours during which the mobile bakery; refrigerator, 25 cu ft.; and rough terrain fork lift truck may be ineffective. These three items begin to fail at temperatures of about 110°F.

Figure 9.2. Probability of equipment difficulty. (Reprinted from SW Asia: Environment and Its Relationship to Military Activities [Quartermaster Research and Engineering Center, July 1959].)

gives information about the number of days of occurrence), it may be assumed that such temperatures will not last more than 4 to 6 hours on any given day.

9.3.9 *Vehicle Operation*

Trucks may have difficulty moving on certain types of desert roads. The following possible solutions are provided:

1. In sandy areas, operate with standard tires at lower pressure. The tire pressure will depend on the loading, the sand conditions, and the desired tire life.

2. All transportation equipment should have low-pressure single tires. Dual tires should never be used because they tend to break up the bearing surface and embed themselves much more than do single tires.*

3. A pair of cleated canvas tracks can be easily rolled up and carried for each light piece of motor equipment. In excessively fine and deep sand, these tracks under the wheels will usually permit passage; this might not otherwise be possible.*

4. Lengths of chain link fence can frequently be used as semipermanent roads in construction areas. This material can be salvaged and used again on another job. The only maintenance required for such tread roads is lifting the mesh when it begins to become covered with sand, and turning it over periodically as it bows from the passage of traffic.

5. When passing through sandy areas, each vehicle should remain in the tracks of the vehicle ahead. Any attempt to form new tracks or to swing out of line will generally result in a stuck truck and a delay to free it.*

6. Frequent stops should not be necessary, but each vehicle should be inspected at every stop to make sure it is not overheating and to see whether the tires are over- or under-inflated. Tires with lowered pressures, and particularly tires designed for higher pressures, generate considerable heat as they grind through deep sand; thus, the pressures will increase and may have to be lowered during stops. The same precaution applies if the convoy has been traveling at fairly high speed over smooth, hard ground where desert temperatures heat the tires enough that internal pressures become dangerous. Tires and cooling systems should be inspected at every stop. Personnel should lubricate their vehicles regularly during travel and promptly repair all minor breakdowns.

9.3.10 *Operation of Earthmoving Equipment in High Temperature Desert Environment*

The following discussion furnishes information and guidance to personnel responsible for using and supervising the operation of engineer construction equipment, primarily earthmoving types. The characteristics, capabilities, and application of equipment for typical construction tasks are discussed, and guides for estimating the output of various items of equipment are provided.

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* Tropical Engineering (U.S. Navy Civil Engineer Corps, Bureau of Yards and Docks, Department of the Navy, 1950-51), p 72.

In addition, maintenance considerations and equipment modifications which improve operation in a desert environment are discussed.

Factors which must be considered in desert operations are soils, high temperatures and solar radiation, and increased maintenance and preparation of equipment for the high-temperature environment.

Desert soils are similar to those found throughout the world. However, in the desert they are found in a more geographically defined area. These soils include zones of large boulders and poorly sorted medium angular gravel; sand and gravel with some larger stone; silty, stoney, and sandy desert; and Aeolian (windblown) deposits which may include evaporite salts. Thus, operational constraints resulting from any peculiarities associated with unique soil conditions in a desert environment are minimal. High temperature factors relating to the equipment and its operation are thus the primary features to be considered.

High temperature affects both the equipment and the operator and must be considered when operating in the desert. Some equipment considerations are associated with the engine/transmission cooling system, low radiant energy absorbing paints, increased or improved engine air filtering systems, fuel contamination due to windblown debris, increased undercarriage wear due to sandy soils, and the need for enclosures or environmentally controlled cabs for operating personnel.

Major equipment manufacturers presently incorporate high temperature design capability into the cooling systems of their equipment so that the equipment can be used worldwide without serious degradation of performance due to high temperature. However, if the existing cooling system is inadequate, it can be modified through approved modification work orders.

The use of light color paints which absorb less radiant energy than dark paints reduces surface metal temperatures. This contributes to a greater efficiency in heat transfer, which results in lower temperatures in fluid reservoirs exposed to direct solar energy. In addition, the lower metal temperatures provide for safer man-machine interfaces such as operation, service, and maintenance in exposed areas.

Increased maintenance in air filtering systems, tracks, and fuel handling systems usually results from operation in the desert environment. This is due to blowing sand, which rapidly chokes air filters, causes rapid track wear, and contaminates fuel handling systems and equipment.

Provisions to reduce operator fatigue due to high temperatures are essential in the desert environment. Canopies to prevent direct exposure to the sun and environmentally controlled cabs can be provided to protect the operator from the solar energy and blowing sand.

Preparation of the equipment for operation in the desert environment is essential. The cooling systems should be clean and functional; equipment surfaces should be free of dirt and grease, and painted with a light color to improve heat transfer from heat sinks to the environment. In addition, the increased service and maintenance increase the logistic requirements for repair parts, maintenance personnel, and facilities.

10.1 Introduction

Both vertical and horizontal structures in specific regions can be constructed with materials available in the region or the adoption of feasible imported construction materials. Certain factors will determine the type of structure to be built as well as the material to be used. Among these factors are climate, labor force, availability of construction equipment, and feasible local and adopted construction materials. The following paragraphs describe construction materials that can be used in the Middle East, their general properties and characteristics, and their applicability to different construction methods. Advantages and disadvantages of each constructed method are discussed.

