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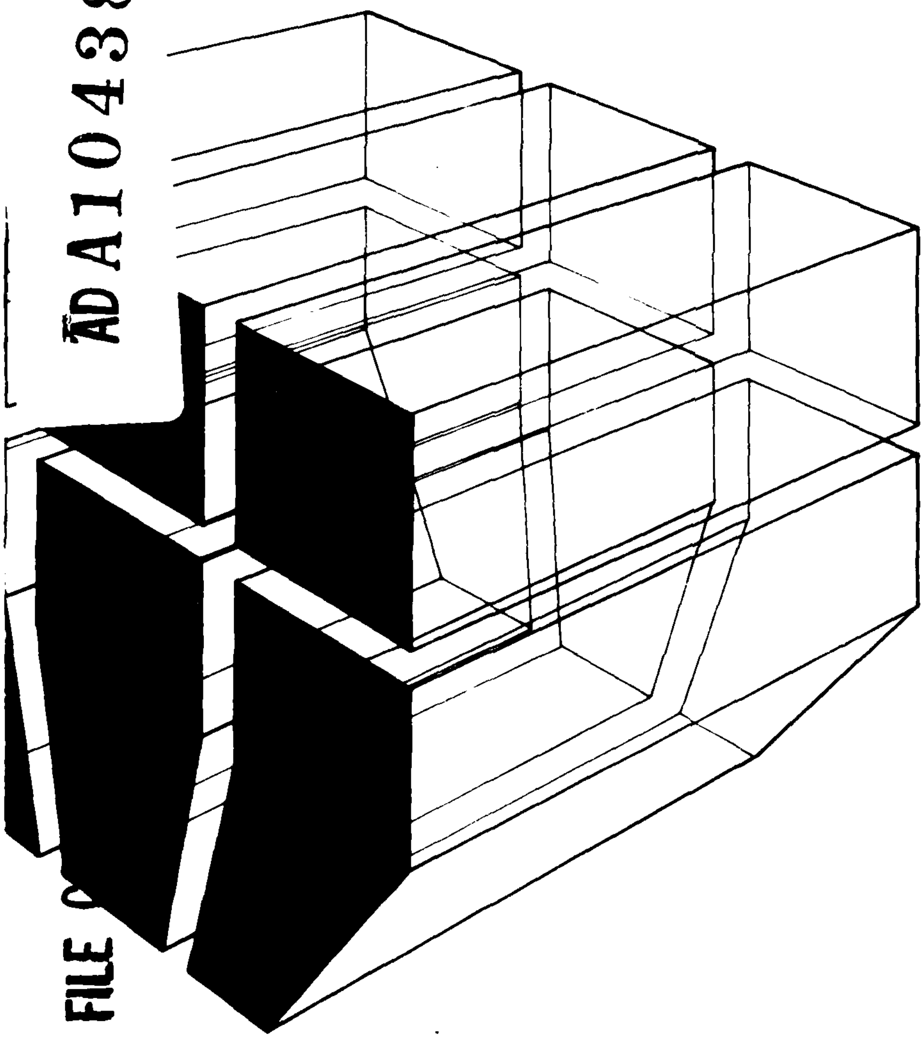
THEATER OF OPERATIONS CONSTRUCTION IN THE DESERT: A HANDBOOK OF LESSONS LEARNED IN THE MIDDLE EAST



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A. M. Kao
P. F. Hadala

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This report consolidates available lessons learned on materials, equipment, planning and design, and construction for use by planners and builders for theaters of operations in the desert regions of Southwest Asia. The topic areas reviewed are: base design, base protection, electrical generation and distribution, water, vertical and horizontal construction, and engineer work factors.

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Purpose

The purpose of this interim report is to consolidate available lessons learned on material, equipment, planning and design, and construction for use by planners and builders for theaters of operations (TOs) in the desert regions of Southwest Asia. This executive summary presents the most significant findings and recommendations of the study.

Assumptions

1. The areas of concern are the desert regions of Southwest Asia.

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

3. Strategic air and sea lines of communication (LOC) terminus points will be constrained to current existing facilities.

4. Some areas in the TO will be subject to hostile fire, and 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.

Base Design

The facilities provided in a TO have a vital impact on military operations. 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. This 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.

Site Selection

The most critical issue in site selection is the availability of a reliable water supply. Chapter 5 of this report details issues related to water supply and distribution in Southwest Asia.

Although desert regions receive little rainfall, when there are rainstorms, they are often intense and of short duration, with associated flash flooding. Bases and facilities should not be sited in natural drainage channels subject to flash flooding.

Base Planning

Summer air temperatures in Southwest Asia can range to 131°F and above. Winds are virtually unceasing, moving great volumes of hot, dry air and abrasive soil particles. Buildings should be grouped in oblong blocks oriented in an east-west pattern to minimize wall exposure to the sun. Buildings should include overhangs or arcades, where possible, to provide additional shade. Building heights should be kept low and uniform to reduce wind turbulence. Street and open space patterns should be designed perpendicular to the wind. Elevation of roadways above surrounding terrain may mitigate some effects of the wind. When time and situation permit, a barrier can be constructed around an installation to divert prevailing winds.

Base Protection

Base protection incorporates camouflage, explosive excavation, mine use, field fortifications, and installation physical security. 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, such as timber and steel, for overhead cover.

Camouflage

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 Field Manual [FM] 90-3, Desert Operations.) Dispersion of 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. 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.

Explosive Excavation

Large soil volumes may have to be excavated for tank obstacles, storage below ground, or field fortifications. The principal problems are (1) emplacing the explosives deep enough to use their full potential, and (2) predicting the resulting crater. The emplacement problem will be difficult in some of the cemented desert soils. Drilling equipment and/or shaped charges offer the only practical solution.

Mine Use

Mine warfare has required major engineer 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 might cause difficulty in using mines to prevent intrusion:

1. Certain cemented or gravelly soils will be difficult to dig for underground emplacement of mines, and, when dug, leave an obvious signature.

2. Drifting sands can cover buried mines so deeply that they will not be effective, and can expose mines that have been previously buried.

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, items such as rails and railroad crossties, beams, and joists from demolished buildings may be available. Competition for such salvaged materials among other high priority uses should be expected. For one- or two-man fighting positions, the problems will be digging certain soils and providing overhead cover. Recently developed concepts for overhead cover support systems -- such as the mylar coated foxhole cover (MIL-C-52707) -- may help solve these problems.

Horizontal Construction

Because of the limited number of existing roads and the difficulty of off-road mobility in the desert, considerable effort may be required to construct, rehabilitate, 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 Technical Manual [TM] 5-330 and TM 5-337 [C1]). In addition, engineer capabilities in horizontal construction will be used in excavation and construction of revetments for ammunition, in POL storage, in the repair of bomb-damaged or sabotaged airfields, and in the construction of assault airstrips and heliports.

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. The two positive notes are: (1) fine and coarse aggregates are widely available, and (2) 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, the capabilities must be available 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 as well as asphalt products, water (seawater is adequate for most requirements), and construction equipment in quantity. Indigenous materials alone are insufficient.

Existing Construction

Where paved roads exist, they will generally be structurally adequate for wheeled-vehicle traffic. Because the area is sparsely populated, few roads exist. This, coupled with poor off-road mobility in sandy areas, increases the size of the road construction workload. Cities and large towns are usually connected by paved roads, but these are often narrow (6-m width) and have thin pavements that will not stand up under use by tracked vehicles. Consideration should be given to widening the shoulders of such roads and using the shoulder for tracked-vehicle operations.

Subsurface Conditions

A concise description of engineering properties of various geographic units found in desert areas is provided in an article by P. G. Fookes.* This should be read by personnel responsible for route and materials selection for horizontal construction. Desert regions can be subdivided into four geographic zones: mountain slopes, the apron fan or bajada, the alluvial plain, and the base plain, which includes subkhas, playas, salt playas, salinas, and sand-dune areas.

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 significant maintenance problems at roadways, airfields, and base areas. Sand also hinders off-road mobility of wheeled vehicles. Mountainous areas account for 35 to 50 percent of desert regions.

Vertical Construction

The chapter on vertical construction identifies unusual construction problems that may be encountered and environmental problems that need to be considered in constructing facilities in desert regions. The chapter also provides recommended methods to eliminate the identified problems or to reduce their impacts. Feasible local construction materials and construction techniques that can be adapted are also identified and described.

Buildings

High solar radiations and diurnal wide temperature variation create uncomfortable interior building conditions. These effects can be minimized by using slab-on-grade foundations, massive exterior walls of materials such as adobe brick, or insulated lightweight wall systems. Wall openings should be shaded during daytime, and outside air should not be used for ventilation

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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), pp 11-23.

during the day. Exterior walls should be light colored, but white should be avoided if glare is a problem. Roofs should reflect sunlight and provide insulation. Interior walls should be minimized.

Foundations must be deep enough to prevent aeolian erosion; soil at corners should be stabilized to prevent erosion. Windows and doors should be tight sealing. Roofs must be adequately secured to prevent wind damage.

Tents

Unconventional methods will be required to tie down tents. Recommended systems include deadman anchors for cohesionless soils, and grouted anchor bolts or wedge anchors in rock. Tents should be double roofed, with white outer roofs. In some situations, erecting tents over excavated holes may improve habitability.

Relocatable Buildings

Prefabricated relocatable buildings have been used extensively by contractors in Southwest Asia. These lightweight structures are adequately insulated, but require mechanical cooling if occupied during the day.

Construction Materials

Corrosive soils found in the region may react with portland cement. Galvanized steel is subject to corrosion and should be avoided in underground applications. Corrosion will also be a problem in areas near coastal regions.

Wood may crack or warp due to solar radiation and low humidity. In addition, wood is in short supply in Southwest Asia.

Locally available construction materials include aggregates, sands, mud for adobe, and bally poles. Expedient methods of using local materials for building construction are needed.

Water Supply, Distribution, and Treatment

Water supply and distribution may be the most critical element in base development in the Southwest Asian TO. The chapter on water is devoted to problems related to treatment, storage, transportation, distribution, use, and disposal.

Treatment

Reverse osmosis (RO) units are limited by the maximum temperature of the feed water. In some situations, feed water may exceed 95°F. Feedwater may have to be cooled to an acceptable level by cooling towers. Some commercial RO units may also be adversely affected by feedwaters with low pH.

Proper storage of treatment and test chemicals and all water supply equipment must be provided. For example, high temperature adversely affects calcium hypochlorite, and results of various common tests of water quality may be inaccurate due to the influence of high temperature.

Some aquifers in Southwest Asia may be contaminated by oil. Other less common contaminants -- such as ammonia, arsenic, and radioactive isotopes -- may be encountered. Aquifers near oil drilling facilities may be contaminated by slurries.

Use

Both discipline and common sense will be required to optimize use of the available supply of water. Reuse of water which would be discarded in other theaters will be required. Seawater, brackish, or otherwise nonpotable water can be used for construction purposes, including concrete production, for facilities having a short anticipated life.

Storage

Water stored in dark containers exposed to the sun can reach 200°F in Southwest Asia. High temperatures can lower the chlorine residual of treated water below acceptable levels. Open tanks must be covered closely to prevent entry of dirt and sand, and diseases such as schistosomiasis. These tanks should then be shaded with a second cover.

Transportation and Distribution

The use of insulated water trailers will reduce heat gain in portable water during transport. Water trailers should be shaded when used as temporary storage/distribution containers.

Pipelines for transporting water should be buried at approximately 18 in. if possible; this does not apply to rapidly relocatable systems such as the Tactical Water Distribution System (TWDS).

Measures must be taken to minimize wastage at final distribution points. Adapters and funnels should be used to eliminate spillage when filling canteens and other containers.

Production

Water supplies used by local populations may cause serious problems if used by troops without treatment or testing.

Vegetation is often a good indicator of groundwater in desert regions, as are old wells. Fresh water may be under salt water in many playas.

Well drilling operations take much time and equipment. Accurate location of suitable, high production groundwater sources is difficult with current state-of-the-art equipment.

Waste Disposal

The limited amount of wastewater which is not suitable for reuse can be effectively disposed of using septic tanks and leach fields. Burn-out and pit latrines are also acceptable methods of human waste disposal, especially if water supply for water-borne sewage is inadequate.

Electrical Generation and Distribution

In Southwest Asia, the requirement to provide adequate electrical energy for the modern integrated force is complicated by the often inhospitable environment. High temperatures, low humidity, and strong winds with associated blowing sands all adversely affect electrical generation and distribution systems.

Electrical Generation

High temperatures may adversely affect the performance of both tactical generators and nontactical generators such as those listed in the Army Facilities Component System (AFCS). Engine-generator sets should be sited so that the wind will carry away heat, not direct it toward another generator or an occupied area. It may be necessary to shade generator sets from direct sunlight to prevent over-temperature shut-down.

Generator sets should be protected, to the extent practical, from blowing sand and dust; of course, adequate ventilation is still required to prevent heat build-up. Exhaust ports and air intakes on nonoperating generator sets should be protected from blowing sands. Fuel and fuel tanks must be protected from blowing sands during refueling operations. An accelerated maintenance schedule must be anticipated.

Corrosive soils in the region may cause problems with various components of electrical systems, especially grounding systems. Galvanized steel grounding rods should not be used in corrosive soil.

In very dry desert soils, conventional power generation system grounding may be inadequate. In coastal regions, where the water table is relatively high, adequate ground may be obtained if several rods are used in parallel. Inland, where the water table is lower, more innovative ground systems are required. One recommended method is to use at least three ground rods connected in parallel, driven into a soil which is conditioned by injecting a conductive liquid, such as seawater, to saturate the subsoil around the ground rods. A system of drilled holes, with rods surrounded by bentonite or similar material may be needed in areas where ground rods cannot be driven.

Electrical Distribution

Low humidity and high temperature cause premature failure of wooden poles used for overhead distribution systems. High temperatures may lead to deformation of insulation. Use of underground distribution systems should be considered to provide protection from intense sunlight.

Host Nation Power

None of the countries in Southwest Asia has standardized power. Frequency and voltage vary from location to location. Distribution networks are limited. Chapter 4 of this report includes a list of power characteristics, by location, for the Middle East.

Port Construction

Certain geographic areas of operations may require use of beach sites for extended periods of time since now there are few -- or no -- facilities for handling containers in most Mid-East ports, and container terminals are only in the planning stage. Wooden and concrete jetties are used throughout the area for shipping crude and refined oil for local consumption and to export oil products.

Characteristics of ports in the Middle East are listed in Ports of the World, 33rd Edition (Benn Publishing Ltd., 1980), and Janes Freight Containers, 12th Edition (Franklin Watts, Inc., 1980). Data presented there indicate three common problems: (1) most ports in the region are not equipped to handle heavy cargo or container lifts, (2) some have less than 40-ft draft available in the channel or at dockside, and (3) warehouse space is very limited.

Factors Affecting Engineer Work Force

The desert is harsh; working conditions can be extremely difficult. High solar radiation, temperature, lack of water supply, and sand storms all contribute to the difficult environment. Chapter 9 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.

Effect on Construction Personnel

High solar radiation can cause heat cramps and heat exhaustion. Water and salt intake must be adequate. When practical, work should be done in the shade or under shelter. Shifts should be scheduled to avoid the hottest portion of the day if possible. Efficiency and production rates will be reduced during periods of high temperature.

Construction and Engineer Equipment Maintenance

Blown dust and sand, as well as extreme temperature, affect equipment as well as men. Accelerated maintenance schecules will be required. Protected maintenance areas will be required for repairs. Vehicle batteries will not operate at full efficiency at high temperatures. Expansion of fuel in tanks and air in tires is a potential problem. Fuel stored at high temperatures may degrade.

Local Labor Forces

Local labor forces in remote areas may be unskilled and unfamiliar with modern equipment and techniques. Simple construction practices may be best in such situations.

Summary

Findings in this report are based on actual field experiences and current knowledge of laboratory personnel, Corps of Engineers employees, and other Army personnel, and on a review of literature pertinent to construction in desert regions.

Harsh environmental conditions in the desert region of Southwest Asia are described. Potential problems that could be created by the environmental conditions are identified. Although some of these problem statements may seem fundamental and obvious, they represent illustrations and statements of principles which should not be ignored in desert environment. Possible solutions to the identified problems are given. However, a number of problems have no suggested solutions due to a lack of information and data. These problems need to be addressed in future research. This report also recommends not only additional studies required for some of the identified problems, but also actions that can be taken to improve the effectiveness of the Army in TO construction in Southwest Asia.

An attempt has been made to present available information that is as accurate and practical as possible in a concise, understandable format. However, it should be noted that this is an interim report and was prepared in a very short period of time. Therefore, it may contain errors or suggested solutions that may not be best for the given problems. Suggestions about improvement, corrections of information, additional material, and construction and equipment performance data will be welcomed from readers since only experience can lead to improvement and refinement of information contained in this report. Comments and recommendations should be sent to the Office of the Assistant Chief of Engineers, HQDA, WASH, DC 20310.

FOREWORD

This study was performed by the U.S. Army Construction Engineering Research Laboratory (CERL) and the U.S. Army Waterways Experiment Station (WES) for the Military Engineering Division, Office of the Chief of Engineers. CERL was the lead laboratory for the study. The work was done for the Defense Supply Service, under MIPR DSS-W-80-026, dated September 1980.

The following people contributed to the technical content of this report: Messrs. J. Benson, S. Koster, J. Matherly, R. McCormack, P. Nielsen, E. Smith, and CPT J. Buckwalter of CERL; and Messrs. J. R. Brown, L. N. Godwin, G. M. Hammitt, G. C. Hoff, W. L. Juft, L. E. Link, E. F. O'Neal, S. G. Tucker, S. L. Webster, and MAJ A. Monahan of WES.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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BASE DESIGN

THEATER OF OPERATION CONSTRUCTION IN THE DESERT: HANDBOOK OF LESSONS LEARNED IN THE MIDDLE EAST

1 INTRODUCTION

1.1 Background

The planning efforts for base development and operational contingencies in Southwest Asia involve unique environmental 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 activities in such areas.

1.2 Assumptions

1. The areas of concern are the desert regions of Southwest Asia.

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, and 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.

1.3 Approach and Scope

Findings in this report were based on actual field experiences and current knowledge of laboratory personnel and other Corps of Engineers employees, and on a review of literature pertinent to construction in desert regions. The report covers the various engineering disciplines involved in base development. These disciplines include base design (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 p E-1

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.

2.2 Planning and Siting

2.2.1 *Problem Statement*

Solar radiation beats down on desert regions with great intensity and is seldom diffused by clouds. Summer air temperatures range up to 131°F (55°C) in the daytime, with night temperatures dropping to 77°F (25°C). Ground temperatures are typically much hotter than these air temperatures, but vary dramatically depending on the ground surface. The exposure of desert facilities to direct sunlight can be minimized by careful design of both the site and the buildings.

Possible solutions:

1. Buildings.

a. Buildings should be grouped into oblong blocks set in an east-west direction to minimize wall exposure to the low sun angles of the morning and afternoon.

b. Building form should use large overhangs or arcades whenever possible to shade walls and openings.

2. Streets, walkways, and parkings areas.

a. Streets should be as narrow as practical, and building setbacks should be minimal so that the buildings can shade a good portion of the walks and streets for most of the day.

b. Parking areas should be at least partially shaded to prevent excessive buildup of heat. Shade can be provided by canvas, mats made out of local materials, building overhangs, and so on.

c. Only the major streets or roadways should be paved. Walks and parking areas should consist of light, coarse materials.

3. Vegetation. Plants act as a sun screen. Whenever possible, existing plants should be preserved and used to reduce the effect of high solar radiation.

2.2.2 *Problem Statement*

Wind in desert areas is practically unceasing and is a major climatic force which must be planned for in these regions. Because the wind moves great amounts of hot, dry air, it severely dehydrates the desert environment. In addition, the wind always carries fine soil particles which abrade building elements, clog mechanical devices, and accumulate on every surface. Because of its destructive potential, the wind must be lifted, deflected, and guided, yet simultaneously used to every advantage for ventilation.

Possible solutions:

1. Buildings. The height of buildings should be kept as low and uniform as possible. The taller buildings among low-rise buildings will create turbulence and eddies.

2. Installations. Where feasible, for longer standards of construction, some sort of barrier, such as the earth barrier shown in Figure 2.1, should be built around the perimeter of the installation to lift and carry the wind.

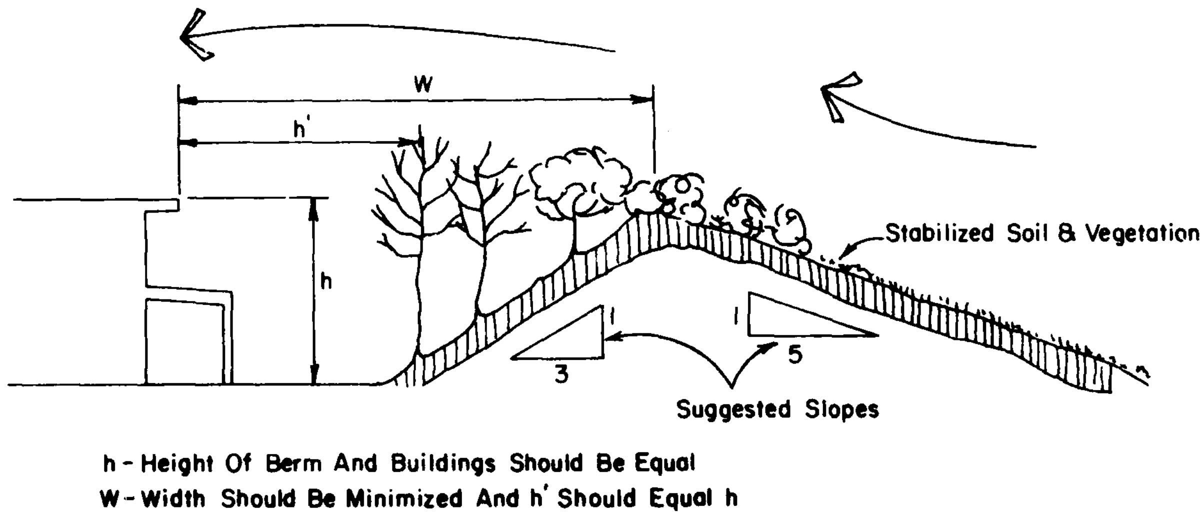

Figure 2.1. Earth barrier.

3. Streets and open spaces.

a. The street and open space patterns should be designed perpendicular to prevailing winds.

b. Open spaces should be limited in size and number as much as possible.

c. Roads, wherever possible, should be located just slightly above the surrounding terrain.

2.2.3 *Problem Statement*

The handling of drifting sand is a problem which cannot be satisfactorily solved without great expenditures of time and resources. Facilities must not be located where drifting sand may be a problem.

Possible solutions:

1. Where possible, drifting sand may be held temporarily with construction similar to the temporary snow fences used along highways in the United States; 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, and then allowing the wind to do the work.

2. Locate facilities where drifting sand is not anticipated to be a problem.

2.2.4 *Problem Statement*

Although much of the desert region rarely receives rain, when there is rainfall it is likely to be intense and sudden, and often causes flash floods because of the relative impermeability of the ground plane.

Possible solutions:

1. Locate natural drainage swales. They must be considered in the early stages of site planning.

2. Installations or buildings within an installation should be kept away from the flood plains of drainage swales.

3. Storm drainage systems should not be built; instead, natural drainage patterns should be established.

4. Buildings should be kept away from low points where there is the likelihood of ponding.

2.2.5 *Problem Statement*

An adequate water supply is critical to the operation of any desert installation. Access to a nearby water source, typically an underground aquifer, is vital to making a site feasible for development.

Possible solutions: see Chapter 5.

2.2.6 *Problem Statement*

Drainage may be critical where there are salt marshes. These are mosquito breeding areas and, in some instances, may present a drainage problem.

Possible solutions:

1. Once drained and properly graded, the hazards are usually permanently removed.

2. Apply "light" oils to the marshy areas to kill mosquito larvae.

3. Larvicides may also be used to kill mosquito larvae. If used, they should be applied by trained personnel since they may be toxic.

BASE PROTECTION

3 BASE PROTECTION

3.1 Introduction

This chapter discusses problems with base protection, which includes camouflage, explosive excavation, mine utilization, field fortifications, and installation physical security. Most of these problems are common to all theaters of operations 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 Camouflage

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, Appendix E1.) 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. Since Army stock camouflage items may not be available for rapid deployment, local materials can be used to fabricate acceptable alteratives. 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 expedient 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. The emplacement problem will be difficult in many of the cemented desert soils. Drilling equipment and/or shaped charges offer the only practical solution. 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.

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

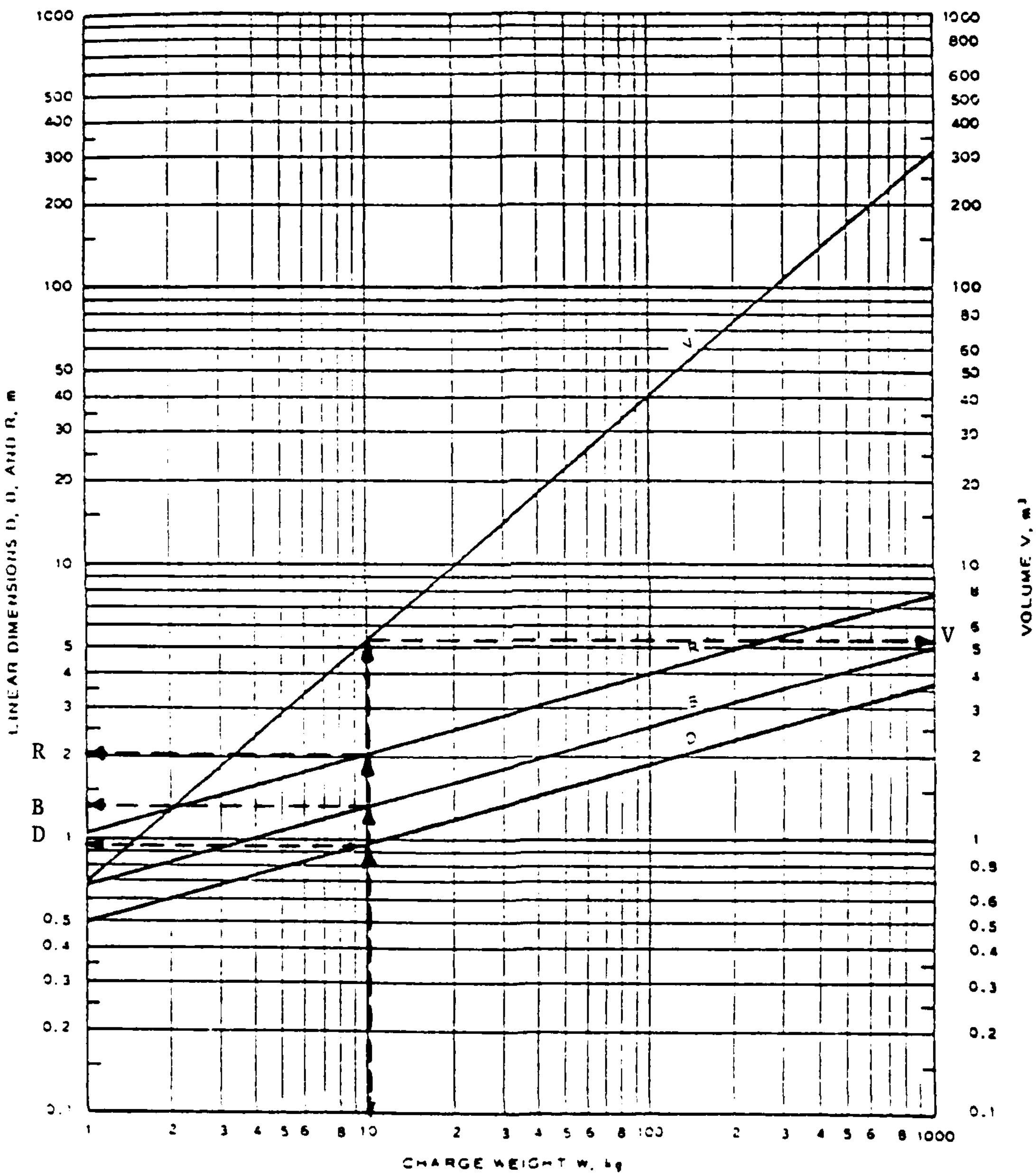

Figure 3.1. Optimum Depth of Charge Burial and Crater Dimensions for Optimally Buried Charges in Dry Gravelly Sand as Functions of Charge Weight.

B = Optimum Depth of Burial

V = Apparent Crater Volume

R = Apparent Crater Radius

D = Apparent Crater Depth

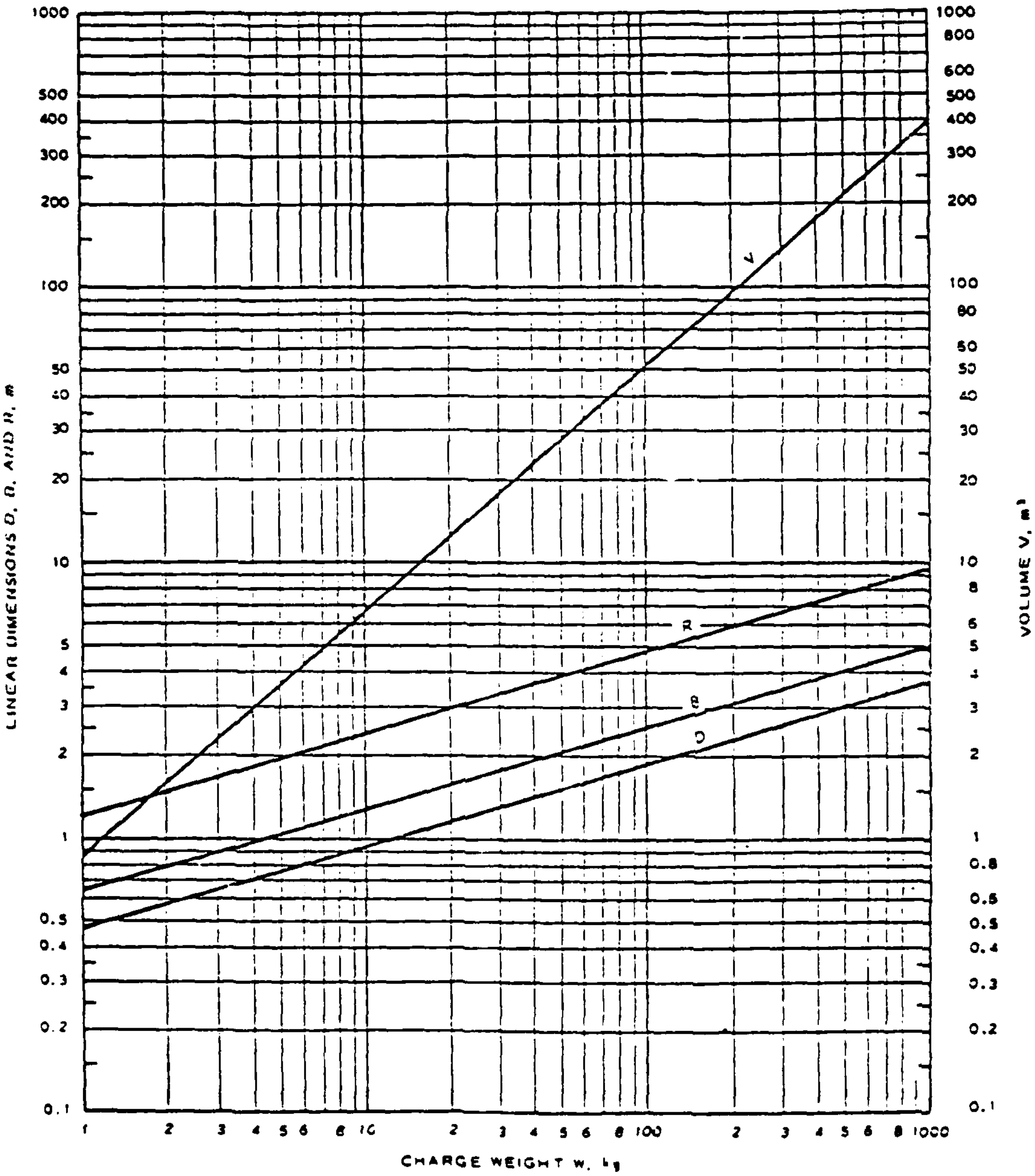

Figure 3.2. Optimum Depth of Charge Burial and Crater Dimensions for Optimally Buried Charges in Weak Sandstones and Shales as Functions of Charge Weight.

3.4 Mine Use

Mine warfare has required major engineer 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 might cause difficulty in using mines to prevent intrusion:

1. Certain cemented or gravelly soils will be difficult to dig for underground emplacement of mines, and, when dug, leave an obvious signature.

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 solve 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 Problems

3.6.1 *Problem Statement*

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, overhead cover that provides shade may be as important as providing 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 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.

Possible solutions: tubular sandbags for overhead cover. The sandbags are 200 cm long and 25 cm wide when empty. When filled and arched they can span a 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 back blast.

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 RDF's sandbag supply.

3.6.2 *Problem Statement*

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 which, without adequate ventilation, could make staying in the bunker unbearable.

Possible solutions: buried frame fabric shelters. These shelters can be fabricated from materials that will be found in built-up areas of the country and materials brough 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. and designed to support 18- to 24-in. 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. of soil cover will provide adequate fragmentation protection.

Special considerations: there are several frame-fabric shelters being considered for type classification. These shelters are lightweight and require little shipping space. The shelters can be erected rapidly by the users with engineer support required only for excavation and placement of soil cover. These shelters have been used by the Israelis in recent years.

3.6.3 *Problem Statement*

Camouflage of tracks, taxiways, pipelines, and other linear features.

Possible solutions: bury pipes, avoid straight lines; use thermal blankets and screens to break up lines and pattern 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.

Don'ts: do not employ common adhesives on taxiways. Loose sand and fire are hazards to jet engines.

Special considerations: pipelines, off-road tracks and taxiways are all highly visible linear signatures and keys to specific target locations. Brush and screens used in a random fashion along pipelines help to 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.

3.6.4 *Problem Statement*

Camouflage of electrical power generation.

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 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.

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.

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.

3.6.5 *Problem Statement*

Camouflage of tall towers and antennae.

Possible solutions: site tall features will 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. Use existing tall structures for antennae emplacements where feasible.

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.

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.

3.6.6 *Problem Statement*

Camouflage of individual buildings and shelters.

Possible solutions: use existing structures where possible and do not modify their exterior appearance. Disperse new structures, shelters, tentage in nongeometrical patterns tied into existing terrain features. Bury structures where forced to use open areas. Use adhesive and local soils for tone down of exposed surfaces. Conceal shadow 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 randomized road networks. Use decoy structures where appropriate to confuse 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, soybean, flour, molasses, etc.; garnish from straw, fabrics, canvas, and trash can be used. Supporting mesh can be made from chicken wire, old fish nets, etc.

