MAR 2 1995

FM 5-430-00-2
AFJPAM 32-8013, Vol II

PLANNING AND DESIGN OF ROADS, AIRFIELDS, AND HELIPORTS IN THE THEATER OF OPERATIONS— AIRFIELD AND HELIPORT DESIGN

HEADQUARTERS,
DEPARTMENT OF THE ARMY
DEPARTMENT OF THE AIR FORCE

DISTRIBUTION RESTRICTION: Approved for public release; distribution is unlimited.

Field Manual
No. 5-430-00-2
Air Force Joint Pamphlet
No. 32-8013, Vol II

Headquarters
Department of the Army
Department of the Air Force
Washington, DC, 29 September 1994

PLANNING AND DESIGN OF ROADS, AIRFIELDS, AND HELIPORTS IN THE THEATER OF OPERATIONS—AIRFIELD AND HELIPORT DESIGN

TABLE OF CONTENTS

Volume I

DISTRIBUTION RESTRICTION: Approved for public release; distribution is unlimited.

---

*This publication together with FM 5-430-00-1/AFJPAM 32-8013, Vol I, 26 August 1994 supersedes FM 5-165/AFR 86-13, 29 August 1975, FM 5-335, 2 December 1985 and TM 5-330/AFM 83-6, Vol 1, 8 September 1968.

Volume II

PREFACE

Field Manual (FM) 5-430 is intended for use as a training guide and reference text for engineer personnel responsible for planning, designing, and constructing roads, airfields, and heliports in the theater of operations (TO).

FM 5-430 is divided into two separate volumes to make it more *user-friendly*. FM 5-430-00-1/AFPAM 32-8013, Vol 1, *Road Design,* encompasses Chapters 1 through 9 and Appendices A through H. FM 5-430-00-2/AFJPAM 32-8013, Vol II, *Airfield and Heliport Design,* encompasses Chapters 10 through 14 and Appendices I through P.

FM 5-430-00-1/AFPAM 32-8013, Vol 1 is a *stand-alone* volume for the design of TO roads. This volume also serves as a detailed description of information common to both roads and airfields, such as site selection, survey and earthwork, clearing and grubbing, base and subbase courses, and drainage.

FM 5-430-00-2/AFJPAM 32-8013, Vol II serves as the basis for airfield and heliport design. It discusses the complete process of airfield and heliport construction from the preliminary investigations, through design criteria, to the final project layout and construction techniques. It is not a *stand-alone* volume. FM 5-430-00-1/AFPAM 32-8013, Vol 1 contains much of the information required to design the substructure of an airfield or a heliport.

The material in this manual applies to all levels of engineer involvement in the TO. The manual is intended to be used by United States (US) Army Corps of Engineers personnel.

The provisions of this publication are the subject of the following international agreements:

- Quadripartite Standardization Agreement (QSTAG) 306, American-British-Canadian-Australian Armies Standardization Program, *Fortification for Parked Aircraft.*
- North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 3158 Airfield Marking and Lighting (AML) (Edition 4), *Day Marking of Airfield Runways and Taxiways.*
- STANAG 2929, *Airfield Damage Repair.*
- STANAG 3346 AML (Edition 4), *Marking and Lighting of Airfield Obstructions.*
- STANAG 3601 Air Transport (TN) (Edition 3), *Criteria for Selection and Marking of Landing Zones for Fixed Wing Transport Aircraft.*
- STANAG 3619 AML (Edition 2) (Amendment 2), *Helipad Marking.*
- STANAG 3652 AML (Amendment 3), *Helipad Lighting, Visual Meteorological Conditions (VMC).*
- STANAG 3685 AML, *Airfield Portable Marking.*

This publication applies to the Air National Guard (ANG) when published in the National Guard Regulation (NGR) (AF) 0-2.

This publication, together with FM 5-430-00-1/AFPAM 32-8013, Vol 1: Road Design (to be published), will supersede Technical Manual (TM) 5-330/Air Force Manual (AFM) 86-3, Volume II, 8 September 1968 anti FM 5-165/AFP 86-13, 29 August 1975.

The proponent for this publication is the US Army Engineer School (USAES]. Send comments and recommendations on Department of the Army (DA) Form 2028 (Recommended Changes to Publications and Blank Forms) directly to—

Commandant US Army Engineer School
ATSE-TDM
Fort Leonard Wood, MO 65473-5000.

Unless this publication states otherwise, masculine nouns and pronouns do not refer exclusively to men.

PRELIMINARY PLANNING

CHAPTER 10

Successful construction of an airfield or heliport requires careful planning accomplished as early as possible. Planning includes–

- *Mission assignment.*
- *Collection of planning data.*
- *Designation of controlling aircraft categories.*
- *Establishment of airfield or heliport construction standards.*
- *Estimation of the required construction effort.*

MISSION ASSIGNMENT

Before actual airfield or heliport planning can begin, a thorough analysis of the proposed mission is necessary. The planner must know what the primary mission will be and what organizations and types of aircraft will be assigned (fighter, fighter-bomber, reconnaissance, tactical airlift, strategic airlift, or a combination of these). Also as important is how long they plan to stay, how many people will be deployed, what level of aircraft maintenance will be required, and whether an aerial port will be needed. Normally, the deploying command will have precise information available to answer these questions.

PLANNING DATA

As with any TO installation, the threat to the airfield is of prime concern. This should be one of the first items of information that you, the planner, should obtain to determine what type of survivability and vulnerability reduction measures will be required. In any environment, aircraft on the ground must be protected, air field systems must always be kept operational, and logistics support must survive to ensure continual aircraft operations.

The threat also will determine–

- How individual facilities and facility groups should be configured, dispersed, or nondispersed.
- Whether utility plants can be centralized or dispersed.
- How much and what kind of protection will be required for parked aircraft.
- Whether vulnerability reduction measures (such as facility protection, camouflage, or concealment) will be needed.

The threat also will drive the size of the airfield. An airfield in a more forward area, employing dispersed measures, will require much more land area than one located in the staging and logistics area, where the threat is little to none. Topographic, climatologic, and hydrologic planning data is used to determine the prevailing wind direction and its expected velocity, temperature and humidity conditions, annual rainfall, terrain conditions, soil characteristics, and location of the site (latitude anti longitude). Personnel use the data to orient the runway, locate sewage lagoons, and locate facilities to make them blend in with natural surroundings. Available drawings, survey maps, and aerial photographs are essential to verify the presence of existing facilities. They are also used to determine the type and amount of vegetation and forested areas so the amount of grubbing and clearing can be determined. These documents also may help determine what kinds of water sources are available (whether it is fresh, brine, or salt water; whether it comes from a well, river, lake, or ocean; what its temperature is; and what its distance is from the site). There are many more questions that could and should be asked. The more answers the planner obtains, the easier the planning job becomes.

AREA DETERMINATION FACTORS

An estimate of area requirements should involve not only space for immediate development but also space for contemplated expansion. Entering into consideration of area requirements are–

- Mission.
- Number of aircraft.
- Type of aircraft.
- Length of stay.
- Size of airfield.
- Degree of passive defense measures.
    - Operational.
    - Maintenance.
    - Servicing.
    - Housing.
    - Administrative.
- Supply.
- Transportation.
- Security.

MILITARY AREAS

The size and type of the required airfield and the possible need for dispersion measures in spacing individual facilities and facility groups should be considered when determining area requirements. Figures 10-1 and 10-2, page 10-4, reflect the general relationship between various aircraft operations and major military fighting and support areas in a TO. It is logical to assume that airfields in the close battle area will require more dispersion and protective measures than those in the support and rear areas. However, missiles and long-range enemy interdiction air forces, if they exist, may be employed against these latter airfields, subjecting them to similar or even greater degrees of dispersion and protection. The major military areas are–

Close battle area. Sector of the battlefield where the commander chooses to conduct decisive operations. Normally under military control of a brigade, division, or armored cavalry regiment. Airfields that fall within the close battle area are also called small austere airfields (SAAFs) because airfield construction, geometries, and marking requirements are austere compared with support and rear area airfields,

Support area. Sector of the TO in front of the communications zone (COMMZ) area. Normally within the Army corps service areas or areas under military control of the fighter or security command,

Rear area. Sector in the TO. Normally within the Army service area or the COMMZ.

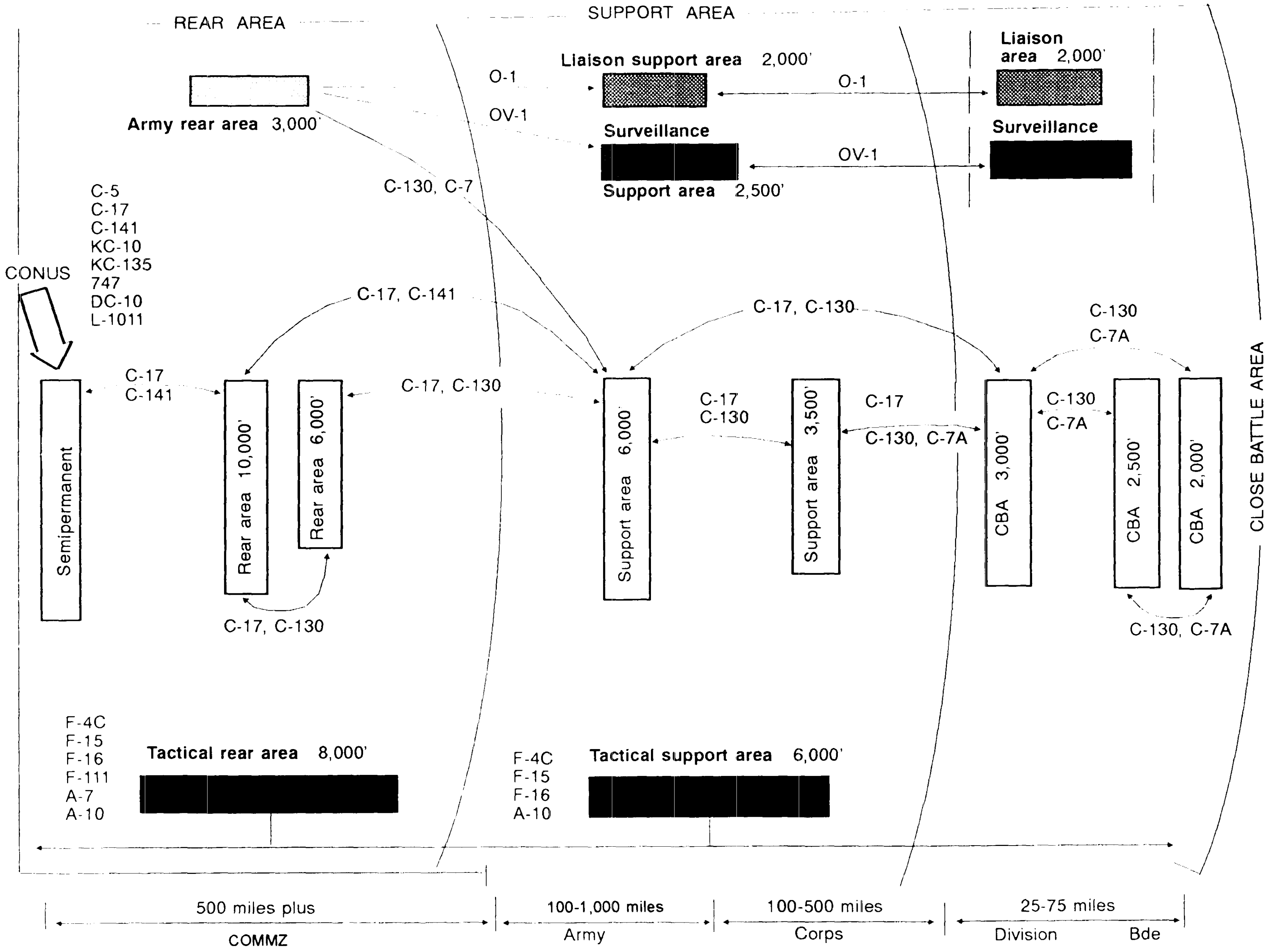


Figure 10-1. Theater of operations airfield locations

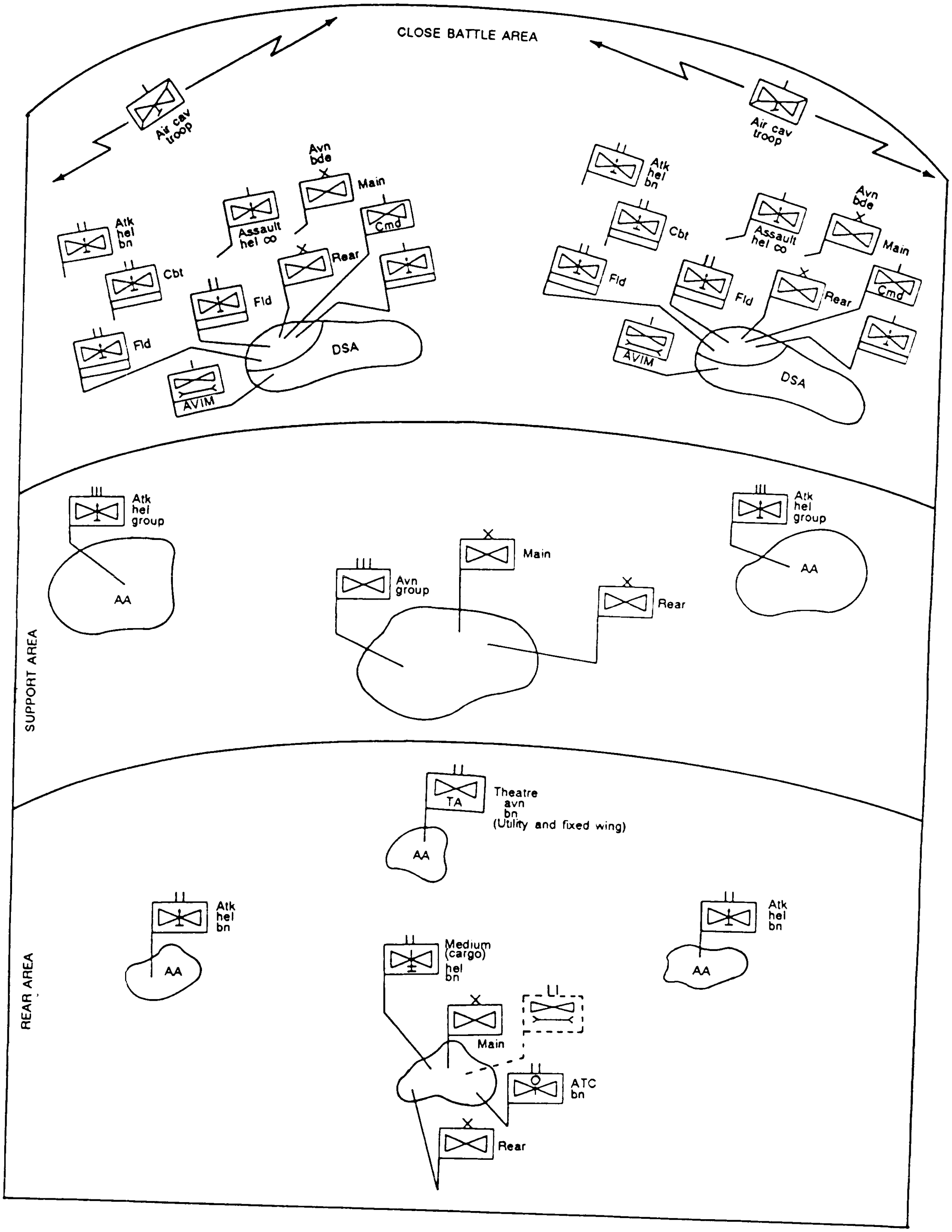


Figure 10-2. Theater of operations heliport locations

CLASSIFICATION

The aircraft airfield classification system in this manual includes all known air missions for fixed-wing aircraft in the TO. The airfield types are derived by combining the appropriate military area with the controlling minimum runway lengths. Examples are close battle area 2,000-foot airfield, support area 3,500-foot airfield, and rear area 10,000-foot airfield. Where airfields are to serve as mission facilities for support of primarily Army aircraft, the second term in the airfield type designation is *Army* liaison and Army surveillance rather than the appropriate minimum runway length. An example is support area, Army liaison 2,000-foot airfield,

The heliport classification system developed in this manual is derived by combining selected helicopters with the appropriate military area. An example is medium lift, rear area heliport.

FIXED-WING CONTROLLING AIRCRAFT

A controlling aircraft is designated for each airfield type to establish limiting geometric and surface strength requirements. This ensures the airfield is adequate for all other possible using aircraft listed for that particular airfield. For example, in a close battle area 3,000-foot airfield, the controlling aircraft is the C-17. However, other possible using aircraft include C-130s and C-12As. Designing the airfield for C-17s ensures that all three aircraft can use the same airfield.

ROTARY-WING AIRCRAFT

Based on different mission requirements, the following helicopters are the controlling aircraft to establish the limiting geometric and surface strength requirements for heliports:

- Observation (light) helicopter (OH-58, Kiowa).
- Utility helicopter (UH-60, Blackhawk).
- Cargo helicopter (CH-47, Chinook).
- Attack helicopter (AH-64, Apache).

AIRFIELD TYPES

The airfield, as discussed in this manual, is that part of the air base devoted to the operation of aircraft. A typical airfield consists of runways, taxiways, hardstands, aprons, and other airfield pavements, shoulders, overruns, navigational aids (NAVAIDs), aircraft arresting barriers, aircraft revetments or shelters, airfield lighting and marking, and approach and clear zones.

Initial Airfields

In an initial airfield, development might begin with a drop zone (DZ), then be expanded into an extraction zone (EZ), and eventually be expanded into an expedient airfield using an unsurfaced landing area or an area surfaced with landing matting or membrane. For detailed planning and geometric data on DXs and EZs, refer to Air Mobility Command (AMC) regulations.

- *Drop zone.* This area is used for delivering supplies by various methods of low-level parachute drop. The DZ should be roughly rectangular, as level as possible, and clear of objects that could damage dropped material and personnel.

- *Extraction zone.* This zone is another example of an area used for delivering supplies and equipment by aircraft without actually landing. At an EZ, the load is removed from the aircraft by a deployed parachute. As the aircraft flies by, a pilot parachute is released. This action deploys a large parachute that, when fully deployed, pulls the load from the aircraft. This is called a Low-Altitude Parachute Extraction System (LAPES].

- *Expedient airfields.* These are unsurfaced and surfaced airfields intended for short-term use. They are divided into several classes based on their location in the TO.

- Close battle area airfields, which include SAAFs, are normally unsurfaced airfields located in the close battle area and are designed for C-17s and smaller assault-type transports such as C-130s. They are designed for up to four weeks of use. These airfields are built to the lowest stan - dards of construction, which may not meet all desired safety criteria. Therefore, operations on this type airfield will be hazardous, inefficient, and limited to good weather and visibility conditions. Operating gross weights may be limited by runway length, runway surface, and weather conditions.
- Support area airfields are normally surfaced (various types of matting and membranes) airfields located in the rear area. They are designed for C- 141s, C- 17s, and smaller assault transports as well as tactical aircraft (surfaced air fields only). They have a life expectancy of one to six months. These airfields are designed to permit full efficiency of operations and support and provide a still greater margin of safety than close battle area airfields. Operations on this type airfield are practical under most weather conditions.

Temporary Airfields

These airfields arc for more sustained use (6 to 24 months), include a higher standard of design and construction, and allow operations under nearly all weather conditions. Rear area airfields are normally surfaced with various types of matting and membranes as well as bituminous asphalt and concrete. They are designed for heavy lift and smaller transports (C- 141s, C-135s, C-17s, and C-130s) as well as tactical aircraft.

Semipermanent Airfields

These airfields are for sustained use and are the highest stan-dard of design and construction for TO air bases. They are only located in the rear area and are used by all mission aircraft. They are constructed of concrete. (rigid pavement) or bituminous asphalt (flexible pavement).

HELIPORT TYPES

The heliport, as discussed in this manual, is that part of the air base devoted to the operation of helicopters. A typical heliport consists of parking pads, taxiways, runways, shoulders, clear areas, overruns, a lateral safety zone, a clear zone, and an approach zone.

Initial Heliports

The development of an initial heliport might begin with an insertion of engineers to clear landing zones (LZs) for individual aircraft or with the use of LZs of opportunity. LZs are then expanded into unsurfaced and surfaced helipads and heliports as required.

- LZs of opportunity are unsurfaced helipads located anywhere in the TO, but they are predominantly in the close battle area. LZs of opportunity require little or no construction effort and may not meet all desired safety criteria. Therefore, operations on this helipad are hazardous, inefficient, and limited to good weather and visibility conditions.
- Close battle area heliports are normally unsurfaced and designed for observation, utility, and attack aircraft. They have a life expectancy of one to four weeks.
- Support area heliports are surfaced (various types of matting and membranes) and unsurfaced (with expedient treatment for dust control) heliports designed for observation, utility, cargo, and attack aircraft. They have a life expectancy of one to six months. These heliports are designed to permit full efficiency of operations. They support and provide a greater margin of safety than shaping area heliports. Operations on this heliport are practical under most weather conditions.

Temporary Heliports

These are for more sustained use (6 to 24 months). They include a higher standard of design and construction and allow operations under most weather conditions. Rear area heliports are normally surfaced with various types of matting and membranes as well as bituminous asphalt and concrete. They are designed for use by all mission helicopters.

Semipermanent Heliports

These are for sustained use and are the highest standard of design and construction for TO heliports. They are only located in the rear area and are used by all mission helicopters. Semipermanent heliports are constructed of concrete (rigid pavement) or bituminous asphalt (flexible pavement).

BARE-BASE AIRFIELDS AND HELIPORTS

A bare base, by definition, is a site with a usable runway, a taxiway, parking areas, and a source of water that can be made potable. It must be capable of supporting assigned aircraft and providing other mission-essential resources, such as a logistical support and services infrastructure composed of people, facilities, equipment, and supplies. This concept requires mobile facilities, utilities, and support equipment that can be rapidly deployed and installed. Undeveloped real estate must be transformed into an operational air base virtually overnight.

In today's world, the concept of the bare base is more important than ever before. While many foreign countries resist development of major fixed installations on their soil, they are subject to internal and external aggression. As a rule, these underdeveloped nations have runways, taxiways, and air terminal facilities that could be offered to our forces during contingency situations. Even though many bare bases are limited and inadequate, there are roughly 1,200 in the free world that could support air operations. Since most of these underdeveloped nations are subject to aggression, the military must be able to deploy and operate from their facilities.

Today's mobility concept is to rapidly deploy a force, complete with shelters and support facilities, that is capable of independently supporting and launching sustained combat operations with the same independence as fixed theater installations. The assumption is that tactical forces will continue to have a bare-base requirement to conduct sustained air operations on a worldwide basis in support of national policy.

The nucleus to today's United States Air Force (USAF) bare-base infrastructure centers is the enhanced version of earlier Harvest Eagle and Harvest Falcon equipment. This equipment has undergone several generations of modernization.

Conversely, the concept of employing this equipment remains unchanged. Harvest Eagle, for example, consists mainly of soft-wall shelters and support equipment generally used to bed down people on deployments of short duration. One complete package provides enough tents and housekeeping items to bed down a force of 1,100 people. Harvest Falcon equipment is also based on 1,100-man increments of equipment divided into four basic package sets—housekeeping set, industrial operations set, initial flight-line support set, and follow-on flight-line support set. The Harvest Falcon package includes vehicular support, general aircraft maintenance and weapons system support facilities, and a broad base of logistics to support an operational squadron.

It is important in the preliminary planning stage to know the location of existing facilities and utilities. As a result, any layouts, drawings, or aerial photographs are vitally needed. As equally important are the lengths and widths of the runway, taxiways, ramps, and aprons. Ask yourself the following questions:

- Does runway lighting exist? If so, is it adequate?
- Is there a requirement for aircraft arresting barriers?
- What kinds of water sources are available? Does the water come from a well, river, lake, or ocean? What is the water temperature? How far away is the water source?

- Is the site being developed using hard-wall or soft-wall shelters? (If the answer is soft-wall shelters, latrines will be field-expedient.)

There are many more questions, but the more answers that are provided, the easier the job.

Although this manual focuses on initial construction of TO facilities, bare bases require the same geometric and construction standards requirements outlined in Chapters 11, 12, and 13. In addition, specific evaluative techniques to determine pavement adequacy to meet mission requirements are outlined in Chapter 12. Because of these facts, specific references to bare-base facilities will not occur later in this manual. However, specific details regarding bare-base operations are in Air Force Pamphlet (AFP) 93-12, Volume (Vol) III.

CONSTRUCTION

Engineer construction units, under the appropriate Army command, are responsible for Air Force/Army construction on a general and direct support basis. The execution of large construction projects is usually based on the general support of missions as defined by project directives. Units assigned in general support of a specific Army or Air Force element also may be assigned in direct support of that element for restoration of the Air Force air base or Army airfield.

ENGINEER RESPONSIBILITIES

When units are executing either general or direct support missions, they remain under Army command and operational control. When executing emergency restoration (close support) plans, units receive and accept detailed operational requirements from the supported commander, either Army or Air Force. As stated in Army Regulation (AR) 415-30/Air Force Regulation (AFR) 93-10, normal maintenance of Air Force air bases is done by the Air Force civil engineering squadron.

The engineer commander is concerned with site reconnaissance, location and alignment recommendations, design of the airfield and support facilities, and actual construction of the airfield. The engineer is usually furnished standard designs for the type and capacity of the airfield required. However, these designs must often be altered to meet time and material limitations or the limitations imposed by local topography, area, or obstructions. The engineer in charge of construction may alter designs within the limits prescribed by the headquarters directing the construction, but major changes must be approved by that headquarters before the work begins. The following are standard design requirements for most airfield construction missions:

- Design of drainage system structures.
- Geometric design of runway, taxiways, and hardstands (including overruns, blast areas, and turnarounds).
- Selection of soils found in cuts and use of soil to improve subgrade.
- Compaction or stabilization requirements of the subgrade.
- Determination of type and thickness of the base and surface courses.
- Selection of grade to minimize earthwork while still meeting specifications.
- Design of access and service roads; ammunition and petroleum, oils, and lubricants (POL) storage areas; NAVAIDs; hardstands; maintenance aprons; warm-up aprons; corrosion control facilities; control towers; airfield lighting; and other facilities.

PLANNING RESPONSIBILITIES

For planning purposes, the Air Force commander will furnish and define aircraft characteristics, broad design layout, and construction criteria. The Air Force commander also may furnish existing plans and specifications to the Army.

Engineer brigades and groups usually do the site reconnaissance, make location recommendations, and complete detailed design work. Engineer battalions usually construct the airfield and adapt the design to local conditions.

PLANNING CONSIDERATIONS

To ensure a proper design, the engineer planner must completely understand the purpose, scope, and estimated duration of the particular mission. (See Field Manual (FM) 5-430-1/AFPAM 32-8013, Vol 1, Chapter 2, for site selection criteria.)

Airfield Location and Requirements

The engineer planner's first consideration is directed toward selecting the site. The operational plan establishes tactical and logistical requirements that, in turn, influence the type of aircraft and number of aircraft missions required. The operational plan allows the planner to determine the number, type, service life, and construction time limitations for airfields required in each military area. The planner then establishes reasonable site requirements for each type of airfield.

Within the established site requirements, as dictated by the tactical situation, the geographic location of airfields is based on topographic conditions (grading, drainage, and hydrology), soil conditions, vegetation, and climatic conditions.

All existing transport facilities (including ports, rail lines, roadnets, and other nearby airfields) that may be used in the assembly and movement of construction equipment and materials to the construction site must be evaluated to determine the best methods and routes.

Construction Capabilities

The planner must evaluate the availability and type of engineer construction forces to determine if construction capability is sufficient to accomplish the required airfield construction.

The type and availability of local construction materials must be evaluated against the total needs of the proposed construction. Examine both the naturally occurring, in-place materials that are to be graded and possible sources of select materials for subgrade strengthening. Requirements for importing special materials for surfacing, drainage, and dust control must be consistent with available construction time and resources.

Tactical Situation

Prepare a plan to keep the construction troops, equipment, and materials safe from harassment and sabotage during construction of the airfield or heliport.

LOGISTIC RESPONSIBILITIES

If an engineer unit is building a new airfield for the Air Force, the engineer unit uses Army channels to obtain necessary Class I, Class III, and Class IV materials. If an engineer unit is in general or direct support of an existing Air Force airfield, the Army engineer unit may coordinate with the base civil engineer to use Air Force Class IV materials on site. Also, the engineer unit in direct or general support of an existing airfield may coordinate for Class I and Class III supplies from the Air Force on a mission-by-mission basis.

CONSTRUCTION PRIORITIES

A completed air base is a major construction project. By planning properly and limiting construction to essentials according to operational requirements, the base can support air operations soon after construction starts. Improvements are made later during use by additional construction as required. Using a final plan as a general guide ensures that the work completed in each step is applicable to further improvements and extensions.

Several development combinations may be selected for planning a new installation or extending an existing installation. Within each development combination, construction will proceed according to the following priorities:

- The first priority of construction provides the most essential facilities for air operations at the earliest possible time. This construction consists of those minimal facilities required at the initial deployment of forces. Primarily soft-wall tent structures, Harvest Eagle kits, innovative and expedient designs, locally available materials and equipment, and any existing, usable airfield and support facilities are used to complete construction. New airfield facilities could begin with a simple DZ, then be upgraded to an EZ, and eventually be expanded to an unsurfaced or surfaced airfield using membrane or landing matting. This construction consists of airfield operational facilities such as runways, taxiways, approaches, and aircraft parking areas of minimum dimensions as well as minimum storage for bombs, ammunition, and aviation fuel. Essential sanitary, electric, and water facilities are also provided.

- The second priority of construction increases the capacity, safety, and efficiency of all operations on the air base. Indirect-support operational facilities; building access and service roads; and essential operational, maintenance, and supply buildings are provided.

- The third priority of construction improves operational facilities and provides facilities for administration and special housing.

- The fourth priority of construction provides general housing.

CONSTRUCTION STANDARDS

Airfields are generally constructed to final quality standards and are developed by adding increments of pavement areas. Support facilities, however, may be constructed to varying standards depending on the duration of the mission and construction effort available. Therefore, airfield and support facilities have separate construction standards. The TM 5-301-series includes standard design drawing for TO construction.