10.2 Construction Materials and Applicability to Construction Methods

10.2.1 *Earth*

The use of earth for building construction results partly from the scarcity of wood and other construction materials, from the ease of such construction, and from its insulation values against both heat and cold. Some kinds of mud make stronger structures than others, and some construction techniques apply better to some kinds of mud. The type of construction method is determined by the type of soil available. There are five main construction methods for earth building: adbobe, rammed earth, pressed blocks, wattle and daub, and cob. Adobe and rammed earth are the most practical. To select the appropriate construction method, the soil must be generally classified into gravels, sands, silts, clays and organic soils. Organic soils are the least suitable for earth construction, and the ideal will be a combination of two types of soils, i.e., sandy clays or clayey sands. However, in very dry regions, clays will work best, if available. Some testing on the strength of earth material has been done. The values range from about 300 to 600 psi (2069 to 4137 KPa) in compression to 60 psi (414 KPa) in tension.

To compensate for the low structural strength of the earth material, walls are built dense and thick. The minimum thickness of exterior load-bearing walls of single-story buildings is usually one-tenth of the height; interior nonload-bearing partition walls are made three-quarters of the thickness adopted for the exterior wall of similar heights. Weighing various factors, including theoretical factors that are not discussed here, it is judged that a normal wall about 10 ft (3 m) high and 12 in. (305 mm) thick should have no greater free length than 30 ft (9 m) without some form of buttressing, by cross walls, engaged piers, or pilasters. The following tabulation indicates more generally what would appear to be reasonable limitations in wall length for single-story walls 9 to 12 ft (2.7 to 3.6) high and 12 in. (305 mm) thick, where there may be window or door openings through the wall:

Condition of Single-Story Wall 9 to 12 ft High from Top of Footing, and 12 in. Thick	Maximum Length of Wall Between Supporting Cross Walls, ft
Wall without openings	30
Wall with an opening or openings of any size not extending more than 4 ft 6 in. either way from the center of the length of the wall between supporting cross walls	24
Wall with an opening or openings near one end only, and not extending beyond the center of the length noted above	21
Wall with any other grouping of openings, or a single opening up to 12 ft wide	18

For walls 14 in. (356 mm) thick and from 9 ft, 6 in. (2.9 m) to 14 ft (4.2 m) high, all the lengths and distances tabulated may be increased by one-sixth; for walls 16 in. (406 mm) thick and from 10 to 16 ft (3 to 4.8 m) high, they may be increased by one-third; and for walls 18 in. (457 mm) thick and from 10 to 18 ft (3 to 5.4 m) high, they may be increased by one-half. For two-story walls, all the heights may be increased by 6 ft (1.8 m) without affecting the lengths as given for single-story walls.

The most practical construction methods, as previously mentioned, are adobe blocks and rammed earth.

1. Adobe blocks: These blocks are made by placing wet mud in forms. The forms are removed a short time after the blocks are made and then allowed to dry for about 1 month. The blocks are held together in the wall with a mortar that can be the same mud used for making the block. The advantages are that unskilled labor can be used, and construction is fast after prefabricating the blocks. The disadvantages are that 20 to 30 days are needed to cure the blocks, it can only be used in limited regions (rain <30 in. [762 mm] per year).

2. Rammed earth: With this method, continuous walls are built by ramming moist soil into position between heavy wooden forms. When a short section of wall is finished, the forms are moved upwards or sideways, and the process is repeated until the walls are completed. Ramming of the soil may be done with light hand or pneumatic tampers; soil should be rammed until it becomes dense and firm. Disadvantages of this method are that it is difficult to do, forms require some skill to build, and it requires the most careful selection of the soil type.

10.2.2 *Soil Cement*

This type of construction material is very useful and economical where sandy silt and silty sand are available. With the addition of about 10 percent of cement by weight, these soils will have proper stabilization to insure a strong and lasting surface for pavement construction. Another requirement for soil cement is that 55 percent or more of the soil should pass the No. 4 sieve; the maximum aggregate size should be 3 in. (76 mm). The amount of water that should be added will depend directly on the moisture-density curve, reflecting the optimum moisture for maximum density. Soil should be pulverized to permit an intimate mixture of soil and cement. (Eighty percent should pass a No. 4 sieve exclusive of gravel retained on No. 4, i.e., 80 percent of 55 percent.) If clay soil is found, the clay must first be stabilized with lime to get a proper blending.

10.2.3 *Wood*

In the more arid regions, the topsoil has been void of nutrients for thousands of years, making it almost impossible to develop forest areas. In the Middle East, Iran, Iraq, the mountains of Lebanon, Asia Minor, and Israel possess most of this natural resource.

10.2.4 *Concrete Masonry*

Concrete blocks are made with aggregates such as coral cinders, expanded shale, sand, gravel, clay, slag, and others. They can be made in different sizes and shapes, and they can be solid or hollow units. The normal size unit for a load-bearing concrete block is an 8- by 8- by 16-in. (203- by 203- by 406-mm) hollow block, which can weigh from 25 to 50 lb (23 kg), depending on the aggregate used in making the block. Block machines are used in fabrication by tamping relatively dry concrete into the mold; the mold is stripped off immediately. In this way, blocks can be made rapidly, using only one mold. If a hand method is used, a more fluid concrete is placed into a set of molds and stripped after the concrete is hardened. However, this method requires many molds. The blocks are held together with mortar. A recommended mortar, proportioned on a volume basis, for exterior walls subjected to severe exposure is one part of portland cement, two parts of hydrated lime, and six parts of sand.