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 any other highly identifiable features at a distance from critical headquarters buildings.

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 nettings 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.

3.6.7 *Problem Statement*

Camouflage of open material storage sites and fuel storage.

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 stocked 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.

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

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.

3.6.8 *Problem Statement*

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: minefield locations should be carefully selected with full knowledge of the possible adverse environmental impacts

3.6.9 *Problem Statement*

Featureless terrain without easily locatable landmarks makes finding and removing friendly minefields difficult.

Possible solutions: starting points should be located and recorded by taking azimuths and distances from more than one landmark and ensuring the landmarks are the most permanent terrain feature available.

3.6.10 *Problem Statement*

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 Resources Inventories, June 1972].)

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 and may be stored in areas up to 160°F. Little information was found on what has been done to improve the mines' ability to function in these extreme temperatures since World War II. However, mines placed in a desert environment may reach temperatures greater than 150°F, due to solar heating, especially if they are surface laid. Further research may be necessary to determine the extent of the problem.

Don'ts: do not store mines in enclosed buildings where temperatures may be expected to exceed 150°F.

3.6.11 *Problem Statement*

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.

Possible solutions: no practical solution was identified during this study.

3.6.12 *Problem Statement*

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 Warefare, North Africa, 1940-1943 [Engineer Agency for Resources Inventories, June 1972].)

Possible solutions: use sentry dogs or other sensors to detect intruders during those periods when haze limits ground visibility.

3.6.13 *Problem Statement*

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 sand storms. Detection capabilities during high temperatures will be reduced because the temperature differentials between target and background will be small. Extreme temperature fluctuations will make it difficult to adjust the dynamic range of infrared equipment. Radar's effectiveness will be reduced during sand storms 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 dog or abrade microphones. Seismic sensors will be difficult to emplace and be less sensitive where bedrock is exposed.

Possible solutions: 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 sand storms (up to 1.0 GHz). When possible, alter terrain to extend effective ranges of sensors.

ELECTRICAL GENERATION AND DISTRIBUTION

4 ELECTRICAL GENERATION AND DISTRIBUTION

4.1 Introduction

High temperatures, low humidity, and strong winds with associated blowing sands all adversely affect electrical generation and distribution systems. This chapter addresses a number of potential problems and possible solutions associated with electrical energy supply in Southwest Asia.

4.2 Power Generation: Heat-Related Problems

4.2.1 *Problem Statement*

The high temperatures, wide range of temperature extremes, intense solar radiation, sand and dust storms, and corrosiveness of soils will cause reduced mean time between failures for all electrical equipment involved.

Possible solutions:

1. Provide extra training sessions to operator/maintenance personnel, stressing the need to be prepared and the importance of conscientious care for the equipment.

2. Prestock as many spares and spare parts as practical.

4.2.2 *Problem Statement*

In austere living standards, a specified electric power level per man is used in determining power requirements. Some previous studies show that a 10 to 1 variation exists in actual requirements for various Army units. Previous experience has also shown a tendency for soldiers to use what they have when a tactical generator (TG) is started, causing increasing power useage with the passing of time. Further, a relatively large TG often must be operated to supply a small load.

Particularly for widely dispersed bases, power will be provided to "cluster" locations. One study has stated an "expectation for 500 locations requiring 1 megawatt or less" for a current force design.* In these instances, the fuel efficiency of the overall power generation task is very low, which causes more fuel demand and failure. Since desert conditions can be expected to increase maintenance times, temporary stoppages, and failure rates, the problem is more severe than normal.

Some previous studies have shown that the probability of mission success is affected if tactical generators must be relied on for base power for more than 30 days.

Possible solutions: No practical solution was identified during this study.

Special considerations: the supplying of "house power" to TO bases should be addressed in detail in future research.

4.2.3 *Problem Statement*

Solar radiation and high air ambient temperatures cause obvious heating problems for all housed and nonhoused engine-generator sets.

Possible solutions:

1. Pre-apply a highly reflective paint coating to the roof or upper surface of the unit.

2. If a temporary tent is used, a reflective fly over the tent will reduce heating due to solar radiation. The fly can be reversed in winter months when the temperature is below freezing and used on the inside of the tent to reflect the heat inward.

Special considerations: the whole area of temporary protective cover for power generation equipment should be addressed in future research.

4.2.4 *Problem Statement*

Current specifications of engine-generator (E-G) sets for tactical use require that rated power supplied at a maximum air temperature of 125°F. Some older sets still in TOEs may have lower operational temperatures. Most of the E-G sets are equipped with automatic thermal cut-outs which disable the set when the temperature exteme is exceeded, but most of the newer units provide less than rated power above 125°F. Desert temperatures probably will be high enough to prevent extended operation even under reduced load.

Possible solutions:

1. Each Army organizational unit should know whether its tactical generators will operate in environments with high air temperatures. This information can be obtained from the Office of the Project Manager for Mobile Electric Power at Fort Belvoir, VA.

2. During the hottest part of the day, operations should be planned to reduce dependence as much as possible on tactical generators which have temperature cut-outs.

3. Avoid placing tactical generators in direct sunlight if possible.

4. If the E-G set must be used during the hottest part of the day, make certain that its connected load is well below rated load.

5. If power is critical to the mission, provide a standby generator which is cool and can run for at least several minutes before overheating.

Don'ts: do not attempt to by-pass the thermal control, since excessive temperature can cause catastrophic damage to the E-G set.

4.2.5 *Problem Statement*

Wind-blown hot air from one engine-generator set can cause a rise in the operating ambient air temperature for another nearby engine generator set. This problem has been experienced by the U.S. Army Corps of Engineers' Mid-East Division in Saudi Arabia. The higher air temperature can cause engine overheating, reduced time between failures, and a need to derate the generator power output.

Possible solutions:

1. The engine-generator sets should be as far apart as possible, consistent with other requirements.

2. When locating or siting the engine-generator sets, prevailing wind direction should be taken into account and the engine-generator located on a line perpendicular to the prevailing wind direction.

3. During hot, windy times the engine-generator sets in down-wind locations should be checked for overheating and shut down when required.

4.3 Power Generation: Sand-/Dust-Related Problems

4.3.1 *Problem Statement*

Sand and dust can damage any machinery. Although the newer TGs and nontactical generators (NTGs) are designed to withstand the effects of sand and dust, extended exposure can cause accelerated wear and premature failure. In particular, some older TGs have slip rings or brushes and nonsealed generator housings. Sand and dust accelerate wear to these components. The air turbine vanes of some generators undergo extensive wear. Other problems include premature bearing failures, premature seal failures, and electrical failure due to abrasiveness against rotating windings in generators.

Possible solutions:

1. Assure that all operator and maintenance personnel are made fully aware of the potential problems due to sand and dust.

2. Require that all Army units which are potential Southwest Asia (SWA) candidates for contingency check in advance to see whether their TGs have brushes or slip rings. If so, replacement should be obtained when possible.

3. If replacement units cannot be obtained, plan to operate the older units as little as possible, especially reduce their operation during times of blowing sand and dust.

4. Where possible, reduce the effects of blowing sand and dust. Ideally, the TGs or NTGs should be operated in shelters with filtered air. However, this will be impossible in the initial base staging period.

Therefore, common sense measures apply. For example, locate TGs in protected areas or use shields to reduce exposure to larger blowing particles.

5. Keep the machinery clean. This can be done by flushing with water, if available. Otherwise, air compressors with air guns for cleaning can be used.

Don'ts: do not apply oil or grease around affected areas because sand and dust tend to be bound and held by the oil or grease.

4.4 Power Generation: Logistics-/Training-Related Problems

4.4.1 *Problem Statement*

Some of the TGs used for precise power generation may not operate properly when paralleled with other similar TGs. This problem results from improper adjustment of the electrical control system and applies specifically to precise TGs above 15 kW in capacity.

Possible solutions:

1. Before mobilization, perform control system adjustments according to maintenance manual directions.

2. If possible, connect the TG parallel to a similar unit and verify proper operation before mobilization.

4.4.2 *Problem Statement*

There are many tactical generators in service which are more than 15 years old. Although these units are fully operational, the added stress of desert operations may cause them to have less than specified reliability; this is true especially for engine-generator sets more than 10 years old.

Possible solutions:

1. Require that all Army units which are possible candidates for Southwest Asia contingencies determine in advance the age of their assigned TGs. On all units older than 10 years, thoroughly inspect all components which may have deteriorated with age.

2. Likely candidates for aging deterioration are radiator hoses, rubber fuel lines, various seals, spark plug wires, and all other nonmetal components.

3. If any component is suspect for any reason, perform necessary preventive maintenance.

4. Assure adequate stocking of repair parts.

5. Assure training of maintenance personnel to effect the best possible repair times.

6. In service, use newer TGs for operations, older units for standby. Use older units during cooler periods of the day.

7. Obtain replacement TGs as soon as possible.

4.5 Power Distribution: Heat-Related Problems

4.5.1 *Problem Statement*

The maximum allowable current in cables is reduced if the cable is subjected to high ambient temperatures because the heat generated in the cable is not dissipated as well in the high temperatures during the summer hot season. An excessive increase in cable temperature will cause insulation failure. The National Electrical Code begins derating cables at 30°C (86°F).

Possible solutions:

1. Denote maximum current according to Tables 4.1 through 4.4. This will reduce the resistive heating load on the cable's insulation.

2. Limit loads during the hottest part of the day.

3. Protect cables from direct sunlight.

4. Use high temperature rated insulation.

Don'ts: do not use cables above their rated current.

4.5.2 *Problem Statement*

When wire with plastic insulation is used in very hot climates where solar radiation is intense, the insulation may become so hot that it can be easily damaged in normal handling. Damage normally results from flowing of the heated insulation.

Possible solutions:

1. Use insulation rated for higher temperatures.

2. Protect cable from direct sunlight during storage -- especially immediately before handling.

Special considerations: the plastic insulation may become hot enough to change shape, showing the contours of the enclosed wire stranding. However, this phenomenon can occur because of a relaxation of insulation molecules, without significant thinning of insulation material. Careful inspection is required to determine whether actual damage has occurred.

Table 4.1

Allowable Ampacities of Insulated Conductors
Rated 0-2000 Volts, 60 to 90°C
(Table 310-16, reprinted by permission from 70-1981,
National Electrical Code®, Copyright© 1980,
National Fire Protection Association, Boston, MA.

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
(Table 310-17, reprinted by permission from 70-1981,
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National Fire Protection Association, Boston, MA.

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	60°C (140°F) TYPES RUW, T, TW	75°C (167°F) TYPES FEPW, RH, RHW, RUH, THW, THWN, XHHW, ZW	85°C (185°F) TYPES V, MI	90°C (194°F) TYPES TA, TBS, SA, AVB, SIS, †FEP, †FEPB, †RHH, †THHN, †XHHW*	60°C (140°F) TYPES RUW, T, TW	75°C (167°F) TYPES RH, RHW, RUH, THW, THWN, XHHW	85°C (185°F) TYPES V, MI	90°C (194°F) 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 for Insulated Conductors Rated 110 to 250°C (Table 310-18, reprinted by permission from 70-1981, National Electrical Code®, Copyright © 1980, National Fire Protection Association, Boston, MA.)

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
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	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	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 (Table 310-19, reprinted by permission from 70-1981, National Electrical Code®, Copyright© 1980, National Fire Protection Association, Boston, MA.)

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

4.5.3 *Problem Statement*

Most of the protective devices used -- such as fuses, fused cut-outs, time delay fuses, circuit breakers, and motor control contactors -- are affected by high ambient temperatures. Because of this, solar radiation combined with high ambient air temperatures can cause tripping and electric circuit shut-down at less than specified current levels. This applies to all low voltage (480 V and below) distribution equipment and motor control centers.

Possible solutions:

1. Base design engineers and personnel should be aware of the problem.

2. Electrical equipment maintenance and operation personnel should be trained to be aware of the problem.

3. The protective devices should be operated at a reduced load compatible with derating requirements.

Special considerations: quantitative data for derating of specific devices could be developed with further research.

4.5.4 *Problem Statement*

The combination of high heat and low humidity can cause wood distribution poles to warp excessively and to crack badly enough that they fail to properly hold and position insulators and other hardware. As a result, faults can occur causing power outages.

Possible solutions:

1. Material other than wood could be used. Concrete poles, for example, could be fabricated on-site but require a long lead time. Various types of metal and fiberglass poles have also been used. Some shipping tonnage advantages could also be realized by selection of poles lighter than wood.

2. The problem could be minimized by specification and use of well-seasoned, high-quality wood.

3. If wood poles are used, maintenance personnel should be instructed to inspect the distribution system regularly. When failure of any wooden component appears likely, preventive repairs should be made.

Special considerations: the use of materials other than wood would require a design, specification, and procurement cycle since the only type of poles now in stock are wood.

4.6 Power Distribution: Sand-/Dust-Related Problems

4.6.1 *Problem Statement*

In desert climates where sand/dust storms are common and where the soil is saline or otherwise tends to be electrically conductive when wet, common practice in distribution system design requires extra creep (longer) high-voltage bushings. Many of the distribution transformers in NTG stock have standard creep.

Possible solutions:

1. Where possible, use transformers with extra creep bushings.

2. Assure that all oil or other contamination is cleaned from the bushings.

Special considerations: the extent to which this problem applies to current NTG stock should be determined by future research.

4.7 Power Distribution: Logistics-/Training-Related Problems

4.7.1 *Problem Statement*

In extremely sandy areas, additional anchors for guy wires probably will be necessary. The anchors used in dense soils will not hold as well in sand. The usual practice of using logs or cut sections of poles for anchors will not work in the desert areas due to lack of indigenous wood and likely shortages due to shipping tonnages required.

Possible solutions:

1. Design distribution system for minimized requirement for poles.

2. Use "on-the-ground" distribution where possible and practical.

3. Make maximum use of poles which have been rejected because of warping and splitting due to high temperatures and low humidity. These poles may be cut into sections which can be used for anchors.

4. Design alternate methods for supporting wires which require less tonnage.

5. Use reinforced concrete poles made on-site if feasible.

6. Develop lightweight wire support systems.

7. Use a combination of overhead, "on-the-ground," and underground distribution to minimize tonnage of distribution system.

Special considerations: the development of design recommendations for concrete or other (including lightweight) poles is a topic for further study.

4.8 Power Distribution: Soils-Related Problems

4.8.1 *Problem Statement*

In very dry desert soils, the standard methods for power plant or distribution system grounding probably will not offer adequate or safe grounding. This problem results from the extremely poor electrical conductivity of sand, sandy soils, or rocky soils when dry.

The Saudi Oriented Guide Specifications (SOGS), TM 5-765, MIL-STD-633E and other references state that the ground resistance for mobile generators and distribution systems should be 25 ohms or less. The Mid-East Division reports that this condition is usually met with conventional ground rods (if several are used in parallel) near coastal areas where the water table in the soil tends to be higher. In inland areas where the water table is lower, however, the ground resistance is likely to be two or more orders of magnitude higher than 25 ohms.

If the ground resistance is too high, then there may be several problems:

1. In three-phase Y generators, where the neutral is electrically connected to the engine-generator set frame, a phase-to-ground fault anywhere on the distribution system will cause the frame of the engine-generator set to rise to the line of neutral voltage relative to ground. Thus, there is a potentially lethal hazard for anyone who even touches the engine-generator set.

2. The ground-fault protectors or ground-fault circuit interrupters typically used with the power plant will not function on an ungrounded system. Thus, at a fault an arcing fault burndown can be caused by the release of a large amount of energy.

3. Location of a fault is more difficult on an ungrounded system.

4. Lightning is more likely to cause system overvoltages on an ungrounded system, with resultant failure in insulation or other components.

5. Because of rotating belts or other parts, significant static electricity is generated by a power plant. In an ungrounded system this static can cause arc-over and resultant failures.

6. Surge, transient, and resonance condition overvoltages are higher on ungrounded systems.

In some applications, leaving a power system ungrounded can offer advantages; most of these do not apply to Army TGs or NTGs, but those that do are outweighed by the advantages of grounding. Thus, adequate grounding is important to successful TO base power generation and distribution.

The problem applies to all power systems, but the solutions are different for the low voltage (480 V and below) than for the high voltage systems.

Possible solutions:

1. For every solution discussed below, safety hazards and hazards to equipment may exist due to large areas of poor soil conductivity. Therefore, it is important that all personnel concerned be aware of the potential problems and be careful around the electrical systems.

Since grounding is such a difficult problem and the solutions vary with conditions and application, it is important that a qualified electrical engineer be assigned the responsibility for grounding design supervision.

2. For low voltage TGs or for the low voltage secondary distribution systems, the conventional grounding method consisting of driving an 8-ft rod to a depth of about 9 ft should be used. In rocky soil or where subsoils are too hard for rod driving, the buried horizontal rod or plate should be used as identified in standard Army policy. Although these conventional approaches will probably provide a high resistance ground, they will provide some ground conductance to prevent static build-up. Since the soil when dry is not conductive and the system voltages are low, the operator probably will not be subjected to lethal hazard even if a fault does occur. In the event of significant rainfall, the driven rod will provide a low resistance ground preventing hazards when faults occur. The safety of the low voltage system can be further improved by use of an extra, dedicated ground wire. This wire should be routed from the engine-generator set to the load or distribution panel to assure more reliable ground connection of all equipment frames or chassis.

3. The high voltage systems (4160 V and 13,800 V) cannot be safely operated without proper ground because of the hazard to operators in the event of a fault. Therefore, a low resistance ground is essential. Methods for obtaining this ground depend on the installation's degree of permanence. If use of facilities for over 3 months is anticipated, the power plants of the Army Functional Components System (AFCS) will likely be used, and grounding should be provided by burial of a grounding grid under the floor and foundation of the power plant building.

If facilities are expected to be used between 1 and 3 months, then the NTG assets should be used, but in less permanent configuration than that shown in AFCS, which requires both vertical and horizontal construction. Under these conditions, several methods are proposed for obtaining grounds. These methods apply to both power plants and substations which have three-phase output. The delta distribution systems from power plant to sub-station need not be grounded. The special grounding methods are:

1. At least three ground rods can be driven in a conventional manner for the high voltage plant and connected electrically in parallel. Using the method outlined in TM 5-765 measure the ground resistance; if it is less than 25 ohms in dry soil conditions, it may be used without further conditioning. If it is greater than 25 ohms, then further steps must be taken to improve soil conductivity. These steps involve increasing conductivity by using conductive solutions to saturate the subsoils around the ground rods. These conductive solutions can be:

a. Seawater or water from oases, streams, lakes, or wells if available in adequate supply. If fresh water is used, it may be made more conductive by addition of common salt, copper sulphate, or magnesium sulphate as described in TM 5-765.

b. If reverse-osmosis (RO) is used in supplying potable water, the reject water from the RO unit will be high in salt and/or mineral content and will have conductivity that is high enough without the addition of more salts.

When the conductive solutions are added to the soils, another hazard can be created in the high voltage gradients within the soil near the ground rods when a fault occurs. This would be true in particular at the outer fringes of the dampened soil area. To prevent this hazard, a trench should be dug beside the ground rod and drain pipe buried in the trench so that the conductive solution may be injected into the subsoil several feet below the surface. Thus, the surface soil will remain dry, preventing the hazard. The three or more ground rods driven should be kept as far as possible from the power plant. Furthermore, to improve safety a fence with warnings can be erected around the ground rod, high voltage gradient area.

2. A second solution to the grounding problem involves using a well-drilling rig to drill until water is reached, and inserting at that depth a grounding conductor of adequate size. If water wells with metal pipe are used, ground connections can be made to the metal pipe if close enough to the power plant.

3. A third possible solution involves the use of a hydrating mineral such as bentonite as a fill around ground conductors in a drilled hole. These minerals draw moisture from the air or surrounding soil. When wet, their conductance is relatively high and they expand, providing a much greater contact area with subsoils -- depending on the diameter of the drilled hole.

Special considerations: further information is needed about the soil and subsoil parameters at the scenario sites so that a more reliable grounding system that is appropriate for conditions can be designed.

4.9 Miscellaneous Electrical Problems

4.9.1 *Problem Statement*

Often around machinery, electrical components such as receptacles, switches, and circuit breakers become coated with oil and grease. When this happens, sand and dust build up on these electrical parts causing difficulties in inserting plugs and in operating switches.

Possible solutions:

1. Use compressed air to remove accumulations of sand, dust, oil, and grease.

2. Wash affected parts with appropriate solvents to remove grease or oil.

4.9.2 *Problem Statement*

Due to the corrosiveness of most of the desert soils of Southwest Asia, potential problems in corrosion of electrical system components exist. This problem applies primarily to ground system components and to electrical connectors, connections, and wire splices.

Possible solutions:

1. TM 5-765 states that the Army may use either copper-clad steel ground or galvanized steel ground rods. If galvanized steel rods are used, the corrosion rates will be high. Where the ground wire or strap normally clamps to the ground rod, a potential problem exists because corrosion may cause the connection resistance to rise beyond acceptable limits. Thus, it is recommended that this connection be welded, brazed, or appropriately soldered. If none of these options is possible, then the use of an anti-oxidant compound liberally applied over the connection is recommended.

2. All wire splices or connections using clamp hardware which will be on the ground or near the ground should also be protected by anti-oxidant compound and carefully wrapped.

3. Any plug-in connectors should be covered by a plastic bag or other suitable cover and kept off the ground when not in use.

Special considerations: development of design recommendations for grounding systems should be addressed in future research.

4.9.3 *Problem Statement*

In desert areas there is little indigenous material available to use as temporary platforms for TGs. A TG should not be placed on loose soil because blowing sand/dust is more dense near the soil surface, and the unit may shift position due to vibration.

Possible solutions: Stable platforms, such as sandbags, may be used to support TGs.

Special considerations: general siting and protection of TGs for desert operation is a subject worthy of further study. Development of design recommendations for temporary protective structures should be considered.

4.9.4 *Problem Statement*

The utility trucks used for constructing an overhead distribution system will be inadequate for pole setting in some soils. The hole-drilling auger will not be able to drill through the packed rock or gravel beds in some soils or in locations where bedrock is shallow. In loose sand, a deeper hole is required, and the hole-drilling auger is ineffective because the hole will cave in. Solutions require additional manual labor and thus more time to erect the distribution system.

Possible solutions:

1. The base design and layout should consider soil/sub-soil conditions from the electrical distribution system standpoint to minimize requirements for pole setting in difficult soil areas.

2. Maximum use should be made of "on-the-ground" or underground distribution in the troublesome areas.

3. Wire support structures, such as "tripods" made from lumber may be used temporarily in the difficult soil areas.

4.9.5 *Problem Statement*

Insulation failures -- due to a process known as treeing -- have been observed in cross-linked polymer cables. The salinity and alkalinity of desert soils make such failures a problem in Southwest Asia. In general, treeing has been noticed more with high voltage (13,600 and up), but is possible in lower voltage cables. Water treeing occurs when the cable -- in addition to being subjected to high voltage stress -- is in a wet location. Most failures diagnosed as being due to treeing occur after cables have been in use for several years.

Possible solutions: use cables with tree-resistant compounds incorporated into the insulation.

4.9.6 *Problem Statement*

In some desert areas, rodents such as kangaroo rats and ground squirrels have gnawed into the materials, including plastics, that are used for wire and cable insulation. If wire is then used on the ground or underground, it will be exposed to the corrosiveness of soils and to electrolytic action if significant water is available. Wire exposed to Southwest Asian soils which are highly corrosive can fail within a few days during the rainy season. Furthermore, defects can cause a safety hazard from potential electric shock.

Areas of application: this problem applies to underground distribution and on-the-ground distribution systems, both primary and secondary.

Possible solutions:

1. If options are available, use the type of cable that rodents will find most difficult to gnaw.

2. If the problem is encountered after a distribution system has been installed, reduce the rodent population in the vicinity by using baits with an approved poison, such as zinc phosphide. If UGD cable is used, the poisoned bait can be set in the immediate vicinity of the fault by burying it in a trench near the wire if the rodents are burrowers, or by simply placing it on the ground if the rodents do not burrow.

3. Workers handling the cable should were gloves because there is some evidence that rodents are attracted to cable that has been touched with bare hands.

4. If the problem occurs extensively, the bait should be "plowed-in" a furrow or small trench as close as possible to the wire.

4.9.7 *Problem Statement*

Use of host nation power would be desirable: (1) it could reduce supply problems for TG (or NTG) fuel, (2) it could reduce the need for extensive use of TGs during initial phases of base construction, (3) in some instances, it could be immediately available, (4) it could relieve personnel pressures for power plant construction and operation during the period of acclimatization to desert conditions, and (5) it could reduce overall logistics requirements.

However, host nation power is not likely to be a viable source for the following reasons:

1. Saudi Arabia is the only country in Southwest Asia using 60 Hz at all. All other countries use 50 Hz power. Much of the electrical/electronics equipment used by the U.S. Army will not operate on 50 Hz power.

2. None of the countries of Southwest Asia has standardized power. Both frequency and utilization voltages vary from one location to another.

3. The transmission/distribution networks of Southwest Asian countries are not extensive and there is little chance of locating a base where sizable amounts of power are available.

4. The quality of available power is unacceptable; there is poor voltage regulation, poor frequency stability, and the possibility of high level transients.

5. The reliability of commercially available host nation power is questionable.

6. The Army does not have conditioners available for converting and regulating host-nation commercial power to usable energy.

Possible solutions:

1. Determine areas where power is useable. Table 4.5 presents data regarding frequency, utilization voltages, and phase for various cities in the indicated Southwest Asian countries.

2. Southwest Asian countries have purchased more than 200 commercial engine-generator sets. Where possible, maximum use of these should be made.

3. If proper voltage is available, some consuming equipment (including lighting sets), some heating equipment, and other noncritical items can operate from power at other frequencies. Specific predeployment surveys of TOE equipment should be considered, and equipment which cannot operate in 50 Hz should be so marked.

Table 4.5

Power Characteristics for Iran and the Arabian Peninsula*

Country/City	Type	Phase	Frequency	Voltage
IRAN:				
Abadan	DC	--	--	110
Ahway	AC	1,3	50	220/380
Babolsar	AC	--	50	220
Hamadan	AC	1,3	50	220/380
Isafahan	AC	3	50	220
Xerman	AC	1,3	50	220/380
Xermanshahan	AC	1,3	50	220/380
Meshed	AC	3	50	220
Mohammerah	AC	3	60	110
Pahlevi	AC	3	50	220/380
Resht	AC	1,3	50	220/380
Shiraz	AC	1,3	50	220/380
Tabriz	AC	3	50	220
Tehran	AC	1,3	50	220/380
Yezd	AC	2	50	220/380
SAUDI ARABIA:				
Dhahran	AC	3	60	110
Jidda	AC	3	60	110/220

(Note: New construction is all at United States standard voltages.)

Country/City	Type	Phase	Frequency	Voltage
YEMEN:				
Hodeida	AC	3	50	127/220
Kuwait	AC	3	50,60	220/240
IRAQ				
Ashar	DC	--	--	220
Baghdad	AC	1	50	200
Basra	AC	3	50	220
Kerbela (or Karbala)	AC	3	50	230/440
Kirkuk	AC	3	50	440/484
Kut	DC	--	--	460
Mosul	AC	3	50	230/400
Qala Salih	DC	--	--	200/235;220/250
Zakho	DC	--	--	450;440/500
Zubair	DC	--	--	220
ISRAEL				
HAIFA	AC	1	50	220
Jaffa	AC	1,3	50	220/380
Jerusalem (New City)	AC	3	50	220/380
Tel Aviv	AC	1,3	50	220

*This information was taken from TM 5-765 dated June 1970, which also tabulates data from all continents.

Table 4.5 (Cont'd)

Country/City	Type	Phase	Frequency	Voltage
JORDON				
Amman	AC	1,3	50	220/380
Jerusalem (Old City)	AC	3	50	220/380
PAKISTAN				
Abbottabad	AC	3	50	230/400
Chittagong	AC	3	50	230/400
Dacca	AC	1,3	50	220
Hyderabad	AC	3	50	220/380
Karachi	AC	--	50	220
Lahore	AC	1,4	50	220
	DC	--	--	200
Multan	AC	1,3	50	230/400
Peshawar	AC	3	50	230/400
Quetta	AC	3	50	230/440
AFGHANISTAN				
Herat	AC	3	50	220
Jalalabad	AC	3	50	220
Kabul	AC	3	60	230
Kandahar	AC	3	50	220
Kunduz	AC	3	50	220
Legrand	AC	3	50	115/200
Littre	AC	3	50	115/200
Mazar-i-Sharif	AC	3	50	220
Paghaman	AC	3	50	220

4. One solution to the problem includes the specification and procurement of a family of power conditioners which can operate from any of the host nation's power systems. This solution in the immediate future would require purchase of current, state-of-the-art power conditioners that are commercially available but are not now in Army inventories. MERADCOM has the responsibility of developing and procuring a family of power conditioners ranging from 1.5 kW to 200 kW, but its efforts are being delayed due to priorities and funding. Increasing the priority assigned could improve the situation.

WATER MANAGEMENT

5 WATER SUPPLY, DISTRIBUTION, AND TREATMENT, AND SOLID WASTE TREATMENT

5.1 Introduction

This documentation is the result of a review of literature, examination of DA and DOD documents, and interviews with personnel having experience/expertise and base development activities.

The areas of applicability for the problem statements in this chapter include all facets of water management and certain elements of wastewater and solid waste management:

1. Production

2. Water treatment for potable and/or non-potable applications

3. Water storage

4. Water transportation and distribution

5. Water use and conservation

6. Wastewater collection and treatment

Significant documentation of experiences in desert environments was found in the literature. FM 90-3 (Desert Operations) and TB MED 507 are particularly useful.

Some of the problem statements in this chapter may seem fundamental and obvious, but they represent illustrations and statements of principles which should not be ignored in the desert environment.

5.2 Production

5.2.1 *Problem Statement*

Plants are extremely valuable as water indicators in desert regions. Experience has shown that the various species of groundwater plants not only indicate the presence of water, but also its quality and approximate depth below the surface. Some species of plants reach water at or near the water table, but most plants get their water from the soil moisture above the water table. In arid regions the presence of plants that tap the water table indicates that groundwater is close to the surface. In more humid regions, the greater abundance of water in the soil reduces the value of plants as indicators of a high water table. Groundwater plants generally occur in a zone around the central playa of a basin, but not in the center itself because of the aklaline clay at the surface. Generally, plants other than cacti, sagebrush, and the yuccas will not grow unless there is a subterranean water table within 25 ft of the surface.

Possible solutions: no practical solution was identified during this study.

5.2.2 *Problem Statement*

Location of water supplies.

Possible solutions: the following was taken from Field Fortification and Equipment (Moscow) regarding Soviet water reconnaissance (1974): "Location of underground water is inferred from marshy and hydrophyllic vegetation (reed sedge, marshy moss, sovel, horsetail, forget-me-nots, etc.). Look for landslides with rusty spots on the surface and presence of old wells."*

5.2.3 *Problem Statement*

Lack of readily obtainable potable water in coastal areas.

Possible solutions: driven well points (sand points) to shallow aquifers.

Don'ts: to prevent clogging of well point by sand, do not pump at high rates.

Special considerations: in coastal areas, freshwater may override salty groundwater. In such cases, freshwater aquifer thicknesses are generally very small. Consequently, water should be pumped out at very low rates to prevent salt water contamination. This method is only applicable at shallow depths (< 40 ft) and in unconsolidated overburden materials.

5.2.4 *Problem Statement*

The discovery that groundwaters of the Middle East are highly corrosive is lost in antiquity. Introduction of modern well-drilling techniques and replacement of native wood casing with steel during the 20th century increased corrosion problems and led to an intense search for causes and corrective treatments. Extreme corrosiveness results from the combined effects of relatively acidic waters with significant concentrations of destructive sulfide ion; unfavorable ratios of sulfate and chloride to less aggressive ions; mineral equilibria of protective films; relative high chemical reaction rates because of abnormal temperatures; and high surface velocities related to well design.

Possible solutions: there is general agreement that conventional corrosion control methods would be ineffective or impracticable. Thus, control must be sought through the use of materials more resistant to corrosion than plain carbon steel where well screens and casings are necessary. Of the alternatives considered, stainless steel appears to be the most promising where high strength and long-term services are required and the alloy's relatively high cost is acceptable. Epoxy resin-bounded fiberglass and wood appear to be practicable, relatively inexpensive alternatives for low strength applications. Other materials, such as high strength aluminum, have shown

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* R. W. Hubbard, "A Brief Analysis of Soviet Hot Weather Operations Doctrine" (USARIEM Briefing Material, 1979).

sufficient promise to merit their consideration in particular locations and uses. The limited experience with pumping in these desert wells leaves uncertainties concerning the durability of conventional pump designs.*

5.2.5 *Problem Statement*

In normal rotary water-well drilling, water in substantial quantities is used as a drilling fluid.

Possible solutions: use foam as a drilling fluid to reduce water requirements (up to 97 percent). An example of a brand name is "Quick Foam" manufactured by Baroid of Houston, TX. Use other drilling methods -- e.g., percussion or rotary-percussion.

5.2.6 *Problem Statement*

Location of expedient water supplies for small troop units in remote areas during operations away from established water distribution points.

Possible solutions: the key indicator of existing local water supplies is habitation. If a small spring or dug well exists, there is a high probability that people are living at that location. If no such sources are available or water quality is questionable, it is at times possible to find shallow groundwater in the alluvial fans at the base of any significant mountain range or in dried up stream channels or wadis. Possible methods to reach water include driving a simple well point, digging a hole with a bulldozer (if available) or, as a last resort, with simple hand tools.

Don'ts: do not assume that all groundwater is potable. All "quick" sources should be tested with the standard test kit for impurities.

Do not dig a small diameter vertical shaft (hand dug well) in alluvial materials without some crude shoring to prevent collapse of the shaft walls.

Special considerations: when digging a well by hand, continue the excavation beyond the depth where water is first detected to accelerate accumulation of water; cover the surface of the hole, if possible, to minimize contamination by dust and debris.

5.2.7 *Problem Statement*

Salt water occurs near the surface in some playas, but fresh water may underlie it (see Reference 3 for Chapter 5).

Possible solutions: no practical solution was identified during this study.

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* F. E. Clark, The Corrosive Well Waters of Egypt's Western Desert (Geological Survey, Water Resources Division, 1979).

5.3 Treatment

5.3.1 *Problem Statement*

Reverse Osmosis (RO) membranes are subject to flux (water production) decline. This is a normal process primarily attributable to the high pressures of operation and aggravated by scaling, contamination, bacterial attack, and high temperature. Cellulose membranes generally have a maximum normal operating temperature of 85°F (29.4°C), although one manufacturer stipulates 95°F (35°C). Polyamide membranes may be routinely subjected to temperatures as high as 95°F (35°C). Water from desert wells sometimes exceeds 140°F. Although both membrane types can withstand even higher temperatures for short periods without ill effects, optimal operating temperatures are generally lower than the maximum value recommended. Due to lower water viscosities at higher temperatures, production by RO units increases with temperature. If the temperature becomes too high, however, compaction and irreversible flux reduction may result. The temperature problem may be complicated by the fact that certain well waters may be characterized by a high iron content.