Construction Standards for Airfields

The standards for airfields are designated as Stages I, II, and III (Figure 10-3). The construction stages establish the sequence of constructing the airfield. They provide for building the airfield in parts so that minimum operational facilities may be constructed in minimum time.

- In Stage I, a loop permitting landing, takeoff, circulation, and limited apron parking is provided. Runway lengths and widths are the minimum required for the critical aircraft. Care must be taken to avoid placing temporary facilities, materials, and other resources in areas that will conflict with later stages.

- In Stage II, a new runway is provided. Stage I runways become a taxiway in stage II: aprons, hardstands, and additional taxiways are provided.

- In Stage III, facilities are further expanded and provision is made to accommodate additional aircraft if necessary. Expedient surfacing is normally used at all airfields. When an existing surface in the staging anti logistics area is not adequate for all-weather operations in support of heavy transport aircraft or high-performance fighter aircraft, an appropriate pavement structure is designed and constructed.

The layout of each field is based on the assumption that the field is constructed on a previously unoccupied site. These layouts

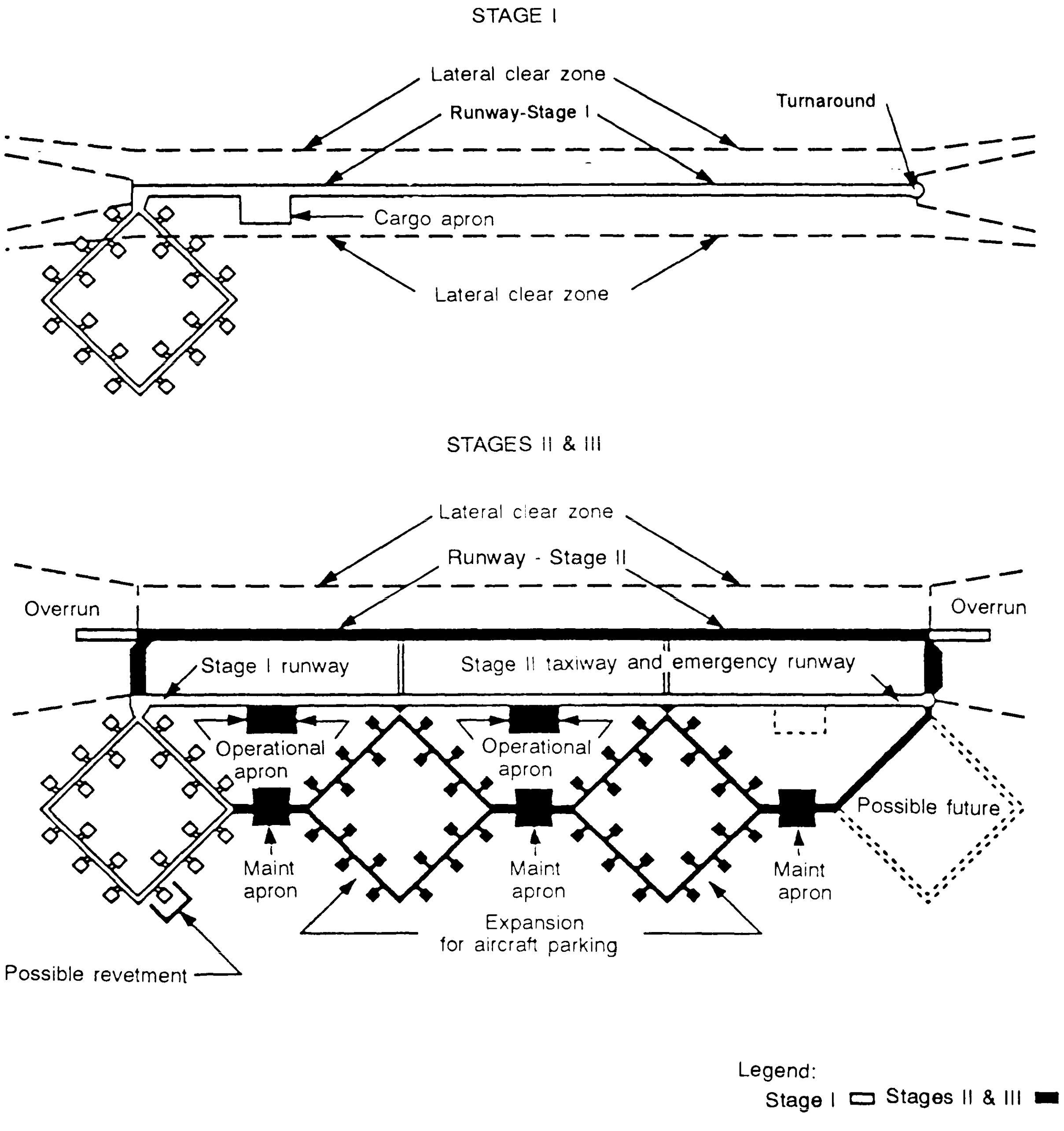


Figure 10-3. Airfield staged construction

are coordinated so that, within terrain limitations, development of a larger field from a smaller one is practicable and is accomplished with minimum construction effort. Existing airfields will be used if they meet the minimum requirements specified in this manual or if they can be economically developed to meet requirements.

Facilities Construction Standards

Regardless of priority or sequence of construction, each facility may be constructed to either of two construction standards. These standards are based on life-cycle costs and the expected duration of facility use. The standards consider the time required to provide the facilities in relation to their expected duration use. Detailed guidance regarding construction standards is in Joint Chiefs of Staff Publication (JCS PUB) 3-01.1.

Initial. The expected use period is up to six months. This is the lowest standard of construction used in the TO. Shelter and utilities are provided by organic equipment.

Temporary. The expected use period is up to 24 months. This construction standard applies to those units whose mission orientation is fixed or has continual use through unit rotation. Shelters are simple, wooden-frame structures, or their equivalent, constructed by using local materials. Utilities and water are provided by using organic means with limited distribution to high-volume users. The nature of materials used and the structural aspects of the designs are such that the life of the facilities will normally exceed five years when appropriate maintenance is performed.

CLASSIFICATION OF FACILITIES

For purposes of classification and easier reference, air-base facilities are grouped in the following categories:

Airfield, Category 1. Includes runways, taxiways, handstands, aprons, and other pavements; shoulders; overruns; approach zones; NAVAIDs; and airfield marking and lighting.

Sanitary Facilities, Category 2. Includes kitchens, dining areas, showers, and latrines.

Direct operational support facilities, Category 3. Includes ammunition storage and storage and distribution of aviation fuels and lubricants.

Maintenance, operation, and supply facilities, Category 4. Includes aircraft maintenance, base shops, operations buildings, base communications, photo labs, fire stations, weather facilities, general storage, and medical facilities.

Indirect operational support facilities, Category 5. Includes roads and exterior utilities such as water supply and electric power.

Administration and special housing, Category 6. Includes headquarters, personnel services, and recreation and welfare facilities.

General housing, Category 7. Includes general housing and troop quarters.

CONSTRUCTIONCOMBINATIONS

When constructing an airfield, the different categories of support facilities may be built to varying standards. A construction combination refers to the support facilities selected and their associated design standards.

The construction combination followed in any construction program is generally established by the theater commander. It is desirable to construct an air base to its final design in a single construction program. Initially, it is often necessary to assign a lower standard construction combination to get the base in operation within available time and construction constraints. In such cases, make every effort to proceed from this to the highest combination selected in one operation. Avoid repeated modifications to any one facility. A schedule of construction for the entire air base, including the construction combinations, is shown in Table 10-1.

Table 10-1. Schedule of standards for air base construction

Facility Category Number	Facility	Priority	Standard of Construction for Combinations					
			A	B	C	D	E	F
			Stage I		Stage II		Stage III	
1	The Airfield	1	I	T	T	T	T	T
2	Sanitary Facilities	1	I	I	T	T	T	T
3	Direct Operational Support	1	I	I	T	T	T	T
4	Maintenance, Operations, and Supply	2	I	I	I	T	T	T
5	Indirect Operational Support	2	I	I	I	T	T	T
6	Administration and Special Housing	3	I	I	I	T	T	T
7	General Housing	4	I	I	I	I	T	T
Legend: I = Initial; T = Temporary								

RECOMMENDED PLANS AND SPECIFICATIONS

As soon as a construction combination is designated, recommended plans and specifications for each facility may be obtained from the Army Facilities Components System (AFCS) under the facility name and design standard chosen. Refer to TMs 5-301-series, 5-303, and 5-304 for AFCS designs.

STAFF CONSTRUCTION SCHEDULES

Staff construction schedules are prepared as shown in Figure 10-4, page 10-14. Such a schedule is usually accompanied by a map overlay (Figure 10-5, page 10-15) to show the location of each airfield construction project in the construction schedule. The construction schedules in Figures 10-4 and 10-5 are summaries of several airfield projects. Completion dates for the various construction priorities on each project and the total number of committed engineer battalions are also shown.

CONSTRUCTION EFFORT FOR AIRFIELDS AND HELIPORTS

Estimation of the construction effort and time required to complete specific airfields and heliports are based upon several factors:

- Volume of earthwork.
- Difficulties of grading and constructing.
- Adequate drainage.
- Site clearance.
- Previous construction experience.
- Capability of the engineer unit assigned.

Developing an accurate estimate is very difficult, as each project must be considered on a case-by-case basis. Often there are many other factors that can have a major effect on construction operations. For example, weather can cause significant delays because extreme temperatures and wet seasons can adversely affect the productivity of both men and equipment. In addition, engineer units often have their own specific modified table of organization and equipment (MTOE), and production comparisons between units can be difficult to quantify.

A reasonable estimate of required construction effort and time required are only made after very thorough research and planning. Therefore, the following section outlines several sources of information to help in the planning and estimating process.

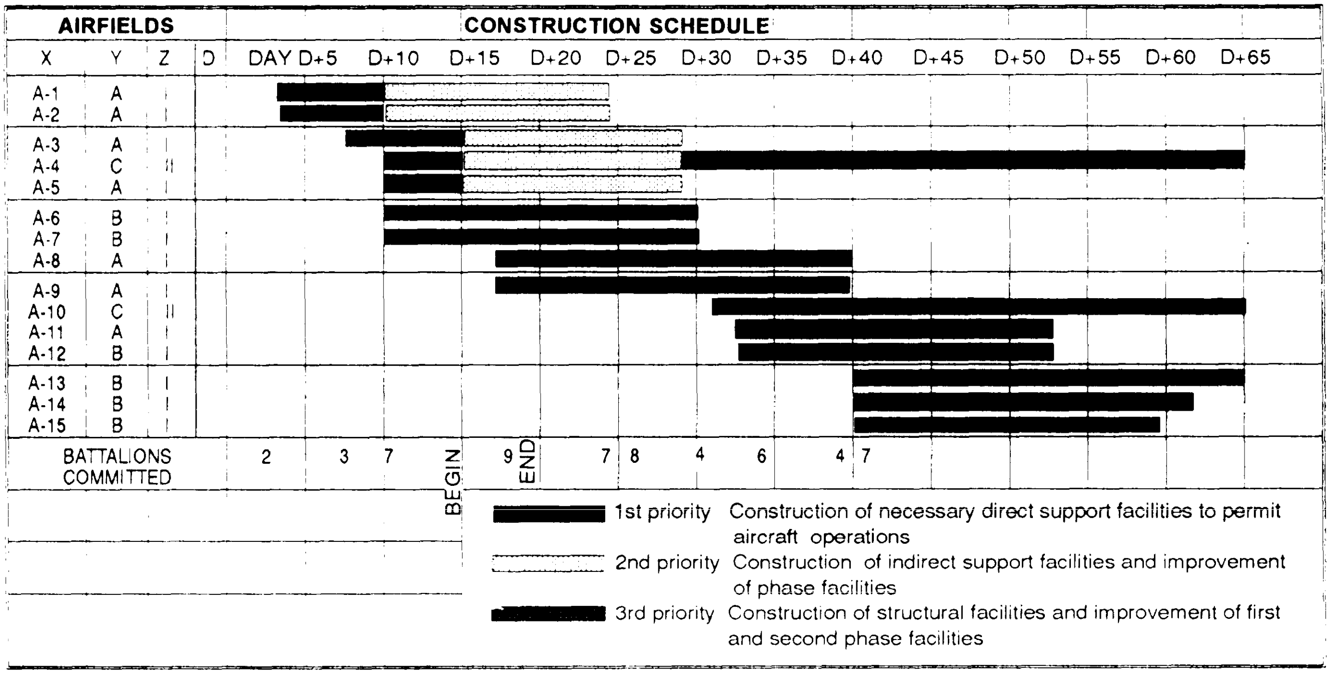


Figure 10-4. Staff construction schedule for airfields

SOURCES OF INFORMATION

A site visit and ground reconnaissance can prove to be the best source of information. It is here that a good picture of what needs to be done can be developed. An opportunity to meet with civilians of the local populace, who are familiar with working in the particular location and environment, can prove invaluable. In addition, there may already be military units that have been operating in the area for extended periods. They should be able to comment on weather, location of raw materials, and transportation assets. If a site visit and ground reconnaissance are not feasible, a considerable amount of essential data can be gathered from the following sources:

Flight information publication, en route supplement. Carried by aircrews, these publications give nominal runway lengths and load capacities and are normally available at Air Force base operations.

Operational navigation charts (ONCs). ONCs provide detailed information for airfields (longer than 4,000 feet) for all countries in the world. Published by the Defense Mapping Agency (DMA). these charts are described in the DMA catalog that should be available at base operations. DMA publications can be requisitioned on Standard Form (SF) 344 and submitted to DMA, Combat Support Center, ATTN: DDCP, Washington, DC 20315. Orders should include the DMA account number (available from base operations). The Defense Switched Network (DSN) number for DMA is 287-2495.

Topographic data.

- DMA, Combat Support Center, Washington, DC 20315. Part 3 of the DMA catalog (Topographic Products) has six volumes, each dealing with a portion of the world. These tactical maps provide topographic information

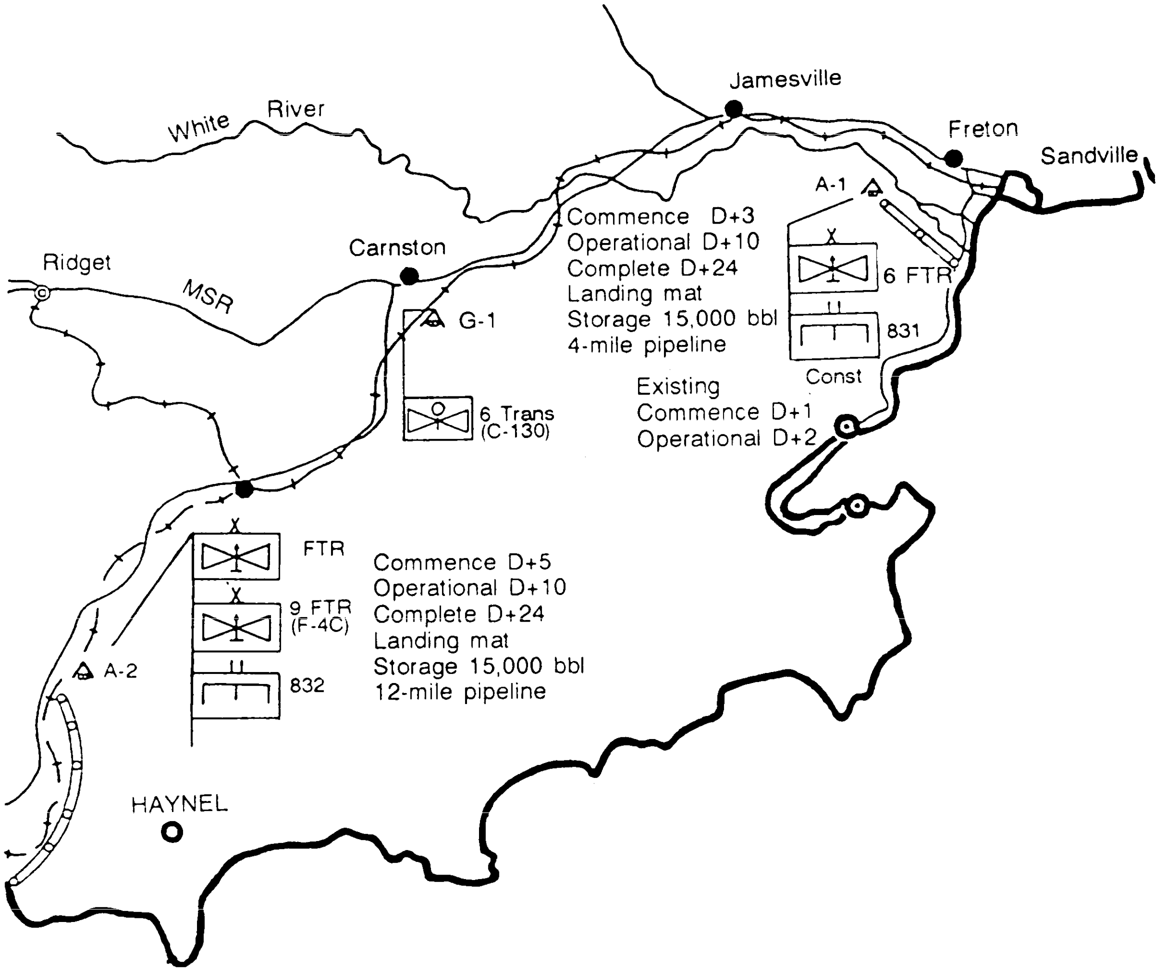


Figure 10-5. Map overlay to accompany staff construction schedule

for a detailed terrain analysis of a proposed site and its environment United States Geological National Survey Center, Military Geology Branch, 12201 Sunrise Valley Drive, Reston, VA 22092.

Climatic data.

- Air Weather Service. (AWS), Environmental Technical Applications Center (ETAC), USAF/ETAC, Scott Air Force Base (AFB), IL 62225. You should furnish ETAC with a concise statement of your requirements in terms of either the environmental factor involved or of the climatological information desired.
- National Oceanic and Atmospheric Administration (NOAA), US Department of Commerce, Washington, DC 20330.

Automated Airfield Information File [AAFIF). The AAFIF is compiled in a classified and unclassified version and contains airfield information useful to the bare-base planner. The source of this document is Mapping and Charting Program Branch (MCPB), St. Louis, MO 63118 (DSN 693-8372).

Pavement evaluation reports. Pavement data for many worldwide allied bases has been compiled in these reports by Headquarters (HQ), Air Force Civil Engineering Support Agency (AFCESA), ATTN: DMP, Tyndall AFB, FL 32403 (DSN 523-6330), or US Army Waterways Experiment Station, Engineer, ATTN: CEWES-6P-T, 3909 Halls Ferry Road, Vicksburg, MS 39180.

Foreign maps. Nearly all foreign governments also maintain mapping agencies. Although DMA maps cover all parts of the world, you may be able to get more up-to-date maps through local sources. The Library of Congress maintains a list of these sources, "Published Sources of Information About Maps," and "Selected List of Map Publishers and Sellers," which you may obtain from the Geography and Map Division, Library of Congress, Washington, DC 20540.

Threat analysis.

- Central Intelligence Agency, "National Intelligence Survey" (Secret), Washington, DC 20505.
- US Air Force Intelligence Service, Assistant Chief of Staff Intelligence, Department of the Air Force, The Pentagon, Washington, DC 20330.
- US Department of State, 2207 C Street, NW, Washington, DC 20520.

Other informational sources are encyclopedia, atlases, road maps, tourist literature, aerial surveys, photographs, the local base intelligence shop, and pocket guides to various countries.

ARMY FACILITIES COMPONENTS SYSTEM

Since its inception in 1951, the AFCS has grown to a mature military engineering construction support system that includes planning guidance, detailed design and construction drawings, computer-updated bills of materials (BOMs), and labor estimates for roughly 2,800 pre-engineered facilities. Some facilities included in the system are administrative, troop camps, hospitals, vehicle maintenance, munitions storage, POL storage and distribution, and general supply storage. The system consists of four Department of the Army (DA) technical manuals.

TM 5-301-series. These manuals, which are generally used by military planners, contain installation, facility, and prepackaged expendable contingency supply (PECS) summaries. The TM 5-301-series is published in four volumes (TM 5-301-1, TM 5-301-2, TM 5-301-3, and TM 5-301-4). Each volume addresses a separate climactic zone: (1) temperate, (2) tropical, (3) frigid, and (4) desert. The summaries appearing in the four volumes include cost; shipping weight and volume of material; estimated man hours and equipment hours to construct each facility and installation: and cost, weight, and volume of the PECS kits. These manuals can be used by planners at all levels without referring to the details contained in TMs 5-302-series and 5-303.

TM 5-302-series. This multivolume manual contains design drawings for installations (groups of facilities and individual facilities) and is of primary interest to the unit charged with the actual construction of the AFCS in a TO. The drawings in TM 5-302-series are keyed to the four climactic zones and the two construction standards of initial and temporary. (See Chapter 3, FM 5-430-1, for definitions and application of stan- ards of construction.)

TM 5-303. This manual is generally used by planners, builders, and supply personnel to-

- Identify and order the material items contained in BOMs.
- Identify the cube and weight of these materials to determine the best method of transportation.
- Identify the estimated construction effort in man-hours.
- Calculate the amount of troop or contract labor required to construct the facility or groups of facilities.

Each item in a facility or PECS kit is identified by a national stock number (NSN) and abbreviated description.

TM 5-304. This manual provides the user with a single source of reference and information about the operation of the system. It provides the background and direction to use the following information in the AFCS:

- Planning tables.
- Design criteria.
- Construction standards/use of construction.
- Drawings.
- Building structure types.
- Material wattage and loss.
- Climatic zones.
- Construction effort/network analysis and the critical path method (CPM).
- Engineer unit capabilities.
- Logistical and cost information.
- Operational conditions.
- Storage and transit conditions.
- Camouflage.

AFCS designs. AFCS designs are categorized as either vertical or horizontal construction. Vertical construction consists of buildings and facilities, generally everything above ground. Horizontal construction consists of roads, runways, site development and site utilities, generally everything at, below, or having to do with establishing grade. TM 5-302-series contains installation drawings providing concepts and details for installations such as the following:

- TO heliports (various size and usage).
  - Site preparation.
  - Surface preparation.
  - Surface markings.
  - Lighting.
- TO airfields.
  - Site preparation.
  - Surface preparation.
  - Surface markings.
  - Lighting.
  - Protective revetments.
  - Classification and identification of soils.
  - Flexible pavement designs.
  - Drainage designs.
  - Ammunition storage.
  - Dry cargo storage.
  - Sewage disposal.
  - Port facilities.
  - Railroad terminals.
  - Medical unit installations.
  - Hospital installations.
  - Maintenance installations.
  - Military prison stockades/enemy prisoner of war (EPW) camps.
  - Troop camp installations.
  - POL installations.

The data for the manuals is maintained by the Office of the Chief of Engineers, US Army. The data in TM 5-301-series and TM 5-303 is available in printouts, magnetic tape, microfiche, or digitized (floppy disk, automated computer-aided drafting and design (AUTOCADD)) format. The drawings in TM 5-302-series are half-sized (14 by 20 inches), reproducible drawings. They are also available upon request, in full-sized (28 by 40 inches), reproducible blueprints. All correspondence and requests for technical assistance, copies of technical manuals, drawings, and information regarding the AFCS should be forwarded to either:

- Commander, US Army Engineer Division, Huntsville, ATTN: CEHND-ED-SY, Post Office (PO) Box 1600, Huntsville, AL 35807.

or

- Headquarters, Department of the Army (HQDA) (DAEN-2CM), Washington, DC 20310.

SUMMARY

A TO air base is not developed overnight. It takes many hours, days, and weeks of advanced planning to (1) gather all the information needed, (2) translate this information into specific requirements to meet mission needs, and (3) develop the base development plan. The base development plan will then be used as part of the basis to determine and ensure that the required manpower, equipment, and materials will be available at the right place and at the right time. It takes the combined talents of the planner, the designer, the constructor, the operator, the supplier, the transporter, and the maintainer to ensure that the best and most effective plan of action to meet mission requirements is developed and implemented.

AIRCRAFT CHARACTERISTICS AND AIRFIELD DESIGN

CHAPTER 11

This chapter provides information on the characteristics of common military aircraft, the design of military airfields, and the interrelation of the two. The design criteria for each military airfield must be formulated individually to satisfy its specific set of operational requirements. The final airfield design must meet the design requirements for the given aircraft and airfield type, allow safe aircraft operations, and be approved by the user. Local conditions and future operations may limit the dimensions of runways and taxiways, their orientation concerning wind, and the treatment of their surfaces. Also exercise practical judgment in the provision for protection and maintenance facilities, the installation of aids to navigation, and the construction of parking areas and storage facilities for fuel and ammunition.

AIRCRAFT CHARACTERISTICS

The airfield design criteria and layouts in this chapter are based on usage by specific aircraft in relative location on the battlefield. The most demanding characteristics of the using aircraft establish the controlling aircraft. Less critical category types of aircraft also may use these facilities. More critical category types may use these facilities only under special limitations. Tables 11-1 and 11-2, pages 11-2 and 11-3, show the important characteristics of selected Air Force and Army aircraft.

CORRELATION OF ARMY AND AIR FORCE TERMINOLOGY

The primary air field complex has three specific types of airfields, As Indicated by its name and anticipated life, each airfield is included in the complex for a specific purpose, and their design criteria are based on requirements for the aircraft shown in Table 11-3, pages 11-4 and 11-5. Note that each type airfield has a controlling aircraft that will ultimately determine the length of the runway (described in this chapter) and the thickness of pavements, subbase, and subgrade (discussed in Chapter 12).

Besides the three primary air fields, there are several special airfields (including DZs, EZs, blocked-out airfields, special operations forces (SOF) airfields, and unmanned aerial vehicle (UAV) airfields) described in detail later in this chapter. Table 11-3 details the requirement for the three primary airfields.

Table 11-1. Characteristics of certain Air Force aircraft

Aircraft Designation		Overall Dimensions (ft)			Weight (kips)		Gear Type	Main Gear Tires		Takeoff (Hard Surface)	
Designation	Name	Length	Width	Height	Basic	Maximum Takeoff		PSI	Contact Area (sq in)	Sea Level Ground Run	0 Wind, ft Clear 50 ft
E-4B	NEACP	231.3	195.7	63.4	482.3	800.0	Twin tandem tricycle	200	232.3	9,200	10,800
EC-18B	ARIA	152.4	145.8	42.5	60.0	336.0	Twin tandem tricycle	155	253.3	8,500	10,020
WC-130E/H	Hercules	99.5	132.6	39.2	83.0	172.0	Single tandem tricycle	116	352.2	3,150	4,300
MC-130E/H	Hercules	108.1	132.6	32.9	83.0	172.0	Single tandem tricycle	116	352.2	3,150	4,300
C-5B	Galaxy	247.8	222.7	65.1	374.0	840.0	Twin delta tandem tricycle	111	297.0	7,200	8,600
C-9C	Nightingale	119.3	93.3	27.5	52.2	110.0	Twin tricycle	148	177.3	4,380	5,530
C-12C/D	Huron	43.8	54.4	15.0	7.8	12.5	Twin tricycle	96	29.3	2,800	3,800
C-17A	NA	174.0	170.0	55.1	268.0	580.0	Twin tandem tricycle	138	322.2	NA	NA
C-20B	NA	83.1	77.8	24.4	41.0	69.7	Twin tricycle	175	89.6	3,700	5,200
C-21A	NA	48.7	39.5	12.3	9.6	18.3	Twin tricycle	146	28.2	4,750	5,000
C-22B	NA	133.2	108.0	34.0	91.6	169.0	Twin tricycle	165	243.3	8,250	NA
C-23A	Sherpa	58.0	74.8	16.3	22.0	24.6	Single tricycle	79	140.1	3,600	4,000
C-130E	Hercules	99.5	132.6	38.3	72.0	175.0	Single tandem tricycle	105	398.8	3,690	5,410
HC-130H	Hercules	108.1	132.6	39.2	130.0	175.0	Single tandem tricycle	105	398.8	3,230	4,430
KC-135A	Stratotanker	136.2	130.8	41.7	104.3	301.6	Twin tandem tricycle	155	227.4	13,500	18,400
C-135A	Stratolifter	134.5	130.8	41.7	109.0	301.6	Twin tandem tricycle	155	227.4	10,600	14,750
F-4C	Phantom II	58.3	38.6	16.4	31.8	58.0	Single tricycle	265	93.5	3,520	4,850
F-5E	Tiger II	48.2	26.7	13.4	9.7	24.7	Single tricycle	318	33.4	2,160	2,900
F-15E	Eagle	63.8	42.8	18.8	31.7	81.0	Single tricycle	305	115.5	3,400	5,500
F-16B	Fighting Falcon	49.5	32.8	16.5	16.9	35.4	Single tricycle	275	53.6	3,225	5,000
F-16D	Fighting Falcon	49.5	32.8	16.7	17.4	37.5	Single tricycle	285	54.8	3,000	4,725
F-100	Super Sabre	57.6	38.8	16.2	23.0	41.5	Single tricycle	310	61.2	4,500	6,800
F-106A/B	Delta Dart	70.8	38.3	20.3	24.9	39.6	Single tricycle	300	60.3	4,300	6,200
F-111E	NA	75.5	63.0	17.1	49.4	100.0	Single tricycle	180	250.0	4,700	5,750
A-7D	Corsair II	46.1	38.7	16.1	21.8	42.0	Single tricycle	280	62.3	6,250	9,200
A-10A	Thunderbolt II	53.3	57.5	14.7	28.0	51.0	Single tricycle	140	31.3	4,000	4,850
AC-130A	Spectre	97.8	132.6	38.3	70.0	124.2	Single tandem tricycle	116	254.3	2,950	3,830
AC-130H/V	Spectre	99.5	132.6	38.2	110.0	175.0	Single tandem tricycle	116	358.3	3,600	5,000
A-37B	Dragonfly	31.8	38.3	9.5	6.5	14.0	Single tricycle	125	51.0	1,590	3,000
OV-10A	Bronco	41.6	40.0	15.2	8.0	14.4	Single tricycle	65	85.1	1,050	1,450
EC-130E/H	Hercules	99.5	132.6	39.2	78.0	175.0	Single tandem tricycle	116	358.3	3,600	5,000
EC-135A	NA	136.2	130.8	41.7	119.3	301.5	Twin tandem tricycle	155	277.4	13,500	18,500
EF-111A	Raven	75.5	63.0	20.0	56.9	100.0	Single tricycle	180	250.0	3,250	4,100

Table 11-1. Characteristics of certain Air Force aircraft (continued)

Aircraft Designation		Overall Dimensions (ft)			Weight (kips)		Gear Type	Main Gear Tires		Takeoff (Hard Surface)	
Designation	Name	Length	Width	Height	Basic	Maximum Takeoff		PSI	Contact Area (sq in)	Sea Level Ground Run	0 Wind, ft Clear 50 ft
E-3A Core	Sentry AWACS	152.9	145.8	41.8	167.8	325.0	Twin tandem tricycle	195	199.2	6,550	9,200
C-140A/B	Jetstar	60.5	54.5	20.5	21.5	40.5	Twin tricycle	220	39.7	3,670	5,150
C-141B	Starlifter	168.3	160.0	39.3	150.0	323.1	Twin tandem tricycle	190	200.7	3,400	4,050
KC-10A	Extender	181.6	165.3	57.8	240.0	590.0	Twin tandem tricycle	190	285.8	10,400	13,600
DC-10-40	NA	182.3	165.3	58.6	271.1	572.0	Twin tandem tricycle	165	319.0	NA	12,250
L-1011-500	Tristar	177.8	155.3	55.8	249.1	450.0	Twin tandem tricycle	175	305.0	NA	NA
B-747-400	NA	231.8	211.0	64.3	392.0	850.0	Twin Tandem tricycle	210	236.5	NA	10,450
B-757-200	NA	155.3	124.8	45.1	126.6	250.0	Twin tandem tricycle	170	NA	NA	7,580
B-767-300ER	NA	180.3	156.1	52.6	194.9	400.0	Twin tandem tricycle	183	251.4	9,500	NA
NA	Tornado (NATO)	54.9	45.6	19.5	31.1	60.0	Single tricycle	NA	NA	2,950	NA

NOTE: Basis data source: Aircraft Characteristics for Airfield Pavement Design and Evaluation, Air Force Engineering and Services Center, Tyndall AFB, Florida, 1988.
*C-17A characteristics based on developmental data.