10.2.5 *Reinforced Gypsum*

From literature available on this material, the optimum mix tested had a water-to-gypsum ratio of 1:2. Reinforcing gypsum with burlap (jute), glass wool mats, galvanized stretched wire mesh, or reeds will improve the properties and strength of plain gypsum. The thickness of gypsum cover must be at least 3/4 in. (19 mm).

1. Burlap:

a. One or two layers.

b. Soak in water for a few hours.

2. Glass Wool:

a. One or two layers (loose).

b. Mats overlapped.

3. Galvanized Stretched Wire Mesh:

a. One or two layers.

b. Straightened in the mold.

c. Openings 1-1/2 in. (38 mm).

4. Reeds:

a. One layer.

b. Spaced 3/4 in. (19 mm).

c. Reed on the span direction.

10.2.6 *Rubble Construction*

Rubble construction is a method in which rubble, such as stone, concrete fragments, broken bricks, and/or other suitable materials, are used with portland cement mortar to form a building material. This type of construction is practical when wood, masonry units, and concrete-making facilities are not available. It can be applied when the materials mentioned above are available due to extraction from an excavation, the effects of demolition, or when buildings are abandoned because of advanced deterioration. Stones, bricks, and/or other hard and durable materials can be laid in courses by using a cement mortar to build foundations, walls, bridge abutments, and retaining walls. A variety of sizes is necessary to avoid using large amounts of mortar. The largest rubble should be placed at the bottom of courses; the top of each course should be covered with a thin layer of mortar to provide a smooth, stable, level surface. The spaces between adjoining materials should be as small as practicable, and the spaces should be filled with mortar and smaller stones. The durability and strength of the construction depends on the materials used and the quality of the mortar joining them.

10.2.7 *Brick*

The following characteristics of brick masonry are significant.

1. Heat-insulating properties. Solid brick masonry walls provide very little insulation against heat and cold. A cavity wall or brick wall backed with hollow clay tile has much better insulating value.

2. Sound-insulating properties. Since brick walls are very massive, they have good insulating properties. In general, the heavier the wall, the better its sound-insulating value; however, a wall more than 12 in. (305 mm) thick does not increase sound insulation much more than a wall between 10 and 12 in. (254 and 305 mm) thick. Dividing the wall into two or more layers, as in the case of a cavity wall, will increase its resistance to sound transmission. Brick walls are poor absorbers of sound origination within the walls and reflect much of it into the structure. Sounds caused by impact, as when the wall is struck with a hammer, will travel a great distance along the wall.

3. Expansion and contraction. Brick masonry expands and contracts with temperature change. Walls up to 200 ft (60 m) long do not need expansion joints. Longer walls need an expansion joint for every 200 ft (60 m) of wall. Much of the expansion and contraction is taken up in the wall itself. For this reason, the amount of movement that theoretically takes place does not actually occur.

4. Abrasion resistance. The resistance of brick to abrasion depends largely on its compressive strength, which is related to the degree of burning. Well-burned bricks have excellent wearing qualities.

5. Weight of brick. The weight of brick varies from 100 to 150 lb/cu ft (p) (2400 kg/m^3) depending on the nature of the materials used in making the brick and the degree of burning. Well-burned bricks are heavier than underburned bricks.

10.2.8 *Water*

The quality of water needed for most expedient construction work is not critical. Seawater or brackish water has been used for mixing concrete in many areas where potable water is hard to get; however, saline mixing water tends to decrease strength. Seawater with a maximum concentration of salts of about 3.5 percent does not appreciably reduce the concrete strength, although it may lead to corrosion of reinforcement. At higher salt concentrations, a strength reduction ranging from 8 to 15 percent can be expected. This may be corrected by using somewhat less mixing water and somewhat more cement. Saline mixing water in concrete tends to cause dampness and surface efflorescence in the hardened concrete and should not be used where surface finish is important or where the mortar or concrete will be covered with plaster. Saline water has a very adverse effect on the strength of concrete made with high aluminum cement. Organic impurities in water may retard setting and hardening of cement, except in artifically contaminated waters, where they do not usually occur to an objectionable extent. It is improbable that water used for curing would attack concrete if it were the type suitable for use as mixing water. Staining or discoloration of the concrete should be the principal curing water problem. Provisions should be made to retain and recycle all water, when possible, at all steps of the concrete operation. Facilities for water storage at the site of the aggregate and/or concrete production must be provided. The mixing water storage should also include provisions for water cooling to help the problem of increased temperatures in fresh and new concrete.

10.2.9 *Aggregates*

In Middle East deserts, waterlain deposits do occur, but they are often subordinate to windlain deposits (e.g., dunes, drift sand, and loess). More significantly, the climate produces intense evaporation, and various salts are deposited at and below the surface. In the areas of interest, the rocks are frequently chalky limestones and dolomites, which have undergone strong upward leaching because exaporation exceeds rainfall. The leaching water carries dissolved minerals, which are deposited near the surface when evaporation occurs, thus forming "duricrusts." Crusts of calcium and calcium-magnesium carbonates are called calcrete and dolocrete, respectively. Many poor limestone and dolomite deposits have been made usable because the duricrust that forms from them is much denser and stronger and can be used as aggregate. In general, a leached layer deficient in the substance forming the duricrust exists below it; this layer is weaker and more porous than the unaltered parent material.