Possible solutions:

1. Cool feedwater (with cooling units dedicated to supply cool water to troops) to optimal operating temperature.

2. The effects of temperature and pressure are closely related. At higher temperatures, hydraulic pressures must be lowered to prevent damage to the membranes.

3. Construct cooling towers. The cooling towers have also been used in desert regions not only to cool the water but also to remove iron.

4. Use cooling towers (pretreatment prior to RO) to lower water temperature and remove iron; RO membranes will not clog as quickly. This solution has been used successfully previously in the Middle East.

Special considerations: this problem statement is applicable to commercially available RO units. Military RO units under development have greater tolerance to high temperature feedwaters. Technical manuals accompanying any fielded military RO units should be consulted to identify feedwater temperature limitations. Solutions are applicable to military RO units.

5.3.2 *Problem Statement*

Low pH well water or pretreatment of feedwater with chlorine may damage reverse osmosis membranes.

Possible solution: no practical solution was identified during this study.

5.3.3 *Problem Statement*

Uniform flows are necessary to avoid localized buildups of ion concentration near reverse osmosis membrane surfaces (concentration polarization). The deleterious effects of this phenomenon are higher osmotic pressure requirement, lower salt rejection, and increased likelihood of scaling and membrane hydrolysis. Manufacturers recommend that feed stream flows not be lower than three-fourths of the nominal design flow.

Possible solutions:

1. Intermittent operation is commonly practiced.

2. Recycle a portion of the product water.

3. Pump feed water from a storage tank located between the well and the reverse osmosis unit.

4. Use 50,000 gal water storage bags as surge tanks for raw water storage. Make certain that these tanks are properly labeled for storage of raw water only.

5.3.4 *Problem Statement*

Waste streams from reverse osmosis units which are treating feedwater with relatively low total dissolved solids may be considered as a water resource for other uses (especially when the feedwater may be in short supply).

Possible solutions:

1. Recycle waste stream into feed stream.

2. Use water for activities which do not require potable water supply.

5.3.5 *Problem Statement*

Instances of well water naturally polluted with petroleum have been documented in the Middle East. Oil contaminated feedwater will quickly foul reverse osmosis unit membranes.

Possible solutions:

1. Run initial oil tests prior to using water for RO.

2. Periodically run oil tests to be sure source is not being contaminated by petroleum.

5.3.6 *Problem Statement*

Certain aquifers may be contaminated by "slurries" used in oil well drilling operations. A desalination facility once chose to use seawater as a feed rather than well water because the well supply contaminated the pumps and membranes with oil; it required 2 weeks to repair the damage. Also, oil slicks and/or emulsified oil may contaminate ocean water which is being used as a feed source to water treatment RO units, thus clogging the units.

Possible solutions:

1. Two passes of the water through treatment units may be required to remove certain contaminants to desired concentrations.

2. Rigorously check the quality of the well water supply, and under no circumstances attempt to use RO units to treat oil contaminated water.

3. Locate water intake in an area or depth where it will not intake oil polluted water.

Don'ts: once RO membranes are contaminated with oil, they become ineffective.

5.3.7 *Problem Statement*

Water treatment equipment break-downs or lack of water treatment equipment may result in an inadequate supply of treated water. Desalination units may produce such high quality water that under increased water demand, blending with sea or brackish water may increase the water supply.

Possible solutions:

1. Use "erdalators" and RO units "side-by-side" and blend the two product streams. Army Medical Department personnel must determine what ratio of desalinated to nondesalinated water to provide as a final product water.

2. Adjust operation controls of desalination units to produce a lower quality (in terms of TDS) but acceptable potable water. Water must still meet health-related water quality parameters, including adequate adequate residual chlorine.

Don'ts: water must still meet health-related water quality parameters, including adequate residual chlorine.

5.3.8 *Problem Statement*

Intake structures for water desalting units in the seas have had problems with clogging.

Possible solutions:

1. Investigate the area to determine the best location for the "intake," on the surface, on the bottom, or anywhere in between.

2. Suspend the intake from a flotation device or permanent structure, and have it so the intake may be adjusted "up" or "down" depending on the conditions present.

3. Establish a strict schedule for maintenance and cleaning.

5.3.9 *Problem Statement*

Middle East well water supplies may contain compounds or substances not commonly measured during routine water quality analysis. These substances may affect troop health or water treatment efficiency.

1. Naturally occurring ammonia has been reported in concentrations up to 2.5 mg/L.

2. Radioactive materials have been used in certain operations of the petroleum industry and may be found in groundwaters.

3. Arsenic exceeding the World Health Organization standards has been reported in some Middle East groundwaters.

4. Excessive concentrations of barium, chromium, copper, fluoride, cadmium, cyanide, lead, magnesium, mercury, selenium, silver, and sulfate have been found.

5. Magnesium sulfate acts as a laxative.

Possible solutions: no practical solution was identified during this study.

5.3.10 *Problem Statement*

Precision instruments may require adjustment several times during the desert day, depending on temperature variation (see Reference 14 for Chapter 5).

Possible solutions: no practical solution was identified during this study.

5.3.11 *Problem Statement*

Ideal storage conditions for calcium hypochlorite (a commonly used Army water disinfectant) are cool and dry. High storage temperature by itself (or combined with storage without protection from high humidity often associated with desert/sea coast environment) results in a loss of chlorine disinfecting strength. Consequently, the safety of water intended for potable activities is suspect. Additionally, the calcium hypochlorite converts to a lime solution which could cause unknown problems with equipment, etc.

Areas of application: treatment.

Possible solutions:

1. Storage of unopened containers of calcium hypochlorite by burial in cool dry soil protected from infiltration by rainfall.

2. Use of old stock first discourages prolonged storage.

5.3.12 *Problem Statement*

Some of the chemical reagents, test papers, etc., stocked in the standard field water-quality testing kit may undergo accelerated decomposition/aging when stored in high desert heat. This is complicated by the fact that many of the tests were designed to be performed at room temperature (70°F). At temperatures associated with desert environments, accuracy and precision may be affected, especially for the following tests: cyanide, nitrate, nitrite, and aluminum. Reliability of water-quality analyses is especially important when evaluating (1) a water source as a potential supply, (2) treatment efficiency, and (3) residual disinfectant.

Possible solutions:

1. Store test kits in refrigerated units.

2. Store test kits out of direct sunlight.

3. Store test kits in water after placing in waterproof container.

4. Wrap with wet cloth and keep cloth wet during daylight hours.

5.3.13 *Problem Statement*

Storage of replacement RO membranes, diatomite filter media, or ion exchange resins under extreme temperature conditions may cause failure or decreased efficiency problems.

Possible solutions: store in cool, shaded areas, such as underground or in canvas shelters.

5.3.14 *Problem Statement*

Feedwater for water supply may become contaminated with chemical warfare (CW) agents in the theater of operation.

Possible solutions: a study investigated methods for decontaminating waters containing CW agents.* The maximum permissible concentrations of CW agents in water are 0.02 mg/L nerve agents, 2.0 mg/L blister agents, 2.0 mg/L arsenicals as arsenic, 20.0 mg/L blood agents, and 0.004 mg/L incapacitants. CBR-contaminated water may be purified by a combination of superchlorination in a Lister bag, activated carbon adsorption, coagulation, filtration, mixed-bed demineralization, and post chlorination. While the standard erdalator

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* Don C. Lindsten and R. P. Schmitt, Decontamination of Water Containing Chemical Warfare Agents, ADA012630 (Army Mobility Equipment Research and Development Center, January 1975).

unit did not remove CW agents from water, the use of the CW/BW pretreatment set, in combination with the erdalator unit, decontaminated the water and incorporated superchlorination, activated carbon adsorption, coagulation, filtration, and post-chlorination. Reverse osmosis and ion exchange processes were capable of removing certain CW agents.

5.3.15 *Problem Statement*

Use of foreign water and wastewater facilities has its own set of inherent problems and characteristics of which DA personnel should be aware:

In developed countries of the world, foreign water processing and distribution provisions will be similar to those found at permanent CONUS military installations and municipalities. The availability and state of repair of such foreign facilities will greatly depend upon how U.S. forces arrive at the site. If there has been moderate to severe war damage, or if water/wastewater management systems have been made, an individual situation analysis would be required to assess the utility of existing facilities.

Operation and maintenance of foreign water management facilities will differ from those of the United States primarily in the areas of spare parts requirements. Certain nations may use more ozone for disinfection -- as opposed to the U.S. customary chlorination of product water. Regardless of treatment method, a residual chlorine level, as established by the Army Medical Department, must be maintained. The pumps, pipes, valves, chemical feeders, and other particular components of a water management system will operate like their U.S. counterparts, but sizes and dimensions will differ. Such differences will create a requirement for different tool sizes, adapters, and non-American standard replacement parts.

The training and experience of water supply operators will not likely be adequate for operation and maintenance of foreign water supply treatment

Possible solution: no practical solution was identified during this study.

5.3.16 *Problem Statement*

Any stage of water management, including open storage of water, distribution, and use, may be susceptible to schistosomiasis contamination. Refer to Figure 5.1 for a depiction of geographic distribution of schistosomes.

Possible solutions:

1. Open storage of water may be conducive to spread of schistosomiasis.

2. Chlorination or other forms of disinfection may be required at several different stages -- post water treatment, storage vessels, end of pipe, distribution, and canteen; therefore, water quality analysis for potability should be conducted routinely throughout the system.

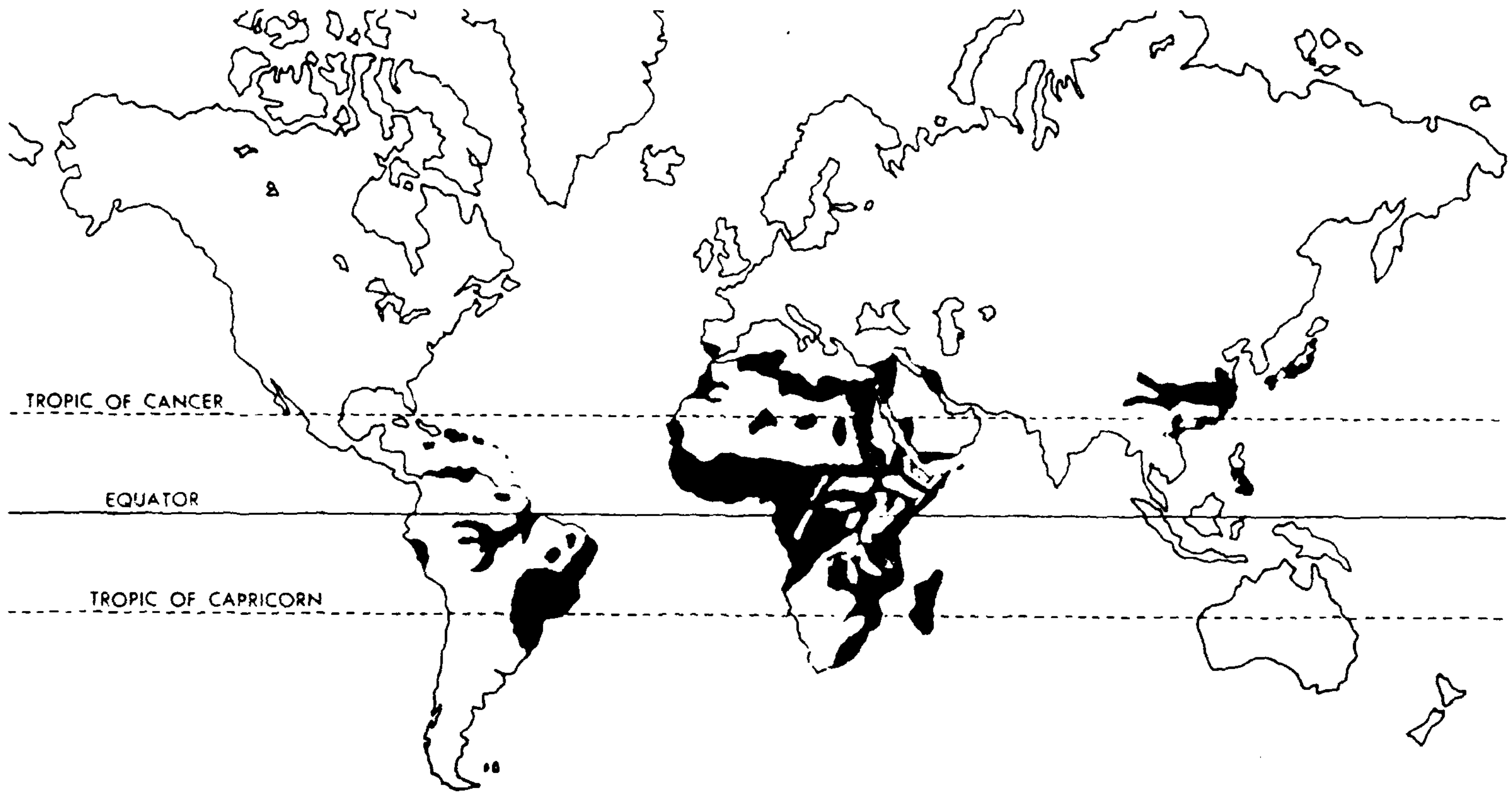

Figure 5.1. Geological distribution of schistosomes (shown in black).

3. Personnel should only urinate at latrines.

4. Avoid areas of standing water.

5. See p 12 of Reference 3 for Chapter 5.

6. In areas where schistosomiasis is known to be present, wells and springs not subject to contamination by drainage and surface runoff should be used as water sources in preference to ponds and sluggish streams. However, where schistosomes are found in water which must be used as a source, the safety measures described below must be observed by water supply personnel.

Filtration and disinfection. All standard diatomite filters of Army issues are dependably capable of mechanically removing a cercariae of the schistosomes from water. A representative of the Army Medical Department will determine what change the presence of schistosomes causes in the local chlorination policy.

5.3.17 *Problem Statement*

Rainfall in the desert, although rare, may be taken advantage of. Rainwater as a source may be sufficient for small units for limited operations, but it should not be considered if other, more reliable sources are available.

Possible solutions:

1. A collecting surface may be constructed of tarpaulins supported by wood, metal, or concrete, and elevated so the water drains into tanks. After the water has been collected, the tanks should be covered to protect the water from further contamination and pollution.

2. Rainwater is unsafe for consumption until tested and treated to the degree required; residual chlorine will be needed. Various atmospheric conditions or flow over impurities upon reaching the collecting surface could render the water unsafe without purification (see p 35 of Reference 3 for Chapter 5). Contact Army medical personnel before use.

5.3.18 *Problem Statement*

Water treatment equipment shipped overland becomes caked with silt and dust and impregnated with sand, and must be extensively cleaned when it arrives at its destination. The dust and sand clog filters and tend to freeze moving parts.

Possible solutions: ensure that all water treatment equipment is thoroughly cleaned upon arrival at its destination, and before put into operation.

5.3.19 *Problem Statement*

Traditionally, water supply, treatment, storage, and distribution equipment has not been placed high on the threat protection priority list. In the desert it is safe to assume that water management components (e.g., sources, treatment, distribution, storage, transportation) may be prime military targets.

Possible solutions: water related facilities should be evaluated as potential threat targets and protected accordingly.

5.4 Storage

5.4.1 *Problem Statement*

High temperatures of chlorine-disinfected water supplies in storage tanks, bladders and/or pipelines may result in a lower than expected chlorine residual due to the tendency for chlorine to readily volatilize to the atmosphere at high temperatures. Consequently, water supplies thought to be potable may be unsafe for primary contact activities such as consumption.

Possible solutions:

1. Surgeon General personnel should provide guidelines regarding application rates of disinfectant to water during treatment, storage, distribution, or use.

2. Additional disinfectant may be added to canteens and other nonbulk water containers before use to compensate for loss of chlorine residual.

5.4.2 *Problem Statement*

Heat has a tendency to build up under single layer canvas covers.

Possible solutions: any shade is beneficial but installation of a second layer of canvas or other material either above or below the primary cover is even more effective. This second layer has to be installed in such a manner as to create a live air space between itself and the primary cover. This space will allow air to circulate, producing a cooling effect.

5.4.3 *Problem Statement*

Storage of water in port areas.

Possible solutions: contractors in Saudi Arabia are using potable water bladders of 50,000 and 100,000 gal capacity manufactured by one of the U.S. rubber companies. These bladders are made of materials approved by the FDA and the Surgeon General. Waterproof membranes, which are FDA approved, are commercially available in widths up to 60 ft and can be used to line holes dug in the ground. Cover to prevent dust infiltration would have to be provided.

Don'ts: The T-17 membrane currently in depot is not approved for use in potable water storage because of two chemicals used in its manufacture.

Special considerations: the use of membrane to line expediently constructed water holes needs further evaluation.

5.4.4 *Problem Statement*

POL containers of 50,000, 10,000, and 20,000 gal cannot be used for potable water storage containers.

Possible solution: see Problem Statement 5.4.3.

5.4.5 *Problem Statement*

Water stored in containers (pipelines, water transportation trucks, drums, cans, bladders) in direct sunlight can reach 200°F. This water cannot be expected to cool much at night because water retains heat so long. In addition, water storage bladders subjected to extremes in temperatures during storage may be susceptible to damage during handling. Certain DA water storage containers are black camouflage or beige. Black containers are especially high absorbers of solar radiation with resultant high water temperature problems.

Possible solutions:

1. Survivor blankets have been known to reduce the temperature of protected equipment by as much as 30°F.

2. Provide shade for the water storage vessels.

3. Provide reflective, light-colored exteriors for the containers.

4. Insulate: light-colored sand reflects a significant amount of solar radiation and can serve as an insulating material.

5. Excavate holes for the tanks or storage bladder and construct a cover with two light-colored layers of canvas.

5.4.6 *Problem Statement*

Water, in storage, forms temperature differential gradients because hot water rises during quiescent storage.

Possible solutions:

1. Take advantage of this fact by drawing water from the bottom when cooler water is desired and drawing water from the top of the storage container when warm water is desired for cooking, etc.

2. Water to be cooled for consumption should be drawn from near the bottom.

5.4.7 *Problem Statement*

Groundwater may be hot or water may become hot with aboveground storage.

Possible solutions: circulate water through lines buried at depths of 5 ft or more.

Don'ts: do not use low conductivity (i.e., plastic) pipe. Do not backfill trenches with hot soil.

Special considerations: this is an expedient method only and would not prove suitable for continuous operation.

5.4.8 *Problem Statement*

Need to provide cool water to personnel. Warm drinking water will not cool the body. Soldiers will not drink enough tepid water to replace lost body fluids. The Army Medical Department recommends a drinking water temperature of $60^{\circ}F$, $\pm 10^{\circ}F$ ($16^{\circ}C$, $\pm 5^{\circ}C$).

Possible solutions:

1. The Isareli Army covers water containers with wet blankets.

2. As a minimum effort, place water containers in shaded areas. If none is available, erect canvas shelters to prevent the direct sunlight from hitting the containers.

5.5 Transportation and Distribution

5.5.1 *Problem Statement*

A hypothetical 70-mi, 6-in. (inside diameter) conduit will take approximately 0.5 million gal of water just to fill it. This raises the following questions:

1. How long will water production facilities require to fill the conduit before the water becomes available at the end of the line?

2. When the decision is made to move the conduit to another location, what measures are taken to ensure that the water contained in the conduit is not wasted? (It will be difficult and time consuming to pump all of the water out of the conduit.)

3. How does one protect this source of water from friendly locals, our own troops and threat forces?

Possible solution: no practical solution was identified during this study.

Special consideration: these problems need to be considered in the planning process.

5.5.2 *Problem Statement*

Pipelines may be used to transport water over terrain that is inaccessible to trucks. Problems may arise with adaptability to field terrain. For instance:

1. Wind may remove sand support of conduit at certain locations causing hose to crimp or conduit to break.

2. Blowing sand may cover the water distribution lines at certain locations, causing the hose to be hidden from view. Wheeled and tracked vehicles may inadvertently damage it.

Possible solutions: no practical solution was identified during this study.

5.5.3 *Problem Statement*

The planned use of water transportation trucks for both potable and nonpotable water distribution will present potential problems: improper segregation of storage vessels, using nonpotable water for potable purposes and vice versa.

Possible solutions: color code the water containers where they are filled and where they discharge water. Just paint the lid, faucet, hose nozzle, etc.

5.5.4 *Problem Statement*

Water distribution systems at or buried near the surface are subject to high temperature during the day.

Possible solutions: do not use dark-colored materials for the pipe; white or light colors will reflect the heat and sunlight better. The light colors also may blend into the surface better and camouflage the pipe.

5.5.5 *Problem Statement*

Plastic pipe (certain types) is subject to ultraviolet degradation if stored outside uncovered in hot environments. The degradation lowers the pressure rating of the piping and can deform pipe ends, making installation difficult (see p 5 of Reference 18 for Chapter 5).

Possible solutions:

1. Do not store in direct sunlight.

2. Bury the plastic pipe used for distribution systems.

3. Cover plastic pipe with sand.

5.5.6 *Problem Statement*

Pipelines -- particularly temporary ones -- are subject to leakage because of the great temperature variations (see p 51 of Reference 13 for Chapter 5). On all lines, especially long ones, consideration must be given to heat expansion. Since, in many places, the deserts have significant temperature drops at night, the diurnal temperature range may be considerable, and unless expansion is provided for, line breakage is possible.

Possible solutions:

1. Full-time maintenance crews should be used instead of making maintenance duties secondary tasks of other personnel.

2. All lines should be placed underground, if possible, to provide a certain amount of insulation and to prevent uncontrollable or excessive expansion of the lines. Cover should approximate 18 in. whenever possible. Deeper coverage is not warranted unless the line will be crossed by heavy traffic, and then it may be better to place the line in a concrete envelope for protection from equipment. Lines should be well marked, particularly in sandy areas, to make inspection and repair easier.

5.5.7 *Problem Statement*

Military units that have water-using missions such as clothing exchange baths, food preparation and servicing or vehicle maintenance are presumed to operate under "austere" conditions at support bases. Their requirement for water can best be met by pipelines, but these activities usually have to rely on incremental supply (see p 2-10 of Reference 4 for Chapter 5).

Possible solutions: provide activities which demand a high priority for water supply their own separate distribution line.

5.6 Use and Conservation

5.6.1 *Problem Statement*

Need for establishing priorities and criteria for water usages inherent to Army base missions.

Possible solutions: there are few environmental factors that affect the soldier's well being more than the availability of an adequate potable water supply. The highest priority should be assigned to providing this water. For a base of moderate size that supports troops in certain geographical areas, the requirement for water for human consumption may constitute a substantial burden on engineer and other units. Establishing priorities for other water usages will, in all instances, depend upon site and mission specific facts which a commander must evaluate. The U.S. Army Logistics Center, Fort Lee, VA, has recommended the water consumption factors in Table 5.1.

Table 5.1
US ARMY LOGISTICS CENTER, FORT LEE, VA
Water Consumption Factors

1. Factors common for all services:

	Gal/Man/Day for Army, Marines, Air Force, Navy
A. Drinking (0.5 gal/man/day for meal beverage)*	4.0
B. Hygiene:*	
Personal (shave, brush teeth, helmet bath, comfort cooling)	2.7
Centralized (2 showers/wk: 3 min at 4.5 gal/shower)	1.3
C. Food preparation (2 "B"; 1 "C": if "C" only, no requirement)*	3.0
D. Vehicles (based upon 25% loss/vehicle/day)	0.3
E. Medical:*	
Hospitals (65 gal/bed)	1.0
Heat treatment (ice/cold water at treatment location)	1.0
F. Graves registration (50 gal/kia)**	0.2
G. Laundry (6 lb/man/wk)	2.0
H. Construction+	1.5
Total (Paragraph 1 only)	17.0

2. Factors different by service:

	Gal/Man/Day Army	Marines	Air Force	Navy
Aircraft (Turbine wash, aircraft wash and flight operations). (Variance due to types of aircraft, equipment to personnel ratio, and flight mission profiles)	0.2	0.7	2.5	5.2
Total (Paragraphs 1 and 2)	17.2	17.7	19.5	22.2

3. Factors for loss:

	Army	Marines	Air Force	Navy
Waste/evaporation (10% of total)	1.7	1.8	2.0	2.2
Total (Paragraphs 1, 2, and 3)	18.9	19.5	21.5	24.4

4. Recommended joint planning factor: 20 gal/man/day (includes waste/evaporation factor but excludes decontamination, POW and refugee requirements). Joint planning factor actually varies slightly based on relative strength of each service in a given scenario; however, variation is less than 2 percent.

*Must be potable. All other water quality must be consistent with intended use.

**Army accomplishes graves registration for all services.

+Dust control must be accomplished by using old oil, contaminated fuels or penaprime.

5.6.2 *Problem Statement*

There are always people who will abuse or misuse water conservation guidelines -- even to the detriment of their own health (e.g., perhaps one will utilize a portion of his drinking water allotment to wash socks).

Possible solutions:

1. Education

2. Peer pressure

3. Command emphasis.

5.6.3 *Problem Statement*

Water for CBR decontamination activities may not be available. The U.S. Army Logistics Center, Fort Lee, VA, has provided the following guidance:

"Decontamination requirements: cannot be reduced to g/m/d factor: the following should be used for planning purposes:

Combat troop - 13 gal per decon application.

Major end items - 200 gal per decon application."

In addition, the following should be considered:

1. Factors apply each time a person or piece of equipment requires decontamination due to the presence of persistent chemical agent.

2. The factors assume that the contaminated units apply sound decontamination principles and conduct appropriate emergency personnel or partial equipment decontamination to minimize the effects of the contamination and the need for complete personnel or equipment decontamination.

3. All personnel and equipment in a given unit (company) are assumed to require decontamination if any personnel and equipment become contaminated.

4. For many pieces of equipment, specific decontamination procedures and times have not been established, especially for aircraft, generators, communications gear and crew-served weapons.

Possible solutions: capture all used water for possible use in decontamination procedures.

Don'ts:

1. Avoid storing used water in open containers.

2. Do not accumulate excessive amounts of used water.

3. Do not ignore handling precautions when reusing water.

Special considerations: used water may include high quality water such as rinse water, or low quality water. Water containing urine is not reusable.

5.6.4 *Problem Statement*

Because of an inadequate water supply, water-using chemical warfare decontamination during graves-registration activities may have to be postponed until after bodies are shipped out of the theater of operations.

Possible solutions: place graves-registration activities low on the priority list if water cutbacks have to be started.

5.6.5 *Problem Statement*

Vehicular (tracked and wheeled) washracks are large consumers of water.

Possible solutions: use air compressors, not water, for cleaning operations. If necessary, use only a bucketful of water to clean areas where air cleaning was ineffective.

Special considerations: in many portions of the desert, mud removal will not be a problem even when it rains because the dried mud is not clay-based and will fall off freely.

5.6.6 *Problem Statement*

Significant water wastage is common when transferring water from bulk storage (such as "water buffaloes") and fabric collapsible containers to canteens, radiators, etc. For example, water buffaloes may have a 1-in. (inside diameter) faucet which, when canteens are filled, may cause half of the water to be wasted.

Possible solutions: use funnels (plastic, paper and/or metal) to transfer liquids where problems exist.

5.6.7 *Problem Statement*

Vigilant administration to conserve water by specific efforts to discourage excessive use of water.

Possible solutions:

1. Issue directives to limit or discourage excessive water use -- such as showers that are longer than necessary.

2. Educate personnel about the extreme value of water and the need for conservation. Make users aware of the value of water in precise terms.

3. In the food-related services, dry cleanup should precede wet cleaning.

5.6.8 *Problem Statement*

Significant quantities of certain wastewaters (e.g., shower and laundry) have the potential to be reused for uses demanding an equal or lower quality of feedwater.

Possible solution: perhaps shower waters could be collected separately, pretreated, or used directly for dust control, vehicle washing, compaction, etc.

5.6.9 *Problem Statement*

Troops must learn to be cautious with local water supplies. It is common for local water supplies to be distributed "in open curb-side ditches, a practice justified by the Moslem belief that all running water is pure. Several times a day, the water -- which comes to the city from the mountains through ancient tunnels or ghanats -- is turned into the ditches, a signal for householders to rush out and fill jars and crocks, and to wash their clothes and even themselves. A refinement on this procedure by the more wealthy residents is to divert the water into basement cisterns from where it is pumped to roof tanks for pressure distribution" (see p 40 of Reference 11 for Chapter 5).

Possible solutions: avoid these water supplies because they have a high potential to cause disease.

5.6.10 *Problem Statement*

Water supply used by the local population may cause serious problems if used by troops. The local populations have become acclimated to the water, which may contain relatively high concentrations of magnesium sulfate or sodium sulfate (500 ppm). Either of these two compounds may have a severe laxative effect on personnel who have not adjusted to the water.

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 become adjusted to the new supply. This problem will be more common with fresh water sources which have been treated with an "erdalator" rather than a desalination unit; erdalator-type devices are not designed to remove from water substances which act as laxatives. Also, high pH (above 9) waters have been known to produce a laxative effect in personnel who drink the water.

Possible solutions: avoid local water supplies unless qualified personnel (Army Medical Department) have tested and approved the water.

5.6.11 *Problem Statement*

Odor and taste problems caused by gases (hydrogen sulfide in particular) make certain well waters unpalatable.

Possible solutions:

1. Aeration

2. Cooling towers remove iron and odors.

5.7 Wastewater Disposal

Simplicity of wastewater treatment techniques under desert stress conditions must be emphasized.

5.7.1 *Septic Tank With Leach Field*

The septic tank or similar device for breakdown of solid material with accompanying leach field is normal treatment for wastewaters in a desert environment. The following statements should be considered when using this disposal technique.

1. This method involves excavation, so limits such as length of encampment, material availability, and equipment should be observed.

2. Since this method does indirectly discharge into the soil, remote siting in relation to any groundwater supply sources is a must.

3. The system should be sealed on the influent side except when receiving the wastewater stream. This will eliminate pest/disease problems.

5.7.2 *Leach Field*

The leach field is an effective method for disposal of liquid waste waters. Considerations for the use of this disposal method are as follows.

1. If liquid wastewaters contain solids or liquids which rapidly solidify, such as grease, then pretreatment is required to prevent clogging problems.

2. Leach fields should not be directly exposed for disease control reasons.

3. Leach fields should be considered as an aid to electrical grounding -- i.e., ground rods can be placed integral or into a leach field (see Chapter 4).

5.7.3 *Pit Latrines and Oil Basin Latrines*

Pit latrines and oil basin latrines are satisfactory for use for temporary, expedient operations. When these methods are employed, refer to desert operations FM 90-3.

5.7.4 *Burnout Latrines*

This is an ideal method of disposal of solid/semisolid human excrement. Use with the leach field for liquid wastewater method is encouraged.

5.7.5 *Problem Statement*

Water-born insect (flies/mosquitoes) infestations of encampment.

Areas of application: people problems.

Possible solutions:

1. Field drainage/seepage trenches/holes should be covered with 6 in. of native soil above porous material and fitted with tight covers or seals at the wastewater entrance.

2. Shower drainage areas should be sprayed with an oil film or larvicides when not in use.

5.8 Solid Waste

5.8.1 *Incineration*

Incineration is the usual method of solid waste disposal in a desert environment. Some basic rules must be considered when incinerating solid waste.

1. The area designated for burning must be sited and cleared so as not to present a hazard, and the burning must be supervised.

2. Complete combustion of all materials which support an environment for the breeding/feeding of disease vectors must be obtained.

3. Minimal storage of solid waste for disease prevention can be obtained through regular incineration.

4. Incineration can be a position identifier.

5. Incineration is not a final disposal technique. Its objectives are volume reduction and disease prevention. Therefore, residue will have to be buried or disposed of in some other way.

5.8.2 *Direct Burial*

Direct burial of solid waste, although not recommended, is used for field-expedient operations or under conditions that do not allow incineration. The following must be considered when using direct burial as a disposal method.

1. In a desert environment, direct burial can be a temporary disposal method because of the mobile/shifting characteristics of the land.

2. Rocky or hard-pan ground conditions limit the use of direct burial as a usual disposal method.

3. Improper burial of solid waste creates breeding/feeding grounds for all types of disease carriers (rats, flies, etc.).

4. Direct burial disposal site can be a position/strength assessment identifier.

5. Under certain field operations, this method of disposal can be used by individual personnel.

VERTICAL CONSTRUCTION

6 VERTICAL CONSTRUCTION

6.1 Introduction

The use of improper building materials, building systems, construction details, or construction techniques would not only create unnecessary problems for construction workers, but would also cause unnecessary maintenance problems for facility engineers. In addition, the improper building systems constructed would adversely affect the working effectiveness or living comfort of the occupants because of inferior or unsatisfactory environments. This chapter identifies unusual construction problems that may be encountered, environmental problems that need to be considered in constructing facilities, and operation and maintenance problems for construction equipment in the desert regions. This chapter also provides recommended methods that can be used to eliminate the identified problems or to reduce their impacts. Feasible local construction materials and construction techniques that can be adapted are also identified and described.

6.2 Buildings

6.2.1 *Problem Statement*

High solar radiation and high diurnal temperature variation in the desert will create very uncomfortable living conditions for building occupants unless proper building types and construction materials are selected.

Possible solutions:

1. Foundations.

a. Use on-grade concrete slab for foundation, whenever possible, to take advantage of the earth's insulating qualities.

b. Raised foundations, whether of the point or perimeter type, should be avoided. Unless the floors can be properly insulated, they will be exposed to the high diurnal temperature variation.

2. Exterior walls.

a. Build exterior walls with massive earthen materials, such as adobe bricks, if feasible. These materials, by their nature and thickness, absorb the heat and reradiate it slowly so that little heat is gained during the day. The ideal thickness of mud walls is 32 in. (80 cm). However, a minimum thickness of 16 in. (40 cm) may be used. Typical construction detail for the traditional mud or adobe wall structure is depicted in Figure 6.1. (Also see Appendix A.)

b. If lightweight wall systems are used, they should be insulated properly. Otherwise, they quickly absorb and transmit an intolerable amount of heat into the building interior.