Table 11-2. Characteristics of certain Army aircraft

Aircraft Designation		Overall Dimensions (ft)			Weight (kips)		Gear Type	Design Gear Load (lb)	Main Gear Tires		Takeoff (Hard Surface)*	
Designation	Name	Length	Width	Height	Basic	Maximum Takeoff			PSI	Contact Area (sq in)	Sea Level Ground Run	0 Wind, ft Clear 50 ft
O-1E	Bird Dog	25.8	36.0	7.5	1.61	2.4	Single conventional	1,150	21	52	390	675
OV-1A	Mohawk	41.0	42.0	13.0	9.91	14.72	Single tricycle	6,097	85	70	1,005	1,450
OV-1B	Mohawk	41.7	48.0	13.0	10.98	15.79	Single tricycle	6,537	93	70	1,410	2,185
OV-1C	Mohawk	41.0	42.0	13.0	10.01	14.82	Single tricycle	6,237	89	70	1,440	2,230
U-1A	Otter	42.0	58.0	12.4	4.90	8.0	Single conventional	3,000	28	102	950	1,630
U-6A	Beaver	30.5	48.0	10.4	3.10	5.1	Single conventional	2,500	25	94	760	1,080
U-8A	Seminole	31.5	45.3	11.6	4.99	7.3	Single tricycle	3,024	35	73	1,265	2,155
U-8F	Seminole	33.3	45.9	14.2	5.49	7.7	Single tricycle	NA	35	NA	1,065	1,660
U-10	Helio	30.3	39.0	8.8	2.31	3.8	Single conventional	NA	30	NA	290	500
U-21A	Ute	35.8	45.9	14.2	5.38	9.5	Single tricycle	NA	46	NA	1,500	2,000

NOTE: Basis data source: Army Aircraft Characteristics, Army Aviation Directorate, Office, Assistant Chief of Staff for Force Development, 1 March 1967.
*(C) FM 101-20

Table 11-3. Minimum geometric requirements for TOE airfields

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Airfield Type	**Airfield Standard of Construction**	**Anticipated Service Life**	**Possible Using Aircraft (US Type)**	**Runway Requirements[1]**																			
				Minimum Length Required (ft)	**Takeoff Ground Run at Sea Level 59° F (ft)**	**Width (ft)**	**Gradients**			**Shoulders**		**Clear Area**		**Overrun**		**Runway End Clear Zone Width**				**Runway Approach Zone Width**			
							Longitudinal (%)	**Transverse (%)**	**Max Grade Change per 200 ft (%)**	**Width (ft)**	**Grade Trans (%)**	**Width (ft)**	**Grade Max Trans (%)**	**Length (ft)**	**Width (ft)**	**Length (ft)**	**Inner (ft)**	**Outer (ft)**	**Max Grade (%)**	**Length (ft)**	**Inner (ft)**	**Outer (ft)**	**Glide Ratio**
Close Battle Area	Initial	0-6 months	C-17/ C-130**+	3,500	3,000	60[3]	0±3.0	0.5-2.0	1.5*	10	1.5-5.0	50	5.0	500	100	500	276	500	5.0	32,000	500	2,500	35:1
Support Area	Initial	0-6 months	C-17/ C-130**+	6,300	3,000	60[3]	0±2.0	0.5-2.0	1.5*	40	1.5-5.0	210	5.0	1,000	180	1,000	600	600	5.0	32,000	600	8,073	50:1
Rear Area	Temporary	6-24 months	C-5** B-1 C-141+ C-17 KC-135 F-117 E-3 F-4/F-15 A-7 F-111 F-16 C-130	14,400	11,500 10,200 8,900 7,600 6,700 9,600 6,540 4,000 6,380 5,400 2,900 4,000	150	0±2.0	0.5-1.5	1.5*	50	1.5-5.0	375	5.0	1,000	250	1,000	1,000	1,000	5.0	32,000	1,000	8,473	50:1

*No change in first 500' at each end.

**Controlling aircraft for runway length.

+Controlling aircraft for surface depth required.

[1] Runway length shall be determined by adjusting the appropriate takeoff ground run of the critical aircraft for temperature, altitude, and gradient. Then apply a safety factor dependent on location. (See Chapter 11.) Compare calculated length with the minimum length required as shown in column 5. Use the greater value.

[2] Length (dimension is always parallel to the taxiway) and width of mass parking apron is determined by number and type of aircraft parked with length parallel to taxiway as follows: Length = (number of rows of aircraft) (length of aircraft, ft + wingspan, ft + 60 ft) + wingspan, ft + 40 ft. Width = (number of aircraft per row + 1) (wingspan, ft + 60 ft) + wingspan, ft - taxiway width, ft ÷ 2.

[3] When C-17 is used, use 90-foot runway width.

Table 11-3. Minimum geometric requirements for TOE airfields (continued)

1	2	3	4	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Airfield Type	**Airfield Standard of Construction**	**Anticipated Service Life**	**Possible Using Aircraft (US Type)**	**Taxiway Requirements**									**Turn Radii (ft)**	**Mass Apron Parking Requirements[2]**						**Warm-Up Apron**
				Length (ft)	**Width (ft)**	**Gradients**		**Shoulders**		**Lateral Clearance Centerline Runway to Near Edge of Taxiway or Fixed Obstacle (ft)**	**Clear Area**			**No Aircraft**	**Aircraft per Row**	**Length (ft)**	**Width (ft)**	**Grade Max Trans (ft)**	**Lateral Clearance Apron Edge to Fixed Obstacles (ft)**	**Width (ft)**
						Longitudinal (%)	**Transverse (%)**	**Width (ft)**	**Grade Trans (%)**		**Width (ft)**	**Grade Max Trans (%)**								
Close Battle Area	Initial	0-6 months	C-17/ C-130**+	3,500	60[3]	0±5.0	0.5-3.0	10	1.5-5.0	350	75	5.0	90	4	4	800	520	1.5-5.0	100	345
Support Area	Initial	0-6 months	C-17/ C-130**+	6,300	60[3]	0±5.0	1.5-5.0	50	1.5-5.0	350	95	5.0	90	18	6	1,295	1,370	1.5-5.0	100	345
Rear Area	Temporary	6-24 months	C-5** B-1 C-141+ C-17 KC-135 F-117 E-3 F-4/F-15 A-7 F-111 F-16 C-130	14,400	75	0±5.0	1.5-5.0	50	1.5-5.0	500	95	5.0	110	18	6	1,856	1,701	1.5-5.0	100	345

*No change in first 500' at each end.
**Controlling aircraft for runway length.
+Controlling aircraft for surface depth required.

[1] Runway length shall be determined by adjusting the appropriate takeoff ground run of the critical aircraft for temperature, altitude, and gradient. Then apply a safety factor dependent on location. (See Chapter 11.) Compare calculated length with the minimum length required as shown in column 5. Use the greater value.

[2] Length (dimension is always parallel to the taxiway) and width of mass parking apron is determined by number and type of aircraft parked with length parallel to taxiway as follows: Length = (number of rows of aircraft) (length of aircraft, ft + wingspan, ft + 60 ft) + wingspan, ft + 40 ft. Width = (number of aircraft per row + 1) (wingspan, ft + 60 ft) + wingspan, ft - taxiway width, ft ÷ 2.

[3] When C-17 is used, use 90-foot runway width.

The Army airfield classification system for TO construction is the same as the Air Force airfield classification system. As described in Chapter 10, airfields are constructed to one of two standards showing the expected life of the airfield. Initial construction airfields are for short-term use (zero to six months) and include close battle area and rear area airfields. Temporary construction airfields are for long-term use (6 to 24 months) and include COMMZ airfields. Permanent airfield construction is discussed in detail in TM 5-800 series publications.

AIRFIELD DESIGN

Army and Air Force staff engineers acting for the Joint Force Commander determine base airfield criteria for a specific TO, and they base criteria on local conditions.

Table 11-3, pages 11-4 and 11-5, shows the controlling characteristics and geometric and minimum area requirements for each airfield. The key to a proper airfield design is the thoroughness and accuracy of a topographic survey with minimum 5-foot contour intervals. (See Appendix C, FM 5-430-00-1/AFPAM 32-8013, Vol 1, for information on subgrade strength requirements.)

TYPICAL AIRFIELD LAYOUTS

Figures 11-1, 11-2, 11-3, and 11-4, pages 11-7 through 11-9, show typical layouts and section views applicable to TO airfields. Figure 11-1 shows the basic airfield layout. For example, to find the geometric requirements for a support area airfield, enter Table 11-3 at the applicable airfield type in column 1, then read horizontally across the table under the various column headings to obtain the required dimensions (geometric requirements).

The circled numbers referring to the various elements of the airfield shown in Figures 11-1 through 11-4 identify the column numbers in Table 11-3, which give the geometric requirements for each element. Use of these figures with the table determines the specific airfield geometric requirements for each critical aircraft in each military area (close battle, support, and rear), as applicable.

ELEMENTS OF THE AIRFIELD

The elements that make up the airfield include runways, taxiways, aprons, and hardstands. These elements usually consist of pavement placed on a stabilized or compacted subgrade, shoulders and clear zones (normally composed of constructed in-place materials), and approach and lateral safety zones (which require only clearing and removing obstructions that project above the prescribed glide and safety angles). The nomenclature for these elements is defined below and shown in Figures 11-1 through 11-4.

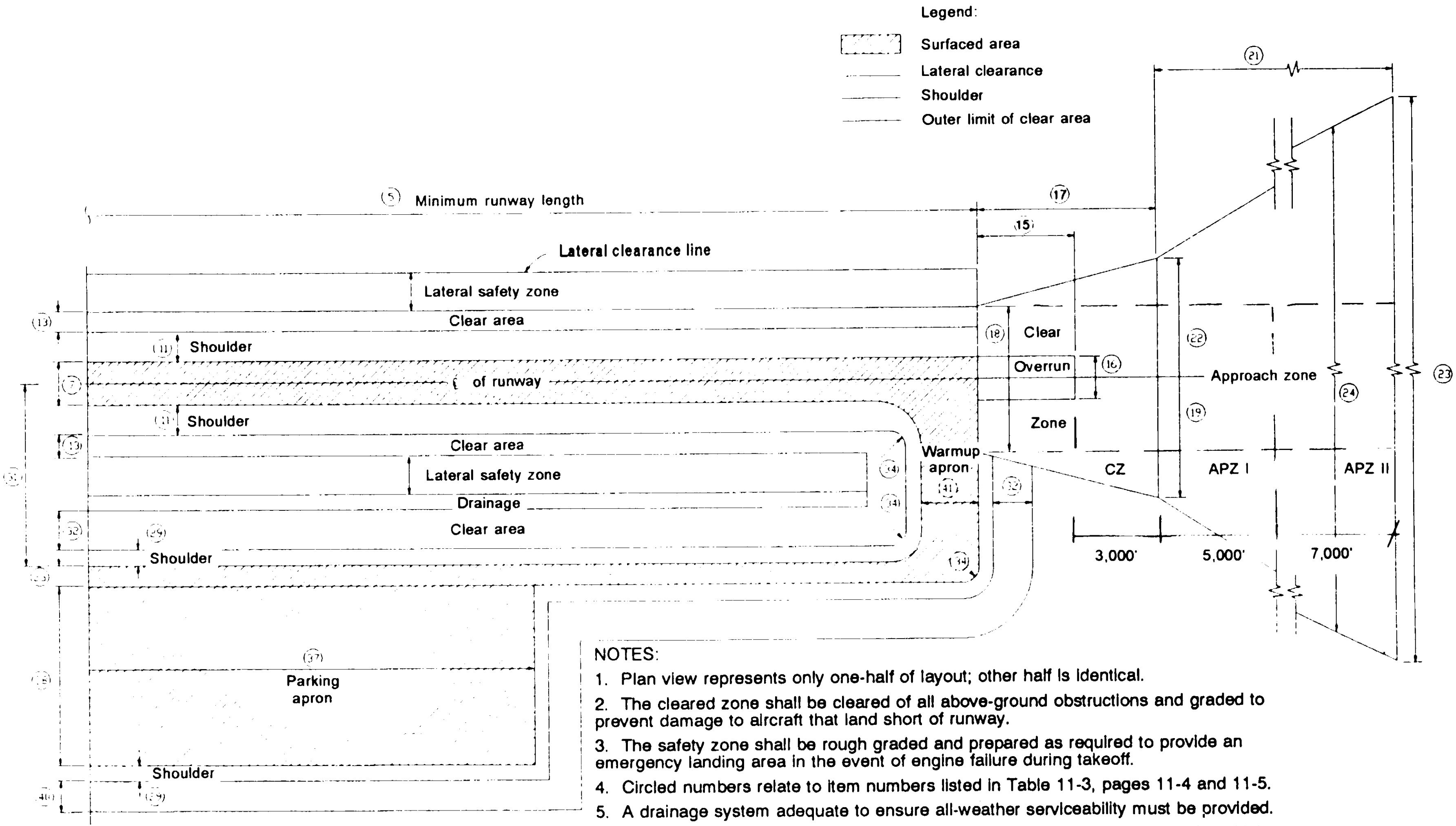
RUNWAY DESIGN CRITERIA

Runway location, length, and alignment are the foremost design criteria in any airfield plan. The major factors that influence these three criteria are—

- Type of using aircraft.
- Local climate.
- Prevailing winds.
- Topography (drainage, earthwork, and clearing).

Location

Select the site using the runway as the feature foremost in mind. Also consider topography, prevailing wind, type of soil, drainage characteristics. and the amount of clearing and earthwork necessary when selecting the site. (See Chapter 2, FM 5-430-00-l/AFPAM 32-8013, Vol 1, for airfield location criteria.)



NOTES:

1. Plan view represents only one-half of layout; other half is identical.
2. The cleared zone shall be cleared of all above-ground obstructions and graded to prevent damage to aircraft that land short of runway.
3. The safety zone shall be rough graded and prepared as required to provide an emergency landing area in the event of engine failure during takeoff.
4. Circled numbers relate to item numbers listed in Table 11-3, pages 11-4 and 11-5.
5. A drainage system adequate to ensure all-weather serviceability must be provided.
6. Runways, taxiways, and apron will be surfaced with AM2 or soil cement for initial standard and bituminous cement for temporary standard construction.
7. The clear zone (CZ), Accident Potential Zone I, Accident Potential Zone II should not have concentrations of troops if at all possible.

Figure 11-1. Basic airfield layout

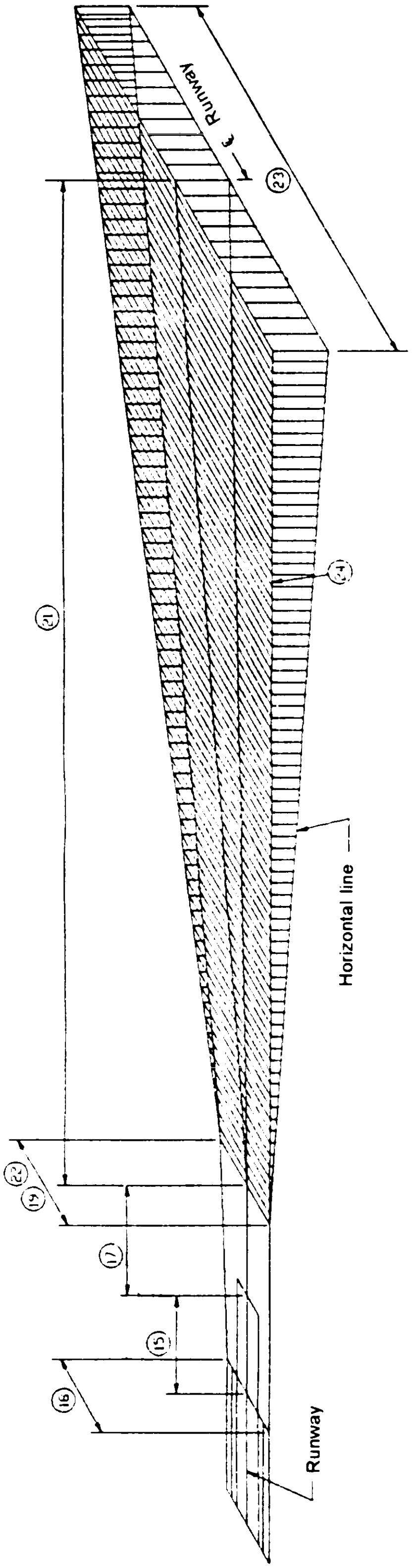


Figure 11-2. Approach zone details

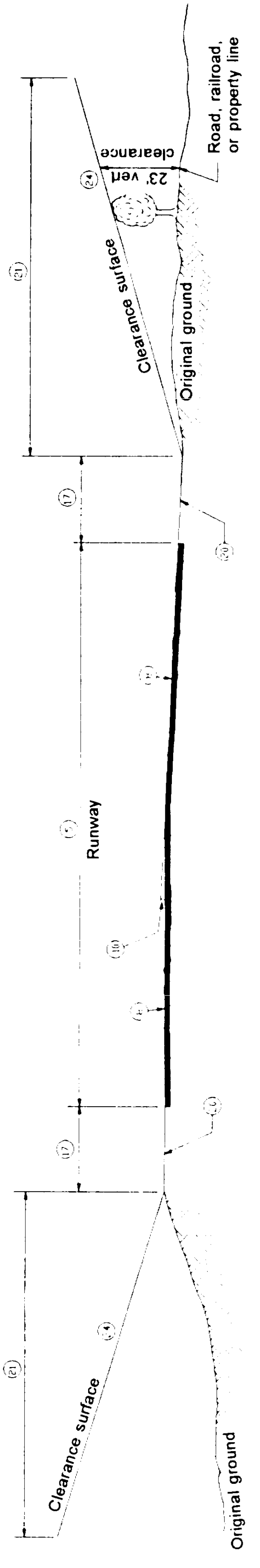


Figure 11-3. Runway longitudinal profile

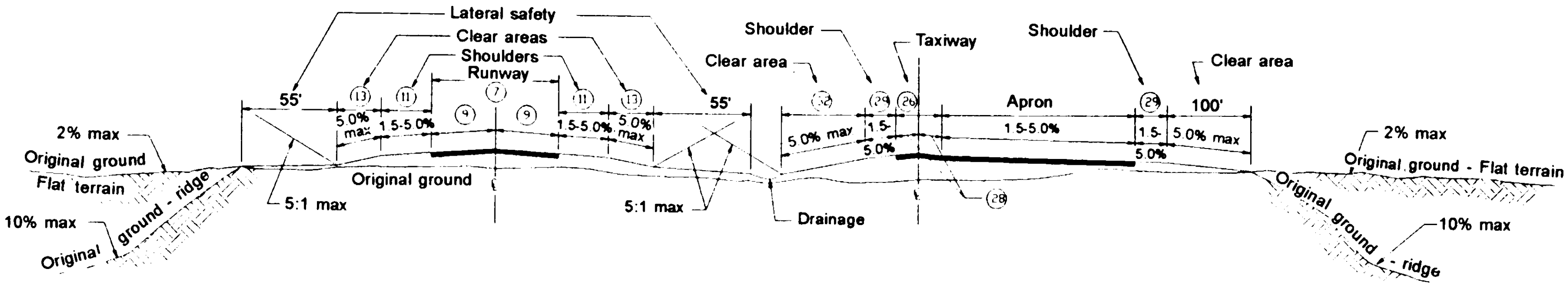


Figure 11-4. Typical runway, taxiway, and parking apron cross section

AIRFIELD DESIGN STEPS

The following is a procedural guide to complete a comprehensive airfield design. The concepts and required information are discussed later in this chapter.

1. Select the runway location.
2. Determine the runway length and width.
3. Calculate the approach zones.
4. Determine the runway orientation based on the wind rose.
5. Plot the centerline on graph paper, design the vertical alignment, and plot the newly designed airfield on the plan and profile.
6. Design transverse slopes.
7. Design taxiways and aprons.
8. Design required drainage structures.
9. Select visual and nonvisual aids to navigation.
10. Design logistical support facilities.
11. Design aircraft protection facilities.

Length

When determining the runway length required for any aircraft, include the surface required for landing rolls or takeoff runs and a reasonable allowance for variations in pilot technique; psychological factors; wind, snow, or other surface conditions; and unforeseen mechanical failure. Determine runway length by applying several correction factors and a factor of safety to the takeoff ground run (TGR) established for the geographic and climatic conditions at the installation. Air density, which is governed by temperature and pressure at the site, greatly affects the ground run required for any type aircraft. Increases in either temperature or altitude reduce the density of air and increase the required ground run. Therefore, the length of runway required for a specific type of aircraft varies with the geographic location. The length of every airfield must be computed based on the average maximum temperature and the pressure altitude of the site.

The pressure altitude is a measure of the atmospheric pressure at the site. The pressure altitude is zero under standard day conditions of 59° Fahrenheit (F) and barometric pressure of 29.92 inches. However, pressure altitude varies with atmospheric pressure and is usually greater than the geographic altitude. Compute pressure altitude by adding the pressure altitude (dH) value (height or elevation differential) shown in Figure 11-5 to the geographic altitude of the site.

The average maximum temperature is the average of the highest daily values occurring during the hottest month of the year. Figure 11-6, page 11-12, shows worldwide temperature values to be used. In using these charts, obtain temperature and pressure altitude values for a specific site by interpolation.

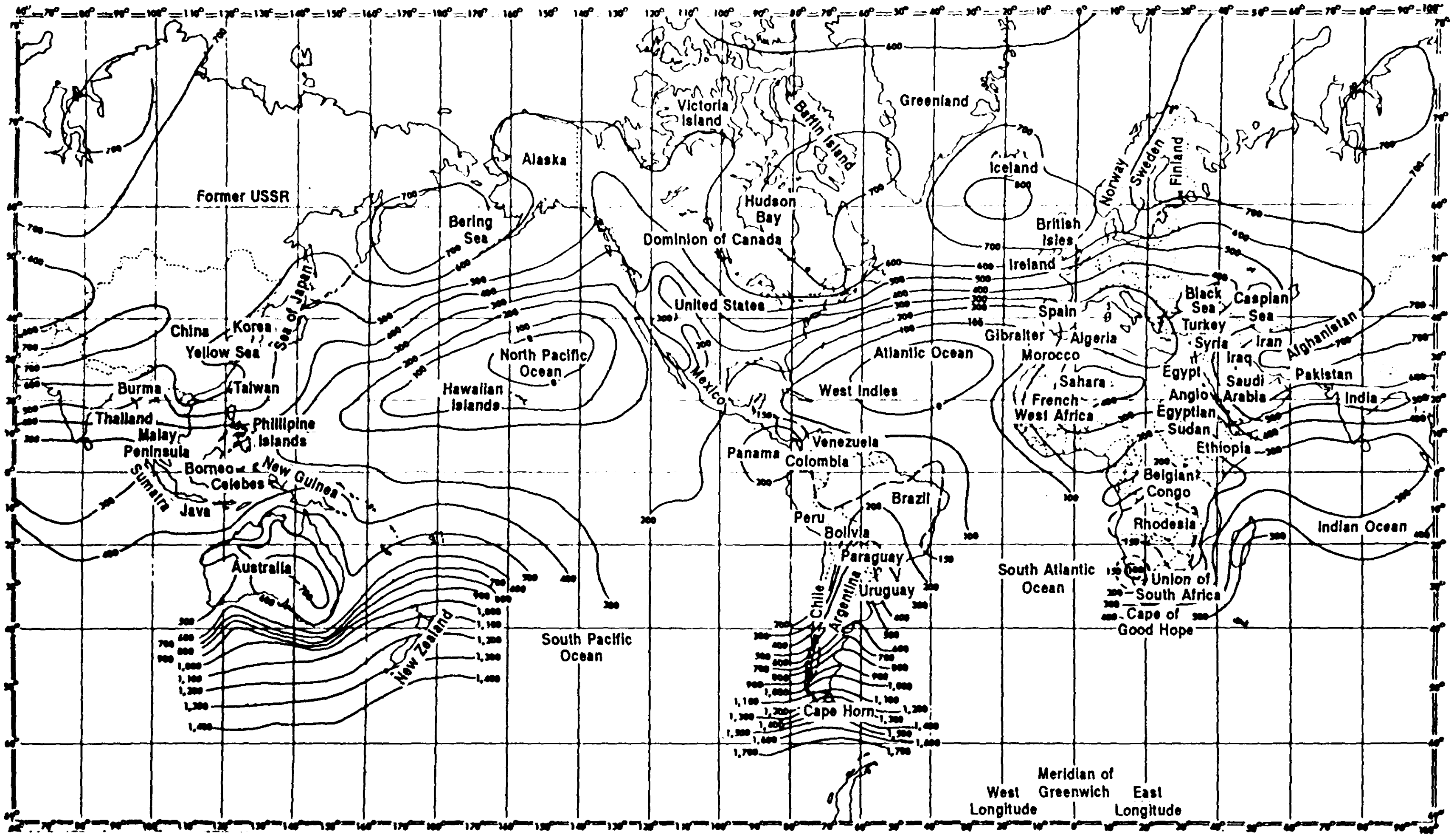
Determining Takeoff Ground Run

Table 11-3, pages 11-4 and 11-5, shows the TGR at mean sea level, 59°F, with a runway effective gradient of 2 percent for most aircraft based on the location within the TO. Use data in Figures 11-1 and 11-2, pages 11-7 and 11-8, if aircraft is not found in Table 11-3. This standard TGR must be increased for different local conditions. The steps used to determine the adjusted TGR follow:

1. Determine the standard TGR for an aircraft shown in Column 6, Table 11-3.

2. Correct for pressure altitude. Add the dH value of the site (from Figure 11-5) to the geographic altitude. Increase the TGR by 10 percent for each 1,000-foot increase in altitude above 1,000 feet. No reduction in TGR is permitted if the pressure altitude is less than 1,000 feet.