The role of water in desert weathering is limited. The products are transported largely by wind and gravity; this tends to create poorly graded deposits of widely different particle size, characterized either by coarse, angular screes (debris heaps) or by aeolian (windblown) dunes, mostly of fine sand and silt. The prevalence of limestones, which weather readily by solution after some mechanical disintegration, combined with the limited movement of surface water, restricts the supply of alluvium. Subsequently, clean, well-graded alluvial sands and gravels are absent from many areas. The superficial deposits considered for use as aggregates in the areas of interest vary widely. Alluvial gravel and sand predominate in Kuwait, along the Oman shore in the Gulf of Oman to Muscat, and also near the common border of Qatar, United Arab Emirates (UAE), and Saudi Arabia. Coastal salt flats or "sabkha" form most of the coastal areas of Saudi Arabia and the UAE. Inland in Saudi Arabia, behind the sabkha, are extensive areas of mainly carbonate rocks with widespread cover of calcrete/dolocrete duricrust. Near Qatar, the soil changes to aeolian sands. The aeolian sands form most of the inland areas of the UAE and extend all the way to the coast from west of Abu Dhabi in the UAE to the Strait of Hormuz. Qatar and Bahrain are mostly carbonate rocks with a duricrust.

1. Alluvial sands and gravels. Downward leaching generally occurs within the limited areas of modern alluviation, and is practically confined to the mountains and their fringes, where periodic flooding may prevent the building of sulphates and chlorides. However, cementation by the less soluble carbonates may still develop, especially in coarse deposits not moved by floods. Active wadis (ravines through which a stream flows) within the mountains and limited parts of their alluvial fans where they emerge onto the desert plains are thus the main sources of relatively clean, well-graded sands and gravels. The deposits are generally torrent-bedded and poorly sorted, so a single pit may be a useful source of well-graded material. The deposits of some active wadis are approaching exhaustion, and all are of limited extent.

Many of the older deposits tend to be cemented with gypsum and/or carbonate and contain friable particles of these materials, clays, or weathered rock; thus, their removal and subsequent crushing is a very dusty operation, and the gravel must be washed before use. The gravel deposits of the Oman Mountains are often rich in serpentinized olivine rocks that contain some unaltered alivine. This source is usually a potential problem in concrete, but for some decades, the fresh gravels from these mountains have given satisfactory service in concrete and asphalt. The older gravel sheets and terraces that occur in Kuwait are workable, if suitable techniques are used. The product will often have good mechanical properties, but will suffer from sulphate contamination. These gravels are usually deficient as sources of fine aggregate because of their cementing by gypsum. Any natural or crushed rock fines produced are usually heavily contaminated by gypsum. Natural silica sands are worked in Kuwait and Qatar, but compared with carbonate sands, they are generally rare in the Gulf area. They usually occur between a layer of gypcrust (calcium sulphate) and a basal gypcrete, the thickness of chemically acceptable sand ranging from 3 to 20 ft (0.9 to 6 m).

2. Coastal sands. The absence of permanent rivers, a corresponding lack of water-deposited silica sands, and the poor gradings of aeolian dunes depend greatly on beach and coastal sands as sources of fine aggregate. These deposits are mainly carbonate sands, consisting of the worn debris of young marine organisms. Carbonate sands are composed largely or wholly of fragile shells or shell fragments of calcium carbonate. The particle shape can vary from round to elliptical to lense-shaped, depending on the type of shells that make up the sand. Coral tends to make irregular, blocky particles. Some carbonate sands are very brittle and fragile. When the grains are smooth and rounded, the sands may provide good workability in concrete but may also be absorptive, have poor gradings, and trap air, chlorides, and sulphates in their porous, sometimes hollow, particles. Many of the older carbonate sands may have experienced some recrystallization of carbonate particles and fusion at contact points, thus making them very difficult to dig and process. Coastal sands, being more or less sorted by wave or current action, may have narrower (and often finer) gradings than are preferred for asphalt or portland cement concrete. They may also contain some hollow shells that may have to be screened off to avoid adverse effects on the strength or density of concrete or asphalt mixes. The proportion of hollow shells retained on a No. 8 sieve should not exceed 3 percent by weight of the entire aggregate samples.

The mixture design can partly compensate for the effects of a poor grading or a high water demand. If this compensation has been made satisfactorily, the main difficulties in the use of beach sands as fine aggregate will most likely be related to unacceptable chloride and sulphate levels, especially where pits have been worked to the water table and allowed to develop into evaporating pans. In these cases, extensive washing of the chloride- or sulphate-loaded sands with nonsaline water may be needed. Coasts facing the prevailing wind may experience further sand-size sorting. Behind the modern beach, there may be wide zones in which the coastal sands are being redistributed and modified into true aeolian dunes. Sand from these areas will tend to become finer and more rounded with increasing distance from the coast because of sorting and polishing by the wind.

3. Windblown (Aeolian) sands. Windblown deposits such as dunes, ripples and ridges, drifts, sand shadows, and screes will be a principal source of fine aggregate. A true dune is a mound or hill of sand that rises to a single summit or peak. Dunes may exist alone or be attached to one another in colonies or dune chains whose coincides with that of the prevailing wind. Dunes can exist independently of any other desert surface feature. Ripples and ridges can occur in certain types of sands and under certain wind conditions. Sand shadows and sand drifts that are caused by a fixed obstruction in the path of a sand-driving wind form behind the obstruction. Angular screes or debris heaps occur when the wind drives off the sand leaving only a coarser material behind. The products that are transported largely by wind and gravity tend to create poorly graded deposits of widely different particle size and generally are viewed with disfavor for use in concrete because of their narrow, fine gradings with silt contents often of about 10 percent. However, they can be used in the absence of more suitable sources.