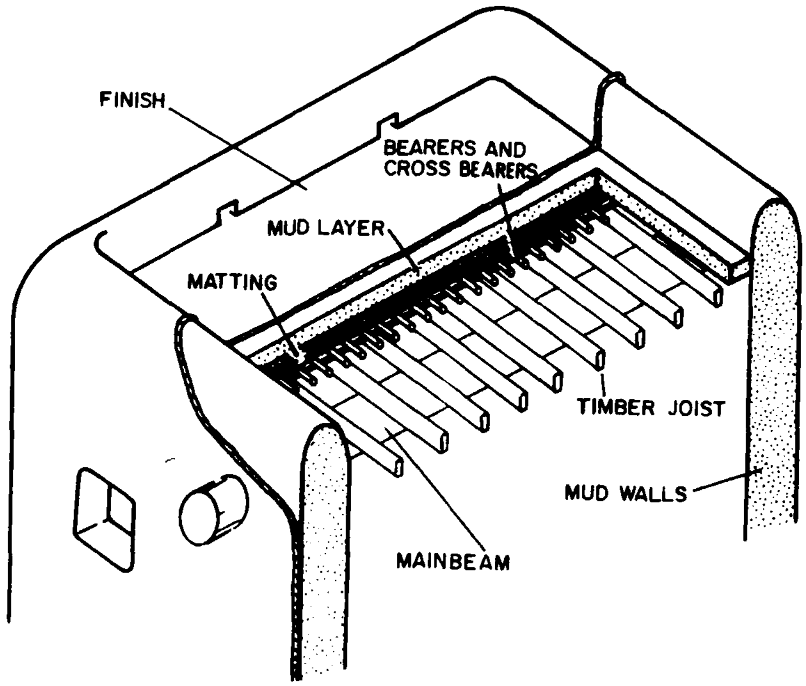

Figure 6.1. Typical construction de.ails for the traditional mud or adobe wall struc.ure.

c. Shutter and/or shade wall openin;s during daytime. Unless wall openings are heavily shuttered or shaded duri ıg the day, they transmit a large amount of heat into the building interior.

d. Keep the number of wall openings to a minimum.

e. Natural ventilation of interior spaces during daylight hours is not recommended. Tests have shown that if ventilated throughout the day, a room's air temperature matches the outside temperature and remains high even after the outside temperature has dropped.

f. Ventilate at night, when the external temperature is low.

g. The most effective height of windows to ventilate for human comfort ranges from 18 to 60 in. (46 to 152 cm) above the floor. In barracks, it is advisable to keep the sill at the height of the beds to ensure 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 (Figure 6.2).

h. The surface of the external wall should be a light color or painted in light earthen colors to reflect high solar radiation.

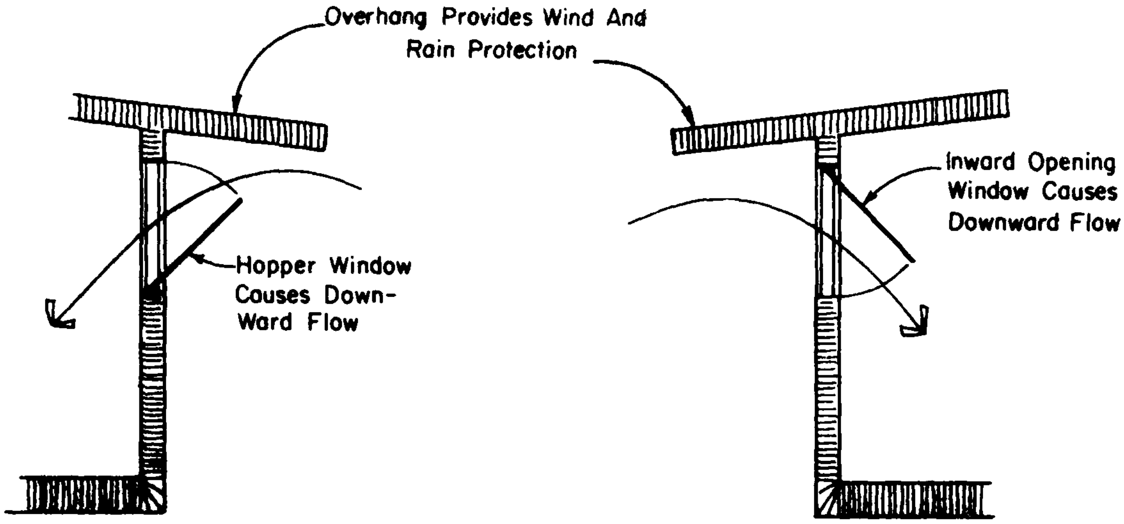

Figure 6.2. Hopper window placement.

3. Roofs.

a. Use a double roof with an air space between layers to reduce solar radiation. A minimum of a 12 in. (30.4 cm), or preferably 24 in. (60.8 cm), air space is required.

b. Thatch, if it can be obtained, is an excellent material for the outer roof in areas not subjected to excessive winds.

c. The outer roof of the double roofed system should be constructed to shade as much of the wall and ground area around the building as possible.

d. Traditional roofs constructed of heavy, thick, and dense materials, such as mud (Figure 6.1), may be used for the inner roof, if practical. This type of roof causes heat emission to the interior to be delayed until the evening -- when temperatures are lowest.

e. Insulation is recommended for lightweight roofing systems to increase thermal time lag.

f. Connections attaching the sheet metal roofing should permit a considerable amount of thermal movement to allow for temperature changes. Movement should not be transmitted to structural supports.

g. Roofs should be painted white or whitewashed to reflect the solar radiation.

4. Interior walls.

a. Use of interior walls should be minimized because they limit the air flow when windows are opened.

b. Where needed, interior walls should be lightweight and light in color.

6.2.2 *Problem Statement*

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.

Possible solutions:

1. Provide vertical control joints in the walls. Proper spacings based on experience in Saudi Arabia are given in Table 6.1.

2. Reinforce horizontal joints (Table 6.1).

3. Use bond beams at appropriate locations, such as over door and window openings in the walls.

6.2.3 *Problem Statement*

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

Table 6.1

Concrete Masonry Wall Joint Placement

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

*Spacing shall not exceed the smaller of the dimension shown. H = height of the wall.
+Joint reinforcement shall include two or more longitudinal steel wires, minimum total area = 0.0346 sq in. (0.223 cm^2).

Possible solutions:

1. Foundation.

a. In windy areas, the foundations must be built deep enough to prevent erosion around the corners of the foundation system (maximum depth of erodible soil plus 18 in.).

b. Use asphalts, oils, chemicals, or gravel backfill to stabilize the soil around the corners of the building foundation.

2. Windows and doors.

a. Exterior doors and windows should be sealed as much as possible. However, no attempt should be made, under normal service conditions, to erect a sand-tight building because this cannot be done.

b. Infiltration of dust can be reduced by using:

(1) Nonoperable windows.

(2) High air intake louvers.

(3) Inertial dust separator.

(4) Air filters.

(5) Positive building interior air pressure.

c. Vestibules may be used to reduce dust penetration in air-conditioned buildings where sensitive equipment is stored.

d. Use either horizontally pivoted (awing and hopper) or vertically pivoted (casement) windows to reduce maintenance problems.

e. Do not use sliding windows because sand and dust accumulate in tracks during dust storms.

3. Roofs. In windy areas, roofing materials must be doubly fastened and roofing systems attached securely to the supporting structure by additional fasteners.

6.2.4 *Problem Statement*

There is too much glare under the sun because the ground plane in the desert region is normally very bare.

Possible solutions: to reduce glare, use subdued, light-earthen-colored paints for exterior walls of buildings instead of white paint.

6.2.5 *Problem Statement*

In many sections of Southwest Asia, insects such as flies will be a nuisance.

Possible solutions: all living and work areas should be screened against insects if possible.

6.3 Tents

6.3.1 *Problem Statement*

Sandy and rocky ground combined with high winds in the desert may cause problems with pitching tents.

Possible solutions:

1. Use 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 6.3).

2. Corkscrew anchors can be used if the required resistance force is not large (the corkscrew anchor is more suitable for clay-like soil).

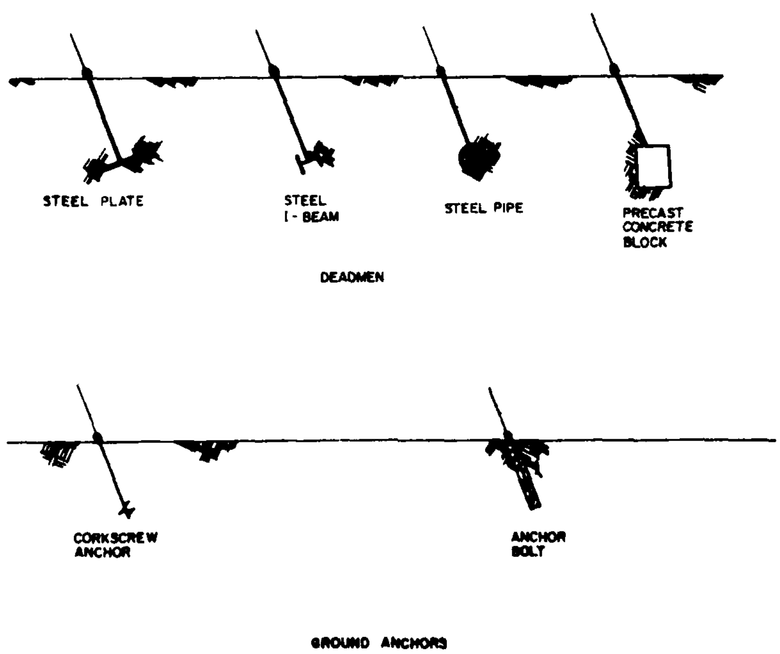

Figure 6.3. Ground anchors.

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.

6.3.2 *Problem Statement*

Tents are the least desirable quarters in the desert region due to high solar radiation, desert winds, and insects. However, they are required for the initial stage of military operations.

Possible solutions:

1. Tents should be double roofed, and the outer roof painted white when possible (see Figure 6.4).

2. Concrete floors under the tents can make the occupants more comfortable.

3. A tent can also be erected over a hole as big as the tent and 3 or 4 ft deep. However, this has both advantanges and disadvantages.

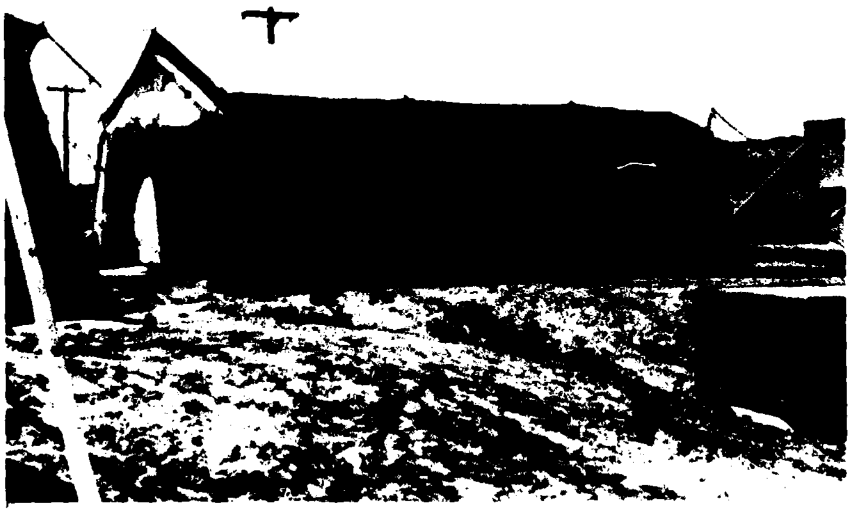

Figure 6.4. Double roofed tent with outer roof in white.

a. Personnel sleep below the hot sand level; cool air falls naturally to the floor.

b. If there are any flies present, they will cluster in the peak of the tent and become torpid during the cool night. They can be swept down into a pan and killed with boiling water before they warm up.

c. One disadvantage is the presence of surface creatures such as scorpions, centipedes, and sand fleas, which will crawl under the sides of the tent for warmth as soon as outside air cools. When they reach the edge of the hole, they fall to the floor.

6.4 Prefabricated Relocatable Buildings

6.4.1 *Problem Statement*

In general, prefabricated relocatable buildings used for offices or barracks are lightweight, and their walls, roof, and floor systems are adequately insulated. They will function well and provide comfortable working or living quarters if they are cooled mechanically. However, without mechanical cooling, the interior temperatures will rise above the outside air temperature and become intolerable during some parts of a day due to high solar radiation and heat generated by the occupants.

Possible solutions:

1. A roof or shade should be constructed over the building.

2. If the windows are not operable, they should be modified or replaced so that they can be opened when the outside temperature is below the inside temperature.

6.4.2 *Problem Statement*

Desert winds can reach almost hurricane force in some regions.

Possible solutions:

1. Buildings should be anchored securely or tied down with cables and anchored securely to the ground (Figure 6.3) in high wind areas.

2. Materials used for the outer roofs must be attached to the supporting structure using additional fasteners.

6.5 Construction Materials

6.5.1 *Problem Statement*

Corrosive soils are abundant in the region; they contain sulfate and chloride, which will react with portland cement.

Possible solutions:

1. Portland cement. Follow the suggested usages given below for portland cement when available:

a. Type I -- Interior, superstructures only

b. Type II -- If tricalcium aluminate is less than 5 percent, use anywhere

c. Type III -- Superstructure, aboveground, no ground contact

d. Type IV -- Seldom used, not readily available

e. Type V -- Any location. Normal for concrete in contact with ground.

2. Galvanized steel pipe.

a. Do not use galvanized steel in contact with ground in Saudi Arabia (except at Khomis Mushayt) and any other locations with similar soils. Galvanized steel corrodes in a short time.

b. Use helical-wound, fiberglass-reinforced pipes, PVC pipes, or asbestos cement pipes.

6.5.2 *Problem Statement*

The air near coastal regions is highly corrosive due to seawater spray.

Possible solutions:

1. Fence.

a. Use only zinc-coated, vinyl-covered steel chain link fabric, gates, posts, and accessories within 5 mi of seawater.

b. Do not use zinc-coated material without vinyl covering within 5 mi of seawater.

c. Do not use aluminum fencing material within 5 mi of seawater.

2. Roofs and exterior sidings.

a. Use asbestos cement sheets if available.

b. Do not use galvanized corrugated metal sheets within 5 mi of seawater. (Galvanized corrugated metal sheets are satisfactory for other interior areas.)

6.5.3 *Problem Statement*

The combination of high solar radiation and low humidity will cause wood to warp and crack severely during construction.

Possible solutions:

1. Minimize the use of wood as construction material.

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 warpage. (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.

6.5.4 *Problem Statement*

Wood is not normally recommended in Southwest Asia 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.

Possible solutions:

1. Utmost care must be taken to limit waste due to cutting, etc. For instance, a centralized cutting yard may be used.

2. Reducing design criteria should be considered when they are not critical and when the reduction will not cause a safety hazard.

3. A raised foundation which requires wood normally is not recommended.

4. See the possible solutions for Problem Statement 6.5.3.

6.5.5 *Problem Statement*

Any metallic object left in the sun will become too hot for handling. Prefabricated tank sections of pipe sections may expand so much they will not fit.

Possible solutions:

1. Place any metallic object under shade, or cover it with something.

2. Use gloves to prevent burns.

6.5.6 *Problem Statement*

There are very few local construction materials (except sands, aggregates, and muds) available in the region. In addition, the qualities of sands and aggregates are not very good in some regions. Nevertheless, these local materials should be used as much as possible.

Possible solutions:

1. At locations where masonry or sun-dried mud brick (adobe) can be obtained easily, they should be used whenever possible. It may seem strange to consider masonry construction "temporary," but it must be remembered that local materials should be used as much as possible, and imported materials as little as possible. Local or native workmen are far more experienced in masonry than in carpentry.

2. Bally poles which are available in Iran can be used for columns, beams, rafters, purlins, etc. A bally pole is a round timber consisting of the trunk of a poplar-like tree and varies from 2 to 8 in. (5.0 to 20.2 cm) in diameter.

3. Timbers from palm trees are also available in some regions and can be used for beams and joists.

6.5.7 *Problem Statement*

Other identified problems related to concrete technology and concrete construction and their recommended solutions are given in Chapter 7.

6.6 Mechanical System

6.6.1 *Problem Statement*

The high alkali content of the water normally found in desert regions causes corrosion problems in water distribution systems and evaporated air cooling units.

Possible solutions:

1. The water that will be used for evaporative cooler should be treated if required.

2. Do not use evaporative cooler where water is at a premium. However, since evaporative cooling units are more economical, use them as much as possible in hot, dry regions if water is available.

3. A traditional method using the same concept of evaporation cooling can be used as shown in Figure 6.5. This is a chimney-type structure with an opening designed to catch the prevailing dry winds. The dry winds are then funnelled down a shaft in which a large porous pot full of water is suspended. The water in the porous pot slowly drops 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.

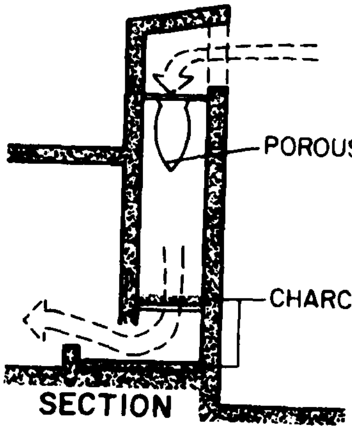

Figure 6.5. Traditional method of evaporative cooling.

HORIZONTAL CONSTRUCTION

7 HORIZONTAL CONSTRUCTION

7.1 Introduction

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 communication (LOC). Because of the limited number of existing roads and the difficulty of off-road mobility in the desert, 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 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. The two positive notes are (1) fine and coarse aggregates are widely available, and (2) 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 is all right for most requirements), and construction equipment in quantity. A total base development cannot be done with indigenous materials alone.

Table 7.1

Engineer Materials for Horizontal Construction
(Available From Depot Sources)

Item	Wt. (Lbs/Sq Ft)	Length & Width (Inches)	Depth (Inches)	FSN
M19 Medium Duty Landing Mat	4.3	50.2, 49.5	1.5	5680-00-089-5920
XM18 Medium Duty Landing Mat	4.9	144, 12	1.5	5680-00-089-7260
M8A1 Light Duty Landing Mat	7.5	144, 19.5	1.1	5680-00-782-5577
AM2 Medium Duty Landing Mat	6.3	144, 12	1.5	5680-NAEL-613370-1
T17 Membrane	0.31	100, 150	0.08	5680-00-921-5809

7.2 Existing Construction

Existing paved roads will generally be structurally adequate for wheeled-vehicle traffic. The dominant characteristic of the area affecting horizontal construction is the absence of existing roadways. Because the area is sparsely populated, few roads exist. This, 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, but often they are narrow (6-m width) and have thin pavements that will not stand up under use by tracked vehicles. Consideration should be given to widening the shoulders of such roads and using the shoulders for tracked-vehicle operations.

7.3 Subsurface Conditions

Fookes* concisely describes engineering properties of various geographic units found in desert areas. His article should be read by personnel responsible for route and materials selection for horizontal construction. Figure 7.1 shows the four geographic zones into which most desert regions can be subdivided: (I) mountain slopes, (II) the apron fan or bajada, (III) the alluvial plain, and (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.

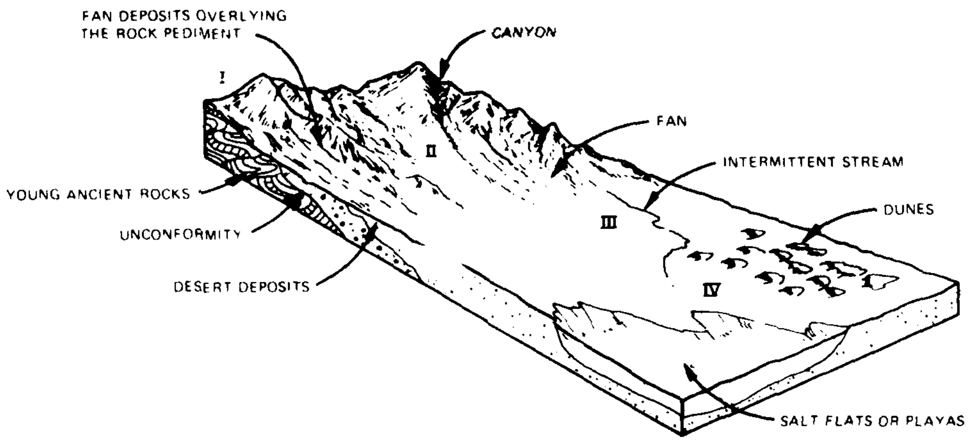

Figure 7.1. Block diagram of hot desert mount and plain terrain showing the four engineering zones (adapted from P. G. Fookes*).

* 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.

Table 7.2

Comparison of Desert Surface Types by Plan Area

(Reprinted from P.G. Fookes, see note, pg 7-2. Reproduced by kind 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
		100.0	100.0	100.0	100.0

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 (see Table 7.1). 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, airfields, and in base areas (discussed in Problem Statement 7.5.2). They also impede off-road mobility of wheeled vehicles.

7.4 Solution to Horizontal Construction Problems

Individual statements follow which describe problems in horizontal construction caused by the Mid-East geographic, geologic, and climatic environments; also included are possible solutions or expedient ways of dealing with these problems. In general, one should look at the methods of construction used in a particular country and evaluate pavement systems. It may be possible and desirable to copy what appears to be the standard practice in the various countries since these standards are often dictated by the availability of engineering materials.

See the Bibliography (p F-6) for literature on horizontal construction and Appendix B for a good overview of geological conditions and soil properties affecting pavement-system construction in the Middle East.

7.5 Problem Areas

7.5.1 *Problem Statement*

Cooling of materials and equipment via excavation.

Possible solutions:

1. Trenches, when coupled with awnings, provide almost complete shade. Trenches should be located on hills if possible, oriented with the long direction the same as that of the prevailing wind and the ends left open to promote air circulation.

2. Burial of materials at shallow depths (approximately 1 to 2 m) reduces maximum temperatures significantly. Temperatures as high as 86^{o}F have been recorded at the 1.2-m depth in the Mid East: this is significantly less than the maximum air temperature recorded, and even very shallow burial eliminates radiant heating effects on dark surfaces.

3. Use of constructed earth berms as windbreaks with gaps to concentrate prevailing winds.

Don'ts: for artillery ammunition storage, where the objective is to keep the temperature below the range where the explosive softens and within the range where the round can be picked up, very shallow burial (15 cm) or shade will suffice. The ammunition should not be buried deeply.

7.5.2 *Problem Statement*

Control of drifting sands.

Possible solutions:

1. Align route or airfield upwind from existing dune areas or sand-source areas.

2. Oil the surface of windblown sand with high-gravity crude oil for temporary dust control.

3. Erect porous barriers (i.e., snow fence or spaced nonporous barriers). Landing mat could be used for this purpose but is probably too precious.

4. Build the roadway on an embankment above normal surface elevation.

5. Dig trenches to destroy the symmetry of a dune; this can accelerate its destruction by wind. Locally experienced people are needed to guide such work. 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.

Don'ts: do not disturb local surface vegetation.

7.5.3 *Problem Statement*

Construction of roads on bases or between bases will require innovative construction techniques to offset the additional time required by harsh environment.

Possible solutions:

1. Use seawater or crude oil for compaction and stabilization.

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 may be used for tank traffic, thereby extending the life of the pavement for wheeled vehicles.

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, soil reinforcement would enhance road construction by conventional methods.

9. Increase use of locally available cutback and emulsified petroleum products.

Don'ts:

1. 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).

2. Do not expect timber to be available for culverts, trusses, etc.

Special considerations:

1. Rippers may be required on large tractors for removal of hardpan.

2. Floods have been known to develop in arid areas within 24 hours of rainstorm.

3. Tires will deteriorate more quickly due to extreme heat.

4. Diverse foundation conditions will exist on any extended stretch of roadway.

7.5.4 *Problem Statement*

Rapid construction of surfaced roads in a desert theater of operation is necessary to transport equipment, personnel, and supplies. However, because of time constraints and the possible unavailability of good-quality aggregates, conventional paving practices cannot be followed.

Possible solutions: use available sands to make sand-asphalt mixtures for temporary, rapidly constructed pavements. The pavement materials could be cold mixed on site. Six to nine percent residual asphalt by weight is usually required. See the section of TM 5-337, "Road Mixes," for construction technology and TM 5-822-5 for design procedures to determine pavement thickness. Because the desert soils are so poorly graded, these procedures may not be conservative. The sand below the embankment should be compacted as much as possible. This surface should be penetrated with MC 250-800 or RC 250-800 at the rate of 1/2 gal/sq yd, blotted with sand and re-rolled to provide a working surface. Sand sufficient to form a 1- or 2-in.-thick layer should be windrowed on this surface and 6 to 9 percent asphalt by weight of liquid (cutback) asphalt (RC or MC 800) or emulsified asphalt (CSS or SS) should be applied in several increments. The material should be thoroughly mixed, spread, and rolled.

Don'ts: avoid placing sand-asphalt mix over uncompacted loose base material. Avoid sand with high percentage of fines passing the No. 200 sieve and a high organic content. Do not use for tank traffic or very heavy vehicles unless absolutely necessary, because the life of this type of roadway is drastically shortened by heavy loads.

Special considerations: the minimum equipment for on-site mixing would be a motor grader, an asphalt distributor, and a 5-ton, steel-wheeled or rubber-tired roller. The mixing of the windrowed material requires a very well trained motor patrol operator. If one is not available, a travelling rotary-type mixer is also needed. A minimum pavement thickness of 4 in. should be considered.

7.5.5 *Problem Statement*

Construction of C-130 airstrips with low-quality materials, lack of water, and limited logistics.

Possible solutions:

1. Construct thicker sections of lower-quality earth materials.

2. Use seawater or brackish water for compaction control instead of potable water.

3. Regrade and compact existing materials as required until construction materials are available.

4. Proper site selection may require minimal construction effort.

5. Certain playa surfaces (salt-encrusted) and sandy areas will support aircraft but not ground support equipment. Aircraft may bring in membrane or matting for off-loading purposes.

6. Increase the flotation of aircraft by decreasing tire pressure.

7. Improvements in moisture may be obtained by transporting water, distributing and covering with an impervious membrane. Moisture will condense under the membrane by hydrogenesis.

8. Use road systems for airstrips by cutting obstructions along the road and widening with material available.

9. Provide refresher training to certain personnel in the selection of the best gradation soils available. Many of the problems anticipated will be the result of poorly graded (predominantly one particle size) soils. Key personnel should be trained to recognize them.

Don'ts:

1. Do not assume that the aircraft can land anywhere for any number of operations.

2. Vibratory compactors should be used instead of pneumatic-tired rollers in sandy areas.

7.5.6 *Problem Statement*

Bridging intermittent streams.

Possible solutions: build a ford instead of a bridge. This may make the roadway unuseable 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.

Don'ts: do not demolish existing bridges to get materials for other uses.

7.5.7 *Problem Statement*

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.

Possible solutions:

1. Use lighter traffic loads and reduce tire pressures.

2. Keep sand wet with seawater. Pumps and hoses would be required for this purpose; 500 gal/min capacity would be required for each kilometer of roadway. Pump capacity given above is an estimate only. Tests in a hot dry environment are needed to verify the estimate.

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. deep in the sand. Tests have shown best performance over buried membrane 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.

Don'ts: 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 at 3- to 4- in. depth.

Special considerations: blowing sands may cause operation problems with the construction equipment and also high maintenance for the roadway or storage facility. Almost anything mixed with a loose sand will improve its trafficability performance.

7.5.8 *Problem Statement*

Dust control will be necessary to prevent increased engine maintenance and reduced propeller-blade life, and to lessen battlefield signature of location.

Possible solutions:

1. Define technology currently being used by contractors operating in the area.

2. Select an asphalt distributor and modify the spray bar to allow application of penaprime type dust-control agents.

3. Install lubrication nozzles on the asphalt distributor bar to allow distribution of DCA 1295, low viscosity dust-control agent for trafficked areas.

4. Use a fiberglass scrim for dust-control reinforcement, especially for low-strength 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).

Don'ts:

1. Do not start from scratch on dust-control chemicals (see Appendix D and DA PAM 525-5, Dust Control, Lessons Learned, February 1969).

2. Do not expect water or light oil applications to suffice.

Special considerations:

1. Highly porous materials to receive control.

2. In lightly trafficked areas, sand will rut, causing deterioration of dust control.

3. Seawater may be used for the prewetting recommended in DA PAM 525-5.

4. Flash point of penaprime and cutback asphalt is about 150°F.

5. Asphalt products will have a tacky surface above 100°F.

7.5.9 *Problem Statement*

Concrete construction presents problems in the Mid-East environment. The lack of water, the high air temperature, locally available aggregate sources, and the lack of in-country production capabilities and construction equipment (for most countries) all make concrete construction in the Mid East a challenge. The suggestions given below for expedient concrete construction will not always result in a good product. They will, however, provide concrete adequate for the period of use assumed in this report (12 months).

Possible solutions:

1. Seawater or brackish water is acceptable for use in concrete. No more than a 15 percent strength degradation will occur. Since a damp surface and surface efflorescences may result, do not use saline waters where a good surface finish is required. Saline water is not acceptable when high alumina cement (black instead of usual gray) is used.

2. Mixing water and aggregate temperatures may exceed 100°F. This will decrease workability. Commercial retarding agents should be added. If not available, add 1/4 to 1/2 lbs. of sugar per cubic yard. Try the smaller amount first.

3. Because of the high rate of evaporation, extra water will be required to keep curing blankets wet. Seawater is satisfactory for this purpose. Alternatively, curing compounds should be sprayed on exposed surfaces.

4. Lumber for form-work is scarce; tilt-up panels may help overcome this difficulty.

5. Many aggregate sources are contaminated with chlorides and/or sulphates. Use Type III (sulfate resistant) cement if available.

6. Available fine aggregates (sands) will usually be very fine and of nearly uniform grain size. This requires extra cement and water in the mix. Silt size (dust) particles should be removed by washing if possible. Use of seawater for this purpose is only marginally safe because it increases chloride concentration.

7. When using natural desert or beach pavements (calcrete duricrusts) for coarse aggregate sources, discard the top 1 ft because it is most highly contaminated by chlorides and sulfates. Most contaminants are in the finer, for easily broken, fraction. Discarding material which passes through a 2-in. grizzly will help reduce contaminants.

8. Natural pavement coarse aggregate source layers vary from 3- to 15-ft thick. The bottom grades into unsuitable materials, and excavation must be stopped when noticeably softer materials are encountered.

9. Limestone, dolomites and igneous rock are prevalent in the mountainous regions. The first two are the preferred coarse aggregate sources.

10. Active wadis and portions of the alluvial fans which occur where the wadi meets the desert plain are good sources of sand and gravels.

Special considerations: simplified mixture proportioning techniques which take into account the unusual aggregate gradings, high water demand, seawater usage, and contaminants are needed. The resulting expected concrete strengths and performance for the available materials and anticipated construction techniques must be established. Rule-of-thumb guidelines for all aspects of concrete production and construction must be identified. Field techniques for concrete materials cooling must be established. Concrete repair materials and techniques for use at elevated temperatures must be developed.

7.5.10 *Problem Statement*

Bomb damage repair in runways on existing airfields required to take C-141 or F-4 traffic.

Possible solutions:

1. The optimum (bomb damage repair) solution for the C-141 appears to be pre-prepared landing mat kits. (See, for example, AF Regulation 93-2, Chapter 5, or Chapter 3 of Airfield Damage Repair, May 1979, Field Reference Document, OCE.) This solution does not depend on local availability of materials, is C-130 transportable, reuseable, and requires a minimum amount of

equipment which is not available in the TOE (power broom and vibratory roller).

2. For the F-4, which requires a smoother operating surface, two solutions are provided. The one requiring least logistical support requires the assurance that stockpiled well-graded coarse aggregate (crushed stone) exists in the urban area that the runway presently serves. (For details, see Chapter 2 of Airfield Damage Repair.) A power broom and a vibratory roller are required. T-17 membrane is used to cover the surface to prevent foreign object damage. The membrane extends several feet beyond the patch and is anchored to the existing pavement by 1/4-in.-thick steel plate strips with predrilled holes for anchor bolts. At each opening in the plate, holes are drilled in the pavement, filled with liquid sulfur or cement grout, and a bolt placed in the hole. If the processed aggregate source is not assured, this approach is undesirable because of both the tremendous amount of equipment required to set up a crusher operation and the possibility that no suitable rock exists in the immediate vicinity.

3. The other F-4 solution is a cement grout system (cement and water only). Items that must be brought in include portland cement Type I, accelerating agents (calcium chloride), visqueen, a finisher screed, and either a 5-yd transit mix truck or a mobile batcher/mixer unit. Locally available cement may be used. In this method, lightly compacted (85 percent of CE55) debris is placed in the bottom of the crater to within 18 in. of the surface. A polyethelene (10 mil visqueen) sheet is placed and a cement-water-accelerator grout is placed on top of the visqueen. Front-end loaders now end-dump small pieces of concrete debris and coarse aggregate into the crater. By gravity, the aggregate displaces the liquid grout and is screeded off at the surface. With 1 percent calcium chloride, by weight of cement, the required strength will be achieved within 10 to 15 hours. While this method does not place such severe requirements on the quality of locally available aggregate, it does require that a stockpiled source be available. If none exists, this option will not work until a quarry or pit is developed and a crusher put into operation.

4. Spall damage repair required for F-4 operation is done with a power broom to clear foreign objects and hand mixed sand-cement mortar to fill small craters.

Special considerations: a laboratory study to determine the effects of high initial ingredient temperature (100°F), 130°F air temperature, and expedient retarding agents on time to initial set, and strength at 8 and 24 hours is needed. Also, the variability due to locally available cements and the need for accelerators should be studied. From this would come grout mix properties that give reliable results every time in the particular environmental conditions of interest.

PORT CONSTRUCTION

8 PORT CONSTRUCTION

8.1 Introduction

Certain geographic areas of operations may require use of beach sites for extended periods of time because 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 are listed in two studies.* A survey of these references reveals 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 draft available in the channel or at dockside. A typical small port involved in coastal trade is shown in Figure 8.1.

8.2 Problem Areas

8.2.1 *Problem Statement*

Rapid dredging of channels with depths of at least 40 ft is needed to accommodate container ships.

Possible solutions: no practical solution to this problem was identified; see special considerations below.

Special considerations: 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. 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 to the completion of large-scale missions such as port rehabilitation.

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* Ports of the World, 33rd ed. (Benn Publications Limited, 1980); James Freight Containers, 12th ed. (Franklin Watts, Inc., 1980).