3. Correct for temperature. If the pressure-corrected TGR is equal to or greater than 5,000 feet, increase the pressure-corrected TGR by 7 percent for each 10° F increase in temperature above 59°F (from Figure 11-6). If the pressure-corrected TGR is less than 5,000 feet, increase the pressure-corrected TGR by 4 percent for each 10°F increase above 59°F. Never decrease

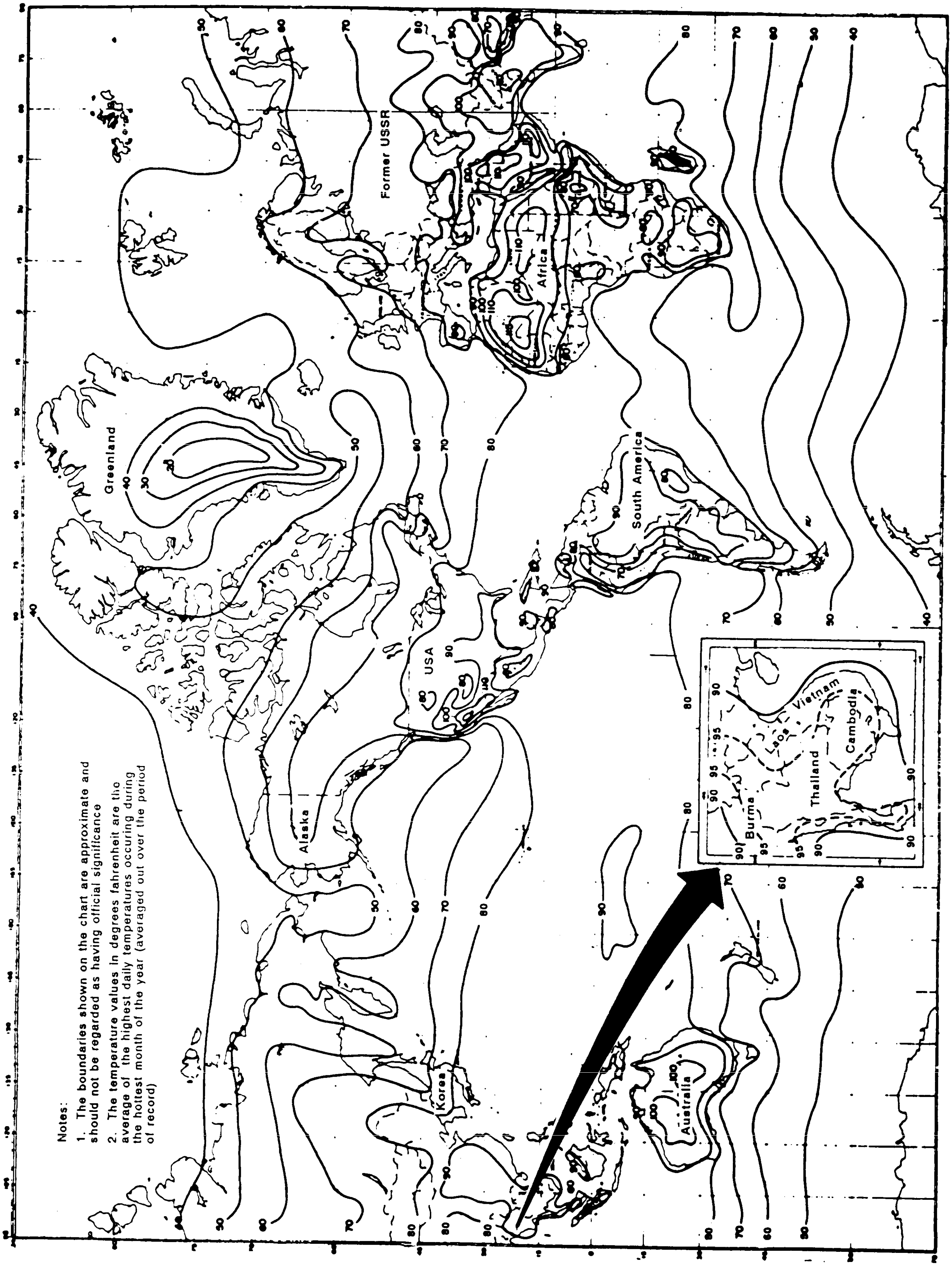


ISOPLETHS OF dH (in feet)

NOTES: 1 The boundaries shown on this chart are approximate and should not be regarded as having official significance

2 Isopleths of dH are lines of equal pressure value The values of dH in feet shown on this map should be added to the geographic elevation at the airfield site to obtain the pressure altitude

Figure 11-5. Isopleths of dH, worldwide



Notes:

1. The boundaries shown on the chart are approximate and should not be regarded as having official significance

2. The temperature values in degrees fahrenheit are the average of the highest daily temperatures occuring during the hottest month of the year (averaged out over the period of record)

Figure 11-6. Worldwide average maximum temperature map the runway length if the temperature is less than 59°F.

4. Adjust for safety. Multiply the temperature-corrected TGR by 1.5 for rear area airfields and by 1.25 for support and close battle area airfields.

5. Correct for effective gradient. Increase the safety-corrected TGR by 8 percent for each 1 percent increase of effective gradient over 2 percent. No reduction in TGR is permitted if the effective gradient is flatter than 2 percent,

NOTE: The term effective gradient, as used here, is the percentage expression of the maximum difference in elevation along the runway, divided by the length of the runway. Table 11-3, pages 11-4 and 11-5, column 7, shows the maximum allowable longitudinal gradients for runways. If the proposed design exceeds Table 11-3, column 7, earthwork must be performed to reduce the gradient. The maximum allowable longitudinal gradient is the steepest slope into which an aircraft can safely land.

6. Round off the gradient-corrected TGR to the next higher 100 feet.

7. Compare the computed value of the TGR with the minimum runway length required (see Table 11-3, column 5). Use the higher of the two values.

The final runway length is the TGR as corrected (if required) for conditions of pressure altitude, temperature, safety factor, and effective gradient and rounded to the next larger 100 feet. Never apply negative corrections to the TGR. For example, do not shorten the runway for operating temperatures below 59°F. Also, the final length of the runway is never less than the minimum length shown in Table 11-3, column 5.

Takeoff Ground Run Determination Example

Assume that a close battle area is to be built for C-17 aircraft and you have the following information: geographic altitude of the proposed site is 1,600 feet, dH value is 100, average maximum temperature is 79°F, and effective gradient is 3 percent.

1. Takeoff ground run.

3,000 feet (ft) (from Column 6, Table 11-3)

2. Pressure altitude correction.

Pressure altitude = geographic altitude + dH value

= 1,600 ft + 100 ft

= 1,700 ft

Correction factor (%) =

$$\left(\frac{1{,}700ft - 1{,}000ft}{1{,}000ft}\right) \times 10\% = 7\%$$

107% of 3,000 ft = 1.07 X 3,000 = 3,210 ft

NOTE: 1,700 feet is the only variable in the equation.

3. Temperature correction.

Correction factor (%) =

$$\left(\frac{79°F - 59°F}{10°F}\right) \times 4\% = 8\%$$

Therefore, increase the corrected runway length by 8%.

108% of 3,210 = 1.08 X 3,210 ft = 3,467 ft

NOTE: The only variable in the equation is 79°F. If the pressure-corrected TGR was greater than 500 feet, the equation would read {(79°F - 59°F)/10°F} x 70%.

4. Safety factor,

1.25 X 3,467 ft = 4,334 ft

5. Effective gradient correction.

Correction factor (%) =

$$\left(\frac{3\% - 2\%}{1\%}\right) \times 8\% = 8\%$$

108% of 4,334 ft = 1.08 x 4,334 ft = 4,681 ft

NOTE: The effective gradient of 3 percent must be less than or equal to Table 11-3, pages 11-4 and 11-5, column 8 = (3 percent). Also, 3 percent is the only variable in the equation.

6. Round up to the next higher 100 feet.

Length of runway = 4,700 ft

7. Check minimum required (Table 11-3, column 5) = 3,500 ft.

Select 4,700 feet as the appropriate length.

Width

The primary factors that determine runway width are (1) the safety of operation under reduced visibility conditions and (2) the degree of lateral stability and control of the aircraft in the final approach and landing. The minimum widths given in the design-criteria tables increase with increased aircraft weight and size because maneuverability decreases as size increases. Where safety requirements permit, the theater Air Force component commander may reduce the widths. Table 11-3 shows required widths of clear areas and dimensional criteria of clear zones.

Approach Zones

Approach zones are at both ends of the flight strip. The end of the approach zone nearest the runway should be as wide as the clear zone that adjoins it. From this width, the approach zone funnels out trapezoidally to the wider dimension at its outer end. (See the design criteria in Table 11-3, pages 11-4 and 11-5, for widths to be used for each type of airfield and stage of construction.) Table 11-3 shows the required length of the approach zone. The following dimensions are required to describe the size of an approach zone:

- Width at the runway end.
- Width at the outer end.
- Length.
- Slope of the plane determined by the glide angle that defines the upper limit of permissible obstructions.

Glide Angle

No obstruction should extend above the glide angle within an approach zone. The upper limit of the glide angle is a sloping plane, extending from the ground surface at the end of the approach zone nearest the runway to a higher elevation at the zone's outer edge. The slope of this plane depends on the glide-angle characteristics of the using aircraft.

The glide angle of an aircraft is a ratio that expresses its angle of ascent or descent, whichever is the most restrictive, as measured at the end of its ground run or at its point of touchdown. Glide-angle ratios, as they are given for various aircraft, include a safety adjustment.

The denominator of the ratio is usually 1 (vertical foot of ascent or descent), and the numerator is a number expressing how many horizontal feet of distance (increased by 10 as a safety quantity) the aircraft must travel to climb or descend that single foot. Glide angles range from 35:1 to 50:1, depending on the location of the airfield.

Approach Zone Dimensions Example

Assume that a design is being prepared for a support area airfield. From Table 11-3, the required width at the runway end of the approach zone (column 22) is 600 feet, the required length (column 21) is 32,000 feet, the required width at the outer end (column 23) is 8,073 feet, and the glide ratio (column 24) is 50:1. Also note that the widths increase when this same type airfield is located in the rear area.

Gradients

The design-criteria table (Table 11-3) contains requirements pertaining to maximum longitudinal grades for runways. For support area airfields, the maximum longitudinal grade (column 8) for the runway and overrun is 2 percent. The corresponding figure for close battle area airfields is 3 percent.

Use ditches at the shoulder edges, parallel to the centerline (longitudinally), to provide adequate drainage. Also, lateral ditches might be required to provide flow of water away from the longitudinal ditches which parallel the runway. Neither longitudinal nor lateral ditches can have side slopes greater than 7:1. This ensures the ditches meet the design drainage requirement but do not present a safety hazard to aircraft running off the runway.

Where there is more than one change in longitudinal grade, the distance between successive points of grade intersection must not be less than the minimum distance given in the appropriate design criteria table. The maximum rate of change of longitudinal grade is 1.5 percent per 200 feet for all TO airfields. These figures pertain to centerline measurements, but higher rates of grade change to permit transverse sloping of the runway may be allowed along the edges of the runway. These requirements will be satisfied by following the vertical curve design procedure discussed later.

When jet aircraft are involved, hold longitudinal grade changes to an absolute minimum. Make any necessary grade transitions as long as possible to keep grade change rates very low.

Crowns or transverse slope sections should have a transverse gradient ranging between 1 and 2 percent. Transverse grades more than 2 percent are a hazard in wet weather because aircraft may slip on wet surfaces.

Grade shoulders to a transverse slope of 1.5 to 5 percent. Permissible transverse overrun grades are the same as those for the runway.

Surface Type and Pavement Thickness

The design-criteria tables contain recommendations on the type of surfaces and thickness of pavement to be used for each type of airfield. Chapter 12 discusses the design thicknesses for unsurfaced, aggregate, and bituminous surfaces.

Shoulders

Shoulders are required for all runways. Shoulders range in width from 10 feet to 50 feet, depending on the airfield's location and the using aircraft. Normally, airfield pavement shoulders are thoroughly compacted and constructed with soils having all-weather stability. Use vegetative cover, anchored mulch, coarse-graded aggregate, or liquid palliative other than asphalt or tars to provide dust and erosion control. When using coarse-graded aggregates, thoroughly blend and compact them with in-place materials to ensure proper binding and to avoid damage to aircraft from foreign objects.

Signal Cables

Communications personnel plan and install telephone and radio facilities, but coordination with the engineers is essential. Lay signal cables that cross the runway before starting the surfacing operation. Place conduits or raceways under the runway every 1,000 feet during construction so that flight operations may continue during future expansions of communication facilities.

RUNWAY ORIENTATION

Runways usually are oriented in accordance with (IAW) the prevailing winds in the area. Pay particular attention to gusty winds of high velocity in determining the runway location.

The established runway direction should ensure 80 percent wind coverage, based on a maximum allowable beam wind (perpendicular to the runway) of 13 miles per hour (mph). This requirement, however, should not cause rejection of a site that is otherwise favorable. Where dust is a problem on the runway or shoulders, locate the runway at an angle of about 10 degrees to the prevailing wind so that dust clouds produced by takeoffs will blow diagonally off the runway,

Gathering Wind Data

Wind data is usually based on the longest period for which information is available. A minimum of 10 years' data showing wind directions, velocity, and frequency of occurrence is necessary for conclusive analysis. Military and civilian maps for all populated areas of the world usually have this information, especially those prepared by marine or aeronautical agencies. If no observations are available for a site, adjust the nearest recorded observations for changes that will result from local topography or other influencing factors. Table 11-4 shows the form in which wind data may be obtained from AWS.

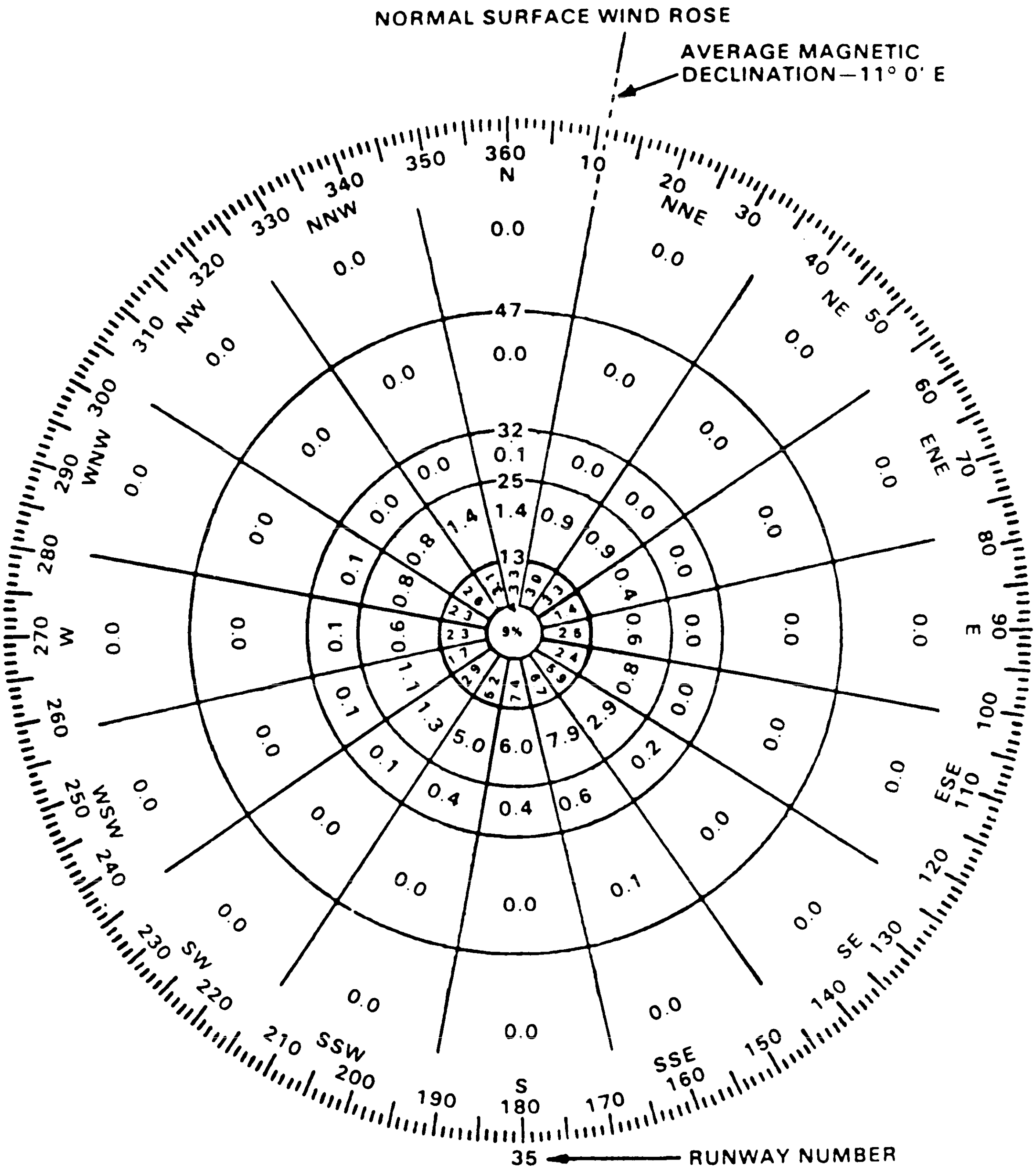
Wind Rose

A wind rose graphically depicts wind velocities, directions, and their probability of occurrence in a format resembling a compass (see Figure 11-7). The radii of the concentric circles arc scaled to represent wind velocities of 4, 13, 25, 32, and 47 mph. The radial lines are arranged on the diagram in a manner similar to a compass card to show directions such as north, north northeast, northeast, cast northeast, and east. Each direction subtends an angle of 22.5 degrees.

The probabilities of occurrence for the wind velocities and directions are recorded in the appropriate spaces on the diagram. The example on page 11-18 uses the wind data to be analyzed from Table 11-4.

Table 11-4. Annual percentage of all surface winds, categorized by velocity (mph) and direction

Direction	Wind Velocity Group (mph)						Total All Groups
	1-4	4-13	13-25	25-32	32-47	Over 47	
	(a)	(b)	(c)	(d)	(e)	(f)	
	Percent						
N	0.3	3.3	1.4	0.1	0	0	5.1
NNE	0.3	3.0	0.9	0	0	0	4.2
NE	0.5	3.3	0.9	0	0	0	4.7
ENE	0.2	1.4	0.4	0	0	0	2.0
E	0.5	2.5	0.6	0	0	0	3.6
ESE	0.3	2.4	0.8	0	0	0	3.5
SE	0.6	5.9	2.9	0.2	0	0	9.6
SSE	0.5	6.7	7.9	0.6	0.1	0	15.8
S	0.8	7.4	6.0	0.4	0	0	14.6
SSW	0.6	5.2	5.0	0.4	0	0	11.2
SW	0.5	2.9	1.3	0.1	0	0	4.8
WSW	0.3	1.7	1.1	0.1	0	0	3.2
W	0.4	2.3	0.6	0.1	0	0	3.4
WNW	0.4	2.3	0.8	0.1	0	0	3.6
NW	0.5	2.6	0.8	0	0	0	3.9
NNW	0.3	3.1	1.4	0	0	0	4.8
Calms	2.0	0	0	0	0	0	2.0
Total	9.0	56.0	32.8	2.1	.1	0	100.0
Period of record July 1976 through July 1986.			Total number of hourly observations - 91,055 - 100 percent				



TOTAL OBSERVATIONS:	91,055
PERIOD OF RECORD:	JULY 1976 THROUGH JULY 1986
WHERE OBSERVED:	FORT LEONARD WOOD, MISSOURI

Figure 11-7. Typical wind rose

Example:

Record 9 percent (the sum of 2 percent calms plus 7 percent winds under 4 mph) within the innermost concentric circle, the radius of which represents 4 mph. Record the percentages 3.3, 1.4, 0.1, 0.0, and 0.0 (shown for the north direction in columns (b), (c), (d), (c), and (f) of Table 11-4) on the diagram (Figure 11-7, page 11-17) between the radial lines showing north and between the concentric circles showing wind velocities of 4-13, 13-25, 25-32, 32-47, and more than 47 mph, respectively. Record the remainder of the data in Table 11-4 on the diagram in the same manner.

Wind Vectors

Figure 11-8 outlines a graphical method showing wind speed and direction. Line D-o represents the direction of the prevailing wind, and line A-B represents the direction of the runway. The velocity of the prevailing wind is scaled off on line D-o and is shown as line c-o. If the scale used is 0.1 inch equals 1 mph (the scale generally used) and the prevailing wind has a velocity of 18 mph, the length of line c-o is 1.8 inches. Determine the wind velocity perpendicular to the direction of the runway by drawing line c-b at a right angle to line A-B. This line measures 0.9 inch and at the same scale represents 9 mph, the crosswind velocity. Line b-o measures 1.56 inches and represents 15.6 mph, the wind velocity parallel to the runway. The designer may use simple trigonometric functions of a right triangle instead of this method. The results can be verified using the P thagorean theorem. (Example: (9 mph)^2+ (15.6 mph)^2= (18 mph)^2)

Graphic Analysis of Wind Rose

Use a thin, transparent, rectangular indicator (Figure 11-9) to analyze a wind rose. This indicator is constructed to the same scale as the wind rose on which it is used. The width of the indicator is based on the acceptable crosswind velocity. With an acceptable crosswind velocity of 13 mph and

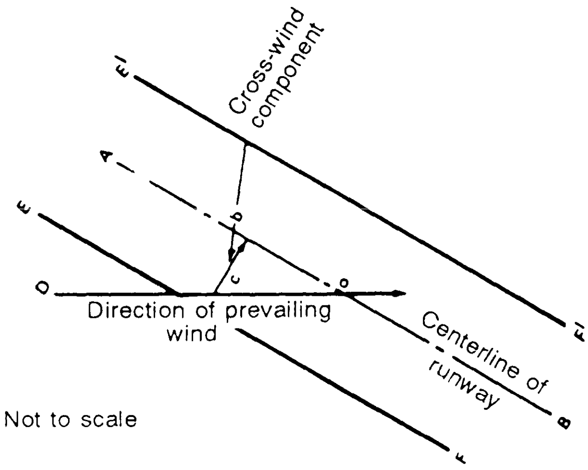


Figure 11-8. Wind vector

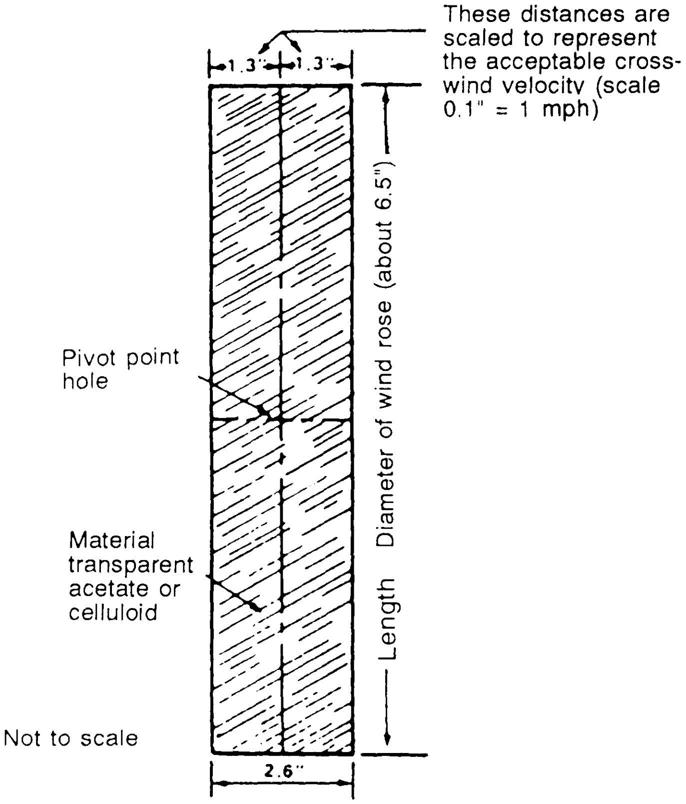
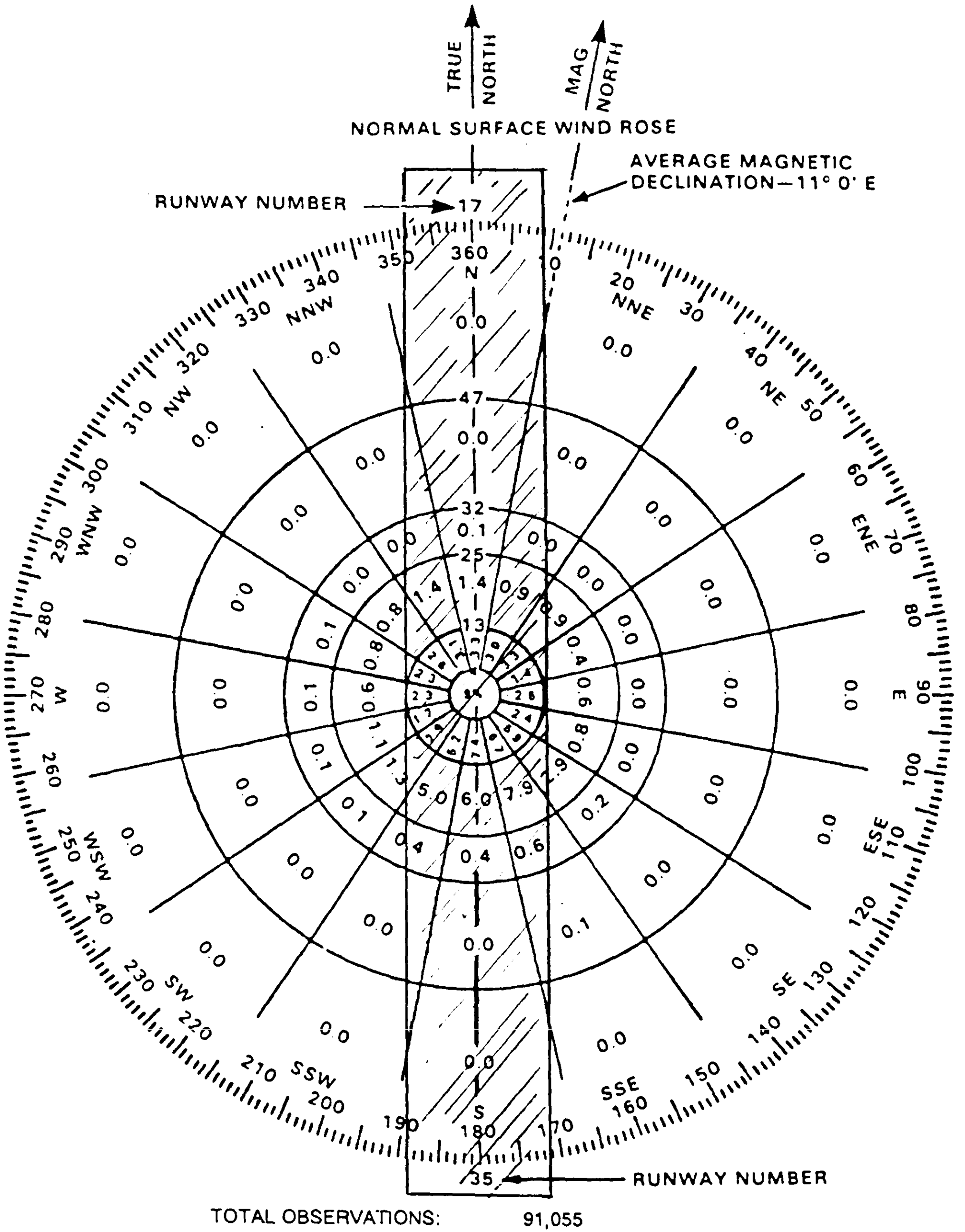


Figure 11-9. Transparent rectangular indicator used in wind-rose analysis

a wind rose scale of 0. 1 inch equals 1 mph, the rectangle is 1.3 inches from its center to its edge and has an overall width of 2.6 inches. The rectangle is slightly longer than 6 inches, the diameter of the wind-rose diagram. The long axis (the centerline) of the rectangle is marked with a fine, opaque line that shows the direction of a runway. A small hole at the midpoint of this line is used for a pivot to rotate the rectangle.

The indicator is securely pivoted at the center of the wind rose (Figure 11-10). Because the edges of the indicator define the limits of the acceptable crosswind velocity



TOTAL OBSERVATIONS: 91,055
PERIOD OF RECORD: JULY 1976 THROUGH JULY 1986
WHERE OBSERVED: FORT LEONARD WOOD, MISSOURI

Figure 11-10. Determination of runway alignment by wind-rose analysis components, the spaces and portions of spaces covered by the indicator represent acceptable surface wind velocities and directions. Rotate the rectangular indicator about its center and orient it so that the total percentages (of occurrence for each wind velocity) is maximized. Total the percentages under the indicator. This total is the percentage of time that crosswind velocities will be within the specified limit for a runway oriented in the direction shown by the rectangular indicator,

Determine the percentage coverage totals with the indicator oriented in several directions. Compare these totals to determine the best runway orientation, as based solely upon surface wind data. If the percentage coverage for one runway is inadequate, make a wind-rose analysis for combinations of runway directions to determine the most suitable combination that will provide the necessary coverage,

Calculating Percentage Covered

Either of two procedures may be followed to evaluate the total percentage covered by the rectangular indicator on a wind rose. One procedure is to calculate the total of the representative percentages covered by the indicator. The other is to calculate the total of the representative percentages not covered by the indicator and subtract this total from 100. Tables 11-5 and 11-6 show examples of each procedure. The wind data in Table 11-7, the resultant wind rose, and the indicator in the position shown by

Table 11-5. Example of wind-rose evaluation (percentage covered)

Direction	Wind Velocity Group (mph)						Total All Groups
	1-4	4-13	13-25	25-32	32-47	Over 47	
	(a)	(b)	(c)	(d)	(e)	(f)	
	Percent						
N	0.3	3.3	1.4	0.1	0	0	5.1
NNE	0.3	3.0	0.9	0	0	0	4.2
NE	0.5	3.3	0.4	0	0	0	4.2
ENE	0.2	1.4	0	0	0	0	1.6
E	0.5	2.5	0	0	0	0	3.0
ESE	0.3	2.4	0.1	0	0	0	2.8
SE	0.6	5.9	0.9	0	0	0	7.4
SSE	0.5	6.7	7.9	0.4	0	0	15.5
S	0.8	7.4	6.0	0.4	0	0	14.6
SSW	0.6	5.2	5.0	0.3	0	0	11.1
SW	0.5	2.9	0.5	0	0	0	3.9
WSW	0.3	1.7	0.1	0	0	0	2.1
W	0.4	2.3	0	0	0	0	2.7
WNW	0.4	2.3	0.1	0	0	0	2.7
NW	0.5	2.6	0.4	0	0	0	3.5
NNW	0.3	3.1	1.4	0	0	0	4.8
Calms	2.0	0.0	0	0	0	0	2.0
Total	9.0	56.0	25.0	1.2	0	0	91.2
The figures presented above are based on the use of the wind data in Table 11-4, the resultant wind rose, and the rectangular indicator positioned as shown in Figure 11-10.							

Table 11-6. Example of wind-rose evaluation (percentage not covered)

Direction	Wind Velocity Group (mph)						Total All Groups
	1-4	4-13	13-25	25-32	32-47	Over 47	
	(a)	(b)	(c)	(d)	(e)	(f)	
	Percent						
N	0	0	0	0	0	0	0
NNE	0	0	0	0	0	0	0
NE	0	0	0.5	0	0	0	0.5
ENE	0	0	0.4	0	0	0	0.4
E	0	0	0.6	0	0	0	0.6
ESE	0	0	0.7	0	0	0	0.7
SE	0	0	2.0	0.2	0	0	2.2
SSE	0	0	0	0.2	0.1	0	0.3
S	0	0	0	0	0	0	0
SSW	0	0	0	0.1	0	0	0.1
SW	0	0	0.8	0.1	0	0	0.9
WSW	0	0	1.0	0.1	0	0	0.2
W	0	0	0.6	0.1	0	0	0.7
WNW	0	0	0.8	0.1	0	0	1.8
NW	0	0	0.4	0	0	0	0.4
NNW	0	0	0	0	0	0	0
Calms	2	0	0	0	0	0	0
Total	0	0	7.8	0.9	0.1	0	8.8
The figures presented above are based on the use of the wind data in Table 11-4, the resultant wind rose, and the rectangular indicator positioned as shown in Figure 11-11.							