4. Dunes. Dunes have many, and varied forms -- so many, in fact, that it is hard to define a universal classification. The simplest forms are commonly known as the barchan or crescent dune and the seif or longitudinal dune. They are all composed of the same type of material; their shapes and sizes are

determined mostly by the prevailing winds. The grading of the material composing a barchan dune is nearly homogeneous from the summit downwards to within a height above the ground of about 5 percent of the summit. This material is usually finer than would be desirable for use in concrete. Below this material, on the windward side, according to the nature of the surrounding country, there may be a fringe of coarse grains and small pebbles that could be used in concrete. This fringe is only superficial and will not extend deeply into the dune. As the barchan dune moves with the direction of the prevailing wind, it leaves behind this coarser marterial and forms a wake of coarse material ridges that could be recovered for use. These ridges can be located by progressing away from the dune and into the wind. For asphalt or portland cement concrete, use only the sand from the top of the windward side of a barchan dune. Avoid using the sand from the bottom of the ship face because it will usually be too fine. The grain-size distribution in the seif dune varies markedly from that of the barchan dune; the coarser grains tend to collect at the foot of the ship face. Coarse-grained residues or platforms, built up and left behind by the passage of a long-continued succession of seif dunes along the same path, are also good sources of coarser grained material.

Dunes can occur both near coastal areas and in the desert. Their location will generally determine their mineralogical composition and grading. In coastal dunes, the grading has been predetermined by the water's flow conditions. The material supplied at any one place is usually very uniform in grain size. Sea sand, which feeds dune growth, tends to be conspicuously free of large grains. The finer grains are deposited on the shore and left high and dry. In desert dunes, the place of origin of the grains is usually obvious, such as an escarpment or a series of depressions where wind erosion is taking place. These dunes tend to have less salt contamination unless they are downwind from sabkhas or salines. Dunes at the leeward edge of sabkhas may be largely composed of gypsum. The range of sand gradings available in dunes is presented in Chapter 7.

5. Ripples and ridges. Pronounced rippling or waving of sand surfaces can occur in sands that have a range of grain size. As the wind carries off the fine sand grains, the coarser grains collect and form periodic crests. Since these grains are not easily moved, they protect the crest and allow it to rise into a region of stronger wind than would otherwise be possible. These ripples can be selectively processed to provide a sand suitable for use in concrete; however, the process may be very labor-intensive.

6. Crushed rock aggregates. Where suitable sands and gravels are unobtainable, crushed rock may be used for both coarse and fine aggregate. The prevalence of limestone has been mentioned, and there may also be local outcroppings of other rock types that may be suitable. Much of the coarse aggregate used in the Gulf, however, has been obtained from the calcrete layer or "pavement" as it is often called. The calcrete pavement is either exposed at the surface or reached by removing a cover of gypcrust or wind-blown sand. For many years, especially in Bahrain and Qatar, calcrete has been worked by prying up loose blocks from the surface for transport to a local crusher. Typically, Gulf calcretes are at least 3 ft (0.9 m) thick and sometimes 16 ft (4.8 m) or more; therefore, quarrying by conventional drilling and blasting is a possibility. Because the calcrete usually has no definite base, passing gradually into the unhardened limestone below, the depth of working must be carefully controlled to maintain product quality. Most calcretes

traditionally used in the area cannot be considered first class materials on purely physical and mechanical grounds, besides their possible chemical problems. One difficulty arises from the random and variable nature of the deposition and hardening process; this causes a lack of consistency in properties such as aggregate crushing value and water absorption. Like other limestones, most calcretes are very dusty when crushed. Crushed rock sands have a poor particle shape and correspondingly adverse effect on concrete workability and density; however, their main drawback, especially where they are derived from calcretes, is that contaminants in the natural stone tend to become concentrated in the fine fraction during crushing. These crushed rock sands may contain as much as 25 percent of total impurities such as gypsum flour, chlorides, clays, and silts. The dust creates a high-water demand in concrete aggregates; there will be shrinkage and other problems associated with a high-water/cement ratio unless the dust is removed.

Special consideration must be given to how aggregate is obtained for processing. In downward leaching areas, contamination by aggressive salts will not usually be serious. However, these areas tend to be localized and contained within generally saline environments. Calcrete development can proceed where more soluble substances are leached downward; then bodies of carbonate-cemented materials may impede the working of a gravel deposit and increase dust. When present, rocks decomposable by weathering, especially igneous rocks, may increase the proportion of unsound material in the aggregate, whether crushed gravel or quarried rock. Processing techniques may have to be designed to reject this material; much dust may result. However, in downward leaching areas, there is a better chance of water being available for dust suppression and washing. In upward leaching areas, selective working of both natural aggregates and quarried rock will usually be necessary. In the Gulf region, much quarried rock will be limestone or its associated calcrete duricrust. If there is a surface layer contaminated with chlorides and sulfates (e.g., gypcrust), this layer will have to be stripped off and wasted. Because of the widespread presence of chemical contamination near the surface, quarried rock will often be preferred to the traditional hand-picked surface stone, if the required physical properties are maintained to an adequate depth.