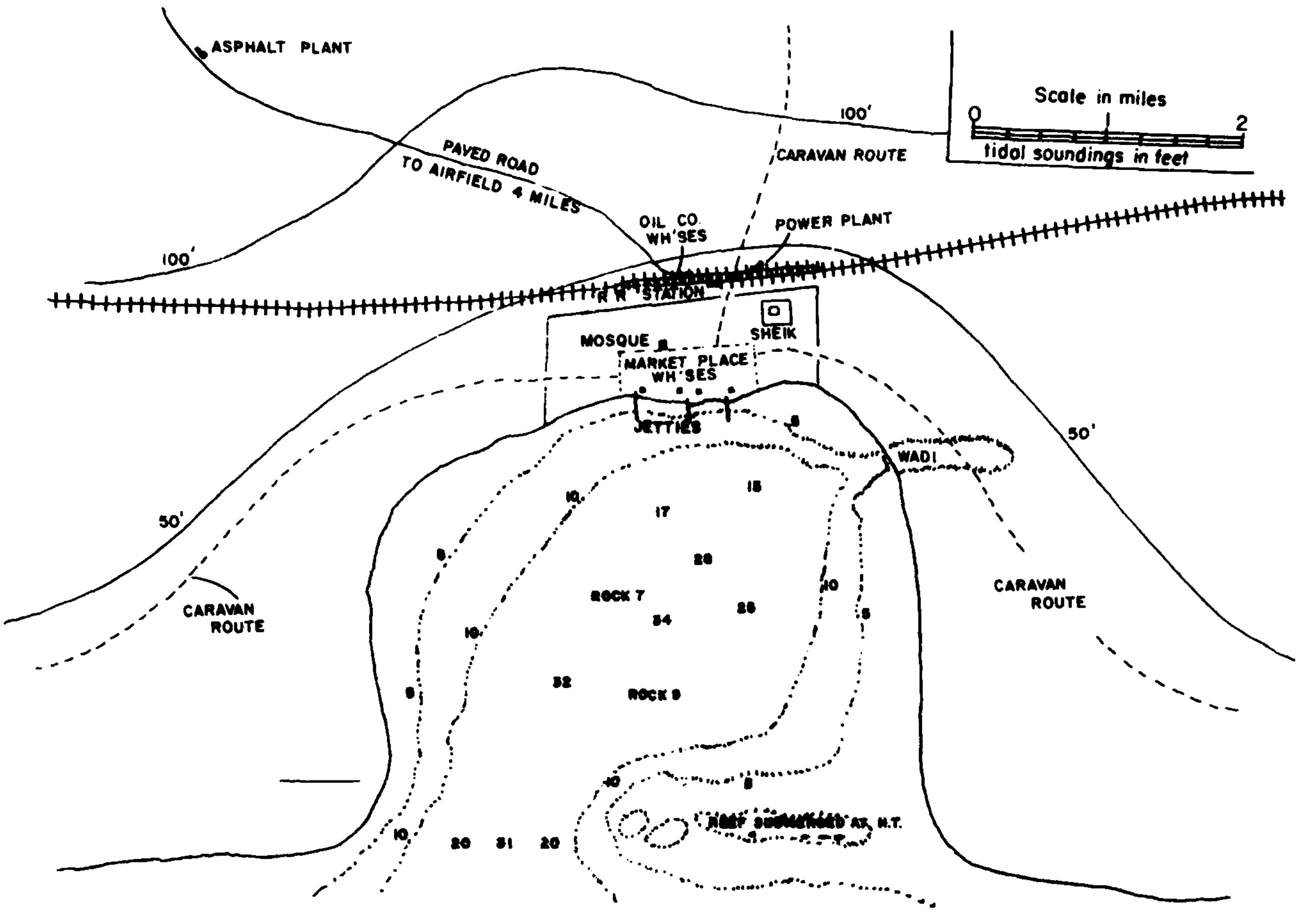


Figure 8.1. Typical facilities in a small port in the Middle East (from Tropical Engineering, NAVDOCKS P-39 [Navy Department, 1951]).

8.2.2 *Problem Statement*

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.

Possible solutions:

1. Familiarization schooling for personnel assigned to rapid deployment force.

2. Importation of allied civilian workers skilled in operation of such equipment.

3. On-the-job orientation for untrained military personnel.

Special considerations:

1. Detailed information should be gathered concerning the type and quantity of equipment available at Persian Gulf ports so that familiarization schooling can be done.

2. On-the-job training is not recommended as the best solution; learning accidents can be costly in an operation for which time is minimal.

8.2.3 *Problem Statement*

Construction, rehabilitation, and/or improvement of POL terminal facilities are needed to achieve an early capability for unloading POL tankers.

Possible solutions: tactical marine terminals consisting of two functional portions, an offshore and an onshore portion. The terminal 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, the hold filled, and then towed to a storage site.

Special considerations: 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 the tankers.

8.2.4 *Problem Statement*

Capability required for the rapid construction of expedient container ports to meet rapid deployable force requirements.

Possible solutions: no practical solutions were identified during this study.

Special considerations: 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.

8.2.5 *Problem Statement*

Removal of horizontal and vertical structures that are damaged beyond repair and are interefering with completion of the port operation mission.

Possible solutions:

1. 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.

2. Blasting techniques have been effective in reducing structures to rubble.

Special considerations:

1. Blasting and the handling of explosives should be done only by trained personnel.

2. Adding a dump truck company could make it easier to handle large quantities of earth, rubble, or damaged construction material.

3. Sub-assemblies salvaged from a destroyed 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.

8.2.6 *Problem Statement*

Lack of adequate road networks from port to inland areas.

Possible solutions: expedient construction techniques may be used with minimum quantities of hauled-in materials to provide binder for in-place, sandy materials. Use of seawater to obtain compaction with heavy construction equipment, dump trucks, etc. 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 coils cannot be completed in the alloted 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.

Special considerations: minimum stand-by force of water trucks and dozers required to smooth road surface as ruts occur from vehicle traffic.

8.2.7 *Problem Statement*

During the rehabilitation of ports, the off-loading of supply ships will be hindered until reconstruction of wharves and quays can be completed.

Possible solutions:

1. Lighterage operations from ships anchored within the harbor to barges for transfer to shore.

2. Lighterage from lighter aboard ship (LASH) or SEABEE ships for over-the-beach discharge of cargo.

3. Use of heavy lift helicopters to off-load break-bulk or container cargoes.

4. *Causeway barges can be used to ferry containers from ship to shore.*

Special considerations:

Lighterage from ships that do not have self-sustaining capacity would require the use of a floating crane or use of helicopters.

2. Lighterage operations cannot be conducted in heavy seas.

3. Discharge or roll on/roll off ships is only possible through the Army's Beach Discharge Light (BDL), of which there is only one.

4. Use of helicopters restricts cargo weight to useful limits of the helicopter. Nominal loads of up to 18,200 lb can be carried by CH-47C helicopters.

5. All of the above methods are time consuming and should only be used until docking facilities are available.

6. Movement of barges will require powered vessels.

7. Causeway barges can handle both container cargo and RO/RO vehicles.

8.2.8 *Problem Statement*

Local timber for piling or wharf superstructures is generally not available.

Possible solutions: 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.

Don'ts: the timing of the operation makes setting up a precast concrete piling manufacturing yard unrealistic. Materials must either be scavenged or imported.

FACTORS AFFECTING ENGINEER WORK FORCE

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 *Problem Statement*

High solar radiation and temperature may cause heat cramps and heat exhaustion.

Possible solutions: to prevent heat cramps and heat exhaustion, the following should be observed.

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 require 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. 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.

Don'ts: the body, especially the head, should not be unnecessarily exposed to the sun.

9.2.2 *Problem Statement*

Occasionally, drinking water must be restricted. The restricted drinking water supply will cause reduction in operational effectiveness and an increase in health hazard.

Possible solutions:

1. The number of working hours should be reduced.

2. The work should be made less strenuous.

Don'ts:

1. The men should not be allowed to work in the sun.

2. Never reduce the amount of drinking water as a "hardening" measure or "toughening" process. This is a dangerous practice -- it only produces dehydration. When water is in short supply, significant water economy can be achieved only by reducing physical activity, or limiting it to early morning and night hours when the heat load is less and thus sweating is reduced. Any attempt at water economy by restricting water intake must be paid for in reduced work capability, reduced efficiency, and increased risk of a heat injury.

Special considerations: Table 9.1 may be used as a guide to estimate the drinking water requirements for personnel exposed to heat. See Appendix C for times to impairment of operational effectiveness for various levels of activities. (Different levels of activities also are defined in Appendix C.)

9.2.3 *Problem Statement*

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 become adjusted to the new supply. This problem will be more common with freshwater sources which have been treated with an "erdalator" rather than a desalination unit; erdalator-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).

Possible solutions:

1. Avoid local water supplies unless qualified personnel have tested and approved the water.

2. Try to keep changes in sources of water supply to a minimum.

9.2.4 *Problem Statement*

In desert regions, night vision of personnel may be impaired by prolonged exposure of the eyes to intense sunlight and reflected light from the earth.

Possible solutions:

1. Provide caps or hats with wide brims or bills to shade the eyes.

Table 9.1

Water Requirements

Activity	Illustrative Duties	Quarts per man per day for drinking purposes (a guide for planning only) WBGT or WD Index* 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. ($WD = 0.85WB + 0.15DB$)

2. Prohibit personnel from working in the direct sunlight without having their heads covered and eyes shaded.

3. Provide sunglasses to all personnel and require that they wear them when they are outside in the daytime.

4. 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 affixed to the head 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 individual with limited vision.

9.3 Effectiveness of Construction Personnel

9.3.1 *Problem Statement*

Reduced efficiency of workers caused by high daytime temperature.

Possible solutions: in many desert areas, night shifts can be used and advantage taken of the night's cooler temperatures. However, this should be weighed against the drawback requiring workers to sleep in excessive daytime temperature.

Special considerations: see Appendix C for limiting environmental conditions for sustained light, moderate, and hard work.

9.3.2 *Problem Statement*

Dust or sand storms not only reduce the efficiency of the workers, but also create problems for the equipment.

Possible solutions:

1. When there are bad sand or dust storms, it is better to stop working than to try to keep things going.

2. Goggles, chapsticks, and skin and eye ointments are required for all personnel.

9.3.3 *Problem Statement*

Numerous species of flies are annoyances in all countries of Southwest Asia. Many other types of insects, such as mosquitoes, fleas, etc., are also found in the region.

Possible solutions:

1. Screen the work areas to stop the flies and mosquitoes.

2. Use insecticides provided by the Quartermaster Corps.

9.3.4 *Problem Statement*

If left in the sun, any metallic object, such as a tool or equipment, will become too hot for handling.

Possible solutions:

1. Need gloves for workers as protection against burns.

2. Store tools or equipment under shade whenever possible.

9.4 Local Labor Force

9.4.1 *Problem Statement*

The native or local laborers in remote areas lack modern construction skills.

Possible solutions:

1. Native laborers are more efficient when working with familiar materials and tools. Therefore, do not attempt to force them to use modern tools unless the training can be done easily.

2. Local or native workmen are far more experienced in masonry than in carpentry. Therefore, use natives for the types of construction they are familiar with.

3. 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.

9.4.2 *Problem Statement*

The language barrier and customs of natives may create problems in dealing with local laborers.

Possible solutions:

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.

9.5 Construction and Engineering Equipment Maintenance

9.5.1 *Problem Statement*

Dust and sand are probably the greatest dangers to the efficient functioning of equipment in the desert. It is almost impossible to avoid particles settling on moving parts and acting as an abrasive.

Possible solutions:

1. Mechanical equipment.

a. Lubrication must be the correct viscosity for the temperature and kept to the absolute minimum in the case of exposed or semi-exposed moving parts.

b. Check lube fittings frequently. If they are missing, sand will enter the housing and cause bearing failure.

c. Teflon bearings require constant inspection to ensure that the coating is not being removed.

2. Filtration (air cleaner).

a. Inspect air cleaners of every type at least daily, or more frequently if operating conditions require.

b. Use filters when refueling any type of vehicle. The gap between the nozzle and the fuel tanks filler must be kept covered.

c. Clean fuel filters frequently.

d. Replace oil filters more frequently than usual.

e. Change engine oil more often than in temperate climates.

3. Engine maintenance.

a. Locate the working spot on bare ground or concrete, if possible, and keep sand swept from the area.

b. If there is a patch of fine, loose sand, locate the work space so that it will not be dusted by every breeze.

c. Do not establish a repair area beside a road.

d. Try to get a canvas lean-to or a half tent when machinery must be opened up for servicing.

e. Keep the whole working area cleared of dust. If possible, dampen the sand, or better still, sprinkle it with used engine oil and cover it with rock to bind it down.

f. When there are bad sand or dust storms, stop working.

g. Keep tools clean.

9.5.2 *Problem Statement*

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.

Possible solutions:

1. Be aware of which vehicle types are prone to excessive overheating and ensure that extra care is applied to their maintenance.

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.

9.5.3 *Problem Statement*

Batteries do not hold their charge efficiently in intense heat.

Possible solutions:

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.

9.5.4 *Problem Statement*

High diurnal temperatures may cause problems for tires and fuel tanks. For instance, if tires are inflated to the correct pressure during the cool night, they may burst during the heat of day. If fuel tanks are filled to the brim at night, they will overflow at midday.

Possible solutions:

1. Check the air pressure when the equipment is operating at efficient working temperature and maintain it.

2. Fill fuel tanks to their correct capacity.

3. Do not service these items during heat of day; the results will be under-pressures and overheating of tires, and a lack of endurance if the fuel tanks were not filled to their correct levels.

9.5.5 *Problem Statement*

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 rise in temperature.

A map may be prepared from gasoline effective 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 drums at various places on the map. Figure 9.1 is such a map, except that effective gasoline storage temperatures have been converted 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 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 Southwest Asia, assuming that the gasoline would be acceptable for 12 months at 100°F. 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, storage times for this gasoline could be obtained from the map by dividing the plotted storage time by 3. Conversely, predictions for a gasoline stable for 2 years at 100°F could be obtained by multiplying by 2 the time shown.

Possible solutions: No practical solutions identified during this study.

9.5.6 *Problem Statement*

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 and becomes less effective above that temperature.

Figure 9.2 shows where temperatures above 110°F 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 (and gives information about the number of days of occurrence), it may be assumed that such temperatures will not prevail for more than 4 to 6 hours on any given day.

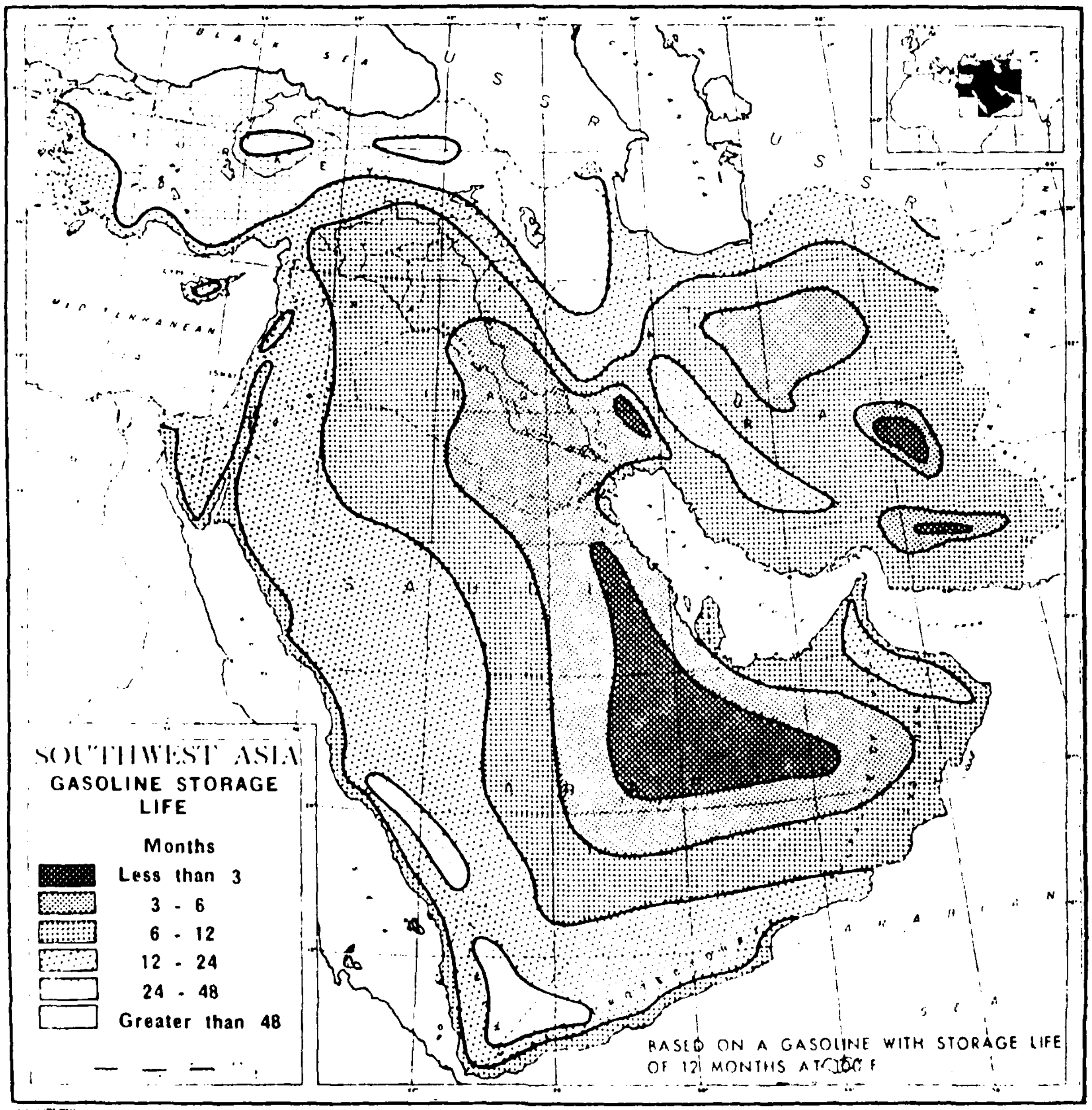
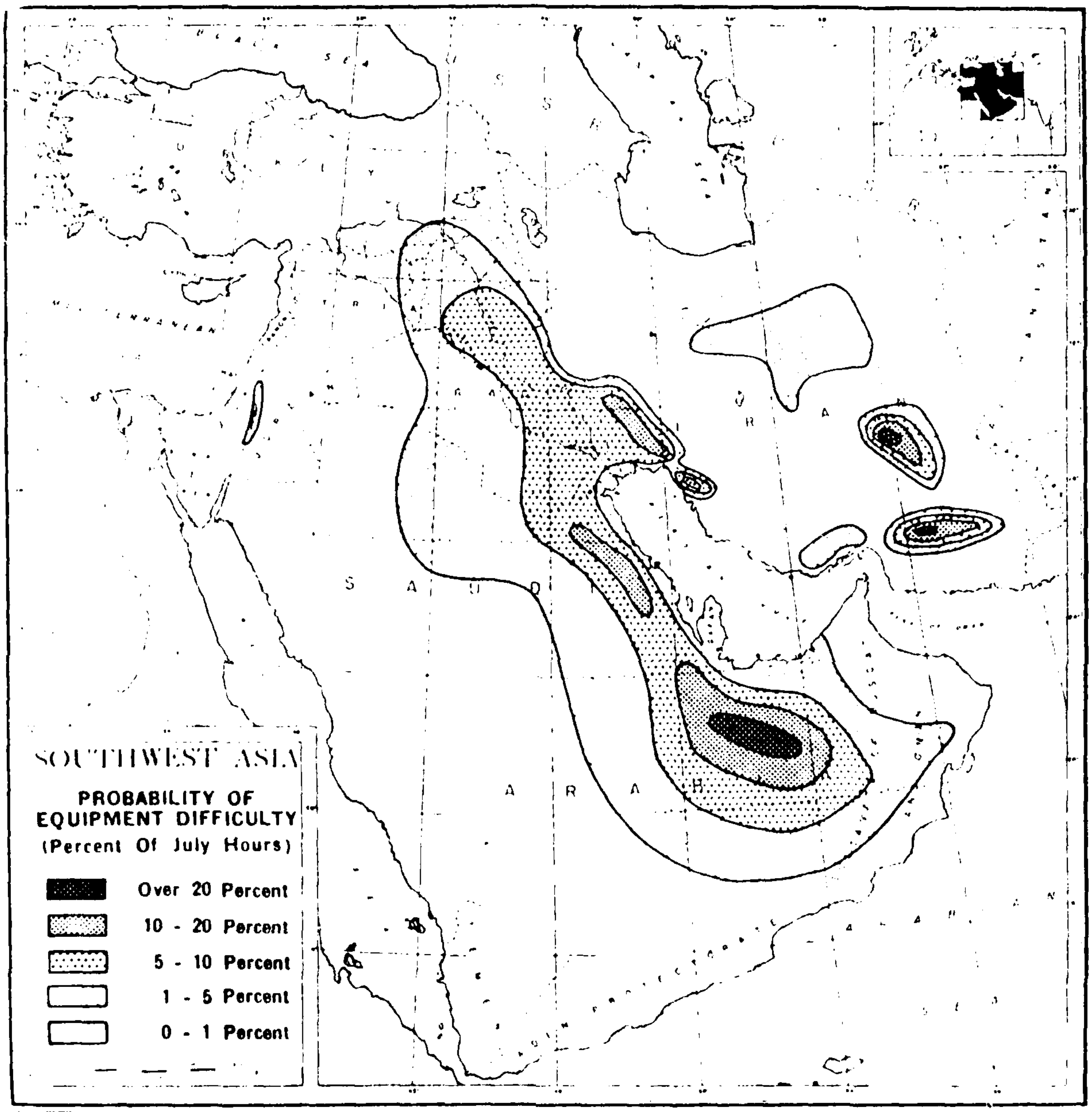


Figure 9.1. Gasoline storage life based on a gasoline with storage life of 12 months at 100°F.

(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).

9.5.7 *Problem Statement*

Fuel lines connected from an engine-generator set to an external fuel tank or storage drum can become heated beyond the fuel's boiling point, causing vapor lock and eventual shut-down of the engine-generator set.

Possible solutions:

1. Where possible, keep the external fuel tank and supply hose or line shaded from direct sunlight.

2. During the hot period of the day, reduce dependence on E-G sets fueled in this way as much as possible.

3. Have an E-G set in ready standby condition with integral fuel tank and using shade or reflective covers where possible.

9.5.8 *Problem Statement*

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.

Possible solutions:

1. Use trained personnel to perform proper maintenance.

2. Develop a redundant air filtering system which uses two elements in series.

3. Provide a proper quantity of replaceable elements.

9.5.9 *Problem Statement*

Due to the climate and physical elements of the environment in the Mid-East there is an increased amount of sand and dust, which causes increased air filter maintenance. If the air filter becomes clogged, the engine will eventually stop, but will not be damaged.

Possible solutions:

1. Erect a barrier or shield on the windward side of the set to reduce sand and dust exposure.

2. Provide an elevated air intake so that the concentration of dust and sand would be decreased, and the size of particles would be smaller.

3. As far as possible, avoid placing the E-G in open areas where a concentrated amount of dust and sand is blowing. In particular, locate the set on the windward side of roads.

4. Develop a pre-filter which filters coarse particles first.

Don'ts: do not attempt to replace air filters during extremely sandy and dusty times. This will expose the engine directly to sand and dust which will shorten its life.

Special considerations: designing modifications of the air filtering system may be very time consuming and costly. Before final recommendations are made, further studies should be done to assess more fully the state of the art in air filtering and determine the effectiveness of, and logistics/training problems associated with, design changes to the engine air filters.

9.5.10 *Problem Statement*

When an engine-generator set is not in use and sand/dust storms occur, the exhaust system can allow infiltration of sand/dust into the engine combustion chambers.

Possible solutions: The operator/maintenance people should be specifically forewarned of this problem and trained to make sure that all exhaust systems are carefully sealed against sand/dust infiltration when not in use.

9.5.11 *Problem Statement*

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 will usually prevent the 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.

Possible solutions:

1. The first, most obvious, solution is to avoid refueling during storms if possible.

2. The E-G set should be operated in some type of shelter or have a shield such as a canvas lean-to or sand bag wall.

3. 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.

4. 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.

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.

Don'ts: do not attach the auxiliary fuel line of a small TG to a large fuel tank, such as fuel barrel, and leave the TG until the fuel supply runs out. Often this causes the TG to run out of oil or coolant liquids. The result is premature catastrophic failure.

9.5.12 *Problem Statement*

Organizational units within CONUS or other parts of the world periodically perform routine maintenance to prepare their equipment for seasonal changes. For cold-weather operation, lighter weight crankcase oil is used. In hotter climates, the lightweight oils are not suitable, and their use can result in reduced engine lifetime.

Possible solutions: assure proper crankcase oil before deployment.

9.5.13 *Problem Statement*

Special precautions must be taken with internal combustion engines used for water treatment, distribution, cooling, etc.

Possible solutions: rules for engine servicing. Servicing engines in the desert is no different from the same work in other climates, but there are certain precautions that must be taken because of the danger of sand getting into working parts.

As soon as the engine is stopped, close all openings with tightly fitting plugs or covers. If there is an air hole in the tank cap, plug it up. Cover the whole machine with canvas and fasten it down. As soon as the exhaust stacks cool off, they should be plugged or covered with tight caps.

Air cleaners and fuel and oil filters need to be checked constantly. Sand can clog air filters so tightly that engines cannot pull their rated horsepower. Set a rigid inspection schedule for all filters and cleaners, and see that it is followed.

Fuel tanks should be filled through a funnel that fits 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. Wipe the tank clean for several inches around the opening before taking off the filler cap. Then place a cloth tightly around the funnel to keep out dust. Remember, a few grains of sharp, cutting sand can completely ruin a diesel fuel pump.

Arrange parking spaces so that vehicles can leave without having to circle around others. Although it is not practical to have equipment so widely dispersed that there is no danger from dust, care should be taken to park the machines so that turning and travel is outside the area and on the side away from prevailing winds.

9.5.14 *Problem Statement*

Trucks may have difficulty moving on certain types of desert roads, and drivers will have to take special precautions.

Possible solutions:

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 which might not otherwise be possible.*

4. Lengths of chain link fence can frequently be used as semipermanent roads in the 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 the 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. Inspect tires and cooling systems at every stop. Lubricate regularly during travel and promptly repair all minor breakdowns.

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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.

APPENDICES

APPENDIX A:

A METHOD OF MAKING ASPHALT-EMULSION-STABILIZED SOIL BRICKS*

Soil Required for Making Stabilized Adobe Bricks

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.

Specifications for soil to be used for 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.

Stabilization with Asphalt

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 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.

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.

Determining the Amount of Stabilizer Necessary

The amount of stabilizer required for mixing can be determined by field tests. It is suggested that one mix 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.-diamter x 2-in.-high and three 4-in. x 8-in. x 16-in. 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 A.1 and A.2.

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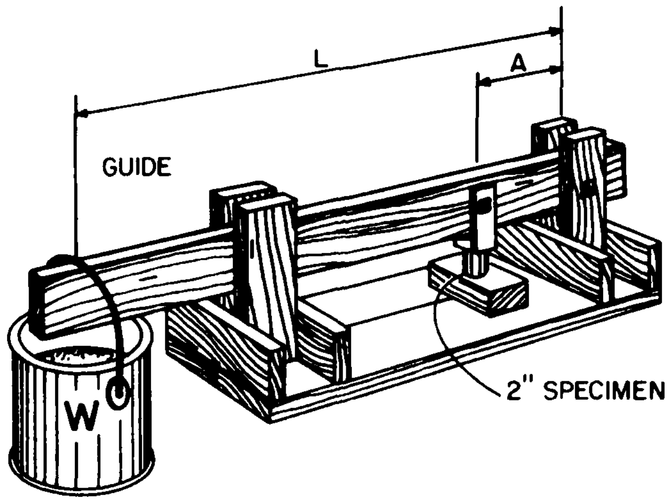
* Summarized from The Manufacture of Asphalt-Emulsion-Stabilized Soil Bricks and Brick Maker's Manual (International Inst. of Housing Technology, California State University, Fresno, 1978).



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

Figure A.1. Compressive strength test set-up.

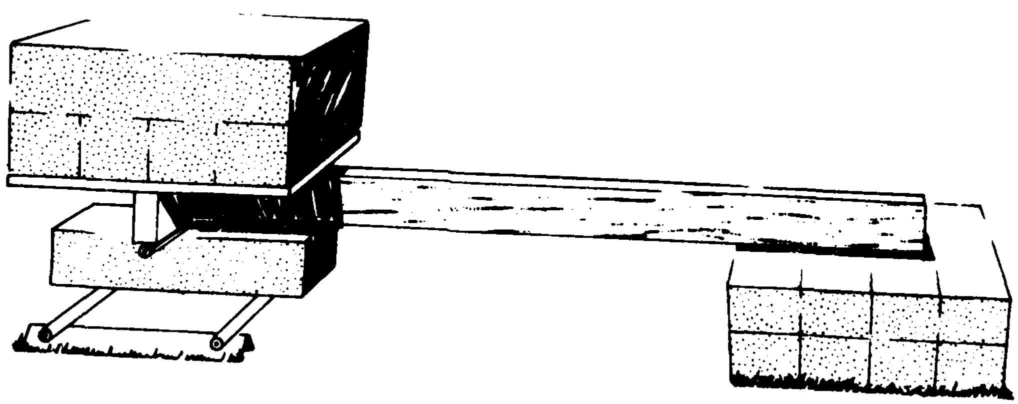


Figure A.2. Modulus of rupture test set-up.

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.

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.

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 placed under the molds to facilitate removal of dried bricks. If available, paper is preferable.

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. 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.

Brick Molds

The most common brick molds are easily handled, contain two, three, or four compartments, and have a maximum length of 32 in. (81.3 cm). Various sizes of bricks can be made, depending on the dimensions of the walls or structures to be built. The most commonly used brick size is 4 in. x 8 in. x 16 in. (10.2 cm x 20.3 cm x 40.6 cm).

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.

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 thirty 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.

Mortar for Adobe Brick

The mortar to be used must be at least as strong as the brick it binds. The mortars in Table A.1 are suggested.

Table A.1

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 gallon 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.)

APPENDIX B:

GEOLOGICAL CONDITIONS AND SOIL PROPERTIES

This appendix reprints P. G. Fookes, "Road Geotechnics in Hot Deserts," The Highway Engineer, Journal of the Institution of Highway Engineers, Vol XXXIII, No. 10 (October 1976), pp 11-23. (This paper is reproduced by kind permission of the Institution of Highway Engineers.)

Road Geotechnics in Hot Deserts

P.G. Fookes, PhD, BSc, MIMM, FGS

INTRODUCTION

In recent years there has been a rapidly expanding road construction programme in many of the world's hot deserts, particularly in the Middle East. Extensive construction programmes are being undertaken both on major projects crossing vast areas of desert and on local feeder roads serving small centres of population. Furthermore a considerable amount of bitumen pavement overlays are being laid on existing surface dressed roads. Many roads are performing satisfactorily but there are many examples of rapid deterioration and even complete failures over a short period of time that cannot simply be attributed to poor construction practice.

This Paper reviews some of the specific problems of road building in hot desert terrains in relation to the particular desert terrain type and the natural processes and surface materials occurring in that terrain. This approach has been adopted to help categorise the engineering problems by desert terrain type (or zone) which enables generalisations to be made about potential problems, their location, occurrence and frequency, and methods of evaluation and design. This approach also makes reconnaissance studies and follow up site investigations more technically efficient and generally easier in terms of cost and time. A working knowledge of desert geomorphological forms and processes is invaluable in helping diagnose design and construction problems.

For the purposes of this Paper a hot arid climate is one where evaporation exceeds precipitation (rain, snow and dewfall) and in many areas of the near and Middle East, especially the Red Sea and the Arabian Gulf and their adjoining regions, large parts of Saudi Arabia, parts of Iraq, Iran, Egypt, Algeria and Libya, it is the normal situation. This climatic regime produces hot desert terrains. Average annual rainfall may only be a few centimetres (even only a few millimetres in some parts) which usually only occurs seasonally and sometimes only from a single cloudburst. Summer shade temperatures are frequently in excess of 40°C and humidities may be around 100 per cent near the coast. The contrast between maximum night and day temperatures and between night and day humidities is often great and in winter night-time frost can occur. Strong and persistent winds are normal in many areas.

P.G. Fookes

BIOGRAPHY

Dr Fookes is a consultant engineering geologist in private practice and is also retained part-time by Rendel, Palmer and Tritton, and Engineering Geology Ltd. He has wide experience in many ground engineering and construction materials fields both overseas and in the United Kingdom. He specialises in investigating problems in various terrain and environmental types. Formerly on the staff of Imperial College, and Binnie and Partners he has published over 50 Papers.

SUMMARY

Hot deserts provide a variety of design and construction problems for engineers which stem from the nature of the dry climatic regime and the desert landforms. Engineering solutions to these problems which are usually based on good practice in other regions, may not necessarily be successful. The problems include: **unstable terrain** *– e.g. wind blown silt (loess) and sand (drifts and dunes);* **aggressive salty ground** *– e.g. sabkhas, salinas, salt playas and some duricrusts;* **unsuitable construction materials** *– e.g. some silts, sands and soft carbonate sediments,* **rapid erosion** *– by wind and floods, especially flash floods.*

In coastal areas, causeways and reclaimed land may also present special problems due to evaporite salts and the leaching and piping of fills.

These problems are discussed in the context of a simple model based on mountain and plain desert terrain and natural desert processes, in which four zones are recognised each with different desert characteristics and different engineering behaviour. Particular reference is made to the near and Middle East.

This Paper will be presented at a joint meeting of the Institution and the Civils to be held in London on January 12th, 1977.

THE DESERT SURFACE

Surface sediments found in the hot arid climates are generally granular and with or without the presence of evaporite salts. They are generally formed by physical weathering of local hills or mountains; the disintegration of bedrock results largely from thermal weathering and to a lesser extent from salt weathering, wind abrasion and other local processes. The products of this type of weathering are generally coarse grained materials. Parent rocks of high silica content (e.g. granites) produce detrital sands and gravels which when sorted and transported by wind give loess (silt sizes grains) or dunes (sand sized) or when transported by flood water give alluvial sands and gravels. Breakdown of calcareous rocks (e.g. limestones or dolomites) result in calcareous sands and gravels and sometimes marls. Therefore, although the size ranges of material in different deserts are broadly similar as they are the product of similar transporting agencies – gravity, wind or water, the composition of desert surface is largely determined by the local bedrock types. Unfortunately for the civil engineer in many near and Middle East locations the local bedrock is of Tertiary limestones, marls, chalks or dolomites and often contains evaporite rock horizons. These latter release salts into the groundwater which, on evaporation, deposit the salts into the desert surface. Hence many near and Middle East deserts are potentially salty.