Table 11-7. Vertical curve length equation for airfields

Invert Curves	Overt Curves		Notes
Length Due to Change of Grade	Length Due to Change of Grade	Length Due to Sight Distance	Pertaining to Length of Curve
$L = \frac{\Delta G}{r^{a}}$	$L = \frac{\Delta G}{r^{a}}$	$L = 2S - \frac{40}{\Delta G}$ Where $S^{b} = \frac{RW^{b}}{2} + 5$	Raise to next higher *even* station
LEGEND: L = length of vertical curve ΔG = change in grade r = allowable rate of change of grade RW = runway length S = sight distance		NOTES: a. The symbol r varies, and the rates of change are listed in Table 11-3 (column 10). b. Enter an equation with RW and S in stations to obtain a value for L in stations.	

Figure 11-10, page 11-19, are used to compile the examples.

Determining the percentage value for a partially covered space requires special consideration. To calculate the representative percentages covered by the rectangular indicator, assume uniform distribution of the percentage of time within each space on the wind rose. For example, if an entire space represents 2.8 percent of the time, one-half of that space represents 1.4 percent of the time. The basic assumption of uniform distribution leads to inaccuracies. A high degree of accuracy in the determination of the proportions of space partially covered by the indicator may be determined by calculation, estimation, or measurement; or it may be determined by using a nomograph (Figure 11-11).

As an example of how the nomograph is used, assume that Figure 11-10 is the wind rose to be evaluated when the runway is in the direction indicated by the rectangular indicator. Also assume that the wind-rose space from which a proportionate percentage is to be determined represents southeast winds ranging from 13 to 25 mph. Because this space is only partially covered by the indicator, the percentage of time (represented by the portion covered by the indicator) must be determined.

In this example, the azimuth of the wind direction (southeast) is 135 degrees. The azimuth of the centerline of the indicator is roughly 181 degrees. Their angular difference is roughly 46 degrees. Figure 11-11 shows that for this angular difference, the rectangular indicator covers approximately 0.3 percent of the space representing winds from 13 to 25 mph. Because the entire space represents 2.9 percent of the time, the 0.3 portion of the space represents 0.9 percent (0.3 x 2.9) of the time. Accuracy to the closest 0.1 percent is the same as that of the basic wind data.

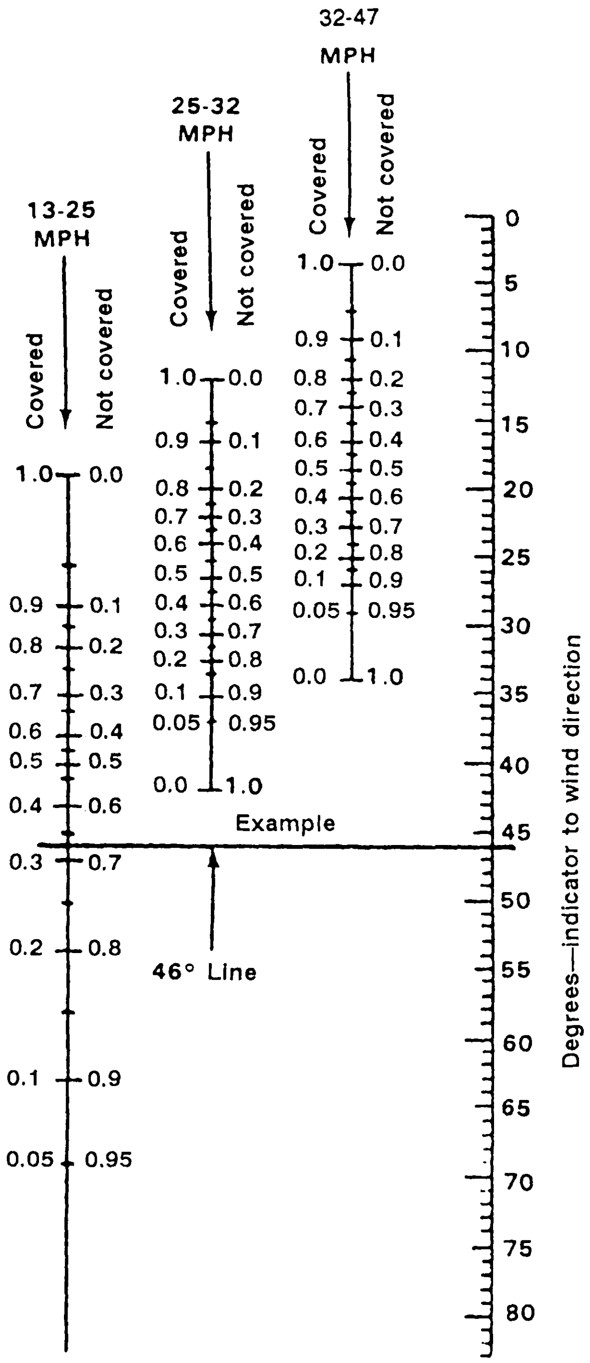


Figure 11-11. Nomograph for estimating wind coverages

Follow a similar procedure for the rest of the spaces and portions of spaces covered by the indicator. Enter the percentages determined into a table similar to Table 11-5, page 11-11. The total of the percentages is the indicated wind coverage of a runway.

Follow a similar procedure when the calculation is based on spaces not covered. The calculation based on spaces not covered substantially reduces the work required. The results of a *not-covered* calculation for the wind-rose analysis in Figure 11-10, page 11-19, are recorded in Table 11-6, page 11-21.

True and Magnetic North Directions

Wind data directions are based on the true geographic north, whereas airfield runway directional numbers are based on the magnetic north. Magnetic declination adjustments must be made in the results of wind-rose runway orientation determinations to show runway directions based on magnetic headings.

VERTICAL ALIGNMENT

Airfield construction specifies a minimum length of each grade line or a minimum distance between the grade line intersection points. Although this specification is based on the type of aircraft involved and the standard of construction desired, a minimum of 400 feet between points of vertical intersection is used.

VERTICAL CURVES

The same vertical-curve design procedures used for roads in Chapter 9, FM 5-430-00-1/AFPAM 32-8013, Vol 1, are used for airfields. However, the curve length may be longer. In many cases, the runway is a segment of a curve, and both the point of vertical curvature (PVC) and point of vertical tangency (PVT) are off the airfield. Confusion of stationing must be avoided. Table 11-7, page 11-21, shows equations to determine the length of airfield vertical curves. For overt curves, use either sight distance or maximum change of grade to determine the curve length. Use whichever length is longest.

Example

A close battle area airfield is to be built to accommodate C-17 and C-130 aircraft. The runway length is determined to be 3,000 feet (after adjustments made to TGR). Figure 11-12, page 11-24, shows the profile and plan views of the selected site with final trial grade lines. To meet the criteria for an unobstructed glide angle of 35:1, the overrun must start at station 0 + 00. Complete the design of the vertical curve to include PVC and PVT, calculate the offsets every 100 feet, and prepare the equation in tabular form.

Solution

1. Determine ΔG.

$$\Delta G = G_1 - G_2 = (+1.0) - (-0.5) = 1.$$

Where G = grade, G_1 = first grade, and G_2 = second grade

2. Determine length (L), because of change in grade.

$$L = \frac{G}{R} = \frac{1.5}{75} = 2 \text{ stations}$$

Where L = length of vertical curve and r= allowable rate of change (from column 10, Table 11-3, page 11-4)

3. Determine sight distances.

$$S = \frac{RW}{2} + 5 = \frac{30}{2} + 5 = 20 \text{ stations}$$

4. Determine L due to sight distance.

$$L = 2S - \frac{40}{G} = 2(20) - \frac{40}{1.5} = 40 - 26.67 = 13.33$$

L = 14 stations (raised to the next higher even station)

Note: Length due to sight distance is greater than length due to change in grade. Therefore, length due to sight distance must be used.

L = 14 stations = 1,400 feet

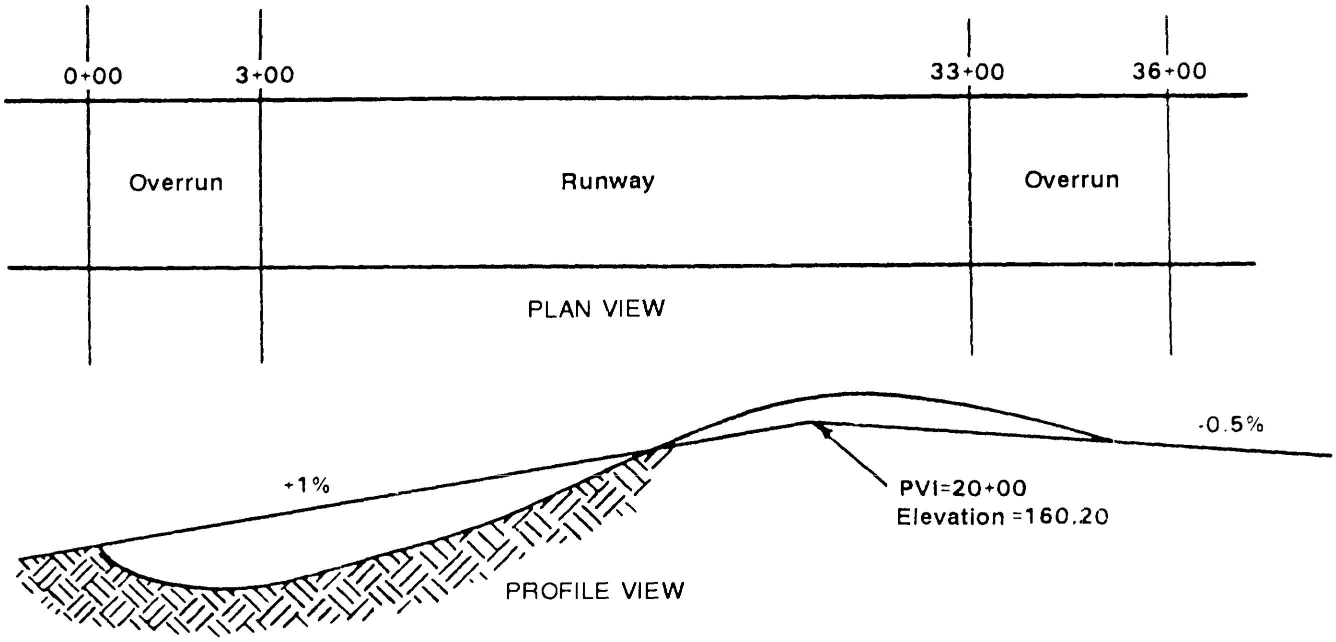


Figure 11-12. Profile of proposed runway

5. Determine the PVC.

$$PVC = PVI - \frac{L}{2} = (20 + 00) - (7 + 00) = 13 + 00$$

6. Determine the PVT.

$$PVT = PVC + L = (13 + 00) + (14 + 00)$$

7. Determine the maximum offset (MO).

$$MO = \frac{L}{8}\,\Delta G = \frac{14}{8} \times 1.5 = 2.63 \text{ feet}$$

8. Determine tangent (grade line) elevations

Left side of curve

Sta 19 + 00 = 160.20-(0.01x100) = 159.20
Sta 18 + 00 = 160.20-(0.01x200) = 158.20
Sta 17 + 00 = 160.20-(0.01x300) = 157.20
Sta 16 + 00 = 160.20-(0.01x400) = 156.20
Sta 15 + 00 = 160.20-(0.01x500) = 155.20
Sta 14 + 00 = 160.20-(0.01x600) = 154.20
Sta 13 + 00 = 160.20-(0.01x700) = 153.20

Right side of curve

Sta 21 + 00 = 160.20-(0.005x100) = 159.70
Sta 22 + 00 = 160.20-(0.005x200) = 159.20
Sta 23 + 00 = 160.20-(0.005x300) = 158.70
Sta 24 + 00 = 160.20-(0.005x400) = 158.20
Sta 25 + 00 = 160.20-(0.005x500) = 157.80
Sta 26 + 00 = 160.20-(0.005x600) = 157.20
Sta 27 + 00 = 160.20-(0.005x700) = 156.80

9. Determine the offset.

$$^{\circ} = \frac{(d)^2}{\left(\frac{L}{2}\right)}$$

$$^{\circ}1 = \frac{(1)^2}{7^2} \times 2.63 = 0.05'$$

$$^{\circ}2 = \frac{(2)^2}{7^2} \times 2.63 = 0.21'$$

$$^{\circ}3 = \frac{(3)^2}{7^2} \times 2.63 = 0.48'$$

$$^{\circ}4 = \frac{(4)^2}{7^2} \times 2.63 = 0.86'$$

$$^{\circ}5 = \frac{(5)^2}{7^2} \times 2.63 = 1.34'$$

$$^{\circ}6 = \frac{(6)^2}{7^2} \times 2.63 = 1.93'$$

10. Determine final elevations.

Station	Tangent Elevation	Offset	Final Elevation
PVC 13 + 00	153.20	0.00	153.20
PVC 14 + 00	154.20	0.05	154.15
PVC 15 + 00	155.20	0.21	154.99
PVC 16 + 00	156.20	0.48	155.72
PVC 17 + 00	157.20	0.86	156.34
PVC 18 + 00	158.20	1.34	156.86
PVC 19 + 00	159.20	1.93	157.27
PVI 20 + 00	160.20	2.63	157.57
PVI 21 + 00	159.70	1.93	157.77
PVI 22 + 00	159.20	1.34	157.86
PVI 23 + 00	158.70	0.86	157.84
PVI 24 + 00	158.20	0.48	157.72
PVI 25 + 00	157.70	0.21	157.49
PVI 26 + 00	157.20	0.05	157.15
PVT 27 + 00	156.70	0.00	156.70

The cross section of a runway may be of two general types-a crowned cross section or a transverse slope cross section as shown in Figure 11-13. Transverse slope cross sections may slope to either side of the runway. The terms *right* and *left*, when used in connection with a runway, refer to the right and left sides of the runway as the observer stands on the centerline and faces the higher numbered stations on that centerline.

Transverse slopes are applied to sections at appropriate stations to make the finished runway surface fit close to the original topography of the site. A sloped runway follows the transverse and the longitudinal shape of the original ground as closely as possible while staying within acceptable grade limitations. Using transverse slopes on a runway reduces the amount of earthwork and drainage construction. The changes in shape and grade of a properly sloped runway are small compared with the runway length.

Runway transverse slopes do not cause a hazard to flight operations. Records show no increase in operational accidents as a result of using transverse slopes. Changes in the transverse slope on airfields used by jet aircraft must be kept to a minimum. Transverse slopes are not needed for roads or taxiways. They usually are located to conform to the existing ground surface,

Limitations

In applying transverse slopes to a runway, it may be economical to change from a left-hand to a right-hand transverse-slope cross section or to change from a transverse-slope cross section to a crowned cross section. These changes may occur often, provided two limitations are observed:

- The longitudinal distance from the center of one transition to the center of the next transition must not be less than 400 feet.
- The length of the transition connecting typical cross sections must be such that the maximum grade limitations in Table 11-3, page 11-4, are not exceeded.

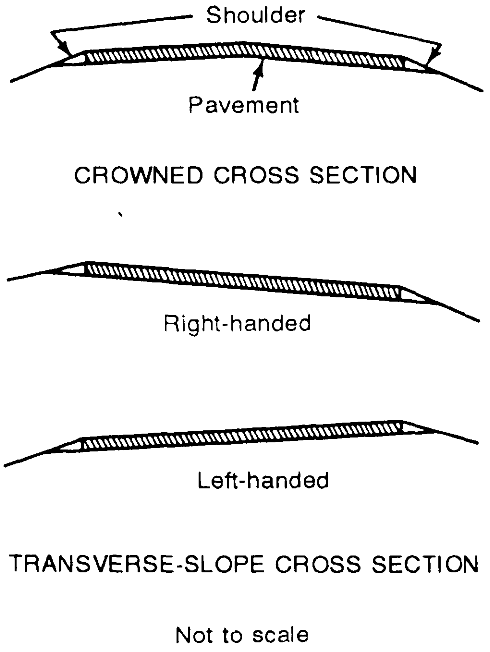


Figure 11-13. Crowned cross section and transverse-slope cross sections of runways

Designing Transverse-Slope Cross Sections

Transverse sloping of a runway is primarily a computing and drafting job. The two main tasks in a sloping problem are-

- Selecting the proper cross sections for various lengths of the runway.
- Designing proper transitions to connect the lengths of different cross-sectional shapes.

These steps are illustrated in Figures 11-14 and 11-15, page 11-28.

Selecting cross sections. Use the following procedure to select proper runway cross sections:

1. Plot the ground profiles at the centerline, left edge, and right edge of the runway as shown in Figure 11-14. Plot each profile with a different color pencil.

2. Determine the relative positions of three profiles at each cross section. When both edges arc below the centerline, use a crowned cross section (does not need to be symmetrical). Use a transverse-slope cross section when one edge is above and the other is below the centerline.

3. Design proper cross-sectional shapes for each distinct length of runway. Observe the two limitations explained earlier. The cross-sectional shapes, as designed, should fit as closely as possible to the undisturbed ground shape within the allowable limitations for changes of grade.

Figure 11-14 shows how cross sections may vary along a runway and how cross sections are selected by comparing the center, left-edge, and right-edge ground profiles. Note that between stations 0 + 00 and 10 + 00, 28 + 00 and 48 + 00, and 60 + 00 and 70 + 00, the right edge of the runway is above the centerline profile while the left edge is below the centerline profile. This suggests using a left-hand, transverse-slope cross section. The three profiles show that a crowned cross section is most suitable between stations 10 + 00 and 28 + 00. Between stations 48 + 00 and 60 + 00 and between stations 70 + 00 and 80 + 00, a right-hand, transverse-slope cross section is best because the left edge is above the centerline and the right edge is below the centerline.

Designing transitions. The upper part of Figure 11-15 shows a transition suitable for changing from a left-hand, transverse-slope cross section to a right-hand, transverse-slope cross section, In Figure 11-15, the dotted line on the plan connects high points of the successive cross sections. A similar situation occurs when the change involves a crowned section. The lower part of Figure 11-15 shows a crowned section, high points, and typical cross sections in a similar fashion. Note that all the cross sections, between and including C-C and D-D, are alike.

When staking out a transition on the ground, use at least five lines of grade stakes. Locate the grade stakes along the centerline. quarter points, and edges of the runway. These are enough stakes for construction, but additional stakes may be required for close grade control.

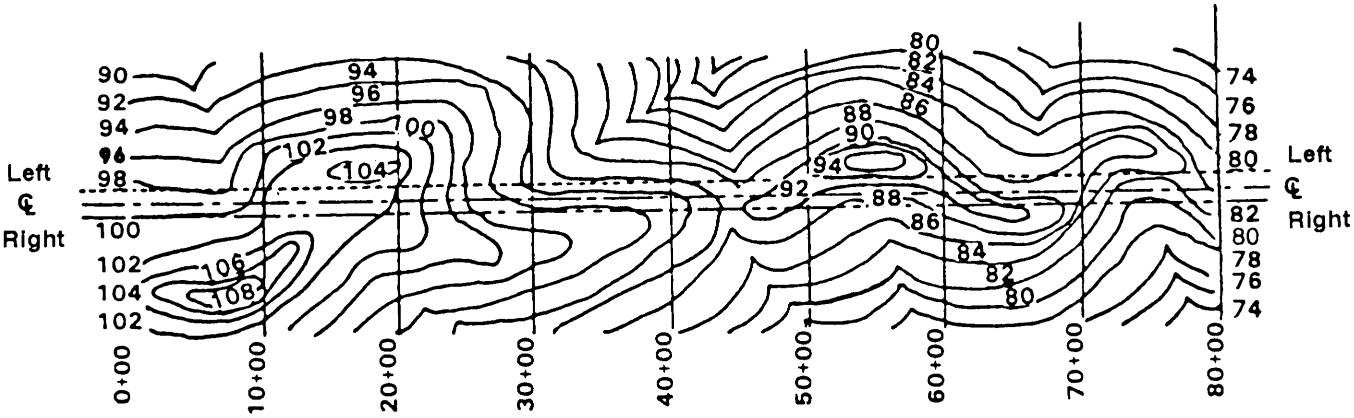
TAXIWAYS

Taxiways are pavements provided for the ground movement of aircraft, They connect the parking anti the maintenance areas of the airfield with the runway. The location of these facilities determines the location of taxiways.

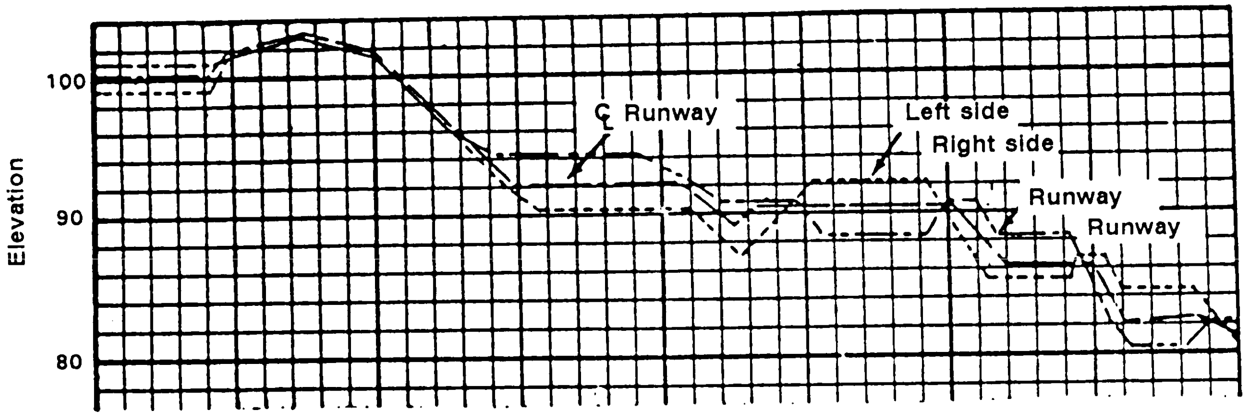
Locate taxiways to provide direct access to the ends of the runway for takeoffs. Avoid designs with long taxiways and designs that require excessive crossing and turning on the runway. Such designs reduce the operational capacity of the runway and cause needless hazards.

Provide cutoff taxiways or exit paths that permit landing aircraft to clear the runway promptly. Excessive cutoffs can complicate the traffic control problem.

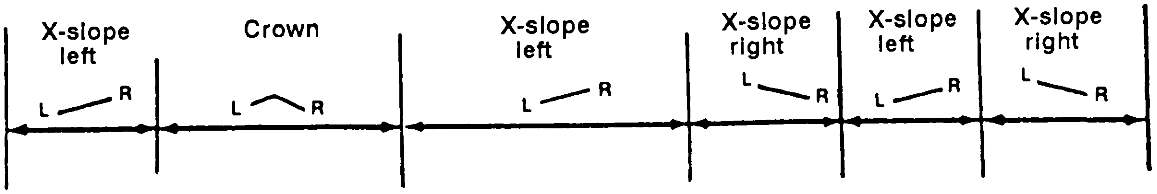
Construct taxiways on a loop system. This provides an alternate route in case a disabled plane or maintenance operations



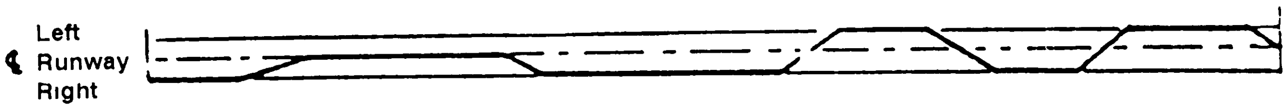
Typical ridge topography showing location of runway



Profiles of original ground along ℄ and edges of runway



Cross sections slopes along runway



Direction of cross slopes showing location of "high line" along runway

Figure 11-14. Determination of runway cross sections

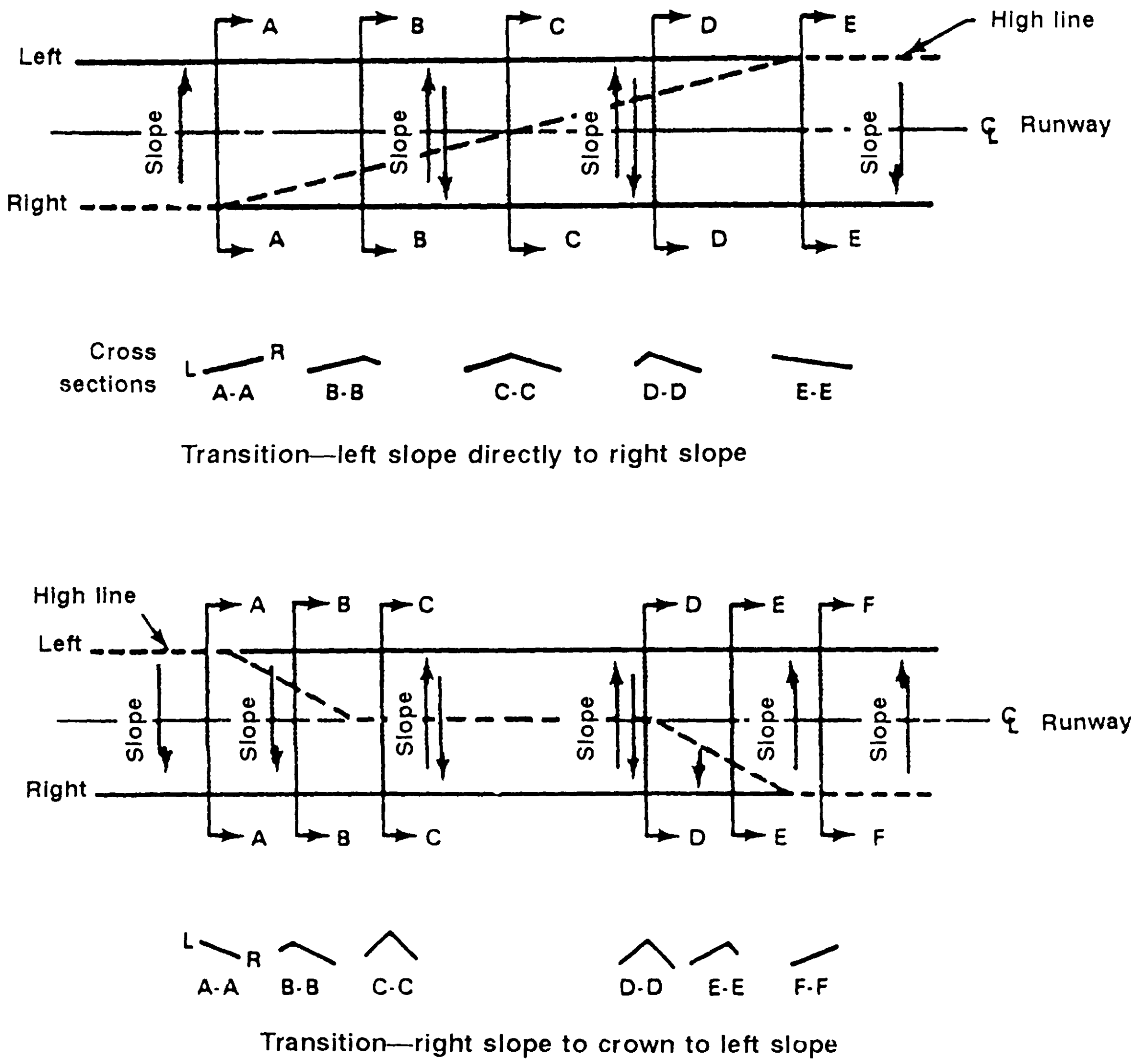


Figure 11-15. Transitions between cross sections

block the taxiway. Make the taxiway parallel with the runway and tie onto it at both ends, thus forming a closed loop.

Straight taxiways are preferred for modern, high-performance aircraft that consume large amounts of fuel. Straight taxiways permit movement from one point to another in the shortest possible time with the greatest fuel savings.

APRONS

In a TO airfield, three types of aprons are used: warm-up, operational, and cargo.

Warm-Up Apron

The warm-up apron, sometimes called a warm-up/holding-pad apron, is a paved area adjascent to the taxiway near the runway end. The warm-up apron permits–

- The final portion of warm-up and engine and instrument checks to be done before takeoff without interrupting normal traffic.

- The flow of traffic from the taxiway to the runway to be uninterrupted in case of breakdowns or malfunctions.
- Jet engine aircraft with high minimum fuel consumption to bypass slower reciprocating engine aircraft between the taxiway and the runaway.
- Aircraft to wait for takeoff clearance without blocking the runway or taxiway.

A satisfactory warm-up apron should-

- Provide a paved area at each end of each operational runway.
- Be large enough to accommodate two of the largest aircraft assigned to the air base simultaneously.
- Be configured to allow 20-foot wingtip clearance between aircraft on the pad and 50-foot clearance between parked aircraft and aircraft passing on the adjoining taxiway.
- Be positioned so the pilot of an aircraft on the holding pad has a clear view of the active taxiway, the control tower, and the runway end where he must move for takeoff.
- Allow parked aircraft to face both the runway end and the taxiway while headed into the wind.

Operational Apron

The paved areas required for aircraft parking, loading, unloading, maneuvering, and servicing are called operational-parking aprons. Aircraft should normally be able to move in and out of parking spaces under their own power.

Consider the following factors when determining the size of the operational apron:

- Aircraft size.
- Aircraft maneuverability.
- Jet engine blast.
- Distance between fueling outlets.
- Fire and explosion hazards.

The minimum wingtip clearance for aircraft taxiing or parked on the operational apron is 10 or 20 feet, depending on aircraft use categories.

The air base commander determines the smallest operational apron required to fit the expected number of aircraft at any particular time. The operational apron provides access to hydrant fueling outlets, maintenance areas, the runway access taxiway, and other facilities to which tactical and support aircraft must taxi from the apron.

Jet aircraft must operate within a designated parking area so the blast velocity and temperature will not injure personnel or damage other aircraft or facilities. Safe clearance to the rear of a jet engine is that area in which the blast velocity does not exceed 35 mph and the temperature does not exceed 100°F. The apron configuration at each base depends on the number and type of aircraft to be parked and the local apron and terrain features.

The operational apron is usually designed to accommodate 100 percent of assigned aircraft, with reductions (based on experience) for aircraft that can be parked in maintenance areas. Also consider the concept of maintaining unit integrity in an operational apron.