Quarried calcretes, after removal of any contaminated surface layer, will also need selective processing to avoid inclusion of the clay pockets and crystals of gypsum or other salts. The rock should appear uniform in hardness and color. Selection can normally be made by eye with a little experience. A useful technique presently used in Saudi Arabia prescreens the quarried material on grizzly screens and rejects the material smaller than 2 to 3 in. (51 to 76 mm) before transferring the oversized rock to the crusher. More than one stage of scalping will improve the product. Multistage scalping really helps the situation but can easily produce waste that represents 50 percent of the volume quarried. Hand selection of rocks from a blown face is an alternative to selection by scalping on a grizzly. Usual processing techniques have a high energy demand. A more suitable method for troops would be to use a bulldozer with a ripper to work only the upper surface of the rock, after removal of any gypcrust or other overburden. Calcrete can usually be ripped only in the open-jointed zone extending to about 3 ft (0.9 m) below the rockhead. If tracked vehicles are operated over the ripped surface and perforated loading shovels are used, most contaminants and inferior rock can be left behind in the worked area. These methods have been used widely on calcrete pavements in Qatar and Bahrain, but they lay waste to wide areas and produce uncontrollable quantities of dust. Gypsum-cemented gravels may be released from their matrix, where there is gypcrust and not gypcrete, by extensive working and processing. Repeated traversing of an area by bulldozer and ripper will sometimes release the gravels; the disaggregated product can then be loaded on screens and the gypsum content reduced by rejection of the undersized fraction. The use of impact or cone crushers, followed by further stages of scalping and a final washing to remove dust (if water is available), should further reduce the sulphate contents.

7. Aggregates for pavements. Properly graded materials for unbound pavement construction are often not available from natural sources without screening and recombining different-sized fractions. Crushing may also be necessary to increase or create a fine fraction. Most of the desert surface is covered by lag gravel, highly fractured calcrete, or aeolian sand, which seldom yields significant material in the middle-sized ranges.

10.2.10 *Concrete Reinforcement*

There is no commercial production of reinforcing steel in the Middle East. All reinforcing steel is imported, mostly from Japan, and is usually available in a wide range of sizes.

10.2.11 *Expedient Reinforcement*

Any type of construction in specific regions may be made with materials available in the region. In some parts of the Middle East, the conventional steel reinforcing bar is one of the most scarce or unavailable construction materials. Some materials, not indigenous, may be available in remote areas or as part of the mobilization materials of the military forces and can substitute for conventional reinforcing materials. Some of these are military wire rope, landing mat, landing mat tie bars, concertina wire, and high tensile steel barbed wire.

10.2.12 *Portland Cement*

Although there is some local cement production in the region, most cement will have to be imported. Many countries ship cement into the region, and it varies in quality. In general, there will be no control over what is received and its quality. If possible, sulfate-resistant and low-heat cements should be used. These are the predominant types imported. Unless bulk handling capabilities are available locally, troop manpower will not be able to handle and transport large quantities of cement with their equipment. Bag handling of cement is very slow, labor-intensive, and not recommended except as a last resort. If none exists locally, airtight storage, which is best accomplished by rubberized bulk bags, must be provided in all coastal areas. Any prolonged storage at the high temperatures of the region will cause the cement to degrade.

10.2.13 *Concrete*

The general absence of good-quality aggregate, both fine and coarse, which makes up 85 percent of the concrete, coupled with a lack of suitable quantities of water for concreting operations will present a challenge to troop construction. High temperatures and strong prevailing winds associated with the area will further compound the problem. The engineer support associated with the size of the operation will probably not have the production equipment needed to make anything more than occasional batches of concrete. Once made, transportation of the concrete will be a problem due to limited vehicular support and lack of suitable surfaces over which to transport it.

Adequate commercial concrete production facilities are widely scattered throughout the Middle East. In areas away from population centers, concrete production will be restricted to the facilities available in the construction support unit, which will consist of small-volume mixers and thus greatly limit concrete production. Unless there is a large supply of local concrete trucks or other methods of moving concrete, the vehicular support for the moving of concrete can be expected to be very limited. Generally, the engineer unit will have no agitating delivery equipment and is restricted to using dump trucks. In most areas, the surfaces over which fully loaded concrete or dump trucks must travel is less than satisfactory. Partial loads may alleviate the problem. Haul times for the concrete must be very short because of the high temperatures, rapid evaporation of batch water, salt concentrations in the aggregate, and lack of agitation. These times could be extended by the use of chemical admixtures.

Most concrete proportioning schemes are dictated by the locally available materials, which are highly variable. The existing technology for developing predetermined concrete mixture designs is limited. The principal problem is that there is no quantifiable base for changing aggregate factors expressed as a percent of the total aggregate as the aggregate characteristics change. Excessive fines, which have a higher water demand, and salt contents, which require higher cement contents to compensate for strength loss, further complicate the problem. The proportions shown in Table 7-4 can be used as beginning points for developing a suitable mixture. Adjustments in the amount of ingredients can be made, usually to obtain a mixture that can be easily placed. The amount of water used in concrete should be kept to the least amount needed to make the concrete workable. The use of chemical admixtures, such as water reducing, retarding, and superplasticizing admixtures, are available for reduced water requirements, improved consistency, and extended working time. However, these admixtures will all have to be brought into the area.