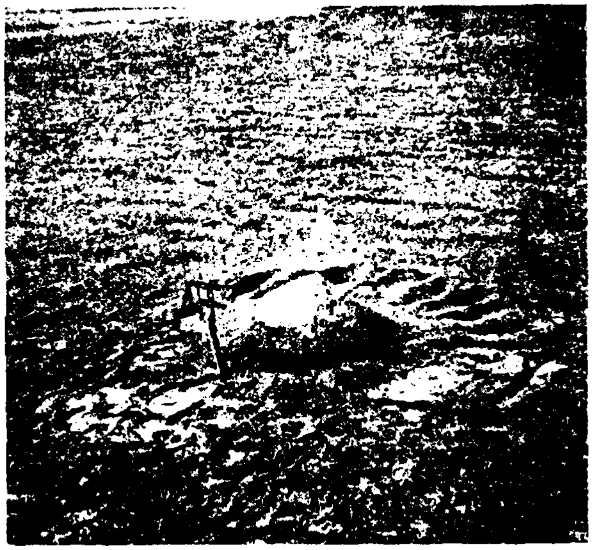
Commonly the world's hot deserts comprise intermontane basins ranging in size from a few hundred metres to tens and even hundreds of kilometres across. They are often centrally draining without outlet to the sea. The basic cross sectional profile comprises a **mountain** and a **piedmont plain**. Although such a profile characterises most deserts it may vary greatly in detail in different locations. For example, in "basin and range" country the ratio of mountain to piedmont plain area may approach one, whereas in the huge expanses of the Sahara or South Australia it is much smaller. A piedmont plain can be composed of various landforms. The basic contrast is between **bedrock pediment** (a bedrock plain) and an **alluvial plain**. In parts of Arizona for example the mountains form 10 per cent of the landform area, the whole piedmont is the remaining 90 per cent of which 50 per cent is alluvial plain, 30 per cent rock pediment and 10 per cent thin alluvial veneer to rock pediment. In the western Mojave desert 30 per cent is mountain, 70 per cent piedmont of which only 7 per cent is rock pediment and the remainder alluvial plain (Cooke & Warren 1973).

For engineering purposes Fookes & Knill (1969), with much idealisation developed a geomorphological division of the mountain and piedmont plain into four sediment deposition zones (Figure 1) which can each be correlated with different degrees of disintegration of the parent bedrock. The sorting of the different sizes of granular material characteristic of each zone being done by the dominant transporting agent in that zone. Rock pediments would occur in zone II of the Fookes & Knill classification. As they are not a granular material they are not the prime concern of this Paper and will not be discussed further. However, their engineering significance in controlling water courses and as foundations to structures and areas for provision of borrow material is important. The Paper principally considers the alluvial piedmont plain which comprises zones II to IV.

Boundaries of the zones run approximately parallel to the mountain ranges and the zones tend to be gradational into one another. The mountains undergo slow erosion and the resulting debris spreads out in colluvial and alluvial fans

Apron fan slopes. Zone II with Zone I mountains in the background. Iran

Erosion in granular fill behind unprotected culvert headwall due to streamflood conditions. Zone III Trucial Coast



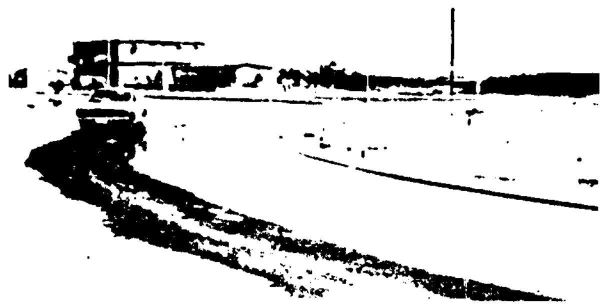
Above: Survey cairn. Zone III. Iran

Wide culverts and training bunds. Zone II/III. Trucial Coast

extending from the mountain slopes into the centrally draining basins of the desert. Coarse-grained material is found near the mountain flanks and buries the underlying rock, while the finer material accumulates some distance away and forms the alluvial plains. In general terms, the greater the distance from the mountains the finer the sediment forming the surface. Drainage patterns develop on the mountain slopes and fans, but generally lose themselves in the central desert areas. Stream flow is intermittent and the watercourses may be dry for long periods even for years.

In semi-desert regions, with rainfalls greater than say 150mm per annum, more clay fraction material and clayey pedological soils tend to occur. Vegetation is

Right: Gabion protection against scour of bridge abutments. Zone II/III. Trucial Coast



Sheetflooding on a roundabout with no designed drainage arrangements. Zone III/IV. Gulf of Oman

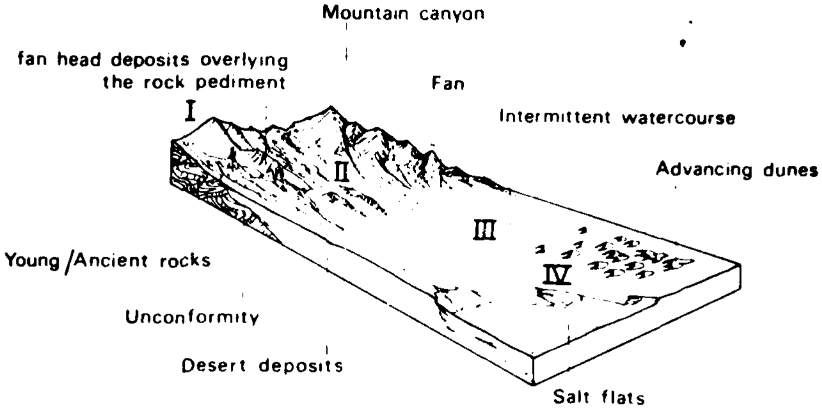
Erosion of shoulder by rain runoff from the road, with damage to pavement by headward erosion. Zone III/IV. Trucial Coast

also more abundant.

Within zone I (the mountains) grading sizes range from poorly sorted medium angular gravel to very large boulders and in this zone and zone II, gravity and water flow provide the main force of movement. In zone II deposition may take place from intermittent sheet and stream flow during short periods of flooding and here the soils are composed of mixtures of angular to sub-angular sands and gravels, with cobbles and boulders included. These sheet flows provide the principal transporting agents to zone III, where two soil types may be differentiated -- silty stony and sandy stony desert. Aeolian (i.e. wind blown) deposits are mainly to be found in the central parts of the desert designated zone IV, where the material is poorly graded. It is principally in this zone that evaporite salts may be found.

Figure 2 shows an idealised cross section across one half of a desert basin — the zones would repeat themselves across the other half *or* meet the coast as a beach or as sabkha. The relative sizes of the zones vary depending on the age of the desert, its overall size, drainage arrangements and so on. Often, however, zone IV or sometimes zone III is the biggest within the basin. As a generalisation, the ground water table is nearest the surface in zone IV. Its closeness to the surface is often of particular importance to the engineering situation especially when the ground water table is within capillary moisture movement reach of the ground surface.

Figure 3 shows typical ranges of grain size within each zone and some plasticity characteristics of the clays (sometimes only rock flour) found occasionally in the zones.



(after Fookes & Knill 1969)

Fig.1 Block diagram of hot desert mountain and plain terrain showing the four engineering zones discussed in the Paper (see also Figure 2)

ENGINEERING CHARACTERISTICS OF THE ZONES

Generalised summaries of the engineering characteristics are given in Figures 2 and 3.

Zone I — the mountain slopes

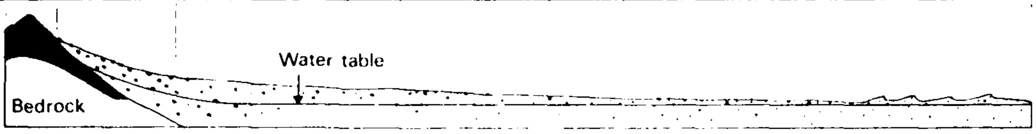
Weathering is active with daily and seasonal temperature changes dominating in the rock shattering process. Gravitational effects together with the ephemeral mountain streams are responsible for removing the rock fragments from the immediate vicinity of the mountain to form large rock scree and talus slopes and small alluvial fans. These rock debris slopes within the mountains consist exclusively of material derived from the adjacent mountain slope and grading sizes range from ill-sorted medium angular gravel to that of a large sized house. Such slopes are generally free of stratification but some imbrication of individual particles may be present; slope angles of up to 38° may be developed.

In some areas, free standing single mountain peaks or a cluster of several peaks, are separated from the mountain range and are surrounded by stony desert or a pediment. These peaks each have their own debris slopes of rock fragments around them and are themselves being slowly eroded by the desert processes.

The engineering characteristics of the coarse deposits are consistent with the grading and type and are not essentially different from steep rock debris slopes in

Windblown sand terrain. Zone IV Near East

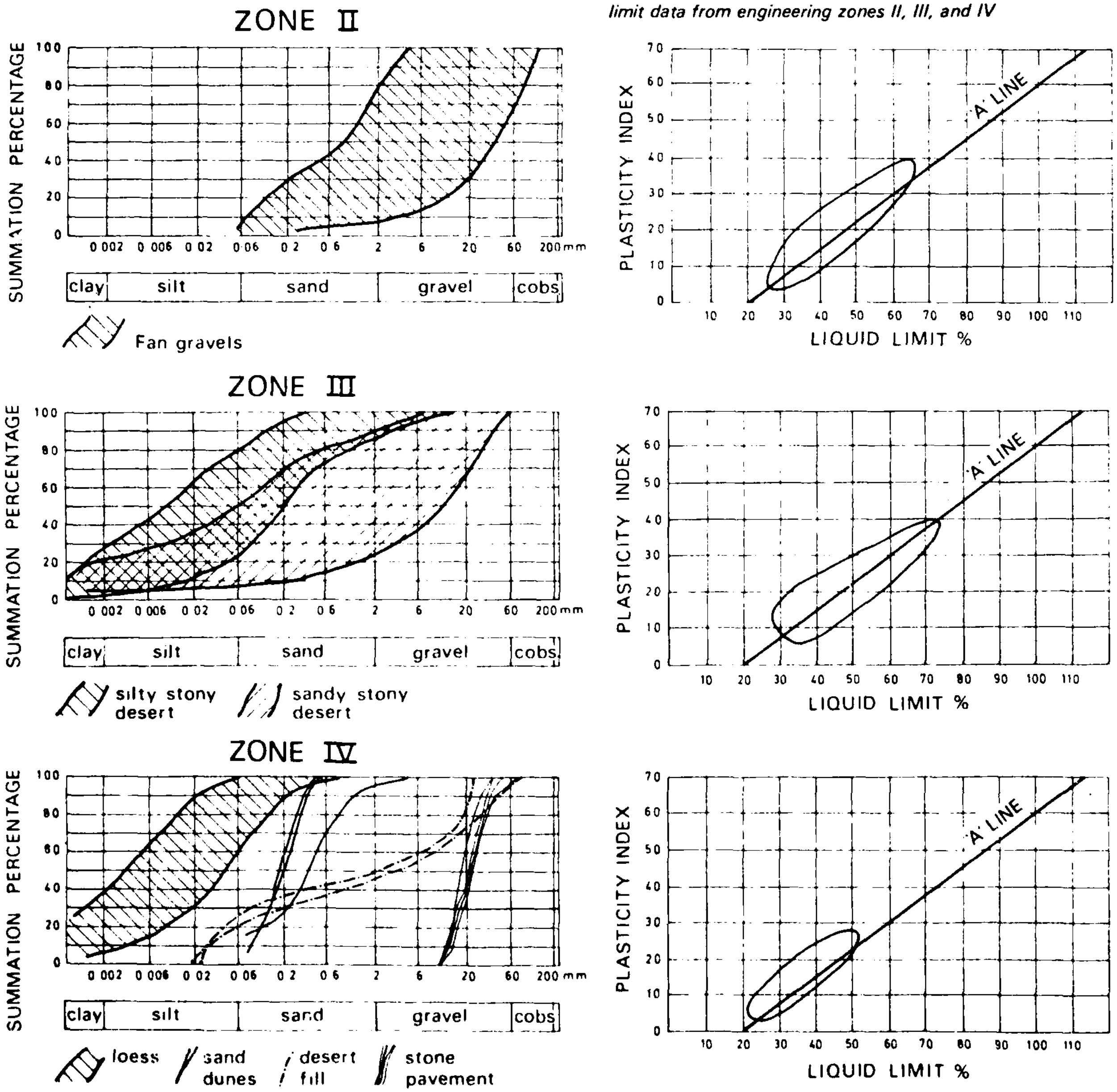
ZONE	I	II	III	IV
PRINCIPAL ENGINEERING SOIL TYPES		Rock fans Boulder gravels	Silty stony desert and sandy stony desert Some evaporites (Could thinly cover a rock pediment)	Sand dunes, loess and evaporites;
SLOPE ANGLE OF DESERT SURFACE		2-12°	½-2°	0-½°
PRINCIPAL TRANSPORTING AGENT OF THE ENVIRONMENT		Gravity and as III Wadis	Intermittent stream flow and sheet floods Shallow anastomosing channels Mudflows Mudfloods	Wind and evaporation Sheetflow Some wadis
GEOTECHNICAL FEATURES		Good for foundation and fill	Generally very good foundation and fill material Saline. May be pervious in foundations	Erratic behaviour to load bearing Migrating dunes Mestable loess Saline Absence of coarse material

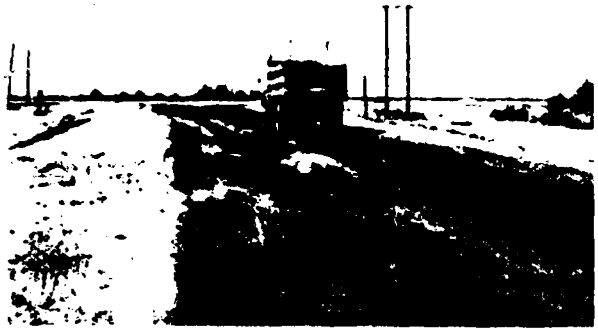


(After Fookes & Knill 1969)

Fig.2 Idealised cross-sections of mountain and plain terrain showing the four engineering zones with brief notes on some of their engineering characteristics

Fig.3 Some typical grading curves and envelopes, and Atterberg limit data from engineering zones II, III, and IV





Foundation failure in soft sands. Zone IV. North Arabian Gulf

Breakup of bitumen stabilised road verge by traffic and rainwater erosion. Sand fill embankment. Zone IV. Trucial Coast

temperate climates and therefore do not require any particular discussion. The bedrock is undergoing fairly active physical erosion and thus deep chemical weathering mantels are not generally developed (as in hot wet climates) though case hardening of some rock types may occur. Discussion of this and related processes is left to zone IV.

This zone may well provide rock borrow material either from conventional quarries in the rock or in pits in the rock debris deposits.

Zone II — the apron fan (or "bajada")

Aprons are formed by the interfingering of rock and alluvial fans that extend more or less continuously around all mountains. Their extent depends on the height of the mountain range, and erodability of the rock types, the larger mountains having apron fans extending for several kilometres. Rock pediments can also occur.

The "soils" are all composed of mixtures of angular to sub-angular clastic debris of sand to gravel grade with associated material that may be as large as cobbles and boulders. Locally clay or silt sized material may be derived directly from fine grained bedrock (e.g. a marl). The coarse deposits have poor to good stratification and in general become finer further away from the mountains, but isolated boulders or groups of boulders in huge trains, may be present. Deposition takes place from intermittent sheet and stream-flow of high velocity occurring during flash floods from storm rains. The accumulation of flood waters in the mountain area may first give rise to a sheet-flood spreading out over the desert floor and as infiltration takes place there is a progressive restriction of the flow to stream beds. The duration of sheet floods is measured in terms of minutes, stream floods in hours and the flow of streams in hours and occasionally days. Snowmelt in high terrains subject to winter snow may give local flood conditions. Mud flows may occur in fine gravels and mud-flow deposits can be common in some areas. The stability of such materials may need to be investigated before construction.

Borrow areas for construction materials of the required grading can usually easily be found in the apron fan. A typical grading curve for zone II material would lie in the envelope for sandy stony desert shown as Figure 3 and a typical set of geotechnical properties from Iran is given in Table 1. Where Atterberg limits are given in this and other Tables and Figures they refer only to material passing the BS 200 sieve, i.e. the silt and clay fraction. For roads, the apron fan deposits generally provide good base and sub-base materials although screening or crushing and screening may be required. This material can also be used for coarse aggregates in grave-bitumen and base

Table 1

Granular soils - Classification test results

Zone	Sample Type	Particle Size (per cent passing)				Atterberg limits			Density/ moisture relationship		California bearing ratio(%)		Water Soluble Matter
		20 mm	2 mm	0.06 mm	0.002 mm	Plastic limit	Liquid limit	Plasticity Index	Max. dry Density Mg/m^3	Optimum Moisture Content	Unsoaked	Soaked	
II	Fan	87	38	-	-	-	-	-	2.12	8.4	53.2	38.7	10.8
II	Fan	63	27	-	-	22	27	6	2.24	7.0	46.3	39.3	0.1
III	Sandy desert	93	54	21	8	18	36	18	-	-	-	-	2.25
III	Sandy desert	83	30	-	-	-	-	-	2.11	9.5	59.2	67.10	1.63
III	Silty desert	97	77	31	-	58	112	50	1.60	20.3	15.7	2.8	41.90
III	Silty desert	-	99	76	35	19	39	18	1.75	18.2	21.8	4.8	1.00
III	Silty desert	-	96	63	20	15	29	17	1.94	12.0	24.0	14.0	0.70
IV	Silty desert	-	100	57	15	26	39	23.5	1.93	17.0	29.8	14.4	0.50
IV	Loess	-	-	83	21	26	64	38	1.57	22.80	11.1	6.5	0.50
IV	Loess	-	-	89	18	17	33	6	1.81	11.59	9.8	4.3	0.60
IV	Loess	-	-	90	20	19	36	17	1.57	23.0	5.1	6.7	0.45
IV	Sandy desert	-	96	14	-	-	-	-	1.96	12.00	15.0	16.5	0.65
IV	Dune sand	-	99	83	9	22	39	17	1.74	18.3	3.9	3.2	1.75

Foundation failure after winter floods. Loess silts. Zone IV. Iran

Capillary moisture rise in fresh sand tipped onto sabkha. Zone IV. Bahrain

courses. The *in-situ* material is a sound foundation with a safe bearing pressure usually in excess of 4kg/cm^2.

The permeability of alluvial fan deposits depends on their grading and porosity, and is a function of the size and continuity of the interstitial voids. For practical purposes, deposits are effectively uncemented within depths of engineering interest and the water tends to move along the partings between successive deposits. However, in the locations where mudflow deposits occur there tends to be a restriction of ground-water flow as such deposits have a compact structure with small interstitial openings. Thus mudflow deposits may form aquicludes in contrast to the streamflow deposits, which are relatively good aquifers. Alluvial fans built up by streams and mudflows may result in confined conditions that, together with the original dip of the fan, tends to make such an alluvial fan an ideal site for recovery of artesian water. However, the recharge of these aquifers is limited, and the tubewells successfully developed in these fans could have relatively limited long-term yields, but may be the only source of water for construction use.

Road location in this zone should be done with the flood potential in mind. There are two areas which can help minimise potential flood danger. Either by locating the road at the mouth of the mountain wadi (boundary of zones I and II) supplying the flood water and debris to

TABLE 2

Outline Summary of Runoff and Soil Characteristics of Desert Zones.

Desert Zone	Typical Soils (Casagrande symbol)	Runoff Hazard	Notes on Road Design.
I	Scarce GP GU GW	Stormflow down hillsides and in mountain canyons. High runoff coefficients say >0.55	Conventional road design for mountain areas. Do not under estimate potential flood conditions because of the 'arid' nature of the terrain. Generally good subgrade conditions.
II	Boulder gravels GP GU GW	Storm wadi flow, possibly some sheetflow. Low to moderate runoff coefficients, say 0.3 to 0.55	Volume of dumped water-transported debris during storm flow may be large. For roads parallel to stream flows, low embankments with strengthened stream crossing areas may suffice. For roads transverse to stream flow, high embankments, numerous wide culverts and bridges. Scour protection for abutments by gabions or similar. Generally good subgrade conditions.
III	GP SW SP	Storm sheetflow and deep wadi flow. Low to moderate runoff coefficients, say 0.2 to 0.5	Scour may be a major hazard. For roads parallel to streamflow, low embankments with strengthened stream crossing areas. For roads transverse to stream flow moderate embankments, numerous wide culverts and bridges, and training bunds, and scour protection. Upstream sides of embankment may require armouring or the whole construction by rockfill. Generally poor to moderately good subgrade conditions.
IV	SU SP ML	Storm sheetflow and shallow wadi flow. Moderate to high runoff coefficients - ground may quickly get saturated (especially ground with high water table), say 0.25 to 0.7	Scour may be a hazard. Generally low embankments, armoured in potential stream flow areas. Training bunds and many small culverts may be necessary in some areas. Generally poor to moderate subgrade conditions especially where groundwater table is high.

Above: Salt blisters. Jet efflux layer to a runway. Sabkha, Zone IV. Arabian Gulf

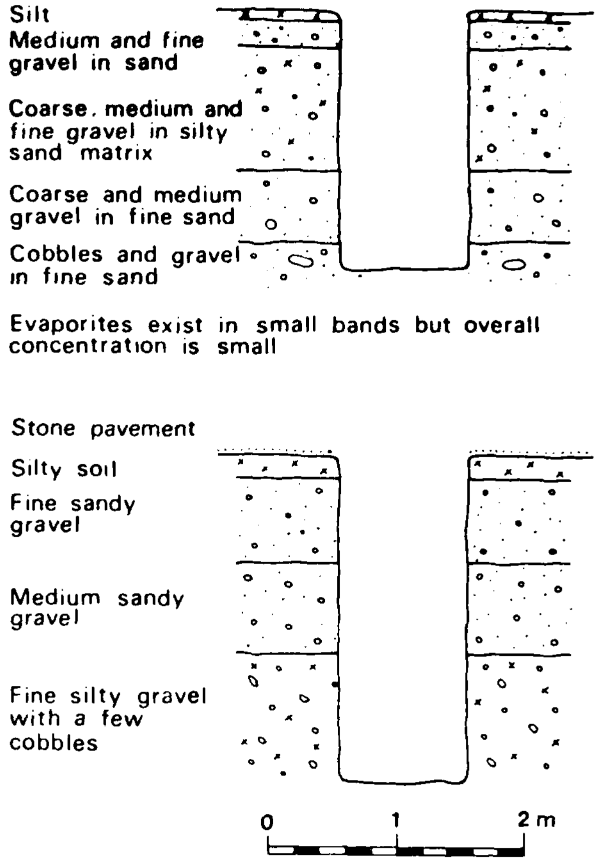


Fig.4 Typical explanatory pit logs from Zone III, Iran

the apron fan *or* by running the road at the lower end of the fan (at the boundary between zones II and III) far away from the mountain slopes. Air photographs are usually valuable in helping interpret the terrain and for locating an alignment. Assessing quantities of water during time of flood is a difficult and little researched art as yet and caution should be exercised in design. Run-off coefficients are quite variable and may typically be quite high ranging from say 0.2-0.8. The analysis of floods in deserts is fairly fully discussed by Cooke & Warren (1973) in relation to geographical studies. If possible an alignment, away from zone II is probably the best solution with the road raised on embankment when it has to cross stream beds in zone III with wide culverts located opposite visible shallow channel mouths coming off the zone II fans. Training bunds of gravel with rock protection or gabions may be needed if strongly erosive conditions are expected (these conditions can be "read" off the ground by the presence of erratic boulders and deep cuts in otherwise generally shallow channels). The embankment itself may also require rock protection or even be locally made of rockfill. Upstream ditching may need to be considered but well away from the embankment so that it cannot be undercut by erosion of the ditch sides. Culvert walls and bridge piers may have to be protected from scour. Table 2 gives in outline a summary of observations and comments on surface water flows in this and the other zones which may help in road design. It is emphasised, because of the general lack of records and understanding of desert catchment characteristics, that careful observations be made of the local ground conditions. The run-off co-efficients in the Table are a guide only.

Zone III – the alluvial plain

This zone is generally quite widespread and may, in places, extend completely across the intermontane plateau to zone II on the opposite side. The soils of this zone are dominantly of silt, sand and gravel grading. Such soils may contain varying but generally small amounts of clay and/or evaporite minerals. In addition, the zone may contain local areas of stationary or mobile sand dunes and loess but discussion of these windblown soils and of evaporite salts is left to zone IV where they are more common.

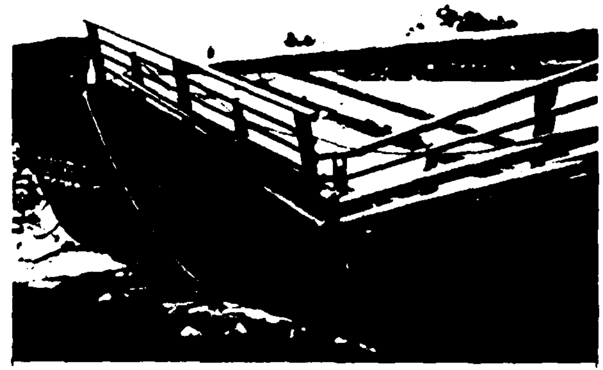
Slopes in zone III are a maximum of say 2° at the margin decreasing to ½-1° towards zone IV. Watercourses are shallow, typically less than 0.5m deep and several tens of metres in width; the drainage channels extend in a distributory fashion towards the central areas where they become topographically indistinct. Transport of sediments is principally by sheet-flow but some stream-flow occurs where shallow channels exist. Flow reaches zone III only at times of heavy cloudbursts. Occasional remnants of Quaternary terraces and lake deposits may be present and these conditions are relics of periods when the water level was at higher elevations.

As a gross simplification engineering soils can be sub-divided into two main types; "silty stony desert" and "sandy stony desert". Grading envelopes produced from several hundred grading curves are given in Figure 3; in addition some typical geotechnical properties are given in Table 1. The percentage of soluble matter reflects the varying amounts of salts present near the desert surface, the other properties being consistent with the grading of the material. In general, the fragments are angular to sub-angular with minor proportions of more rounded shape; ventifacts (wind shaped stones) are common. Over long distances, the two soil types may be observed to be sheet-like and interdigitate with each other. In addition, minor lenses or sheets of either the more silty or more gravelly material may interfinger throughout the main soil type. If the lenses are uniform silt or silty sand grade, or are uncemented openwork gravel, then engineering problems can arise below the water table. The silty and sandy stony desert soils, however, in general are quite satisfactory for road construction and provide good foundations because the water table is too deep to influence most engineering operations. In areas where lines of qanats cross the road a specific investigation should be carried out as collapse of a near surface tunnel could cause settlement of the road or structures.

Results of laboratory CBR tests indicate that, for typical desert soils, a minimum thickness of about 15cm of sub-base material would be generally sufficient to provide the necessary bearing capacity for a road pavement. Usually soils are of low plasticity, with acceptable shrinkage and compaction characteristics. Exploratory pits may stand with vertical walls for many months or even years until infilled with blown sand or channel wash material. Figure 4 shows logs of typical exploratory pits from Iran and indicates the distribution and thickness of material types, which are the usual products of sheet-flood and stream-flood environments. Every possible gradation between these types of deposit can occur. The deposits of sheet floods and less violent stream-floods tend to have a high percentage of silt-sized particles and, therefore, in general form the silty stony desert. Whereas deposits of stream floods tend to have a high percentage of sand-sized particles and, therefore, in general form sandy stony desert.

Evaporite salts may occur and could be fairly evenly dispersed (in any one area) throughout the soil profile, with a

Salt weathering on stone pitching to bridge abutment. Salina, Zone IV. Trucial Coast



Collapse of road bridge due to sulphate attack on mass concrete centre pier. Near East

tendency to be concentrated a few centimetres below the surface, where for example layers of fibrous gypsum can accumulate.

Zone IV — the base plain

Perhaps generally the most widespread of all the zones and also probably the one with the most engineering problems. The zone tends to be irregular in shape and its margins may be constantly changing. Inland it occupies the central areas of the piedmont plain and centrally draining basins and is surfaced by the finest materials, clays, silts and sands, winnowed out by the transporting agencies, principally the wind. It often margins coastal areas where marine agencies help sort the wind blown materials and may additionally provide marine clays, silts and sands. Salty coastal areas are sabkhas.

Average ground slope is from 0° to ½°, but locally, as little hills of bedrock or small cemented cliffs or sanddunes, slopes of limited extent may be much steeper.

Although windblown material tends to predominate and great quantities of dust (silt) and sand are moved during periods of high wind, water plays an important part. Flash floods are relatively rare and any meandering stream actually reaching zone IV is usually short-lived after the downpour, but the standing water table, which may be quite near ground surface can dominate the desert processes, as this zone usually represents the local base level down to which wind erosion can take place. Wind erosion more or less stops when sand and silts are damp; capillary moisture movement from the water table to ground surface readily occurs if the water table is high and if continual evaporation takes place. In these conditions a thick salt crust can build up from continual precipitation of salts dissolved in the groundwater even if they are in very weak dilutions. Crystals of these salts are also blown by the wind and can contaminate dunes and other parts of the desert surface. Capillary moisture movement depends on many factors but it can be up to 3m above the water table in fine soils.

Moisture and chemical movements over long periods of time give rise to numerous forms of case hardening of rock surfaces and the development of various forms of "duricrust". The latter is often, but not always, a precipitation of calcium carbonate (chalk or "limestone") as calcrete. Duricrusts have a large variety of local names (Goudie 1973). Moisture movement in clays and clayey silts can cause considerable swelling or shrinkage (e.g. gilgai topography). Effects due to different moisture conditions on desert surfaces create easily identifiable patterns readily interpretable from walkover surveys or air photographs (e.g. Neale 1973).

For ease of description it is best to discuss separately, from a road engineering viewpoint, the more common and important desert features. In practice combinations of features often occur.

Duricrust being eroded. Sabkha. Zone IV. Bahrain

Scarp of bedrock with duricrust capping. Zone IV. Bahrain

Clayey pumped fill in newly reclaimed land showing drying cracks. Granular dozed fill in background. Arabian Gulf

Clayey Soils. These soils are usually formed by deposition of clay minerals *or* even very fine particles of rock *or* chalky precipitates, in water. Near coasts they may be former shallow sea deposits, now forming land (as in parts of the Arabian Gulf); inland they may be from temporary lakes (playas) or rivers. They are often contaminated with silts, sands and salts. Perhaps most commonly they are calcareous.

They can frequently be classed in the CI to CH range on the Casagrande classification. When dry they usually have high shear strengths but this drops to low values when wet and they may have marked swelling and shrinkage characteristics on wetting and drying, which can give pavement difficulties unless they are kept at a reasonably constant moisture content. Tomlinson (1957) gives a good discussion of their performance in airfield construction. Table 3.

Table 3

Cohesive soils - Classification Test Results

Location of Sample	Atterberg Limits: Liquid Limit %	Plastic Limit %	Plasticity Index	Shrinkage Limit %	B.S. Compaction Tests: Max. dry Density Mg/m^3	Optimum Moisture Content %	Modified AAHSO Density test: Max. dry Density Mg/m^3	Optimum Moisture Content %	Casagrande Classification.
Baghdad Civil Airport, Iraq	51	25	26	-	1.61	22	1.81	17	CH
Amara-Basra Road, Iraq	44	21	23	-	1.62	23	-	-	CI
Braim, Abadan Island, SW. Iran	59	24	35	-	1.63	21	1.83	16	CH

Tomlinson (1957)

Road Research Laboratory Note No. RN 942/FR.

Silty Soils. Windblown silts, the loesses, sometimes occur in deserts and if they have not been redeposited by water may be metastable, that is in this context they can quickly collapse on wetting (especially if under load) but in the dry state can have good strength and bearing characteristics. Loess plains may have underground drainage channels which may not be easily visible from the ground surface, and loess can readily pipe by internal erosion from percolating groundwater. A general solution to geotechnical problems provided by metastable loess is to consolidate by flooding and rolling prior to construction or to admix with coarser material to make more suitable

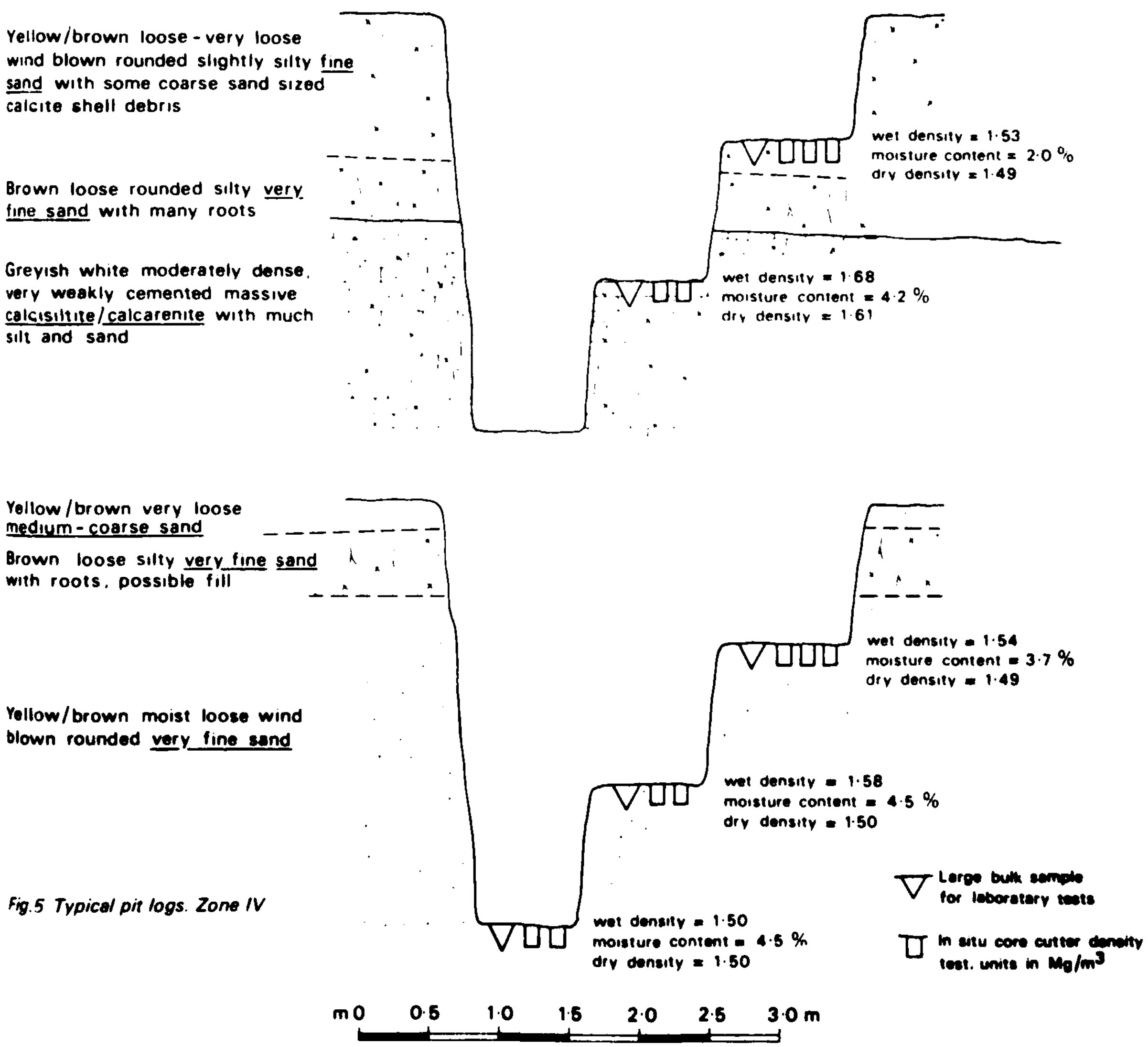


Fig.5 Typical pit logs. Zone IV

grading, especially if it is to be used as embankment. For geotechnical discussion on loess see Holtz and Gibbs (1951) and on desert loess in Iran see Fookes and Best (1969).