Cargo Apron

Besides the normal tactical mission, some air bases have a supplementary cargo or transport mission. Such a mission affects airfield layout and criteria in two ways-the pavement may have to be strengthened, and additional operational (loading and unloading) aprons must be provided. These additional requirements are determined by frequency of operation, total number of cargo aircraft involved, air-traffic-control rate, runway saturation rate, and station workload capabilities.

Experience from within the TO or a specific assessment by the troop transport commander should determine apron requirements. Use an estimate of 10 percent of the total number of cargo aircraft in the operation, or estimate the additional apron areas required by multiplying the number of aircraft to be accommodated at anytime by the factors shown in Table 11-8.

CALIBRATION HARDSTAND

Modern tactical aircraft contains navigational, bombing, and gunnery equipment that must be maintained within a given accuracy to produce the desired precision. To ensure these results, the equipment must be properly calibrated at fixed intervals after each engine change or anytime a major modification is made to the aircraft. Failure to perform this calibration periodically reduces the ability of the aircraft to complete its assigned mission.

A calibration facility normally consists of a calibration hardstand and a firing-in butt. This facility provides a suitable means for aligning an aircraft or the precise calibration of all types of navigation, bombing, and gunnery equipment in the aircraft. The calibration hardstand was formerly called a *compass swinging base.* For nontactical missions, this facility is limited to the hardstand required for calibration.

Table 11-8. Factors for determining cargo apron areas

Aircraft Type	Area per Aircraft (square yards)
C-130	4,280
C-141	6,290
C-5A	12,450
C-17	11,250

The hardstand is a level, surfaced area marked with precision alignment indications accurate to within 0.25 of 1 degree. Because of the calibration operation involved, locate the paved hardstand in an area where the local magnetic influence is at a minimum.

CORROSION CONTROL HARDSTAND

Aircraft must always be kept clean. Dirt, grime, oil, and grease on aircraft increase airflow drag, promote corrosion, change balance, slow the dissipation of heat from the engines, and prevent effective aircraft inspection for airframe and mechanical failures.

Aircraft corrosion control facilities, called *washing areas,* are specifically designed with the necessary tools for washing and cleaning aircraft quickly and efficiently. The design must provide adequate drainage facilities to dispose of large quantities of water, oil, and other substances.

AIRCRAFT PROTECTION FACILITIES

Aircraft revetments may be needed for protection against small-arms fire, mortars, strafing attacks, and near misses with conventional bombs and to prevent sympatthetic detonation of explosives on nearby aircraft. Any of the various types of open revetments or soft shelters may be used. Chapter 14 discusses revetment details.

AIRCRAFT MAINTENANCE FACILITIES

The maintenance mission and facilities of air bases depend on the number and type of aircraft assigned and the degree of maintenance desired. The theater commander specifies the maintenance mission. Therefore, it is impossible to forecast the exact type of facilities required at any TO base. In general, the following guidelines may be used:

Initial Construction

On air bases provided with initial facilities, no area is specifically laid out as a maintenance site. Aircraft maintenance is done at the parking aprons. Portable nose hangars or improvised portable shelters that fit over the engine may be used to protect personnel from advance weather. Mobile shops containing tools and necessary power equipment are transferred from aircraft to aircraft as needed. Aircraft requiring major repairs or overhaul are sent to rear area maintenance facilities if possible.

Temporary Construction

An air base provided with temporary facilities usually has a maintenance site that has facilities needed for the proper and efficient maintenance and repair of aircraft. Keep the area free of all structures and other facilities except those directly concerned with technical functions. The maintenance site should contain the required hangars, shops, and covered and open storage. Covered floor space requirements can be met with tentage, prefab or portable structures, frame TO fixed structures, or converted existing structures. The choice of facilities depends on locale, tactical situation, weather conditions, duration of operational usage, and related factors.

In a moving tactical situation or under temporary static conditions, tentage or converted existing structures are normally used. Prefab, portable, or frame TO fixed structures are used under more stable conditions. For information on portable structures and frame TO fixed construction, see FM 5-430-00-1/AFPAM 32-8013, Vol 1, and TM 5-302-series. An important factor in the relative locations of maintenance facilities, particularly hangars, is the functioning of the control tower.

AIDS TO NAVIGATION

Aids to navigation are both visual and nonvisual. Nonvisual aids are required to guide and control flying activities, particularly with instrument flight rules (IFR), when weather or other conditions demand instrument flying. Visual aids are necessary with visual flight rules (VFR) when flight operations are conducted at night or under conditions of reduced visibility. For a detailed discussion of aids to navigation, see Air Force Instruction (AFI) 32-1044 for Air Force airfields and TM 5-823-4 for Army airfields. Principal aids to navigation are airfield markings, airfield lighting, and NAVAID. Control towers are grouped with NAVAIDs.

Airfield marking and lighting aids to air navigation are considered as elements of the airfield. They are related to construction stages discussed in Chapter 10 as follows:

- Stage I construction is authorized under construction combinations A and B.
- Stage II construction is authorized under construction combinations C and D.
- Stage III construction is authorized under construction combinations E and F.

NAVAID facilities are related to construction types as follows:

- Initial construction of NAVAID facilities is authorized under combinations A and B (Table 10-1, page 10-13).
- Temporary construction of NAVAID facilities is authorized under combinations C, D, E, and F (Table 10-1).
- At no time will temporary NAVAID facilities be emplaced on a temporary runway.

AIRFIELD MARKING

THIS SECTION IMPLEMENTS STANAG 3158 (EDITION FOUR) AND STANAG 3685 (EDITION TWO).

The airfield marking system is a visual aid in landing aircraft. It requires illumination from either an aircraft lighting system or daylight. Standards for airfield marking have been adopted by the Army and Air Force. Determination of an airfield marking system is a TO responsibility and is a prerogative of the etheater commander. The methods and configurations described here are those most commonly applicable to TO use. For a more detailed discussion of airfield marking, see TM 5-823-4, TM 5-302-series, AFCS facility drawings, and AFI 32-1044.

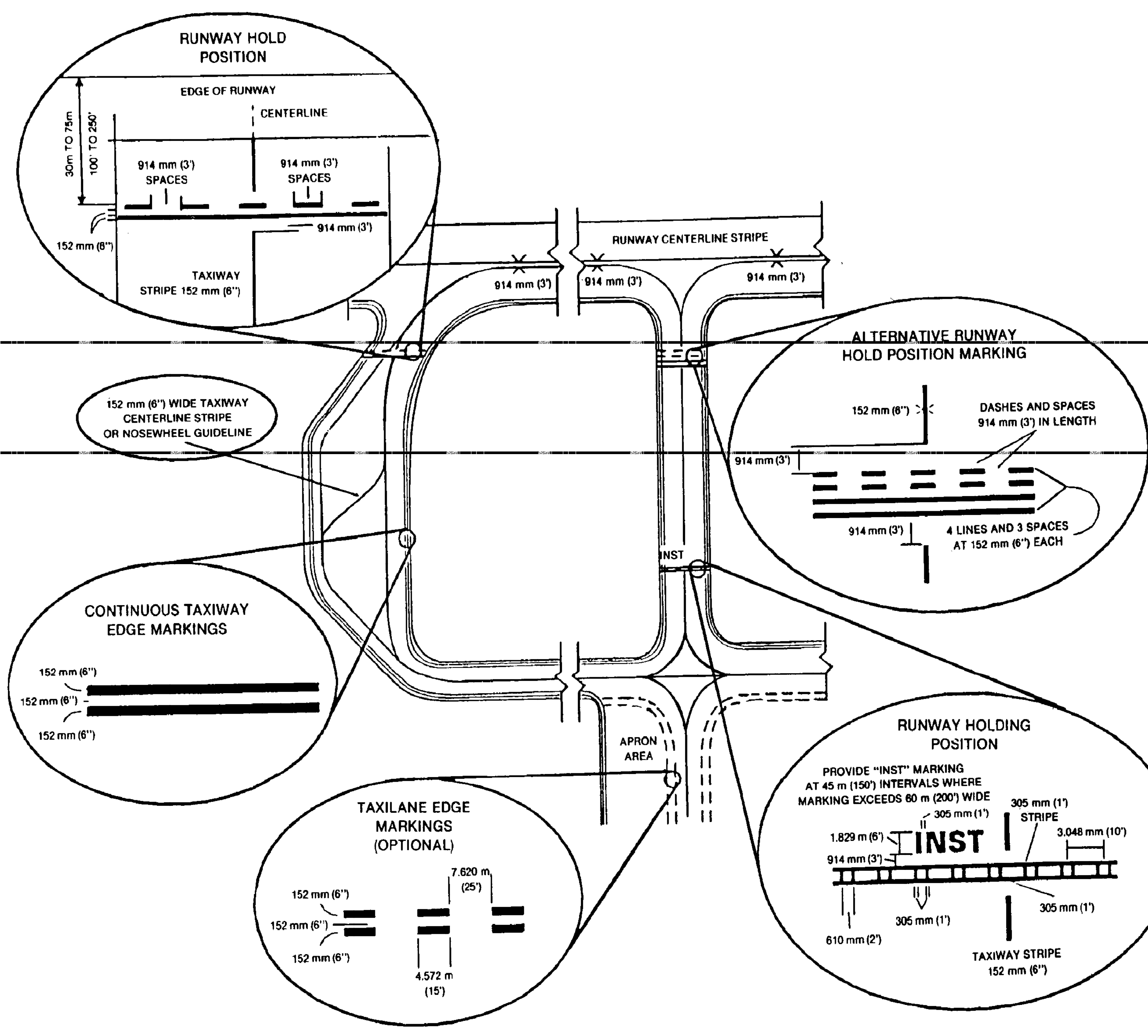
Runway Markings

The following four elements of markings apply to runways in general. Figure 11-16 shows the proper use of these markings.

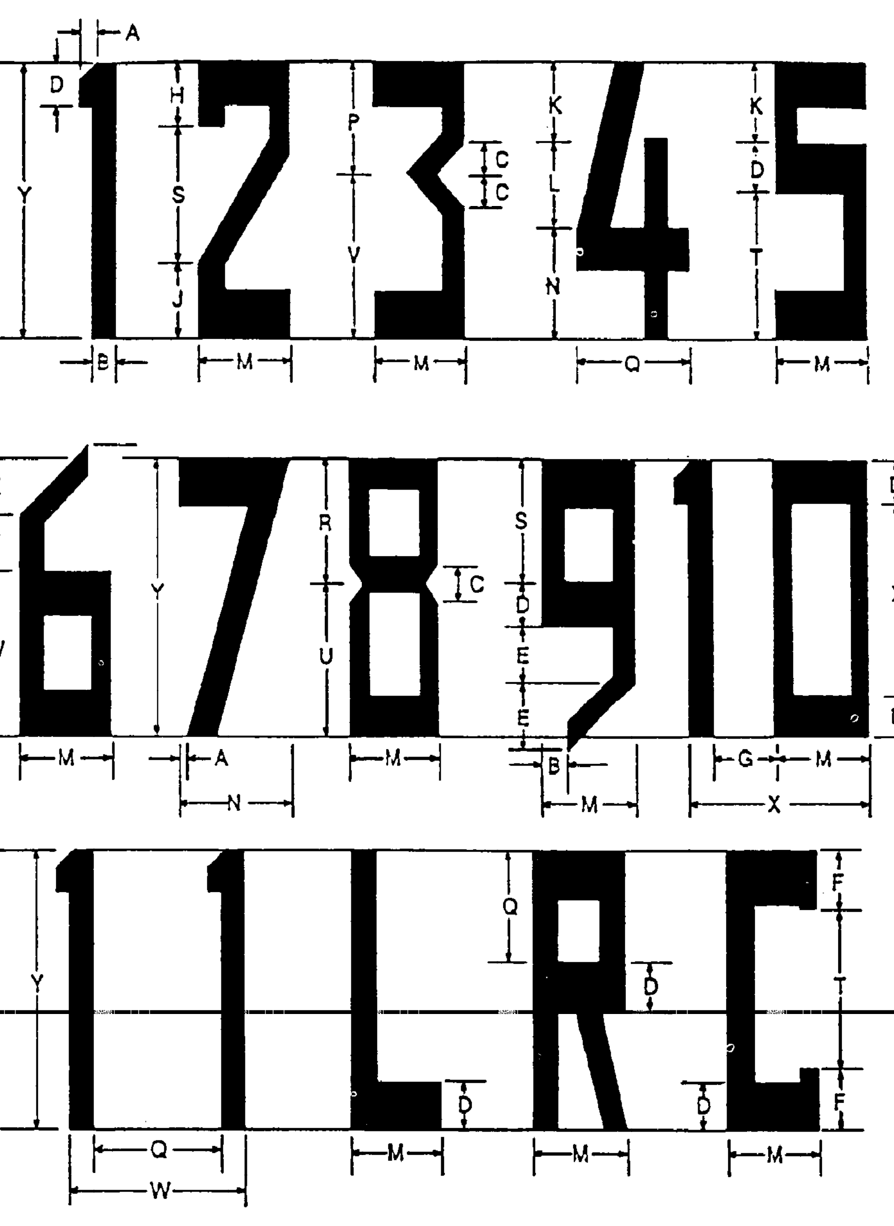
- *Centerline marking.* The centerline marking is a broken line with 100-foot dashes and 60-foot blank spaces. The minimum width for the basic runway centerline marking is 18 inches. For precision and nonprecision instrument runways, the minimum width is 3 feet.
- *Runway designation numbers.* Runway designation numbers are required on all runways (basic, precision, and nonprecision instrument). They are not required on a minimum operating strip or short-field assault strip. The numbers designate the direction of the runway and accent the end limits of the landing and takeoff area. Figure 11-16 shows the dimensions and forms of standard direction numbers. The number assigned to the runway is the whole number closest to one-tenth the magnetic azimuth of the centerline of the runway, measured clockwise from magnetic north. Single digits are preceded by a zero.
- *Threshold marking.* Threshold marking is required on all precision—and nonprecision-instrument runways. Threshold markings for runways at least 150 feet wide are shown in Figure 11-16. On runways less than 150 feet wide, start the threshold markings 10 feet from each edge of the runway. Reduce all other widths in proportion to the reduction in the overall width of the threshold marking.
- *Touchdown-zone markings and edge stripes.* Keep their use in the TO to a minimum because of the time and effort required to obliterate them if the tactical situation requires it. Touchdown zone markings and edge strips are required on runways served by a precision instrument approach.
- *Fixed-distance markings.* Fixed-distance markings are rectangular painted blocks 30 feet wide by 150 feet long beginning 1,000 feet from the threshold. They are placed equidistance from the centerline, 72 feet apart at the inner edges. They are required on all runways that are 150 feet wide or wider, 4,000 feet long or longer, and used by jet aircraft.

Expedient Runway Marking

For expedient construction, surfacing is normally soil-stabilized pavement, membrane, or air-field landing mat. Do not provide runway direction numbers on landing mat surfaces. Put an inverted *T* at the end of the runway, combined with a centerline stripe, and edge markings, combined with a transverse stripe mark at the threshold, at 500 feet and at the midpoint of the runway.

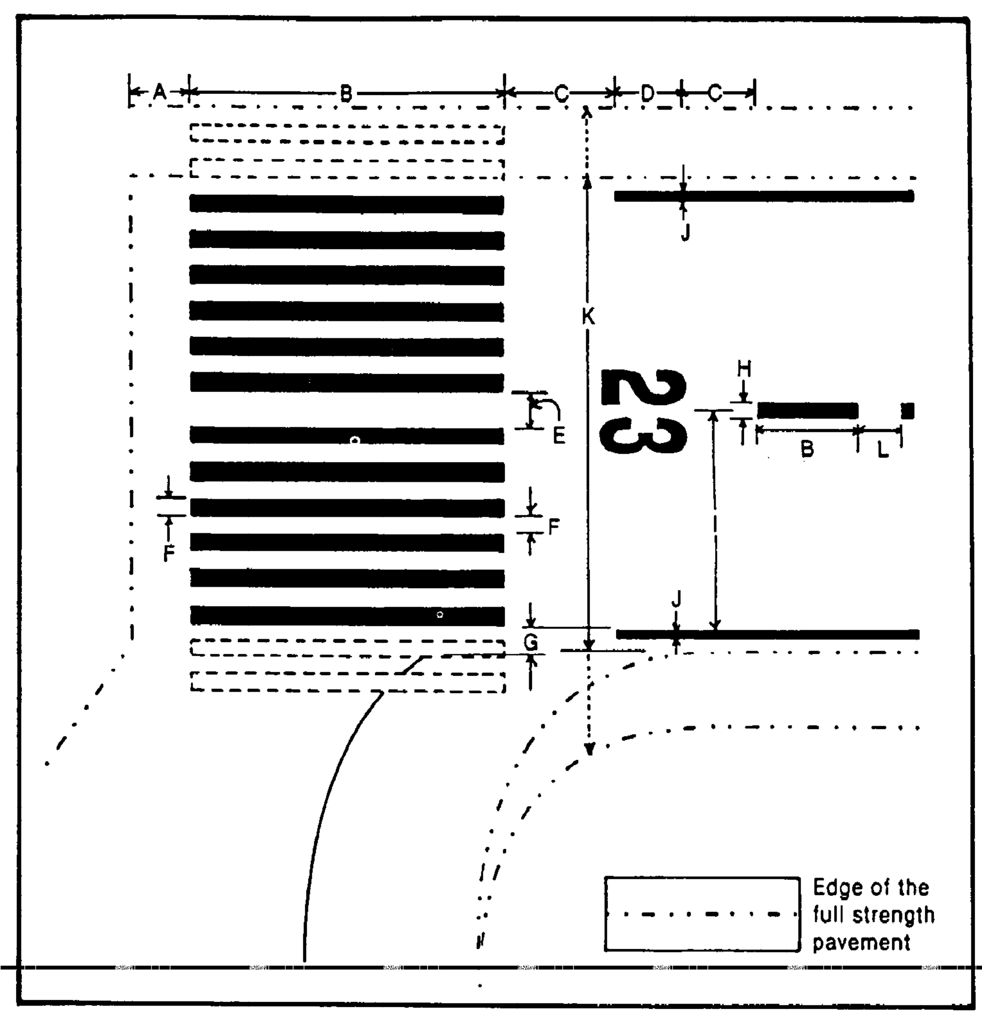


TAXIWAY MARKINGS



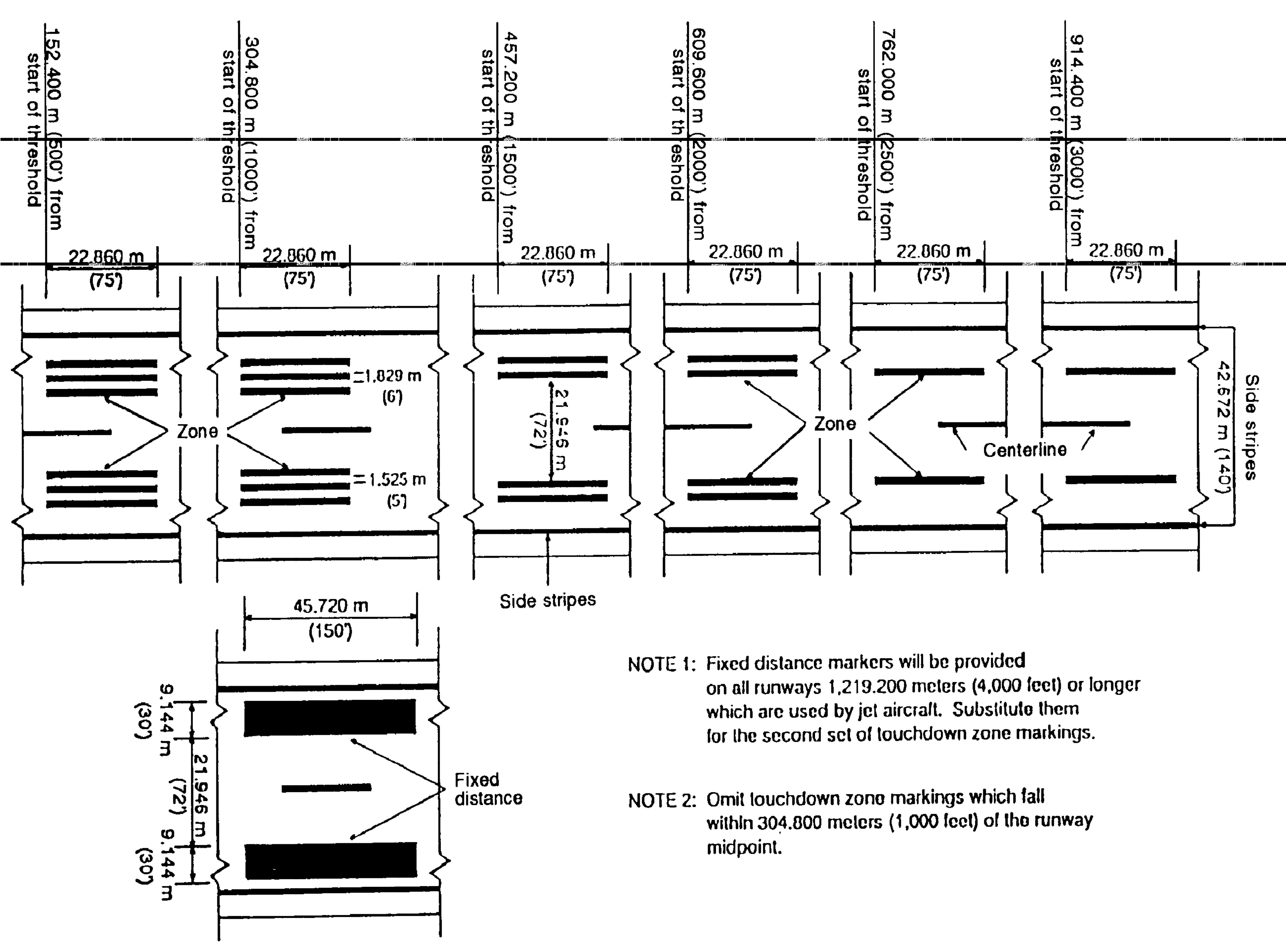
Dimension	Milli-meters	Feet	Dimension	Milli-meters	Feet	Dimension	Milli-meters	Feet
A	305	1.0	J	2590	8.5	S	4115	13.5
B	762	2.5	K	2743	9.0	T	4877	16.0
C	1066	3.5	L	2896	9.5	U	5182	17.0
D	1524	5.0	M	3048	10.0	V	5486	18.0
E	1981	6.5	N	3505	11.5	W	5639	18.5
F	2134	7.0	P	3658	12.0	X	6096	20.0
G	2286	7.5	Q	3810	12.5	Y	9144	30.0
H	2438	8.0	R	3962	13.0			

RUNWAY DESIGNATION NUMBERS AND LETTERS



Dimension	Meter	Feet
A	6.100	20.0
B	30.500	100.0
C	12.200	40.0
D	9.150	30.0
E	3.660	12.0
F	1.830	6.0
G	1.520	5.0
H	0.460-0.920	1.5-3.0
I	21.336	70.0
J	0.914	3.0
K	45.720-60.960	150-200
L	18.288	60.

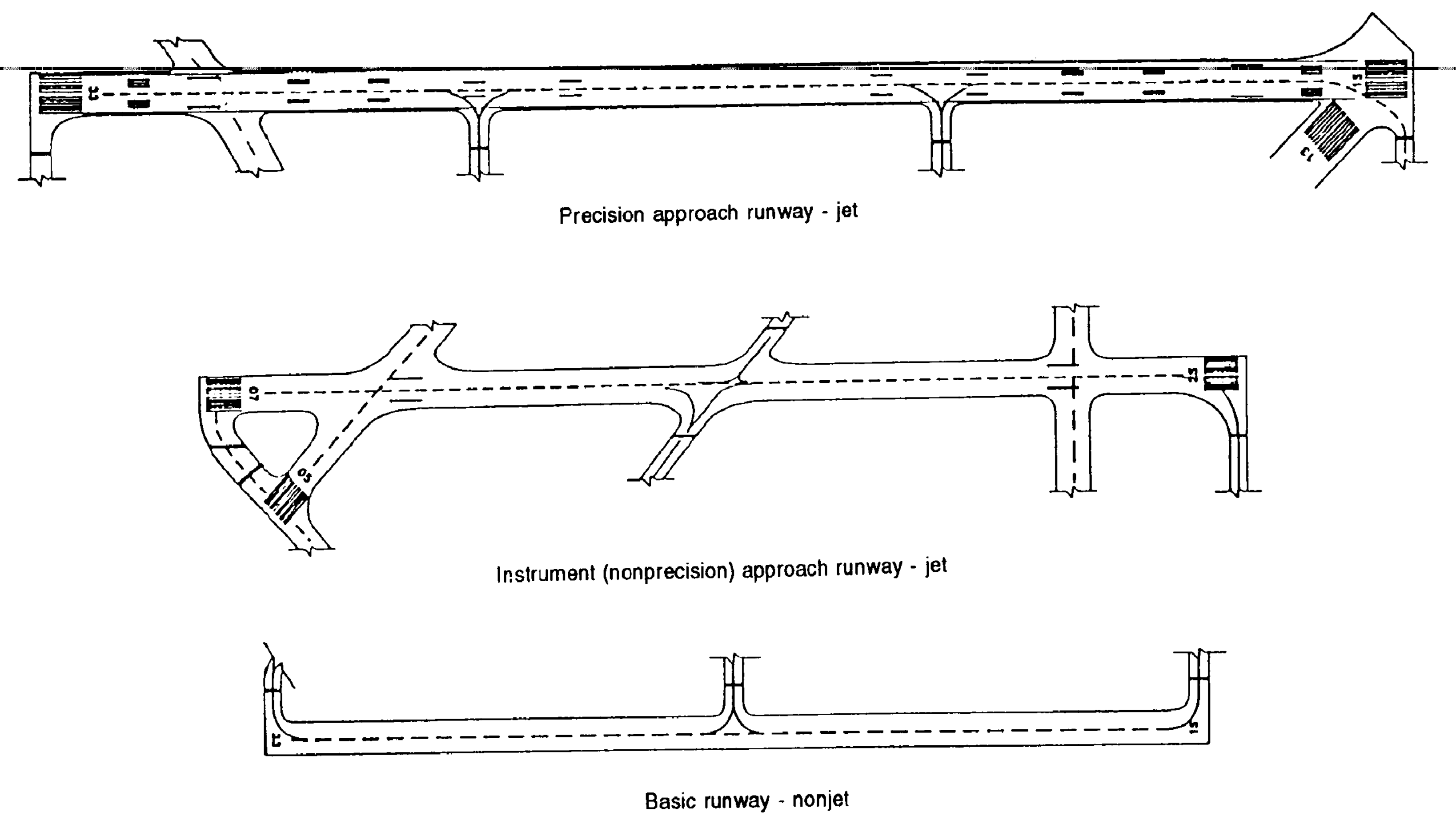
THRESHOLD , DESIGNATION NUMBER, EDGE STRIPE, AND CENTERLINE LAYOUT



NOTE 1: Fixed distance markers will be provided on all runways 1,219.200 meters (4,000 feet) or longer which are used by jet aircraft. Substitute them for the second set of touchdown zone markings.

NOTE 2: Omit touchdown zone markings which fall within 304.800 meters (1,000 feet) of the runway midpoint.

TOUCHDOWN ZONE AND FIXED DISTANCE MARKINGS


Precision approach runway - jet

Instrument (nonprecision) approach runway - jet

Basic runway - nonjet

RUNWAY MARKING SCHEMES

Figure 11-16. Markings for Army runway and landing zone

Taxiway Marking

Mark taxiways to conform with the following requirements shown in Figure 11-16.

- Centerline stripes. Mark each taxiway with a single, continuous stripe along the centerline, These stripes should have a minimum width of 6 inches. At taxiway intersections with runway ends, taxiway stripes should end in line with the nearest edge of the runway. At taxiway intersections, the taxiway centerline markings should intersect.

- Holding line marking. Place a taxiway holding line marking not less than 100 feet and not more than 200 feet from the nearest edge of the runway or taxiway that the taxiway intersects (see Figure 11-16, page 11-23). Measure this distance on a line perpendicular to the centerline of the runway or taxiway that is intersected. Increase the distance from the minimum 100 feet to whatever distance is necessary to provide adequate clearance between large aircraft operating on the runway or taxiway and the holding aircraft.

Marking Materials and Methods

The materials and methods used in airfield marking must provide visual contrast with the airfield surface, They vary primarily with the type of surface and less directly with the construction type or stage. Fewer permanent materials require constant maintenance. Use the following guides to select marking materials:

- Paint is used only on permanent surfaces.

- Lime is used primarily for marking unsurfaced areas such as earth, membranes, or similar surfaces.

- Oil or similar liquids are used for marking unsurfaced areas.

- Panels made of materials such as cloth or canvas, properly fastened to the pavement, may be used for many marking requirements.