The very hot temperatures of the Middle East will affect the consistency of the fresh concrete and make it very difficult to place. Most of the concrete will have been made with high water/cement ratios, high cement contents, and aggregates that promote bleeding. The concrete will receive little, if any, consolidation treatment. In the case of flatwork, it may even be spread by a road grader or dozer rather than conventional screeds. The cement, aggregate, and mixing water can all be expected to be about 115°F (46°C) at the time of batching; the final concrete temperature will be even higher. This temperature is very undesirable for many reasons. Shaped storage should be provided for both the cement and aggregate to reduce their initial temperatures. As noted earlier, the sprinkling of aggregate stockpiles to cool them may create other problems. Some type of cooling should be applied to the mixing water through either a cooling plant or by adding ice. If possible, all mixers should be painted white to help relieve the solar heat development problem. When mixed, concrete temperatures should be kept as low as possible.

Quality control of the concrete ingredients and the freshly mixed concrete can be expected to be nonexistent. The technical specialist in the engineer unit is responsible for the concrete technology; without special training in the materials and problems of this region, he or she will not be able to respond satisfactorily to problems as they occur. If any quality-control programs are begun, the control tests must be very simple and rapid. Some of the established tests do not fit these criteria.

There will be short finishing times due to the area's hot temperatures and strong winds. Shading and windscreens are a necessity to prolong the finishing period and to reduce evaporation from the concrete surface. The quality of finishing will be marginal because the labor can be considered unskilled. Although rapid production will be required, some curing will be needed to avoid excessive and severe plastic and drying shrinkage cracking. The general lack of water suggests that either curing compounds or curing membranes be used. Either of the two would have to be brought in. Any water suitable for mixing concrete can also be used to cure it. As noted above, windscreens and shades would also be a great help.

10.2.14 *Rolled Compacted Concrete*

This new construction method will apply when rapid placement of slabs on grade, such as paving for highways and airports, is desired and also when specialized equipment (slip forms, conventional pavers) and skilled labor are absent. Most of the problems generally associated with desert weather concrete work -- such as increased water demand, slump loss, and plastic shrinkage cracking -- are not severe in rolled compacted concrete (RCC) construction, primarily because of low water requirements and the method of transportation, placement, and compaction used. Basically, the method is a no-slump concrete transported by a truck, spread by a front-end loader, and compacted by a vibratory roller. The water content (pounds per cubic yard) for manufactured aggregates must be between 195 lb (88 kg) for 3/8-in. (10-mm) maximum size aggregates to 130 lb (59 kg) for 6-in. (152-mm) maximum size aggregate. When natural aggregates are used, the water content may have to be adjusted. The RCC must be placed in layers that are thin enough to allow complete compaction by the vibratory roller. The optimum placement layers range from 8 to 12 in. (203 to 305 mm). Spreading is aided by consistent and symmetrical placing. Rubber-tired hauling equipment can operate on the freshly compacted surface with no adverse effects on the concrete. However, provisions must be taken to keep the hauling equipment from tracking in mud and dirt, which would have an adverse effect on concrete quality. The minimum number of passes for a given vibrating roller to achieve full consolidation depends mostly on the concrete mix and layer thickness. Tests should be done before or during the operation to determine the minimum number of passes. Generally, and to illustrate production and complementary equipment, a 6-ft-wide (1.8-m) vibratory roller (of appropriate design) must make four passes at a speed of 2 miles per hour in a 10-in. (254-mm) layer of no-slump concrete. At this rate and profile, the roller can compact more than 350 cu yd (266 m^3) per hour. A conventional batch plant would require about four 4-cu yd (3 m^3) mixers or one large 12 cu yd (9 m^3) mixer to match the compaction capabilities of one large roller on a continuous placement operation. The required curing and protection of the RCC is generally consistent with the treatment needed for conventional concrete.

10.3 Cement Production Facilities (From CEMBUREAU)

AFGANISTAN

City	Projected Capacities, Metric Tons	Year
1. Pol-i-Khomri	NA*	NA
2. Herat	NA	NA
3. Jabul-e-Seraj	NA	NA
4. Kandahar	NA	NA

BAHARIN

DJIBOUTI

EGYPT

5. El-Mex	800,000	1982
6. Helwan	5,000,000	1982
7. Tourah	1,600,000	1982
8. Suez	1,000,000	1981
9. Quattamia	1,400,000	1983
10. El-Tabbin, Helwan	300,000	1983

ETHIOPIA

11. Addis Ababa	75,000	1980
12. Dire Dawa	30,000	1980
13. Gurgussum, Massawa	40,000	1980
14. Asmara	NA	NA

IRAN

15. Doroud	1,350,000	1979
16. Shirez	900,000	1979
17. Abyek	2,100,000	1979
18. Behbehan	850,000	1979
19. Isfahan	650,000	1979
20. Kerman	1,500,000	1980
21. Loshan	720,000	1979
22. Rey	148,000	1980
23. Mashhad	560,000	1979
24. Soufian	850,000	1979
25. Damavand	675,000	1979
26. Shemal	90,000	1979
27. Tehran	2,340,000	1979
28. Aryamehr, Isfahan	2,000,000	1979
29. Kermanshah	660,000	1979
30. Neka	600,000	1979

*NA = Not available.