Sandy Soils. Most sands in deserts are the direct or indirect result of wind transport even if they are no longer in the form of dunes. They are perhaps the most extensive of all the soil types. They have typically a single sized grading curve (Figure 3) and this characteristic often makes them difficult to drive a light vehicle over and gives difficulties during compaction. They occur frequently in a loose state with low *in-situ* densities due to the poor packing of the uniformly graded materials deposited in a subaerial environment. They therefore also have a low allowable bearing capacity because of the potentially large settlement due to their low density and also if weak cementation is present the possible collapse of the material under load. Therefore, density characteristics in the sub-grade and under structures is important, especially in depth. Figure 5 is of test pits in typical zone IV sands from Libya and illustrates some of the common characteristics. The sands are uniformly graded in the fine sand range with silt contents from 0-10 per cent by weight and medium sand 0-15 per cent. Uniformity coefficients of these sands ranged from 1.25 per cent to 1.88 per cent indicating their uniform grade. Their effective size (size of the smallest 10 per cent in millimetres) was from 0.08-0.10mm, again giving only a small range. Comparative wet and dry sieving of the *loose* sands showed only small differences indicating little cementation was available from breakdown by the wet sieving. Lightly cemented sands and silts can also be present as indicated on Figure 5. Heavy Proctor tests gave a big range of maximum dry densities from 1.65 to 1.95 mg/m³ at moisture contents ranging from 7.5 to 11 per cent. Unsoaked CBR values not surprisingly were also widely ranging from 3-30 per cent but with most results in the 7-20 per cent range. Soaked CBR's gave consistently low values and were always less than 10 per cent with most in the range 2-4 per cent. Table 4 gives a selection of results.

TABLE 4

Desert Zone IV Sands - Classification Test Results

Brief Description	Depth m.	Optimum moisture content	Maximum Dry Density Mg/m³	CBR% Unsoaked		CBR Soaked		Total water soluble Salts %	pH value
				Top	Bottom	Top	Bottom		
Fine sand	0.1	9.5	1.720	12	15	5	8	0.05	9.2
Fine sand	0.1	9.0	1.682	11	13	2	2	0.03	8.5
Slightly silty fine sand	1.0	9.5	1.979	8	11	2	2	0.04	8.7
Slightly cemented silty sand with nodules of calcrete	1.9	6.7	2.076	29	37	9	21	0.04	8.5
Calcarenite*	2.0	9.5	2.013	74	87	24	39	0.05	8.7

* For terminology see Fookes, P.G. & Higginbottom I., 1975. '*The classification and description of near-shore carbonate sediments for engineering purposes*'. Geotechnique. Vol. 25 No. 2 pp 406-411.

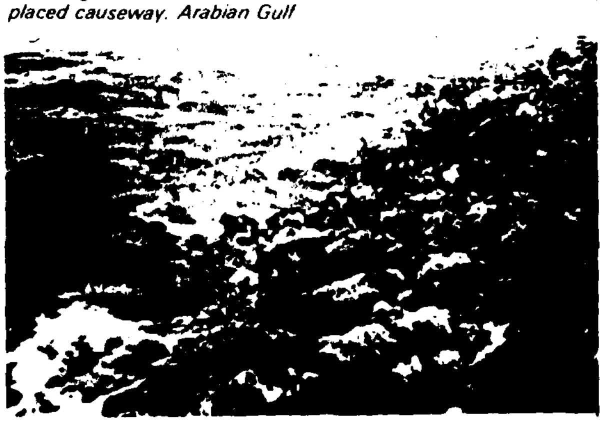
The moderately dense fine sands which may be lightly cemented can show differential settlements under load and even metastable settlements similar to the loesses. *In-situ* dry densities of these sands ranged from 1.45 to 1.65 mg/m³ Shear box tests on disturbed samples gave an angle of internal friction of 31° for a maximum density of 1.62 mg/m³ and 26° for the loosest state of 1.2 mg/m³ Oedometer tests carried out on undisturbed samples at natural moisture contents gave coefficients of volume compressibility (m_v) in the range 0.006 to 0.014cm²/kg at a loading of 1 kg/cm². *Settlements at this loading were* in the range 0.4 to 1.5 per cent but at 2 kg/cm² overall settlement during testing increased between 1.2 to 2.2 per cent. Wetting of the samples at this load caused approximately another 2 per cent metastable settlement. Metastable settlement was observed even on loadings less than 0.75 kg/cm².

Dry sands may compact reasonably well with vibrating equipment but careful field trials to get optimum conditions will be necessary. When the sands are used as fill even slight adjustments to the grading curve of true windblown sand, as the adding of silt or gravel, can give significant improvement to the compaction performance of the material. Laying and rolling in thin controlled lifts helps produce stable fills, and sand fill embankments can be constructed with the shoulder zones of a more stable material. Again field and laboratory trials are strongly recommended. For structures on low bearing capacity sands piling may be necessary and recently vibro flotation and dynamic compaction techniques are reported to have been used with success. Small plate bearing tests can be a valuable guide to settlement characteristics in certain situations.

Active Windblown Sands. Problems due to wind erosion of embankments and the migration of dunes and sand drifts can be common. Sand is generally moved by saltation and to a lesser extent by suspension, creep and gravity. The study of sand movements, dune patterns and so on is too big a subject to compress adequately here but Cooke and Warren (1973) give a most readable and comprehensive account. Dune movements can be largely predictable and therefore avoidance of mobile dune fields (viz. families of barchans or sief dunes which may move say, one metre a month downwind) by choice of alignment, if possible, may be the best solution. Reconnaissance investigations including study of satellite imagery and conventional air photo interpretation are therefore most useful to delineate sand source areas, mobile and dead dune complexes, rates and directions of advance. If crossing small dunes is unavoidable, they can be successfully immobilized by a variety of ways depending on circumstances. Table 5 modified after Kerr and Nigra (1952) summarises some possibilities.

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.

Leaching of fines from desert fill by wave action on a recently placed causeway. Arabian Gulf



Loss of fines from end tipped desert fill reclaimed land by wave action. Arabian Gulf

Table 5 - Objectives and Methods of Dune and Drift Sand Control

	OBJECTIVES
1.	The destruction or stabilisation of wind blown sand accumulations in order to prevent further migration and enroachment.
2.	The diversion of wind blown sand around works requiring protection.
3.	Stopping sand movement in front of the works to be protected
4.	Aiding sand movement in order to avoid desposition over a specific location, especially by surface smoothing and obstacle removal

	METHODS
	The above objectives are achieved by the use of one or more types of surface modification. Potentially more attractive methods first.
1.	Align route upwind of sand source to avoid major dune fields.
2.	Oiling involves the covering of wind blown materials with a suitable oil product (e.g. high gravity penetrating oil) which stabilises the treated surface and may destroy dune forms. Often a quick, cheap and effective method.
3.	Fencing the use of relatively porous barriers to stop or divert sand movement or destroy or stabilise dunes. Cheap, portable and expendable structures are suitable (using, for example, palm fronds, chicken wire or snow fencing).
4.	Planting of appropriate vegetation designed to stop or reduce sand movement, bind surface sand and provide surface protection. Early stages of control may require planting or sand stilling plants (e.g. Ammophila arenaria (beach grass), protection of surface (e.g. by mulching), seeding, and systematic creation of surface organic matter. Planting is permanent and attractive, but expensive to install and maintain.
5.	Paving is designed to increase the saltation coefficient of wind transported material by smoothing or hard-surface a relatively level area, thus promoting sand migration and preventing its accumulating at undesirable sites. Often used downwind of fencing where wind is unladen of sediment, and paving prevents its re-charge. Paving may be with concrete, asphalt or wind-stable aggregates (e.g. crushed rock or gravel).
6.	Panelling by erection of solid barriers to the windward areas to be protected, designed either to stop or to deflect sand movement (depending largely on the angle of the barrier to wind direction). In general, this method is unsatisfactory and expensive, although it may be suitable for short-term emergency action.
7.	Trenching cutting of transverse longitudinal trenches across dunes destroys their symmetry and may lead to dune destruction. Excavation of pits on the lee of sand moulds or on the windward side of the works to be protected will provide temporary loci accumulation.
8.	Removal of material - rarely successful and not normally long term.

Ideally for dune areas flat roads are to be preferred but the embankment should be gently 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 superelevation 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, stabilise the sand between the cut and the fence (Table 5) and then increase the height of the fence whenever it loses its trapping efficiency.

It is important to remove all obstructions up-wind 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.

Oil stabilisation adjacent to the road is not necessary unless it is desired to prevent scouring of the up-wind side of the embankment. Scouring of the up-wind side of the embankment can be completely prevented by an application of a high gravity penetrating oil. Crushed rock or gravel of medium to coarse grading, marl, or a liberal application of heavy asphaltic oil will also serve, though they are more expensive than the penetrating oil treatment.

Migrating dunes that are approaching the road are another serious hazard. Destruction or immobilisation 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 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 upwind of the road as it could destroy any existing natural thin crust or sparse binding vegetation which in turn could lead to sand near the road being mobilised by the wind.

Salty Soils. Salts from local bedrocks go into solution in the groundwater and these salts and salts in seawater in near coast locations can then be precipitated by evaporation in any drying situation above the water table. Of the many different salts perhaps the commonest aggressive ones are calcium sulphate, magnesium sulphate, sodium sulphate and sodium chloride and these can be found in amounts varying from a trace to virtually 100 per cent, in most of the world's deserts. Therefore it is always advisable to test for salts in soils and in groundwaters — not by single samples but by a profile of samples taken down an exploratory pit face and then repeated for other pits as the terrain changes.

Certain natural conditions produce exceptionally high salt concentrations in zone IV (and sometimes zone III). Local names for these conditions are many and bewildering; at the risk of gross oversimplification these have been reduced to **playa, salt playa** and **salina** in Figure 6 and Table 6 to show the relation of these conditions to the water table. To these must be added the **sabkha**, the coastal approximation to the salina.

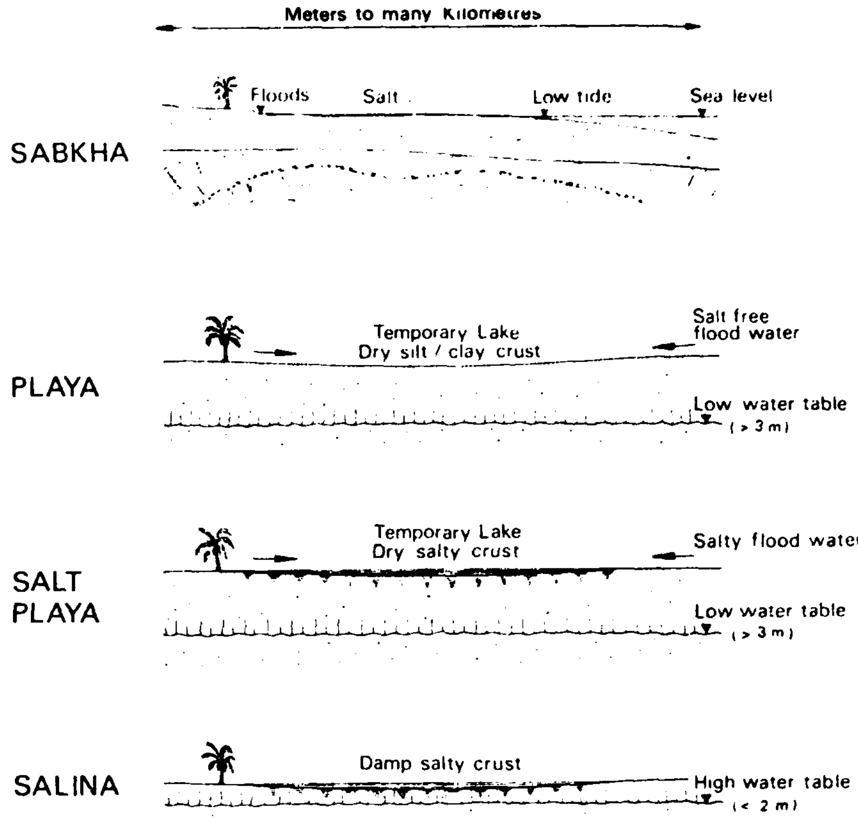
Salts, especially the sulphates, can physically disintegrate rocks (and aggregates, blacktop and concrete), especially those with high porosities, by a variety of methods. This attack occurs commonly and is a natural form of weathering which occurs little in Britain (except for coastal cliffs) and is the result of salts crystallising out in the pores of the rock (or concrete etc.). Expansive forces are quickly set up by the growth of crystals *or* by differential volume changes in the crystals due to day/night temperature fluctuations *or* by hydration/dehydration cycles with climatic moisture changes. Therefore, depending on circumstances, rock fill, coarsely granular bases and sub-bases and even porous bitumen road surfaces can be severely disintegrated by salt movements within them and distress and failure can result. It is important to note that inert unbound rocks and finely granular materials do not suffer as in a sense they are already disintegrated. In many circumstances salt may act as a satisfactory binder in low cost unsurfaced roads (e.g. Fumet (1960), Fenzy (1966), Ellis & Russell (1973)).

Potentially dangerous conditions for surfaced roads are therefore in salina and sabkha terrains, i.e. high water tables and high salt contents, especially where the local aggregates are friable and porous (e.g. some sandstones, some limestones, chalks, weathered igneous rocks). Engineering solutions to these conditions are by the avoidance of those areas by route alignment, raising the road on fine fill embankments of low permeability (i.e. for a low capillary rise), use of inert aggregates for the base (i.e. stone of low percentage loss to the ASTM weathering test C-88, high SG, low porosity) and with a dense, thick asphalt or bituminous wearing course. In critical situations use of an impermeable membrane to act as a positive cut off at, say, the top of the formation, can be considered to reduce moisture movement *or* use of a bitumen/ sand mix as a low permeability carpet *or* by bituminous soil stabilisation. In thin constructions, for example jet efflux areas round runways, or pedestrian pavements, surfaces can heave up by salt blisters forming under the blacktop which quite quickly (within months) can rupture and disintegrate. Salty soils (salina or sabkha material) as fill for surfaced roads should therefore only be used after careful laboratory and field examination and preferably after long term trials. Acid soils and salt concentrations of greater than 0.05 per cent sulphates and 0.5 per cent chlorides are reported to be harmful. For discussion see Weinert and Clause (1967) and Weinert (1964).

Concrete is also attacked by physical salt weathering mechanisms as well as by classical "sulphate" chemical attack. Therefore serious consideration must be given to protection of concrete structures in salty areas. For discussion of concreting in desert areas see Fookes and Collis (1975(a)&(b)) and (1976).

Land reclaimed by fill of sandy material may quickly turn into a salina, i.e. develop a salty crust, if it has a high water table. The new land will, therefore, suffer from the same disadvantages as natural salinas. For further discussion see Fookes and Collis (1976). **Duricrusts.** A general term for a variety of surface materials which for engineering purposes can be simplified to two principal forms.

Crusts, a weak layer up to tens of centimetres thick overlying a desert soil, e.g. a gypcrust is formed of gypsum crystals and **cretes**, a natural concrete, a hardening of rock surfaces, can be hundreds of centimetres thick, e.g. calcrete is formed by precipitation of



(After Fookes & Collis 1975[a])

Fig.6 Idealised cross-sections of sabkha, playa, salt playa and salina terrain. Zone IV. (see also Table 6)

Table 6 - Some specific salty soil types in zone IV and their engineering significance.

Name	Terrain	Ground water table	Salts	Special significance	Construction technique
SABKHA	Coastal flat, inundated by sea water either tidally or during exceptional floods.	Very near the surface	Thick surface salt crusts from evaporating sea brines. Salts usually include carbonates, sulphates, chlorides and others.	Generally aggressive to all types of foundations by salt weathering of stone and concrete and/or sulphate attack on cement bound materials. Evaluate bearing capability.	Carefully investigate. Consider tanking concrete foundations; using SR cement. For surfaced roads consider using inert aggregate, capillary break layer or positive cut-off below sub-bases. Use as fill suspect. May not be deleterious to unsurfaced roads.
PLAYA	Inland, shallow, centrally draining basin - of any size.	Too deep for the capillary moisture zone to reach the ground surface but area will be a temporary lake during floods.	None if temporary lake is of salt free water.	Non-special. Ground surface may be silt/ clay or covered by windblown sands. Evaluate bearing capability.	Non-special.
SALT PLAYA	As Playa but often smaller than a playa.	As Above but lake of salty water	Surface salt deposits from evaporating temporary salty lake water. Salts usually include chlorides and sometimes nitrates, sulphates and carbonates.	Can be slightly to moderately aggresive to all types of foundations by salt weathering and sulphate attack. More severe near water table.	As Sabkha.
SALINA	As Playa	Near surface, capillary moisture zone from salty groundwater can reach the surface.	Surface crusts from evaporating salty groundwater. Salts include carbonates and many others.	Can be slightly to exceptionally aggressive to all types of foundations by salt weathering and sulphate attack.	As Sabkha.

(After Fookes & Collis 1975(a))

calcium carbonate; silicrete from precipitation of silica, ferrocrete of iron and so on. These duricrusts are quite common in zone IV and in wadis and on rock outcrops in other zones. There are many variations on this general theme and each situation requires its own investigation. However, a few generalisations can be made for highway engineering purposes.

Friable, soft or damp crusts may indicate the presence of a fairly high water table, they may be made of salts particularly aggressive to rocks and concrete. Their use as fill, and their bearing characteristics are quite variable depending on the local circumstances and therefore, they should always be investigated. Some crusts are advantageous both as fill and in bearing capacity. Some are the opposite. Many are salty.

Cretes are much harder and often make good borrow materials for aggregate but, and this is especially true for concrete aggregates, they must be carefully evaluated first from both a mechanical and chemical standpoint. Underneath its case hardened surface the rock tends to be more porous and friable and therefore a simple visual examination of the surface is often quite misleading and is not adequate to make judgements on whether to open as a quarry, rip out a cutting or use as a load bearing strata. A drilling investigation is required.

Some hard duricrust surfaces are dissected or nodular in character and intermixed with the hard material are sands and silts deposited from wind or from rare rainwater flows. Winning this surface can present an attractive proposition as it is often easily rippable. The as-loaded material is thus a mix of silt/sand and ripped nodular rock, which can be quite gap graded (see 'desert fill' grading Figure 3). Care, therefore, has to be taken when placing this mixed material as fill to ensure good compaction. If it is used for causeway construction especial care has to be taken over its grading otherwise the fines are removed by water action and differential settlement can then occur. This can be overcome by adjusting the poor grading of the material *or* protecting the as-placed poorly graded material with suitably designed side filters. Rockfill construction, if suitable rock is available, is an attractive alternative.

ENVOIE

In order to get the relative proportions of the various desert surfaces in perspective, Table 7 gives a comparison of desert surface types in the world's major deserts. It has been modified from Clements *et. al.* (1957) to suit the terminology used in this Paper. The extensive dune areas of the near and Middle East are worth drawing attention to these are the really arid areas where wind transport dominates. In slightly wetter areas as south western United States, Iraq and Iran, sand dune areas are less and alluvial fans greater in extent.

Table 7 - Comparison of Desert Surface Types by Plan Area

Geographical Zone	Likely occurrence commonest in engineering zone.	Sahara	Libyan Desert	Arabia	South Western 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
		100.0	100.0	100.0	100.0

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See also: Fookes, P.G 1976. *Inherent Ground Problems.* Symp. on Engineering Problems associated with ground conditions. Geol. Soc. London. November.

APPENDIX C:

FACTORS AFFECTING WORKERS' EFFECTIVENESS

The information in this appendix is from Southwest Asia: Environment and its Relationship to Military Activities (Quartermaster Research and Engineering Center, July 1959).

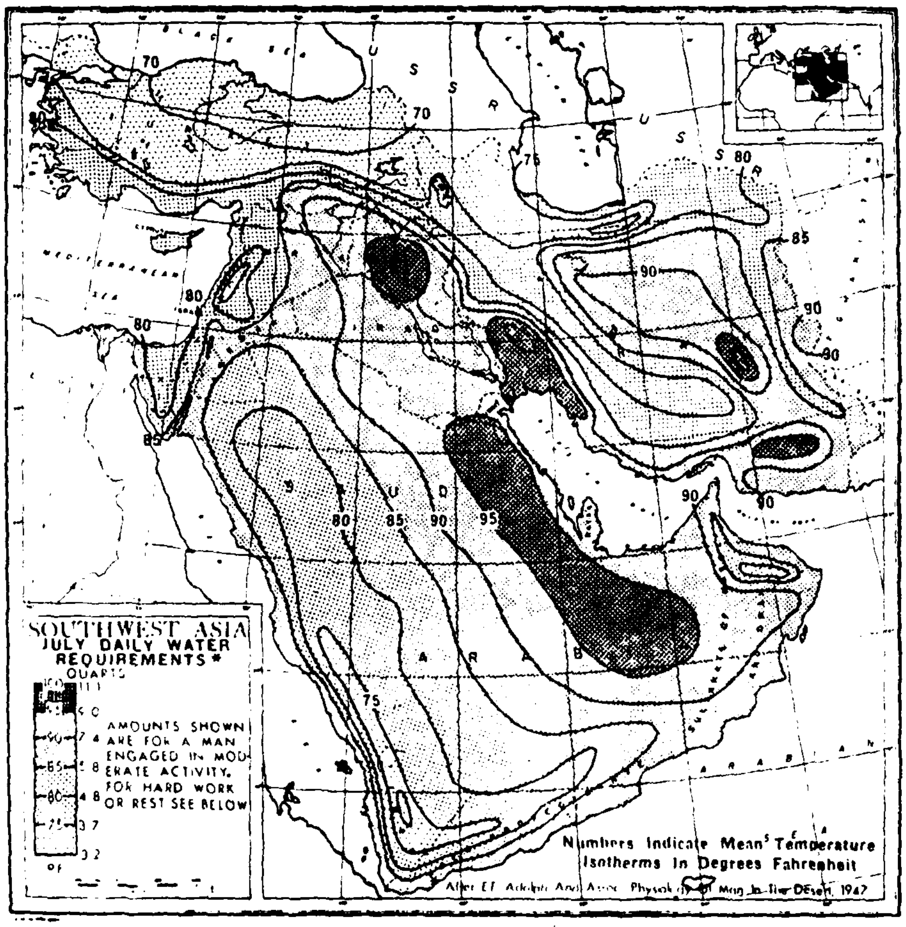
Table C.1

Energy Expenditures for Various Activities and General Classification of Different Levels of Activities

General Classification	Specific Activity	Energy Expenditure Cal/min	Energy Expenditure Cal/hr
"Sedentary to Light" (75-150 Cal/hr; 1.3-2.5 Cal/min)	Resting quietly	1.3	78
	Loaf in barracks	1.6	96
	Clerical, sitting	1.6	96
	Toilet	1.7	102
	Drilling	1.8	108
	Anti-gas drill	2.0	120
	Fatigue details	2.2	132
	Inspection	2.2	132
	Weapon training	2.2	132
	Hand grenade drill	2.3	138
	Gas mask drill	2.3	138
	Polishing brass	2.4	144
"Moderate" (150-300 Cal/hr; 2.5-5.0 Cal/min)	Cleaning kit and rifle	2.7	162
	Driving car	2.8	168
	Manual of arms	2.8	168
	Rifle marksmanship	2.8	168
	Cleaning equipment	2.9	174
	Touch football	3.1	186
	Bayonet drill	3.3	198
	Sentry duty	3.5	210
	Driving tank over rough terrain	3.5	210
	March with 60 lb. pack at 2 mph	3.9	234
	Digging foxholes	4.0	240
	Close order drill	4.2	252
	Mass games	4.5	270
	Field march	4.8	288

Table C.1 (Cont'd)

General Classification	Specific Activity	Energy Expenditure Cal/min	Cal/hr
"Hard"	Cleaning artillery pieces	5.1	306
	Quick marching	5.6	336
(over 300 cal/hr	Obstacle course	5.6	336
over 5.0 cal/min)	Digging trenches	6.0	360
	Snowshoeing	6.2	372
	Field march with rifle	6.5	390
	Marching (3 mph with 24-lb. pack and rifle)	6.6	396
	Skiing	6.6	396
	March over snow at 2.3 mph	6.7	402
	March on road at 3.4 mph	6.9	414
	Rifle exercises	7.5	450
	Creeping and crawling with full equipment	7.9	474
	Field march with rifle and 27 lb. pack at 3 mph	8.0	480
	March with 60 lb. pack at 4 mph	8.9	534
	Drill at double time	18.3	1098



This map of daily water requirements for men performing moderate work in July can be applied almost equally well in August. If one is interested in average July daily water requirements at a place where the map shows the mean temperature to be 95°F (at the head of the Persian Gulf) one refers to the legend, which shows that the average daily requirement for the month is 9.0 quarts. To find the requirements for personnel resting or doing heavy work, refer to Table 9.1.

Figure C.1. July daily water requirements.

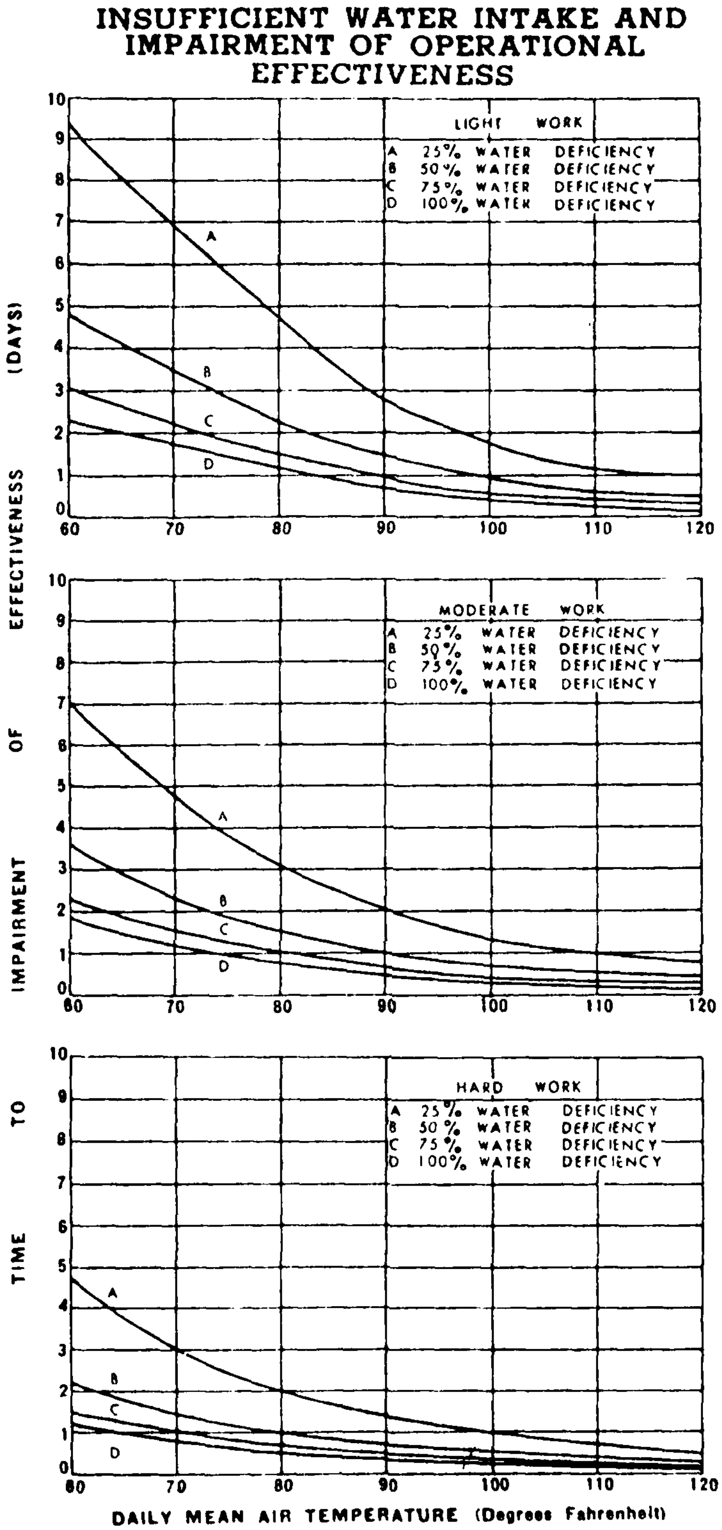
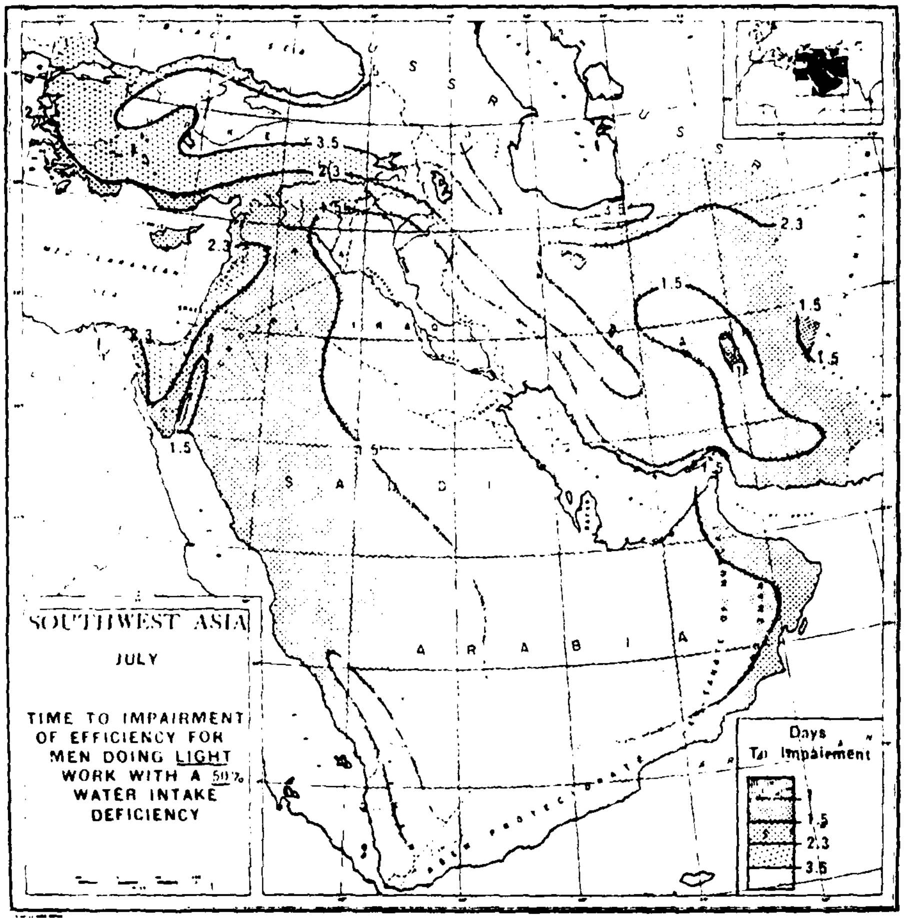


Figure C.2. Insufficient water intake and impairment of operational effectiveness (see Figure C.3 for explanation).



When water intake is not adequate to replace the water lost from the body, dehydration occurs. When the amount of body water lost exceeds 5 percent of the body weight (about 3.5 quarts), operational effectiveness is impaired. The three graphs in Figure C.2, for three levels of work, show the time (vertical scale) required for impairment of effectiveness at various average daily temperatures (horizontal scale). Each graph has four curves representing different levels of water deficiency. The three maps in Figures C.3, C.4, and C.5 show the number of days to impairment in July for three different levels of work. As an example, Figure C.4 shows that at the head of the Persian Gulf, the time to impairment for men doing light work with a 50 perent water deficiency is 1.5 days. By referring to the top graph in Figure C.2, corresponding figures for 25, 75, and 100 percent water deficiencies can be determined. Similar procedures can be followed for the other two maps and graphs in the series.

Figure C.3. Time to impairment of efficiency for men doing light work with a 50 percent water intake deficiency.

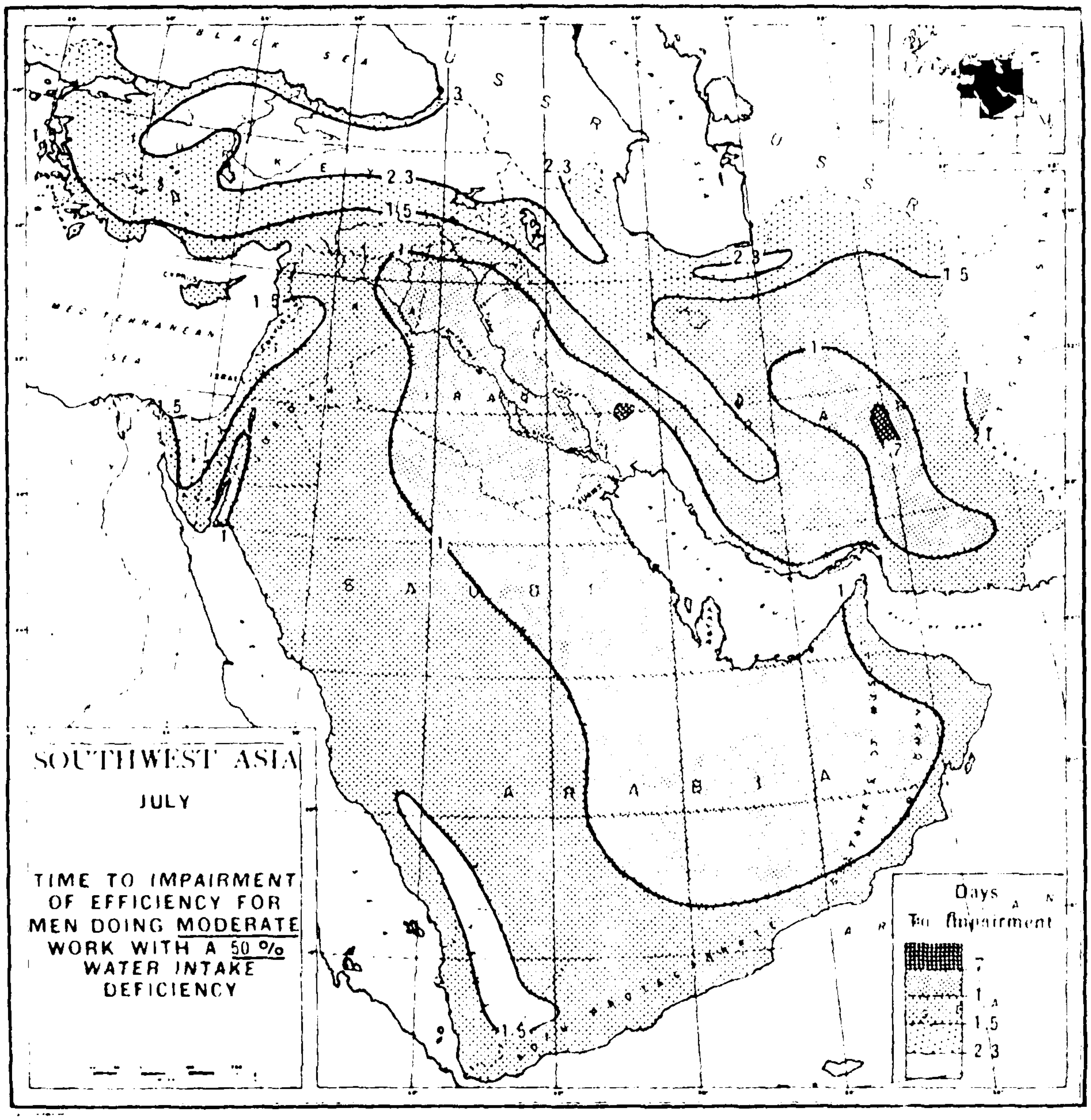


Figure C.4. Time to impairment of efficiency for men doing moderate work with a 50 percent water intake deficiency (see Figure C.3 for explanation).