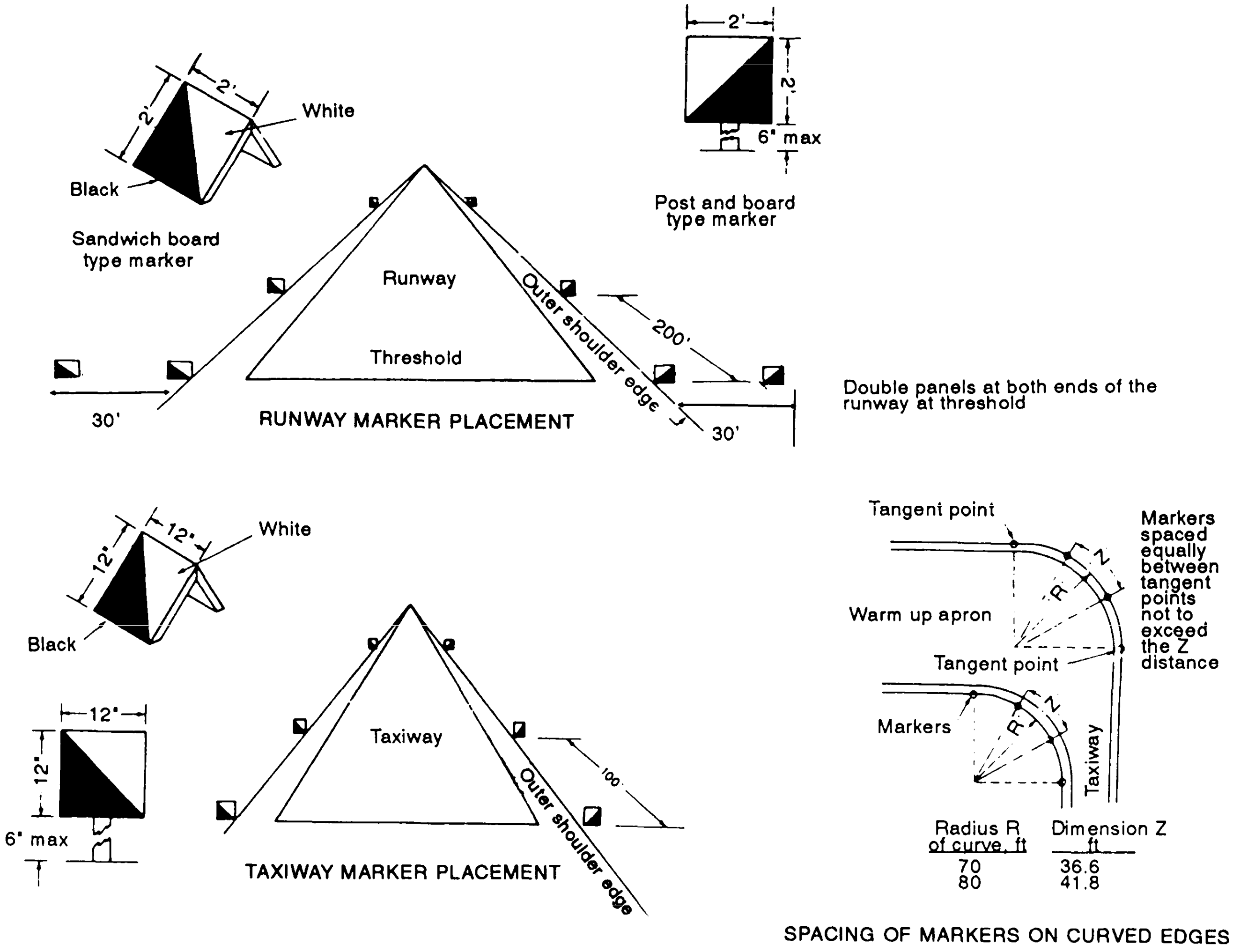
Use yellow flags to show temporary obstructions caused by flying accidents or enemy action. As temporary expedients, sandwich-board markers or stake-mounted signs may be used to define the runway width. These markers, 2 feet by 2 feet in size, have black-and-white triangles on each side, They are spaced 200 feet apart longitudinally on the outer edge of the runway shoulder.

For taxiways, sandwich-board markers or flat pieces of wood or metal painted with black-and-white triangles may serve as expedient markers. Fasten these 12- by 12-inch markers to stakes and place them 100 feet apart along the outer edge of the taxiway shoulder.

All expedient markers should be lightweight and constructed to break readily if struck by an aircraft. They should never be hazardous to aircraft. Figure 11-17 shows several types of expedient markers. Markers for snow-covered runways should be conspicuous. Upright spruce trees, about 5 feet high, or light, wooden tripods may be used. Place the markers along the sides of the snow-covered runway. Space them not more than 330 feet apart and locate them symmetrically about the axis of the runway. Place enough markings across the end of the runway to show the threshold. Aluminum powder and dyes can effectively mark snow in the runway area.

AIRFIELD LIGHTING

Airfield lighting includes the systems of illuminated visual signals that help pilots in the safe, efficient, and timely operation of aircraft at night and during periods of restricted visibility (IFR conditions). In general, airfield lighting is comprised of runway lighting, approach lighting, taxiway lighting, obstruction and hazard lighting.



NOTE: Markers for the runway and taxiway may be either the sandwich board type or the post and board type.

Figure 11-17. Types of expedient airfield markers

beacons, lighted wind direction indicators, and special signal lights. Not all these items are included in TO airfields. Normally, all lighting (except certain obstruction lighting) is controlled from the control tower. The lighting system includes all control devices, circuit protective devices, regulators, transformers, mounting devices, and accessories needed to produce a working facility.

The configuration, colors, and spacing of runway, approach, and taxiway lighting systems are uniform regardless of the anticipated length of service of the installation, the mission of the tenant organization, or the method of installation.

The colors and configuration used in airfield lighting generally are standardized on an international scale, and there is no difference between permanent and TO installations. The basic color code follows:

- Blue-taxiway lighting.
- Clear (white)-sides of a usable landing area.
- Green-ends of a usable landing area (threshold lights). When used with a beacon, green indicates a lighted and attended airfield.

- Red-hazard, obstruction, or area unsuitable for landing.
- Yellow-caution. When used with a beacon, yellow indicates a water airport.

Airfield lighting requirements are detailed in AFI 32-1044.

Runway Lighting

Runway lighting, the principal element of airfield lighting, provides the standard pattern of lights to outline the runway and to show side and end limits. Side limits are marked by two parallel rows of white lights, one row on each side of and equidistant from the runway centerline. Lights within the rows are uniformly spaced, and the rows extend the entire length of the runway. End limits are outlined by green runway threshold lights, which are visible from all sides and vertical angles.

Space runway threshold lights along the threshold line, which is 0 to 10 feet from the end of the runway and perpendicular to the centerline extended off the runway. Runway lighting is divided into two classes-high intensity to support aircraft operations under IFR conditions and medium intensity to support aircraft operations under VFR conditions.

Approach Lighting

This system of lights is used to guide aircraft safely to the runway on airfields intended for instrument flying and all-weather operations. The system is installed in the primary approach to the Stage II runway. Its use is generally confined to installations that are or will be provided with precision, electronic, low-approach facilities. Never use approach lighting with a medium-intensity runway lighting system.

Taxiway Lighting

When an airfield becomes fully operational, lights and reflectors are used to increase safety in ground movements of aircraft. Taxiway lighting is standardized. In general, blue taxiway lights mark the lateral limits, turns, and terminals of taxiway sections.

Reflectors are also used to delineate taxiways. Standard taxiway reflectors are panels approximately 12 inches high by 9 inches wide. Both sides of the panels consist of a retroreflective material that reflects incident light back to the light source (aircraft landing or taxiing lights). Mounting wickets can be manufactured locally from galvanized steel wire, size Number 6 or larger. The wire, cut into 42-inch pieces, is bent into a U-shape so parallel sides are 7 1/2 inches apart.

Install reflectors along straight sections and long-radius curves at 100-foot intervals. At intersections and on short-radius curves, set the reflectors 20 feet apart and perpendicular to one another. Embed wickets 12 to 15 inches in the ground and set them firmly. When reflectors are set where grass or other vegetation grows 2 inches or more in height, treat the ground surface with engine oil or salt to prevent this growth.

Beacons

Airport-type beacons are not commonly used in a combat zone. They may be used in rear areas of the TO. Mobile beacons are sometimes employed to transmit orders of the day, Beacons are considered organizational equipment and are not part of the construction program.

Lighted Wind-Direction Indicators

These indicators provide pilots with visual information about wind directions. Under conditions of radio silence, they are the only means available to the pilot to determine direction of landing and takeoff.

Special Signal Lights

Signal lights may be used to convey operating information to pilots during periods of radio silence. Such signals may be used to transmit orders of the day and to aid in air and ground traffic control. No standards for TO construction of signal lights are presently available. The theater commander determines the criteria necessary for construction.

Expedient Lighting

Expedients may be used for lighting if issue equipment is not available, Lanterns, smudge pots, vehicle headlights or reflectors may be used to distinguish runway edges. Reflectors are also useful when placed along taxiways and at handstands to guide pilots in the dark. An electrical circuit may be laid around the runway with light globes spaced at regular intervals and covered by improvised hoods made from cans. A searchlight, pointed straight in the air, is sometimes used as a substitute for beacon lights. The searchlight is placed beyond the downwind end of the runway. When the pilot is oriented, the searchlight is lowered so its beam shines down the runway to light it.

Portable airfield lighting is available for use. It is normally used when permanent lighting has been damaged or is not available. Tables 11-9 through 11-11, page 11-39, and Figures 11-18 through 11-20, page 11-38, show portable marking standards. Table 11-9 indicates portable markings for fixed-wing landing zones.

Lighting and Communication Cables

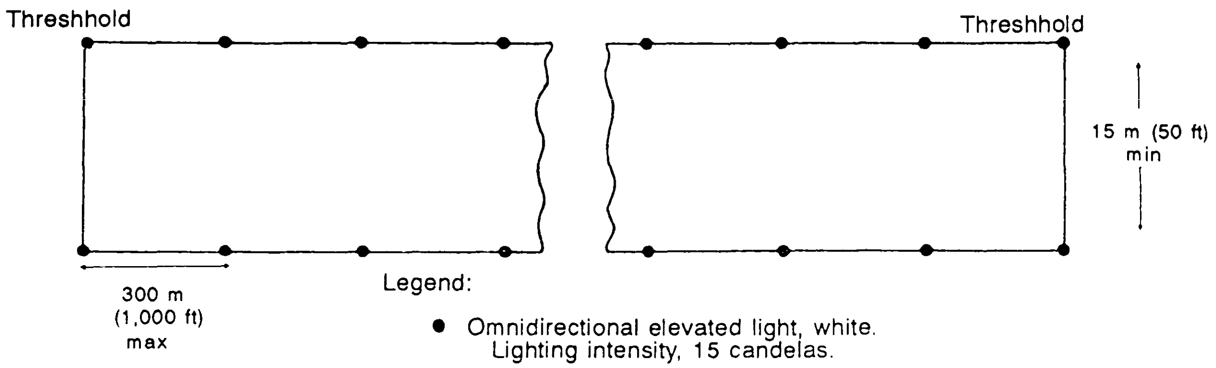
Place cables for lighting and communication in ducts when passing under taxiways, runways, ditches, and streams or where it is difficult to reach the cable for repairs. At a minimum, place three ducts transversely under the runway at its midpoint, one duct under the runway at each end, ducts under the taxiway approaches on both sides and both ends of the runway, one duct under the perimeter taxiway directly opposiste the three ducts under the midpoint of the runway, and ducts under all taxiways at all junctions with the runway or other taxiway. Locations may be

Table 11-9. Portable lighting requirements (operating criteria)

System Type	Visual Conditions	Maximum Installation Time	Typical Operational Period
1	Night Met vis 7 km	20 minutes	8 hours
2a. Visual approach	Night Met vis 3.7 km	20 minutes	8 hours
2b. Instrument approach	Night Met vis 800 m	20 minutes	8 hours
3	Day/Night Met vis 400 m	4 hours	Continuous

Table 11-10. Portable lighting requirements (light-fitting specifications)

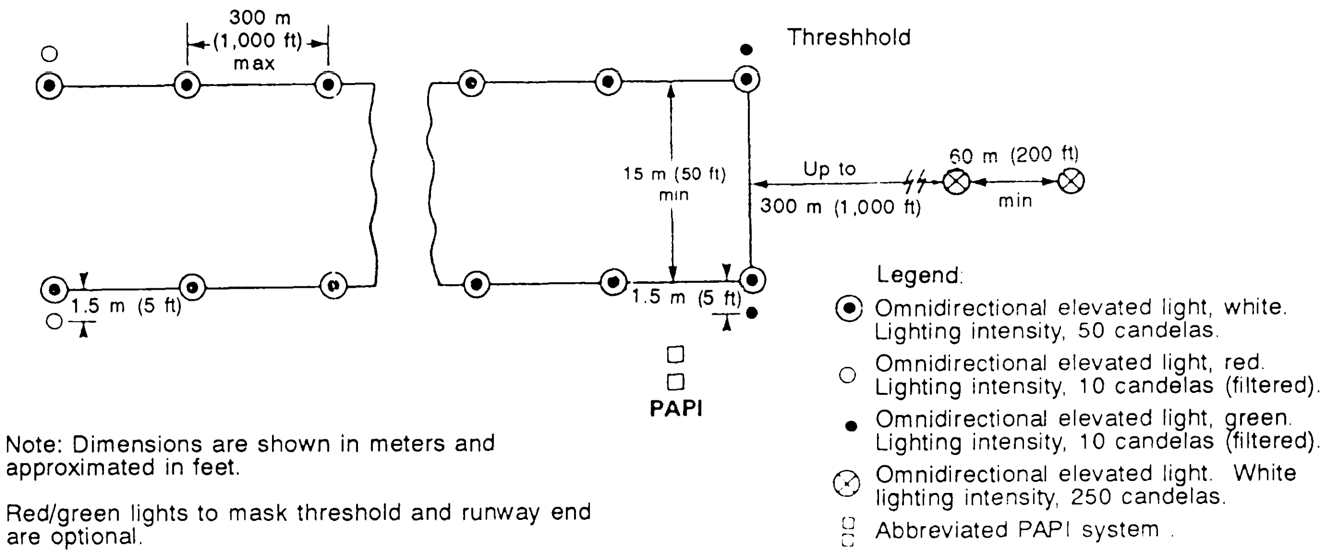
Light	Beam Spread	Intensity (Candelas)	Location
A	Omnidirectional	15	Runway edge
B	Omnidirectional	50	Runway edge
C	Omnidirectional	250	Approach
D	Uni-bidirectional	5,000	Runway edge, approach



Legend:

● Omnidirectional elevated light, white. Lighting intensity, 15 candelas.

Figure 11-18. Expedient airfield lighting layout - Type 1 System



Legend:

⊙ Omnidirectional elevated light, white. Lighting intensity, 50 candelas.

○ Omnidirectional elevated light, red. Lighting intensity, 10 candelas (filtered).

● Omnidirectional elevated light, green. Lighting intensity, 10 candelas (filtered).

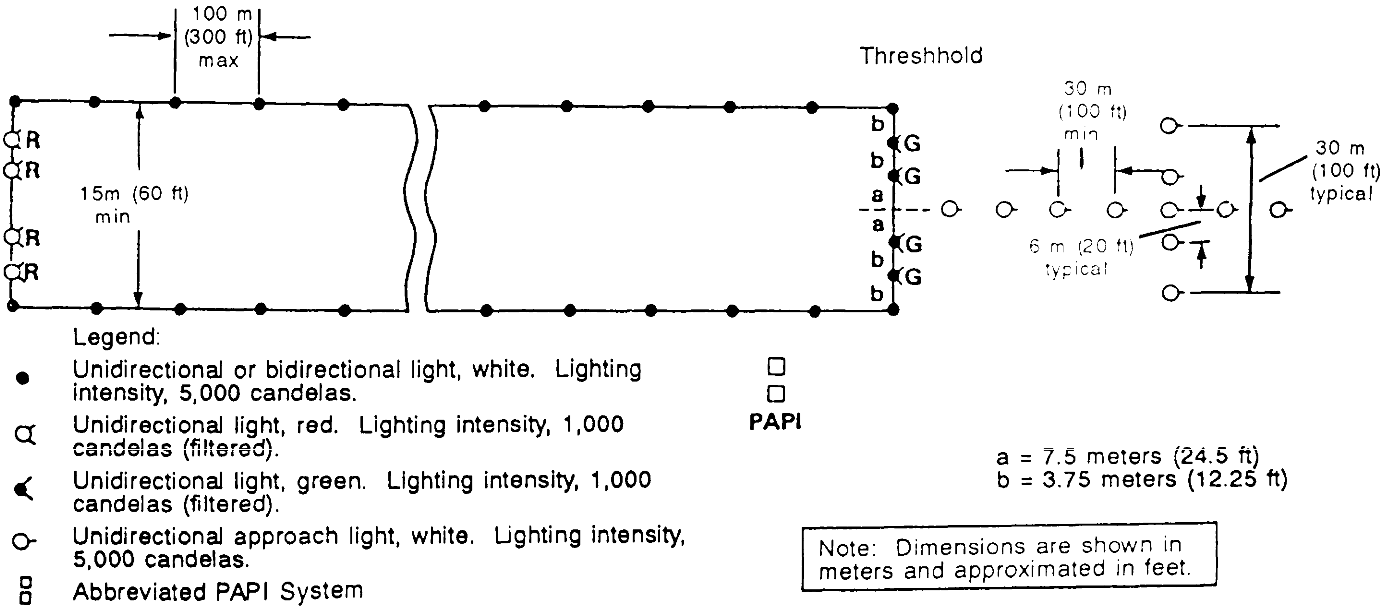
⊗ Omnidirectional elevated light. White lighting intensity, 250 candelas.

□ Abbreviated PAPI system .

Note: Dimensions are shown in meters and approximated in feet.

Red/green lights to mask threshold and runway end are optional.

Figure 11-19. Expedient airfield lighting layout - Type 2 System



Legend:

● Unidirectional or bidirectional light, white. Lighting intensity, 5,000 candelas.

ᗡ Unidirectional light, red. Lighting intensity, 1,000 candelas (filtered).

◀ Unidirectional light, green. Lighting intensity, 1,000 candelas (filtered).

○ Unidirectional approach light, white. Lighting intensity, 5,000 candelas.

□ Abbreviated PAPI System

a = 7.5 meters (24.5 ft)
b = 3.75 meters (12.25 ft)

Note: Dimensions are shown in meters and approximated in feet.

Figure 11-20. Expedient airfield lighting layout - Type 3 system

Table 11-11. Portable lighting requirements (light-system specifications)

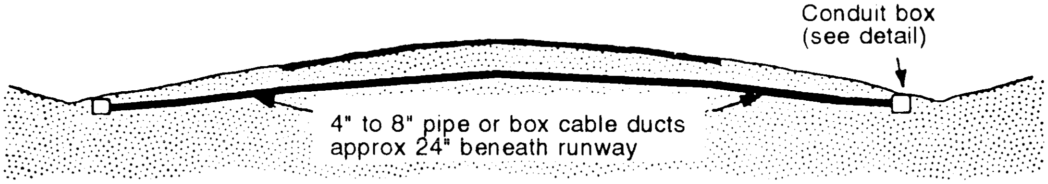
System Type	Light Type
1	A (Runway edge)
2	B (Runway edge) C (Approach) High intensity VGSI
3	D (Runway edge, approach) High intensity VGSI

modified or ducts may be added if required by field conditions.

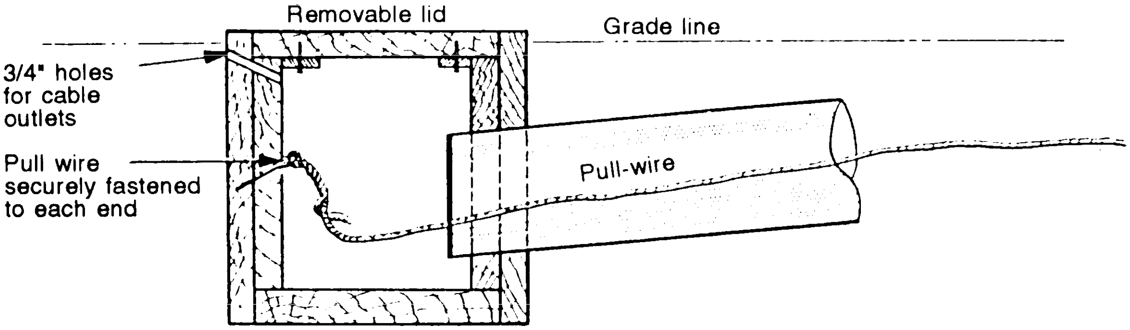
The cable duct should be 4 to 8 inches in diameter or an equivalent rectangle. It may be made with lumber, drain tile, building tile, water pipe, or corrugated metal pipe. To facilitate drainage, the duct may be placed roughly parallel to the runway surface. For convenience in stringing the communications circuits through the duct, leave a pull wire (approximately 9 gauge) in place during construction. Enclose each end securely in a conduit box with a heavy plank cover to keep earth out and to eliminate hazards to aircraft wheels. (See Figure 11-21.)

Obstruction Marking and Lighting

This type marking and lighting must be kept to a minimum in a TO, particularly in a combat zone. Specific criteria and details follow, Additional criteria can be found in TM 5-823-4.



RUNWAY CROSS SECTION



CROSS SECTION OF CONDUIT BOX
(strong wood box about one foot cube)

Figure 11-21. Cable duct details

OBSTRUCTION MARKING

THIS SECTION IMPLEMENTS STANAG 3346 (EDITION 4).

Obstructions are marked either by color, markers, or flags. Mark objects by color according to the following requirements:

- *Solid*. An object whose projection on any vertical plane in a clear zone is less than 5 feet in both dimensions and is colored aviation-surface orange.
- *Bands*. An object with unbroken surfaces whose projection on any vertical plane is 5 feet or more in one dimension and less than 15 feet in the other dimension. It is colored to show alternate bands of aviation-surface orange and white. Any skeleton (broken surface) structure or smokestack-type structure having both dimensions greater than 5 feet and is colored in alternate bands of aviation-surface orange and white.

The widths of the aviation-surface orange and white bands should be equal and should be approximately one-seventh the length of the major axis of the object if the band has a width of not more than 40 feet nor less than 1 1/2 feet. The bands are placed perpendicular to the major axis of the construction. The bands at the extremities of the object should be aviation-surface orange. Figures 11-22 and 11-23, pages 11-41 and 11-42, show the color requirements.

Checkerboard pattern. Objects with unbroken surfaces whose projection on any vertical plan is 15 feet or more in both dimensions. They are colored to show a checkerboard pattern of alternate rectangles of aviation-surface orange and white (Figure 11-23). The rectangles are not less than 5 feet and not more than 20 feet on a side, and the corner rectangles are aviation-surface orange. If part of or all the objects with spherical shapes do not permit the exact application of the checkerboard pattern, modify the shape of the alternate aviation-surface orange and white rectangles, covering the spherical shape to fit the struttural surface. Ensure the dimensions of the modified rectangles remain within the specified limits.

Marking by Markers

Use markers when it is impractical to mark the surface of objects with color. Markers are used in addition to color to provide protection for air navigation.

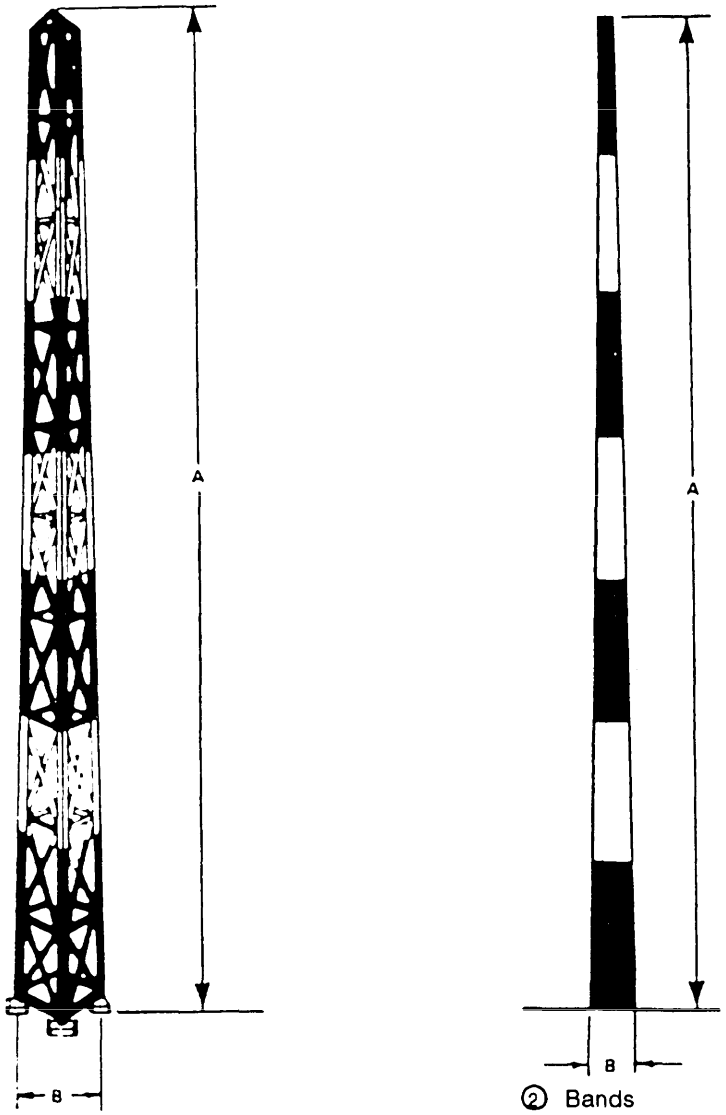
Obstruction markers should be distinctive so they are not mistaken for markers employed to convey other information. Color them as specified earlier. Markers should be recognizable in clear air from a distance of at least 1,000 feet in all directions from which an aircraft is likely to approach.

Position markers so the hazard presented by the object they mark is not increased. Locate markers displayed on or adjacent to obstructions in conspicuous positions to retain the general definition of the obstructions. Markers displayed on overhead wires are usually placed not more than 150 feet apart, with the top of each marker not below the level of the highest wire at the point marked. However, when overhead wires are more than 15,000 feet from the center of the landing area, the distance between markers may be increased to not more than 600 feet.

Marking by Flags

Use flags to mark temporary obstructions or obstructions that are impractical to mark by coloring or by markers. The flags should be rectangular and have stiffeners to keep them from drooping in calm or light wind. Use one of the following patterns on flags marking obstructions:

- Solid color, aviation-surface orange, not less than 2 feet on a side.
- Two triangular sections–one aviation-surface orange and one aviation-surface white–combined to form a rectangle not less than 2 feet on a side.
- A checkerboard of aviation-surface orange and aviation-surface white squares, each 1 foot plus or minus 10 percent on a side, combined to form a rectangle not less than 3 feet on a side.



① Bands

A & B—5 ft or more

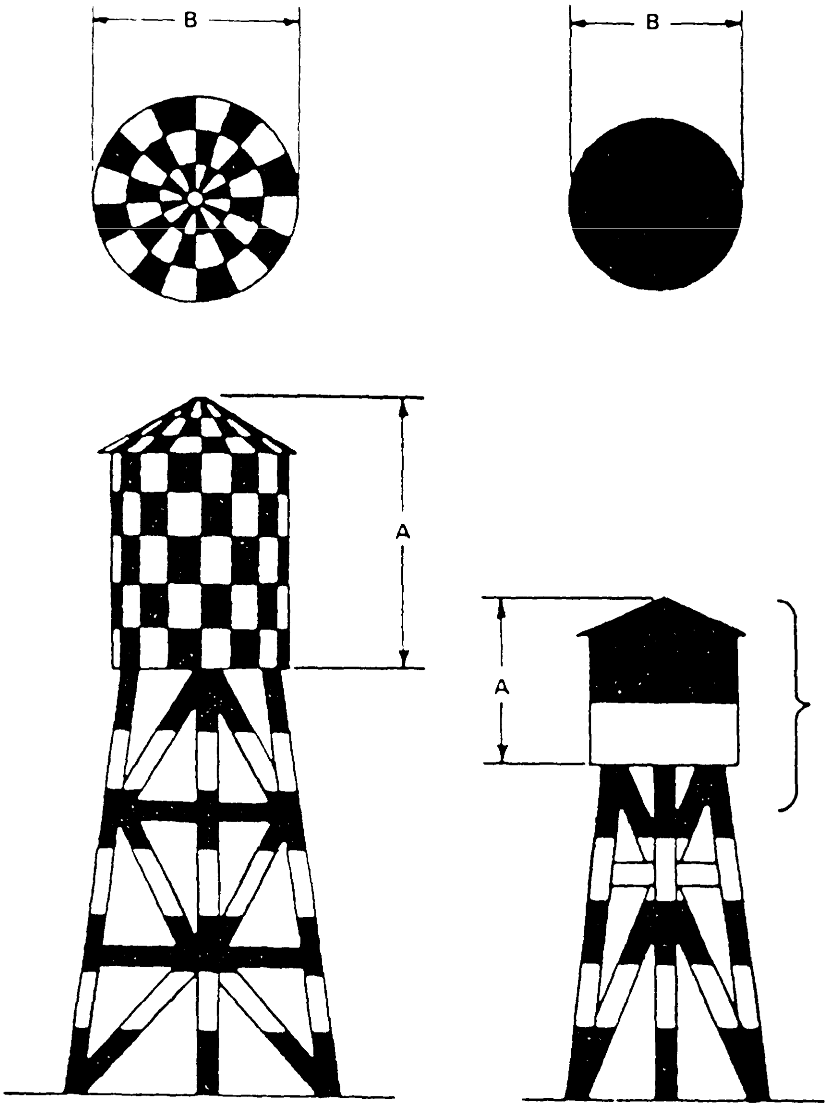
Applicable for skeleton and smokestack-type objects

② Bands

A—5 ft or more
B—less than 15 ft

Applicable for an object with essentially unbroken surfaces

Figure 11-22. Painting of towers, poles, and similar obstructions



Marking criteria shown in Figure 11-22, page 11-41, applies

Checkerboard pattern

A & B—15 feet or more

Applicable for an object with essentially unbroken surfaces

NOTE: For skeleton-type tower supports, marking criteria shown in Figure 11-22 applies.

Figure 11-23. Painting of water towers

Position the flags in such a way that the hazard they mark is not increased. Display flags on top of or around the perimeter of the highest edge of the object. Flags used to mark extensive objects or groups of closely spaced objects should be displayed at approximately 50-foot intervals.

OBSTRUCTION LIGHTING

Obstruction lights show the existence of obstructions. These lights are aviation red, with an intensity of not less than 10 candlepower. The number and arrangement of lights at each level should be such that the obstruction is visible from every angle. Figures 11-24 through 11-26, pages 11-44 through 11-46, illustrate methods of obstruction lighting.

Vertical Arrangement

Locate at least two lamps at the top of the obstruction, either operating simultaneously or circuited so that if one fails the other operates. An exception is made for chimneys of similar structures. The top lights on such structures are placed between 5 and 10 feet below the top. Where the top of the obstruction is more than 150 feet above ground level, provide an intermediate light or lights for each additional 150 feet or fraction thereof. Space the intermediate lights equally between the top light (or lights) and the ground level.

Horizontal Arrangement

Built-up and tree-covered areas have extensive obstructions. Where an extensive obstruction or a group of closely spaced obstructions is marked with obstruction lights, display the top lights on the point or edge of the highest obstruction. Space the lights at intervals of not more than 150 feet so they show the general definition and extent of the obstruction. If two or more edges of an obstruction located near an airfield are at the same height, light the edge nearest the airfield.