City	Projected Capacities	Year
IRAN (Cont'd)		
31. Kerman	700,000	1979
32. Hamadan	600,000	NA
33. Bandar Abbas	1,000,000	NA
34. Ghom	600,000	NA
IRAQ		
35. Baghdad	NA	NA
36. Falluja I	NA	NA
37. Falluja II	NA	NA
38. Hindiyah Barrage	NA	NA
39. Kufa I	NA	NA
40. Kufa II	NA	NA
41. Badoosh	NA	NA
42. Hammam Al-Alil	NA	NA
43. Samawah	NA	NA
44. Um Qasr	NA	NA
45. Sarchinar, Sulaimaniyah	270,000	1980
ISRAEL		
46. Har-Tuv	800,000	1982
47. Ramla	1,000,000	1982
48. Haifa	1,000,000	1982
JORDAN		
49. Fuhais	1,800,000	1982
50. Qasr-El-Hallabat	1,200,000	1980
KUWAIT		
51. Shuaiba	1,425,000	1980
LEBANON		
52. Chekka (Hery)	1,900,000	1980
53. Chekka (Private Port)	450,000	1979
54. Chekka	153,000	1980
OMAN	NA	NA

City	Projected Capacities	Year
PAKISTAN		
55. Wah R.S. Rawalpindi	450,000	1980
56. Rohri, Sukkur	270,000	1980
57. Gharibwal, Distt., Jhelum	540,000	1980
58. Manghopir, Karachi 26	280,000	1980
59. Iskanderabad, Distt., Mianwali	255,000	1980
60. Abottabad-District Hattar	660,000	1980
61. Shantinagar, Karachi 12	180,000	1980
62. Dandot, District Jhelum	58,000	1980
63. Iskanderabad, Distr., Mianwali	15,000	1980
64. Hyderabad	1,080,000	1980
P.D.R. YEMEN	NA	NA
QATAR		
65. Doha	270,000	1980
SAUDI ARABIA		
66. Jeddah	600,000	1982
67. Rabigh	1,350,000	NA
68. Qassim	600,000	1981
69. Hofuf	1,350,000	1980
70. Ain-Dar	1,900,000	1981
71. Riyadh	1,300,000	1980
72. Jizan	1,400,000	1983
73. Yanbu	350,000	1980
SOMOLIA	NA	NA
SUDAN	NA	NA
SYRIA		
74. Adra-Damascus	550,000	1980
75. Bourg Islam	82,000	1979
76. Muslimiyeh	450,000	1979
77. Sheik Said	202,000	1979
78. Hama I	110,000	1979
79. Hama II	412,000	1979
80. Dummar	280,000	1979
81. Tartous	NA	NA

City	Projected Capacities	Year
TURKEY	NA	NA
UNITED ARAB EMIRATES	NA	NA
YEMEN, ARAB REB.		
82. Bajil	80,000	1980

10.4 Concrete Block Plants Operating in Mid-East

Kuwait

National Industries Company
P.O. Box 3358, Safat
Kuwait, Arabian Gulf

Abdulla A. Al-Ayoub & Bros.
B.O. Box 155, Safat
Kuwait, Arabian Gulf

United Arab Emirates

Raknor Private Ltd.
P.O. Box 883
Khor Khuwair
Ras Al Khaimah, U.A.E.

Saudi Arabia

Dabbagh Establishment
P.O. Box 2677
Jeddah, Saudi Arabia

Almoajil Cement Products Plant
P.O. Box 53
Dammam, Saudi Arabia

Al-Ghazi Trading & Importing Co.
P.O. Box 4105
Jeddah, Saudi Arabia

Sam Whan Corp. of Korea
P.O. Box 5743
Riyadh, Saudi Arabia

Kong Yung Construction Co., Ltd.
P.O. Box 1035
Dammam, Saudi Arabia

Kuk Dong Construction Co. Ltd.
P.O. Box 1752
Dammam, Saudi Arabia

S.A.I.C. Ltd.
P.O. Box 900
South Central Market Street
Jeddah, Saudi Arabia
  Plant Sites: Jeddah & Rihadh

Tradco Vulcan/Aramco
P.O. Box 84
Dhahran Airport
Dhahran, Saudi Arabia
  Plant Sites: Dhahran & Abqal

LIST OF ABBREVIATIONS

AFCS	Army Facility Component System
BCY	In-Bank Cubic Yards
BDL	Beach Discharge Light
DCPD	Dicyclopentadiene
DP	Dipentene
GEP	Gas Engine Powered
GP	General Purpose
IBCF	In-Bank Correction Factor
ISB	Intermediate Staging Bases
LASH	Lighter Aboard Ship
LCY	Loose Cubic Yards
LOC	Lines of Communication
LP	Liquid Propane
LWRU	Laundry Wastewater Reuse Unit
MEP	Mobile Electric Power
MEPP	Mobile Electric Power Program
MTBF	Mean Time Between Failures
NBC	Nuclear, Biological, Chemical
OCONUS	Outside Continental United States
OGD	On-the-Ground Distribution
OHD	Overhead Distribution
RCC	Rolled Compacted Concrete
RDF	Rapid Deployment Force
RO/RO	Roll On/Roll Off
ROWPU	Reverse Osmosis Water Purification Unit
SAE	Society of Automotive Engineers
SF	Swell Factor
SWA	Southwest Asia
SWRU	Shower Wastewater Reuse Unit
TENV	Totally Enclosed Non-Ventilated
TG	Tactical Generators
TO	Theater of Operations
TOE	Table of Organization and Equipment
TWDS	Tactical Water Distribution Set
UGD	Underground Distribution
USE	Underground Secondary Electrical
USMC	U.S. Marine Corps
WPU	Water Purification Unit

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