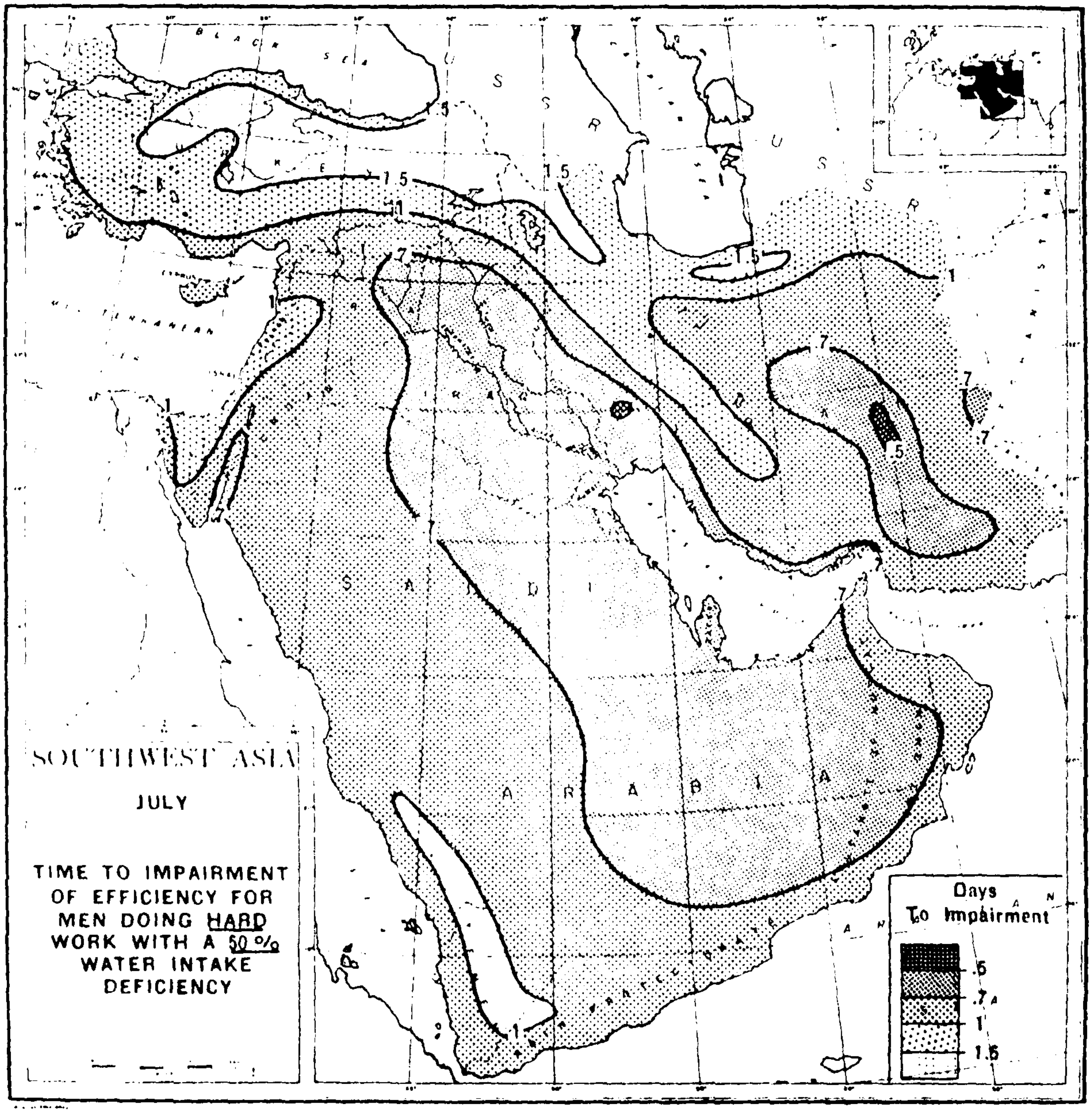
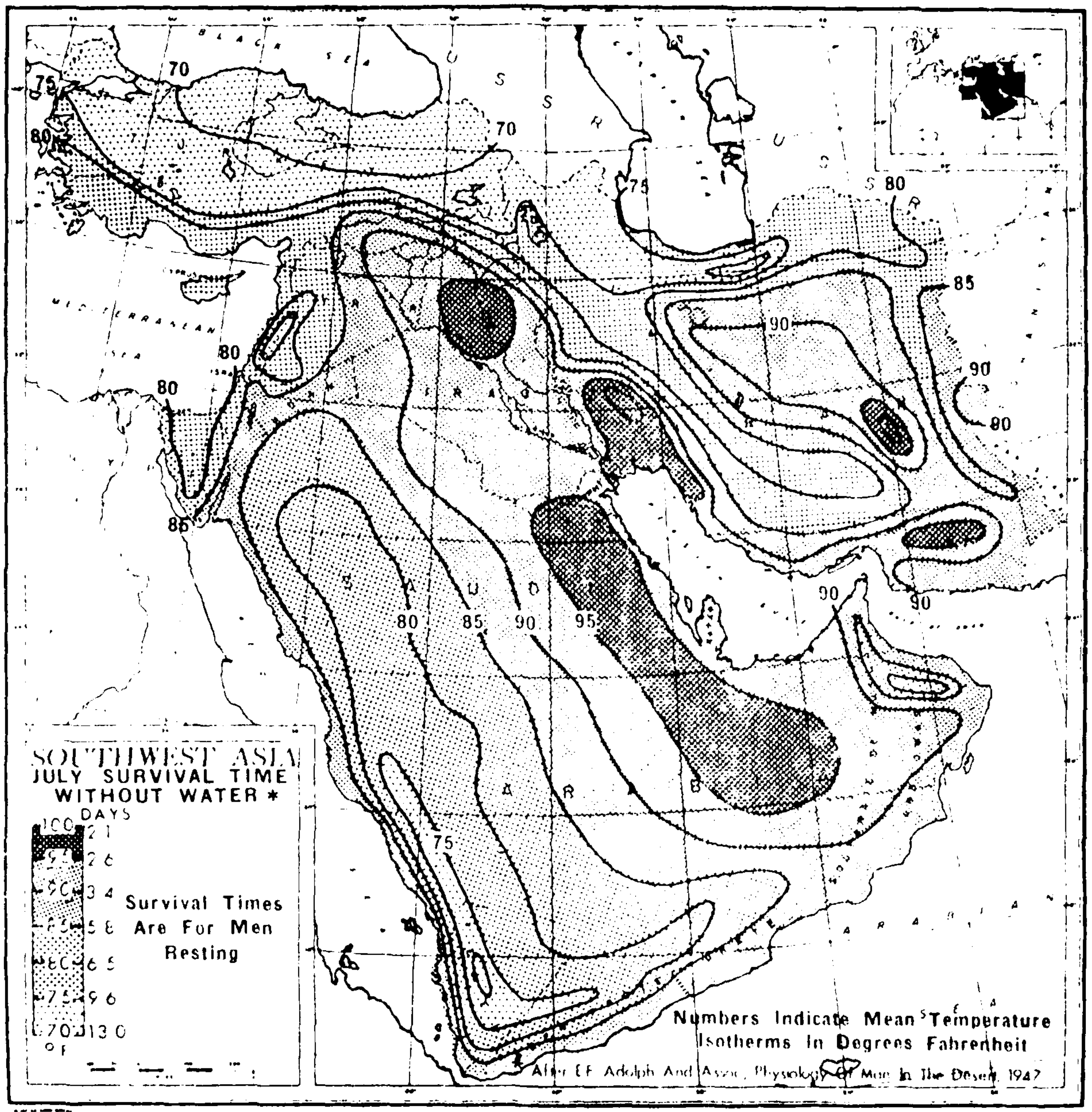


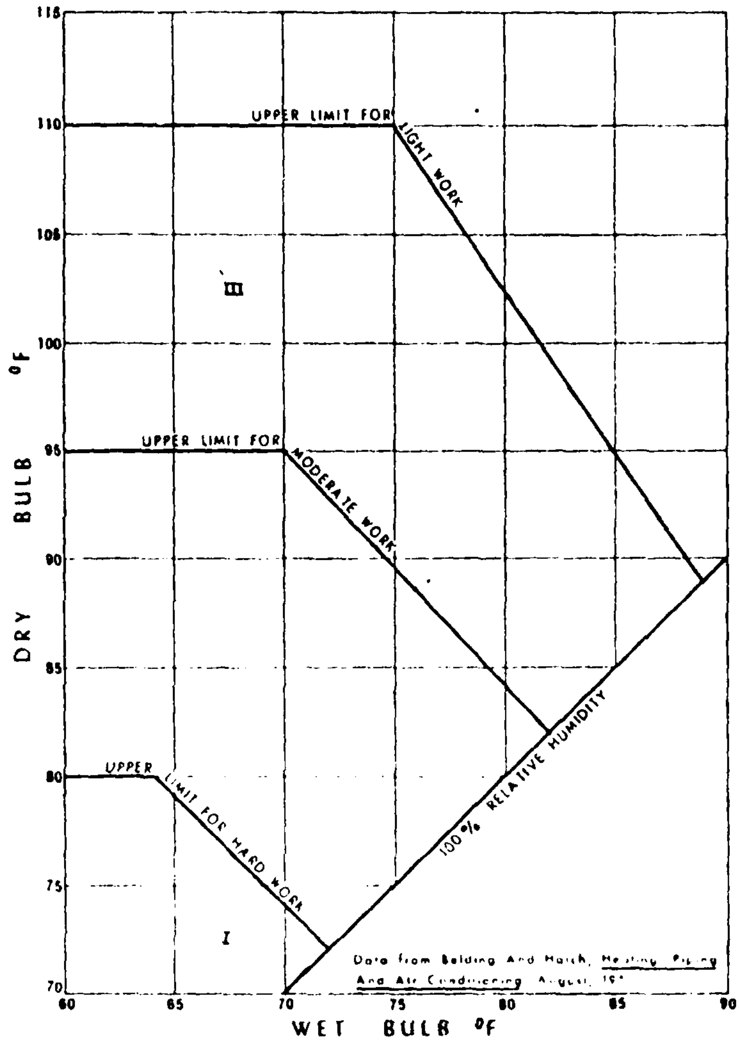
Figure C.5. Time to impairment of efficiency for men doing hard work with a 50 percent water intake deficiency (see Figure C.3 for explanation).



This map shows the predicted survival time for resting men when drinking water is not available. Survival is not considered likely when body water loss exceeds 20 percent of body weight (about 14 quarts). Because survival time is influenced both by the air temperature and by activity level, anyone involved in a survival situation should avoid all unnecessary physical activity and seek shade in the daytime. Necessary activities should be carried out at night.

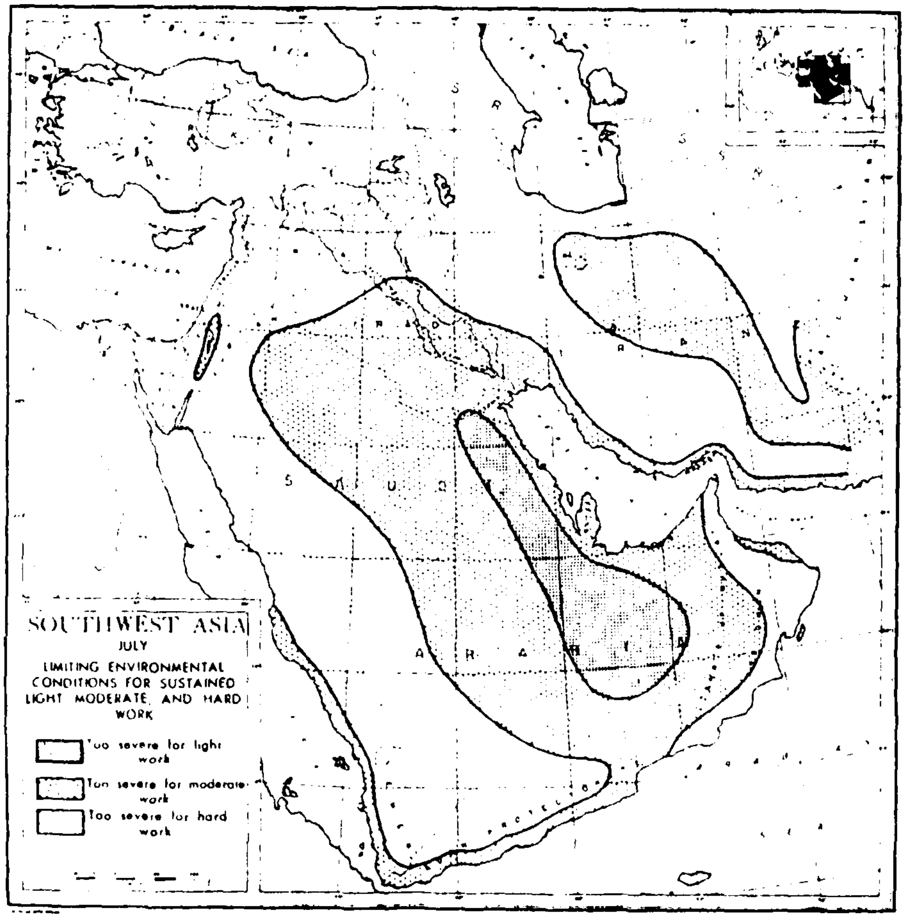
Figure C.6. July survival time without water.

LIMITING ENVIRONMENTAL CONDITIONS FOR
SUSTAINED WORK IN THE HEAT



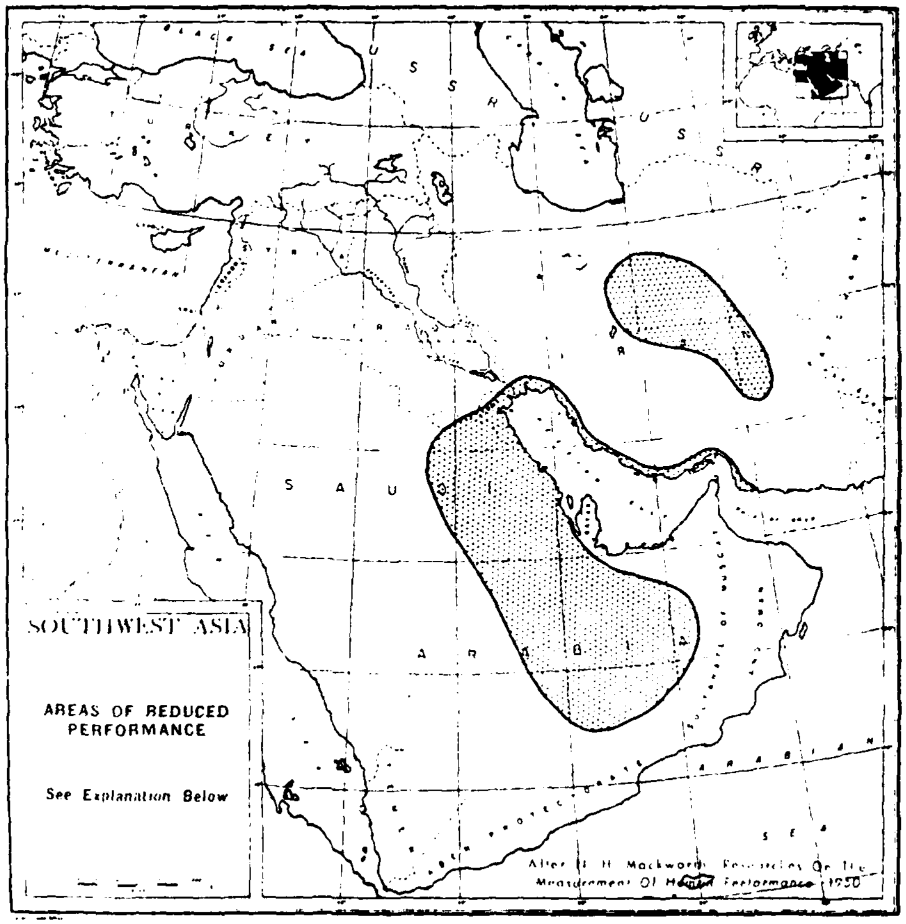
Limits on sustained work are imposed by heat (dry bulb) and humidity (wet bulb) in combination. To determine the upper level of activity that can be maintained under various conditions, locate the point of intersection of dry bulb and wet bulb temperatures in Area I, II, or III on the graph which indicates work capability in terms of maximum effort that can be sustained for 8 hours. For example, with a dry bulb of 90°F and wet bulb of 70°F, nothing more than moderate work can be performed on a sustained basis; with the same dry bulb and wet bulb of 80°F, only light work should be attempted. It should be kept in mind, however, that even hard work may be done for shorter periods. This method of estimating work capability necessarily presupposes constant conditions, although there is always variation over an 8-hour period.

Figure C.7. Limiting environmental conditions for sustained work in the heat.



Heat stress conditions from the graph in Figure C.7 are mapped above for July. Temperature and humidity data for the normal daytime working period were estimated from the mean values available and evaluated in terms of the graph. The map above shows that there is a sizable area where average conditions in July are too severe even for sustained light work. This should be interpreted as meaning that approximately half the days are less severe than the average, and on the most severe days, work can be done for periods somewhat shorter than 8 hours. Nevertheless, it would be advisable to have as much hard work as possible done at night during summer in order to take advantage of the less severe conditions.

Figure C.8. Limiting environmental conditions for sustained light, moderate, and hard work.



This map shows areas where the performance of men doing light skilled tasks will be reduced by about 25 percent. This is not necessarily a decrease in the amount of work done, but rather an increase in number of errors. For example, a competent radio operator located in one of the stippled areas on an "average" day in July will make 25 percent more errors than he would if the temperature were 85°F and the relative humidity 63 percent. If the operator, however, is highly skilled, he probably will suffer little or no performance decrement under the severe conditions. (Basic information on the performance of men under hot conditions was taken from N. H. Mackworth, Researches on the Measurement of Human Performance, Medical Research Council [Great Britain] Spec. Rpt. Ser. #268, 1950.)

Figure C.9. Areas of reduced performance.

APPENDIX D:

DUST ABATEMENT

This appendix is Lesson 17, "Dust Abatement," from Military Engineering: Lessons Learned, Department of the Army Pamphlet 525-3 (HQDA, October 1967).

LESSON 17
DUST ABATEMENT

Dust as a military problem dates back to the earliest recorded military history and descriptions of ancient battles frequently note that enemy movements were first detected by the clouds of dust raised by thousands of marching men. Today it is not so much the dust raised by marching men as the dust stirred up by the helicopter, the airplane, the truck, and the tank. And the problem is not so much one of giving away troop maneuvers, as how to cope with the increase in maintenance on items of equipment caused by dust and the degrading effect on the health and morale of troops who must live in the dust. Experience in Vietnam indicates that the life of helicopter rotor blades may be reduced as much as 70 percent by dust abrasion. Dust ingestion may reduce helicopter engine life as much as 50 percent. Dust is increasing the cost of helicopter maintenance in Vietnam by many millions of dollars yearly. In addition, dust is a serious operational hazard and a number of aircraft accidents have occurred because the pilot lost visibility in the dust cloud.

The control of dust is a major engineering problem of direct concern to the Army. Dust which may be defined simply as fine particles of soil which become airborne, may be generated by the downdraft of helicopters, by aircraft propeller wash, by engine exhaust blast, or by the draft of moving aircraft. The kneading and abrading action of aircraft and vehicle tires loosen particles from the ground surface which become airborne, and create the dust cloud. Moving ground vehicles generate dust clouds through the abrading action of tires and disturbance of the air.

There is no single method which is best for controlling dust in all situations. Instead, the engineer has available a wide variety of materials and techniques from which a selection must be made based on local conditions. The spectrum of these materials and techniques varies from the construction of conventional roads with sound, dustfree surfacing through the use of expedient surfacing materials such as landing mats and membranes, to the use of various dust palliatives. Selection of the best materials and techniques for a given situation requires consideration of the traffic to be carried by the surface, the source of the dust, the soil type, and the availability of materials.

Dust palliatives cover the dust source area with a thin protective layer, cement dust particles together, or cause dust particles to agglomerate into larger particles not readily airborne.

Although dust palliatives may be used on traffic areas, they should primarily be considered for use on non-traffic areas such as the shoulders of airstrips (fig. 18) and the space between helipads. If used on traffic areas, one important factor in determining suitability of the palliative is the extent to which the surface will rut. If the soil bearing capacity is such that the surface will rut under traffic, a shallow depth palliative treatment can be broken up and subsequently stripped from the ground surface. Some palliatives will withstand deformations better than others, but ruts 1½ to 2 inches deep will usually result in the destruction of any thin layer or shallow-penetration dust-palliative treatment. As a general rule, the use of dust palliatives for traffic areas of airfields or for roads should be considered only when the surface is sufficiently firm to support the design traffic loads with little or no rutting. If used where ruts are likely to occur, palliation will be shortlived and frequent retreatment will probably be necessary.

Using Aircraft	Maximum Effort Control: Runway Shoulder* ft	Maximum Effort Control: Taxiway Shoulder ft	Minimum Effort Control: Runway Shoulder* ft	Minimum Effort Control: Taxiway Shoulder ft
C-133	80	40	40	20
C-141	75	40	40	20
C-124	70	35	35	20
C-130	60	30	30	15
C-135	55	30	30	15
C-123	50	25	25	15
CV-2	40	20	20	15
CV-7	40	20	20	15
OV-1	20	20	15	15
O-1	20	20	15	15
F-4C	20	20	15	15
F-101	20	20	15	15
F-102	20	20	15	15
F-104	20	20	15	15
F-105	20	20	15	15

* Widths indicated for runway shoulders are applicable also to areas adjacent to overruns and parking aprons.

Figure 18. Recommended widths for dust control treated areas adjacent to traffic areas.

The U.S. Army Waterways Experiment Station, published Miscellaneous Paper No. 4-756, "Guide Manual for Selection and Use of Dust Pallatives and Soil Waterproofers in the Theater of Operations", which indicates a wide selection of materials for dust control and/or soil waterproofing is available to the engineer; however, no one material can be singled out as being the most universally acceptable for all problem situations. The various types of materials have been grouped into five general classifications as follows: (a) Group I, bituminous materials; (b) Group II, cementing materials; (c) Group III, resin systems; (d) Group IV, salts; and (e) Group V, miscellaneous materials.

A summary of various materials potentially suitable for theater-of-operations use and a guide to their application as either a dust palliative or a soil waterproofer are given in figure 19. It should be recognized that the information which is presented in figure 19 is based on limited testing of these materials to date by the U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, for the particular application to the military theater-of-operations airfields or roads. However, the data presented represent the best estimate that can be made of the applicability of the materials based on existing information.

For traffic areas not suitable for the use of dust palliatives, the engineer must either provide a dust-free surface using sound conventional materials, or use one of the newly adopted landing mats or membranes.

USE OF PENEPRIME

The most effective use of PENEPRIME for dust-proofing non-traffic areas on all soils in RVN has been straight PENEPRIME applied at an average rate of 0.5 gallons per square yard. No satisfactory solution has been found for stabilizing clean sands through surface penetration only, but PENEPRIME applied at a rate of 0.5 to 0.9 gallons per square yard performs better against wind erosion than any other material tested to date. PENEPRIME mixed with about 3 parts of diesel fuel has been moderately effective in dust-proofing unsurfaced roads or roads with laterite base courses. The initial application of the mixture is effective only for periods of 1 to 2 weeks, but subsequent treatments tend to build up longer lasting protection.

NEW MATERIALS

The Army R&D program has recently evaluated some 140 materials to secure a lighter-weight, longer-lasting dust-proofing treatment than is possible with PENEPRIME or other more conventional materials. Six new items are undergoing field test evaluation now by AMC/TECOM. One of these, "UCAR-130", a polyvinyl acetate emulsion, has given outstanding performance in laboratory and small scale field tests. One thousand barrels of UCAR-130 are being sent to RVN for trails on both roads and non-traffic areas.

POTENTIALS OF T-17 NYLON MEMBRANE

Tests at the Waterways Experiment Station and in RVN have demonstrated that the new T-17 membrane gives excellent performance for both water-proofing and dust-proofing newly graded or unsurfaced roads. The tests show that the membrane will support high volumes of ground vehicle traffic on silt and clay subgrades for periods of several months. This procedure could easily provide an all-weather, dust-free road surface until conventional base courses and pavements can be constructed. This procedure has not received wide spread use in RVN because most of the T–17 is required for airfield and heliport surfacings.

OIL APPLICATION

Boat oil #9150–231–6654 or 55 (mineral oil with additives) applied by an asphalt distributior at a rate of 0.25 gallon per square yard is an effective means of controlling dust. Oil applied to a road surface at this rate will penetrate the surface to approximately ¼ inch and allow traffic on roads immediately after application. The surface produced by this oil is extremely impervious to water, is dust free, and stands up well under heavy traffic. However, since the surface remains slippery for a minimum of 2 hours after application in most areas, it is recommended that the oil be applied only on one side of the roadway at a time, and the skidding hazard publicized.

(1) Material	(2) Form of Material	(3) Acceptable Application Methods (s)	(4) Applicable Soil Range	Primary Function, Area of Application, and Degree of Effectiveness+ — Dust Palliative — (5) Traffic	(6) Nontraffic or Limited Traffic	(7) Waterproofer (Traffic or Limited Traffic Areas Only)	Quantity Requirements ++ — (8) gal per sq yd	(9) lb per sq yd	(10) Minimum Curing Time Requirements	(11) Remarks
Group I: Bituminous Materials										
Cutback Asphalts										
a. RC-70 to RC-250	Liquid	Admix	Gravel to sand	M	V	M	0.18-0.25	1.5-2.0	12-24 hr	All cutback asphalts will require preheating for penetration or admix application
		Penetration	Gravel to silty sand	M	V	X	0.25-0.50	2.1-4.0	12-24 hr	
b. MC-70 to MC-250	Liquid	Admix	Sand to silt	M	V	M	0.25-0.55	2.0-4.5	>24 hr	
c. MC-30 to MC-250	Liquid	Penetration	Gravel to silty sand	M	V	X	0.25-0.50	2.1-4.0	>24 hr	
d. SC-70 to SC-250	Liquid	Admix	Sand to clay of moderate plasticity	M	V	M	0.55-0.72	4.5-6.0	>24 hr	
		Penetration	Gravel to silty sand	M	V	X	0.25-0.50	2.1-4.0	>24 hr	
Road Tars										
a. RT-3 to RT-6	Liquid	Admix	Gravel to clay of moderate plasticity	V	V	V	0.30-0.50	2.5-4.0	Several days	Same comments as above for cutbacks
b. RT-1 to RT-6	Liquid	Penetration	Gravel to silty sand	X	X	X	0.25-0.50	2.1-4.0	Several days	
Emulsified Asphalts										
a. SS-1 or SS-1h (Anionic)	Liquid	Admix	Gravel to silty sand	X	X	X	0.10-0.50 (diluted)	0.8-4.0	Several hr	Requires water for dilution and requires careful control for proper emulsion break. Dilutions up to 5:1 by water are used
		Penetration	Gravel to silty sand	X	X	X	0.10-0.50	0.8-4.0	Several hr	
Special Asphalts										
a. Peneprime#	Liquid	Penetration	Gravel to clay of moderate plasticity	M	V	M	0.25-0.5	2.1-4.0	6-8 hr	Excellent penetration ability; requires heating for spraying

Figure 19. Summary of Soil Stabilizing Materials for function of Dust Control and/or Soil Waterproofing.

(1) Material	(2) Form of Material	(3) Acceptable Application Methods (s)	(4) Applicable Soil Range	Primary Function, Area of Application, and Degree of Effectiveness+: Dust Palliative: (5) Traffic	(6) Nontraffic or Limited Traffic	(7) Waterproofer (Traffic or Limited Traffic Areas Only)	Quantity Requirements ++: (8) gal per sq yd	(9) lb per sq yd	(10) Minimum Curing Time Requirements	(11) Remarks
				Group II: Cementing Material						
Portland Cement	Powder	Admix	All	S	S	S	--	1.5-4.0	12-24 hr	Normally used for strength, but will also provide modest benefits for dust control and waterproofing when used in low quantities as a soil modifier
Lime (Hydrated)	Powder	Admix	Clays of moderate to high plasticity	S	S	S	--	1.5-4.0	12-24 hr	(Same as cement above)
				Group III: Resinous Systems						
Lignin	Liquid or powder	Admix	Sand to clay of low plasticity	S	S	S	--	4.0-8.0	12-24 hr	Benefits may be only temporary since resin is water soluble
		Penetration	Sand to silty sand	X	X	X	0.50-1.0	4.0-8.0	2-6 hr	
Concrete Curing Compound (with paraffin base resin)	Liquid	*Penetration	Silts to clays	S	M	X	0.1-0.2	1.0-2.0	2 hr	Fairly viscous, requires special spray nozzles, forms thin, moderately flexible film on surface when cured; curing depends on temperature and humidity

\+ Relative degree of effectiveness is indicated as follows: S - slightly, M - moderately, V - very, X - Applicable, but effectiveness unknown, Blank - not applicable.
++ For all admixture treatments, the quantities indicated are for a 1-in. depth of treatment and assume a compacted dry density of 100 lb per cu ft.
* Proprietary material.

Figure 19 -- Continued.

(1) Material	(2) Form of Material	(3) Acceptable Application Methods (s)	(4) Applicable Soil Range	Primary Function, Area of Application, and Degree of Effectiveness* — Dust Palliative — (5) Traffic	(6) Nontraffic or Limited Traffic	(7) Waterproofer (Traffic or Limited Traffic Areas Only)	Quantity Requirements ** — (8) gal per sq yd	(9) lb per sq yd	(10) Minimum Curing Time Requirements	(11) Remarks
				Group IV: Salts						
Sodium Cholride	Granules	Admix	Gravel to silt (with fines present)	S	S	--	--	0.4-0.8	0	All salts are corrosive to metal; subject to leaching; rely on absorption of moisture from air to palliate dust. Brine solution forms surface crust
Calcium Chloride	Powder or flakes	Admix	Gravel to silt (with fines present)	S	S	--	--	0.4-0.8	0	
Brine Solution	Liquid	Penetration	Sand to clay of low plasticity	S	S	--	0.5-1.5 (20% solution)		0	
				Group V: Miscellaneous Materials						
Water	Liquid	Penetration	All	S	S	--	(As needed)		0	Temporary measure only
Various Oils	Liquid	Penetration	All	S	X	--	0.5-1.0		0	Temporary measure only; may require frequent application

Figure 19 -- Continued.

Column 3 shows the acceptable method of application. Where a material may be applied either as an admixture or as a surface penetration treatment, the preferred and most generally used method is indicated first.

Column 4 states the applicable soil range, i.e. the range of soils which will normally result in reasonably satisfactory results with the particular material. In some instances, the materials may be used outside of this range but with the recognition that the effectiveness which could be achieved will be decreased. In general, granular-type soils (gravel to coarse sand) may or may not require treatment for dust control or waterproofing, depending on the amount of fines present. Fine sands (e.g. dune or windblown sands) will probably require a dust palliative but not a waterproofer. Soils ranging from silty sands to highly plastic clays may require a dust palliative and/or soil waterproofer.

Column 5, 6, and 7 show the primary function of the materials as either a dust palliative or a soil waterproofer and, where known, the relative degree of effectiveness that can be expected for the indicated function. The applicability to both the traffic area (column 5) and nontraffic area (column 6) is given under the dust palliative function. The waterproofing function is given for the traffic area only (column 6), since there will not be a general need for maintaining strength in nontraffic areas. If such a requirement arises, the materials indicated as suitable for traffic area can be considered acceptable for use in nontraffic areas.

Column 8 and 9 indicate quantity requirements applicable to the soil range indicated in column 4. The lower quantity of the range shown is generally suitable for the coarser soils, and the higher quantity is needed for the finer soils. These quantity requirements are given only as a general guide; in some cases, effective results may be achieved with lesser or greater amounts than those given in the table.

Column 10 indicates minimum curing time for the various materials. The curing requirements are specifically pertinent to the function as a dust palliative and/or waterproofer in traffic areas. In nontraffic areas, curing is not usually critical, and adequate dust palliation can be expected immediately after an admixture is compacted or, in the case of penetration materials, immediately after the liquid has been completely absorbed by the soil surface.

Figure 19 -- Continued

ABBREVIATIONS

APPENDIX E LIST OF ABBREVIATIONS

AFCS	Army Facilities Components System
ALOC	Air Line of Communications
BW	Biological Warfare
CBR	Chemical/Biological/Radiological
CW	Chemical Warfare
E-G	Engine-Generator
Hz	Hertz (cycle per second)
JCS	Joint Chiefs of Staff
kW	Kilowatt
MED	Mid-East Division (Corps of Engineers)
MERADCOM	Mobility Equipment Research and Development Command (U.S. Army)
MW	Megawatt
NEC	National Electrical Code
NTG	Nontactical Generator
RO	Reverse Osmosis
ROWPU	Reverse Osmosis Water Purification Unit
SLOC	Sea Line of Communications
SWA	Southwest Asia
TDA	Table of Distribution and Allowances
TDS	Total Dissolved Solids
TG	Tactical Generator
TM	Technical Manual
TO	Theater of Operations
TOE	Table of Organization and Equipment
TPFDD	Time Phased Force Deployment Data

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