Lighting of Overhead Wires

When obstruction lighting of overhead wires is needed, place the lights not more than 150 feet apart at a level not below that of the highest wire at each point lighted. When the overhead wires are more than 15,000 feet from the center of the landing area, the distance between the lights may be increased to no more than 600 feet.

METHODS OF LIGHTING CONSTRUCTION AREAS

Three methods are used for lighting construction areas:

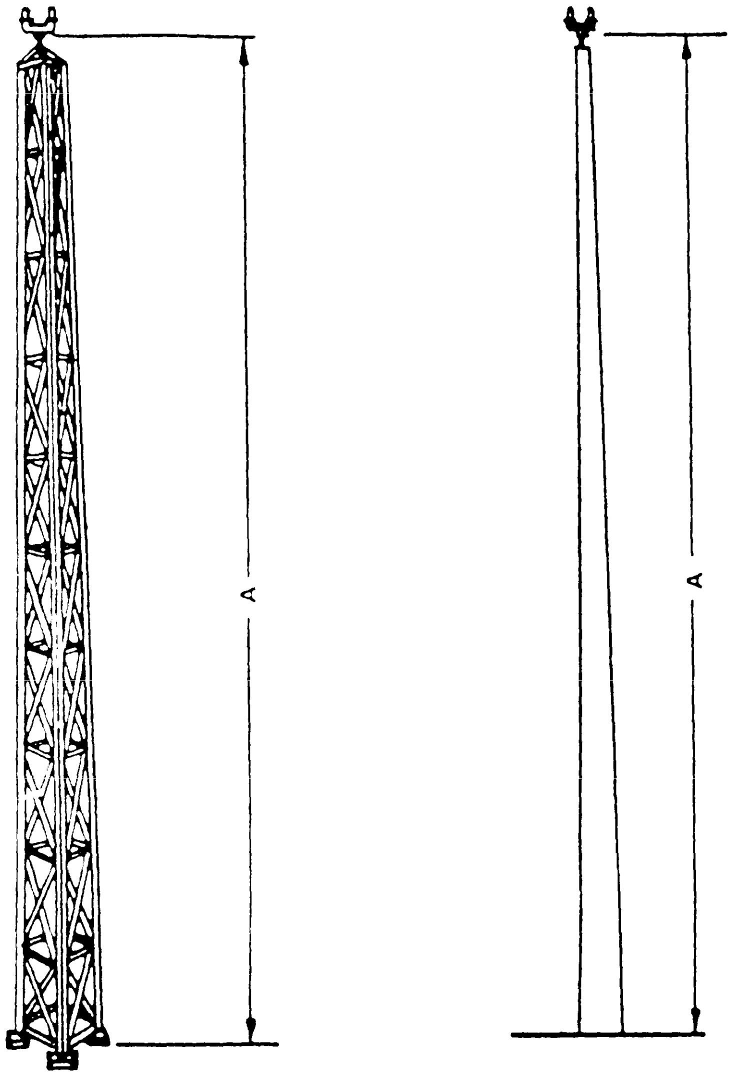
- Method A is normally confined to emergency airfields and to emergency repairs at more permanent installations. Precision methods of layout are not used, cables are laid on the ground, and lights are stake-mounted. The wind indicator is pipe-mounted instead of being placed on the tower.

- Method B is an upgrade of Method A, when emergency repairs might take a longer time to accomplish. Precision methods of locating fixtures are also not used. Cables are buried at least 6 inches. Remote control features, which are not usually provided with Method A installations, are used in Method B.

- Method C is used when installing airfield lighting. Construction should approach the standards outlined in AFI 32-1044 and TM 5-823-4. Cables are buried 24 inches below the finished grade. Lighting fixtures are precisely located and mounted in concrete bases. The wind indicator is tower-mounted.

NAVIGATIONAL AIDS

Navigational aids refer to the ground equipment and supporting facilities that provide electronic (radio and radar) assistance in the navigation of aircraft. NAVAIDs consist of components of equipment, housing, and utilities. Each component serves a specific mission in directing or assisting the direction of airborne aircraft.



A—not more than 150 ft

NOTE: Where *A* exceeds 150 feet, intermediate lights will be required for each additional 150 feet, or fraction thereof.

Figure 11-24. Lighting of towers, poles, and similar obstructions

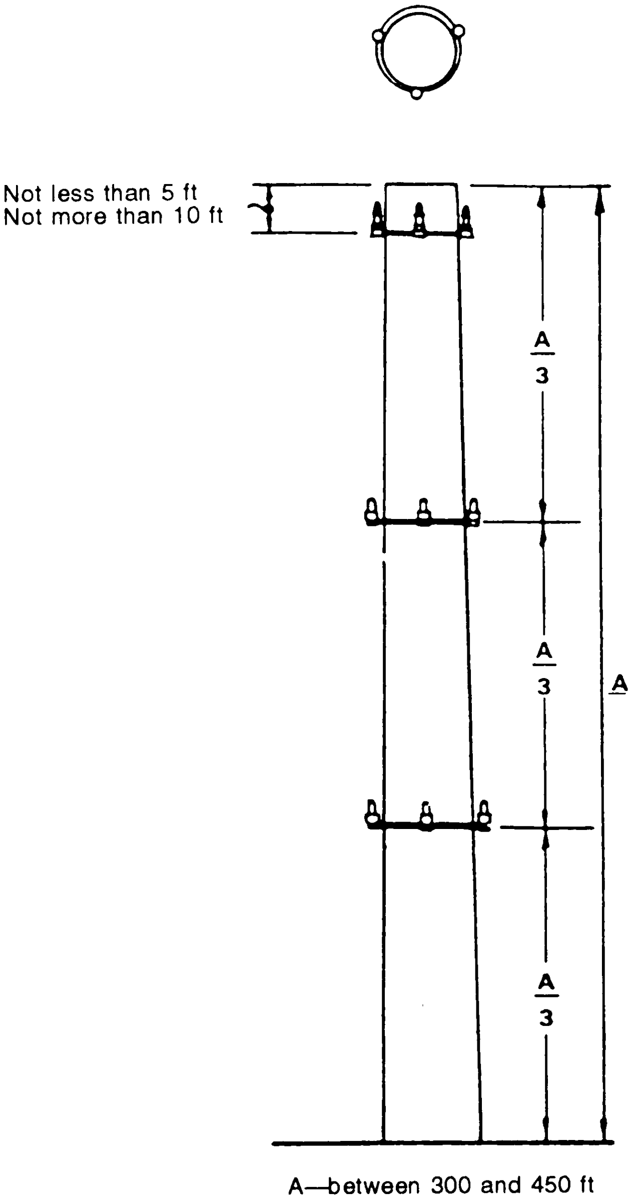
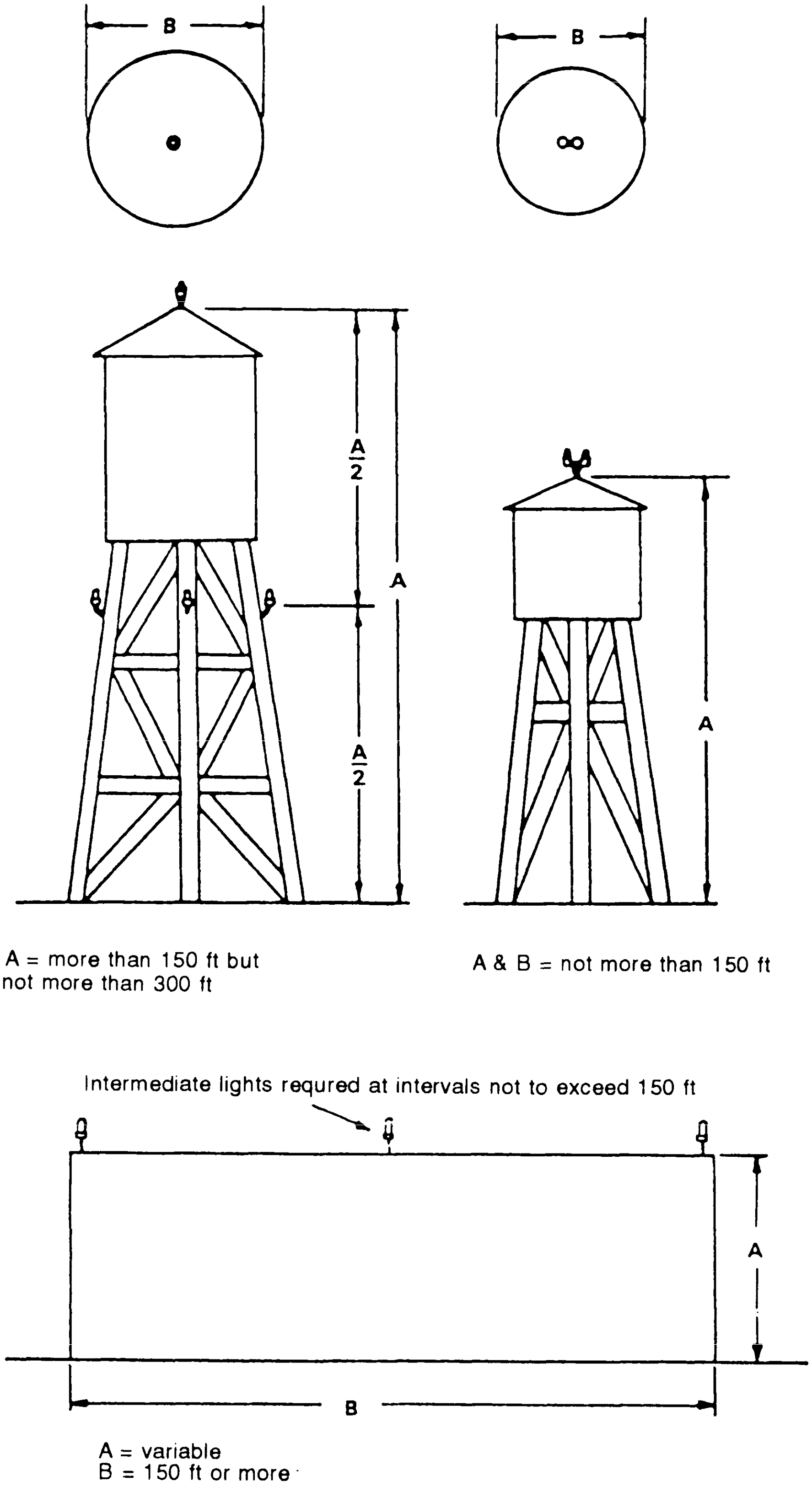


Figure 11-25. Lighting of smokestacks and similar obstructions



A = more than 150 ft but
not more than 300 ft

A & B = not more than 150 ft

Intermediate lights requred at intervals not to exceed 150 ft

A = variable
B = 150 ft or more

Figure 11-26. Lighting of water towers and similar obstructions

The NAVAIDs used in a TO include–

- Mobile and air-transportable search and precision approach radar ground-controlled approach (GCA).
- Radio homing beacons.
- Ultrahigh frequency direction finders (UHFDFs) and omnibearing distance equipment–tactical air navigation (TACAN).
- Radar beacons (RACONs).
- Remote receiver and transmitter buildings for temporary construction (used with control tower).
- Control tower.

Criteria and Requirements

Not all systems listed are required at any one base. Requirements are determined by factors such as base mission, type of aircraft, geographic location, terrain, and meteorological conditions. Final selection of the facilities required is made by the theater commander and requires technical determination by the AFCS or United States Army Aeronautical Services Office (USAASO).

When facilities selection is made, consider survivability by hardening (if use permits), tone down, camouflage, concealment, and other measures designed to complement any base vulnerability reduction program. The following NAVAIDs are the minimum desirable for planning and obstruction design purposes:

- Priority l-Mobile GCA and homing beacon on TACAN.
- Priority 2-UHFDF.
- Priority 3-RACON.

Most NAVAID equipment is portable and has self-contained housing that is adequate for short-time use. In more deliberate construction and for supporting hardstands or cable line, additional construction must be performed and building materials provided. The AFCS personnel provide, install, and erect all equipment, cables, and antennas. The USAASO personnel provide technical assistance only.

The construction force provides and constructs prefab housing, access roads, hardstands, and foundations (bases) for antennas. The construction force also cuts ditches or trenches for laying cable, although the actual cable laying and antenna erection are done by AFCS personnel supported by construction forces. The final siting of all facilities is done by AFCS and USAASO personnel. In this section, only approximate siting is given. Thus, NAVAIDs are considered in planning the layout of other facilities on a base. (See Figure 11-27, page 11-48.)

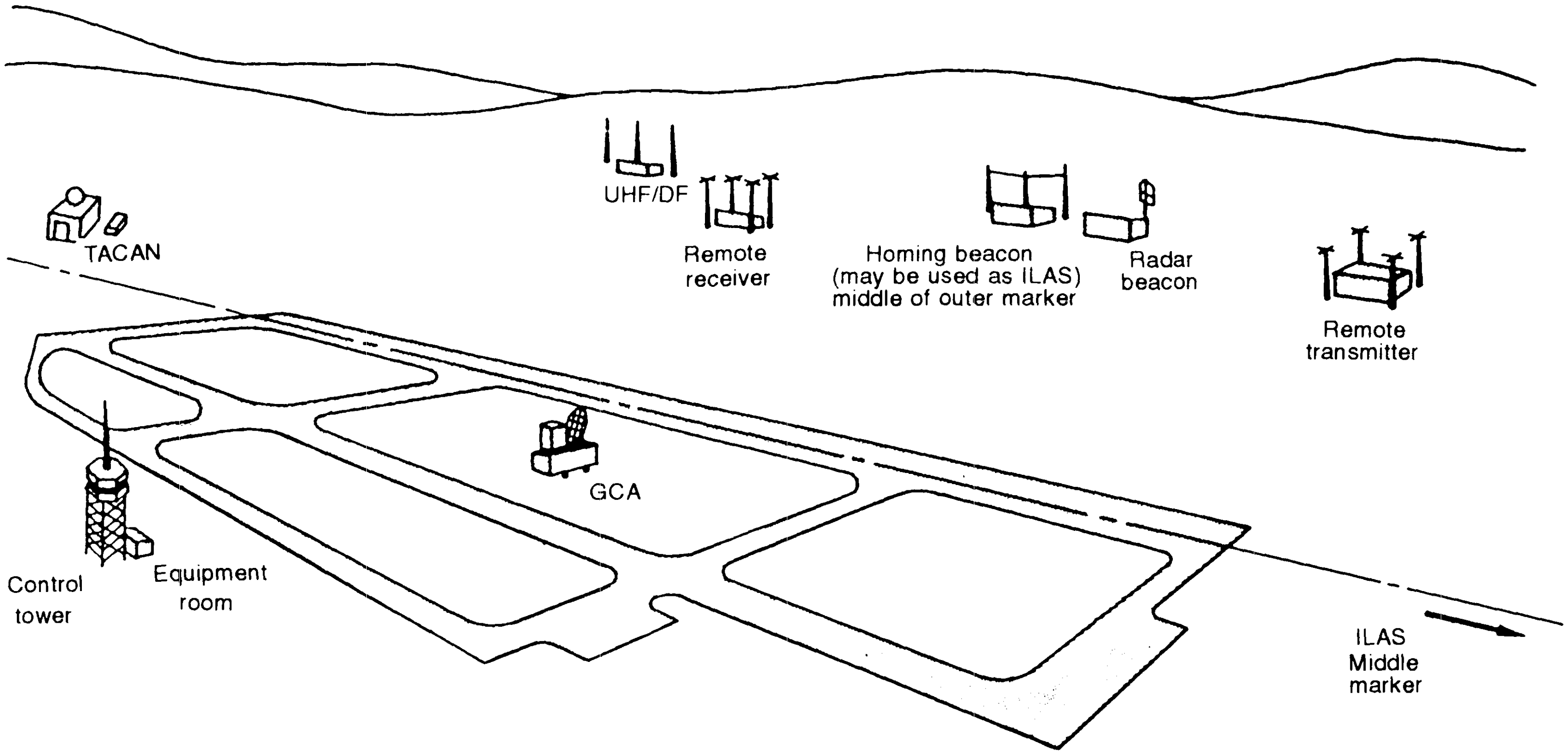
Adoption of standard NAVAID buildings (types T-0, T-1, T-2, and T-3) has been made by using fractions of the basic 20- by 48-foot prefab building. The type of building used depends on the power supply generators required. In all field- and intermediate-type facilities requiring a shed for a power unit, cable is laid on the ground between the power shed and the equipment. For temporary-type construction, direct burial power cable is used. Remoting cable is buried only in temporary-type constriction.

The selection of cable size depends on the distance over which the cable must carry power. Cable is not listed in BOMs, but it must be considered in planning and logistics.

Equipment and Power

The following is a summary of commonly used NAVAID equipment and the power requirements for each group of related equipment:

Precision Approach Radar (GCA). The AN/CPN-4, AN/ MPN-11, and AN/TSQ-71 apply to all types of construction because these units are housed in mobile shelters. An access road, turnaround loop, and level hardstand for an approximate wheel load of 9,000 pounds should be provided. In temporary-type construction, an underground transformer vault with 120/208-volt (v), 3-phase, 4-wire, 60-hertz (Hz), 45-kilo-volt-amp (KVA) transformer secondary service; a 100-ampere disconnect switch; and a



NOTES:

1. The facilities shown are for temporary-type construction. For initial-type, replace most equipment by trailers as indicated in the text.

2. TACAN and GCA are connected to control-tower equipment room by telephone lines only. Telephone lines may be routed to avoid pavement regardless of length. All other equipment is connected to equipment room by control cable as well as by telephone lines. Control cable may be routed around to avoid pavement but not past limiting length of cable.

3. Provide three 4-inch ducts across runway and taxiway at midpoint and quarter points to permit routing of control cable if necessary.

Figure 11-27. Typical location of NAVAID facilities

26-pair telephone cable to base main frame are required. The access road and hardstand normally are paved. Power requirements for GCA equipment are–

- AN/CPN-4. 16-kilowatt (kw), 120/208-v, 3-phase, 4-wire, 60-Hz.
- AN/MPN-11, 20-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.
- AN/TSQ-71. 10-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.

Radio homing beacon. Either an AN/MRT-7 (1/2-ton trailer), an AN/MRN-13 (1/2-ton trailer), or an AN/GRN-6 (3/4-ton truck) is applicable to field and intermediate construction. The AN/URN-5 or BC-446 is applicable to temporary construction. Power requirements for radio homing beacons are–

- AN/MRT-7. 5-kw, 120-v, l-phase, 60-Hz.
- AN/MRN-13. 5-kw, 120-v, l-phase, 60-Hz.
- AN/GRN-6. 5-kw, 120-v, 1-phase, 60-Hz.
- AN/URN-5. 6.9-kw, plus 10 kw for heaters, 120/240-v, l-phase, 60-Hz, 3-wire.
- BC/446. 5.5-kw, plus 10 kw for heaters, 120/240-v, l-phase, 60-Hz, 3-wire.

In initial construction, trailer-mounted units without additional housing are sufficient. Keep access roads and hardstands to a minimum. In temporary construction, use one of the appropriate NAVAID buildings.

UHFDF. The AN/MRD-12 and AN/MRD-13 are used in initial construction, or an AN/MRD-12 can be used with the AN/MRN-13 control tower. In temporary construction, use either AN/CRD-6, AN/FRD-2, or AN/URD-4. Power requirements for UHFDF equipment are–

- AN/MRD-12. 5-kw, 120/240-v, 1-phase, 60-Hz.
- AN/MRD-13. 5-kw, 120/240-v, 1-phase, 60-Hz.
- AN/CRD-6. 4.3-kw, plus 10 kw for electric heater, 120/240-v, 1-phase, 60-Hz.
- An/FRD-2. 4.3-kw, plus 10 kw for electric heater, 120/240-v, 1-phase, 60-Hz.
- AN/URD-4. 5-kw, 120/240-v, 1-phase, 60-Hz.

In initial construction, the trailer-mounted equipment only requires access roads and hardstands. In temporary construction, the equipment is housed in a prefab shelter or in one of the NAVAID buildings.

TACAN. Use the AN/TRN-6 or the AN/TRN-17 in all types of construction. Both pieces of equipment are air-transportable and are housed in prefab shelters. Power requirements for these systems are–

- AN/TRN-6. 20.5-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.
- AN/TRN-17. 10-kw, 120-v, 1-phase, 60-Hz.

RACON. Either the AN/CPN-6 or AN/FPN-13 is used in all types of construction. In initial construction, the equipment is housed in 16- by 32-foot tents. In temporary construction, one of the NAVAID buildings is used. The RACON power requirements are-

- AN/CPN-6. 16.5-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.
- AN/FPN-13. 26.9-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.

Remote receiver and transmitter building. In initial construction, use separate buildings to house the receiver and transmitter. Power requirements for the receiver and the transmitter are–

- Receiver. 5-kw, 120-v, l-phase, 60-Hz.
- Transmitter. 15-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.

Control tower. In initial construction, use the AN/MRN-15 control tower mounted on a 1/4-ton trailer, the AN/TSQ-70 mounted on a 3/4-ton truck, or the AN/MRN-12 mounted on a 1 1/2-ton trailer with associated receiver and transmitter equipment. In temporary construction, construct a control tower with a 16- by 20-foot room at its base and use an AN/FSQ-75. The power required is 12-kw, 120/208-v, 3-phase, 4-wire, 60-Hz.

SPECIAL AIRFIELDS

As previously stated, special airfields include DZs, EZs, and SOF airfields; blacked-out airfields; and airfields for UAVs.

DROP ZONES

DZs are used for delivering supplies by various methods of low-level parachute drop. The DZ should be as level as possible and clear of objects that could damage material and personnel being dropped. While the following paragraphs prescribe the normal minimum DZ sizes, for other than Air Force unilateral airdrops, the ground commander may waiver these minimums on a *by-exception* basis. Specific details on DZ operations are contained in Air Mobility Command (AMC) Regulation (Reg) 55-60.

Tactical Airlift Drop Zone

Tactical DZs (DZs that have not been formally surveyed) are sometimes selected to support highly mobile ground forces. These DZs are evaluated and approved using tactical survey procedures (see paragraph 1-27, AMC Reg 55-60). The DZ size should be determined by mode of delivery, load dispersal statistics, discussion with the receiving unit, and professional judgment.

Recoverability of air items and survivability or recoverability of the load should be considered. For example, small trees covering the entire DZ might limit the recovery of air items but allow complete recovery of the loads. Table 11-12 shows the minimum DZ sizes.

High-Altitude Airdrop Resupply System

Table 11-13, page 11-52, shows the minimum DZ sizes for the High-Altitude Airdrop Resupply System (HAARS) anti the High-Velocity Container Delivery System (HVCDS).

Special Operations Airdrops

During special operations airdrops, the minimum DZ sizes shown in Table 11-14, page 11-53, normally apply unless they are precluded by mission requirements.

Area Drop Zones

An area DZ (see Figure 11-28, page 11-54) consists of a start point (point A), an end point (point B), anti a prearranged flight path (line of flight) over a series of acceptable drop sites between these points. The distance between points A and B generally should not exceed 15 nautical miles (NM)/28 kilometers (km), and changes in ground elevation along the line of flight should not exceed 300 feet/90 meters. Drop sites along the line of flight should not be located more than 1/2 NM/km on either side. The reception committee is free to receive the drop at any location along the line of flight, and the drop is made once the prebriefed DZ visual signal or electronic NAVAID has been identified and located. DZ signals/NAVAIDs may be displayed or turned on during any portion of a 10-minute window. Ensure they are displayed/turned on 2 minutes before the aircraft is scheduled to arrive over that segment of the DZ.

Table 11-12. Size criteria for tactical airlift DZs

Altitude (AGL)	Width (See Note 1)	Number of Containers		Length (See Note 2)
		Single	Double	
Container Delivery System C-130				
To 600 ft	400 yd/365 m	1	1-2	400 yd/370 m
		2	3-4	450 yd/410 m
		3	5-6	500 yd/460 m
		4	7-8	550 yd/500 m
		5-8	9 or more	700 yd/640 m
Above 600 ft	Add 40 yd/35 m to DZ width and length for each 100 ft above 600 ft (20 yd/18 m added to each side of the DZ).			
Container Delivery System C-141				
To 600 ft	450 yd/410 m	1	1-2	590 yd/540 m
		2	3-4	615 yd/560 m
		3	5-6	665yd/610 m
		4-8	7-16	765 yd/700 m
		9-14	17-28	915 yd/835 m
		15-20	30-40	1,065 yd/975 m
Above 600 ft	Add 40 yd/35 m to DZ width and length for each 100 ft above 600 ft (20 yd/18 m added to each side of the DZ).			

Heavy Equipment			
Altitude (AGL)	**Width (See Note 1)**	**Length (See Note 2)**	
		1 Platform	**Additional Platforms**
To 1,100 ft	600 yd/550 m	1,000 yd/915 m	Add 400 yd/370 m (C-130) or 500 yd/460 m (C-141 or C-5) to trailing edge for each additional platform.
Above 1,100 ft	Add 30 yd/28 m to width and length for each 100 ft above 1,100 ft (add 15 yd/14 m to each side of the DZ).		

Personnel			
Altitude (AGL)	**Width (See Note 1)**	**Length (See Notes 2 and 3)**	
		1 Parachutist	**Additional Parachutists**
To 1,000 ft	600 yd/550 m	600 yd/550 m	Add 75 yd/70 m for each additional parachutist to trailing edge (100 yd/90 m when using CAPES).
Above 1,000 ft	Add 30 yd/28 m to width and length for each 100 ft above 1,000 ft (add 15 yd/14 m to each side of the DZ).		

NOTES:

1a. For day visual formations, increase width by 100 yd/90 m (50 yd/45 m each side).
1b. For SKE formation, increase width by 400 yd/370 m (200 yd/185 m each side).
1c. Official sunset to sunrise, increase width by 100 yd/90 m for single-ship visual drops (50 yd/45 m each side) or 200 yd/180 m for visual formations (100 yd/90 m each side).
2. Official sunset to sunrise, increase length by 100 yd/90 m for visual drops 50 yd/46 m each end).
3. For CCT/pararescue unilaterial operations, see para 1-4d. Controlled exit (CAPES) and alternating door (ADEPT) procedures do not apply to CCT/pararescue operations.

Table 11-13. Size criteria for delayed opening (HAARS and HVCDS) DZ

HAARS CDS			
Altitude (feet AGL)	**Width (yards/meters)**	**Length (yards/meters)**	
		1-8 Containers	**9 or More Containers**
Up to 3,000	500 yd/460 m	1,200 yd/1,100 m	1,900 yd/1,740 m
Above 3,000	Add 25 yd/23 m to each side and 50 yd/46 m to each end for every 1,000-ft increase in drop altitude.		
HIGH VELOCITY CDS*			
Altitude (feet AGL)	**Width (yards/meters)**	**Length (yards/meters)**	
		1 or 2 Containers Single or Double	**Additional Containers**
Up to 3,000	580 yd/530 m	660 yd/600 m	Add 50 yd/45 m to trailing edge for each additional container.
Above 3,000	Add 25 yd/23 m to each side and 100 yd/90 m to each end for every 1,000-ft increase in drop altitude.		
*NOTE: Using 12-, 22-, or 26-foot ring slot parachutes.			

Circular Drop Zones

A circular DZ is a round DZ with multiple run-in headings. The size of the DZ is governed by mission requirements and usable terrain. The radius of a circular DZ corresponds to the minimum required distance from the point of impact (POI) to one of the trailing edge corners of a rectangular DZ for the same type and number of loads being dropped (see Figure 11-29, page 11-54). In other words, the entire DZ box must fit inside the circle. The POI of a circular DZ is normally at the DZ center.

Drop-Zone Markings

DZs are normally marked with a raised angle marker (RAM) or VS-17 marker panels, omnidirectional visible lighting systems, and if required, rotating light beacons. Virtually any type overt lighting or visual marking system is acceptable if all participating units are briefed and concur in its use. Other day markings or visual acquisition devices include colored smoke, mirror, railroad fusees, or any reflective/contrasting marker panel (space blanket). In some cases, geographical points may be used. Night markings or acquisition aids may include a B-2 light gun, flares, fire/fire pots, railroad fusees, flashlights, or chemlights. Combat control units also may use specialized clandestine infrared (IR) lighting systems. Electronic markings may be used for either day or night operations.

Tactical Airlift Drop-Zone Markings

Timing points. Timing points are not normally required for tactical airlift airdrop operations. If they are needed to meet mission requirements and the terrain allows them, timing points should be equidistant from the extended DZ centerline–no more than 1,300 yards (1,183 meters) before the POI and 300 yards (273 meters) to 400 yards (364 meters) (350 yards (319 meters)

Table 11-14. Size criteria for special operations DZs

Type Drop	**MC-130 (WxL)**	**AWADS (WxL)**	**C-130 (WxL)**	**C-141 (WxL)**
Marked Drop Zones				
Personnel (CARP)	300x300 yd 275x275 m	600x600 yd 550x550 m	600x600 yd 550x550 m	600x600 yd 550x550 m
(GMRS)	300x300 yd 275x275 m	300x300 yd 275x275 m	300x300 yd 275x275 m	300x300 yd 275x275 m
Add 75 yd (69 m) to the length for each additional parachutist.				
CDS/CRS (CARP & GMRS)	400x400 yd 365x365 yd	400x400 yd 365x365 m	400x400 yd 365x365 m	450x590 yd 410x540 m
For all except C-141, add 50 yd (45 m) to the DZ length for each additional container. For C-141, increase DZ length IAW para 18-2c(2) of 1 SOCOM Reg 350-2.				
HSLLADS (CARP & GMRS)	300x600 yd 275x550 m	NA	NA	NA
Recovery Kit (CARP & GMRS)	200x200 yd 180x180 m	400x400 yd 365x365 m	400x400 yd 365x365 m	NA
Heavy Equipment (CARP & GMRS)	600x1,000 yd 550x915 m	600x1,000 yd 550x915 m	600x1,000 yd 550x915 m	600x1,000 yd 550x915 m
For all except C-141, add 400 yd (366 m) to DZ length for each additional platform. For C-141, add 500 yd (457 m) to DZ length for each additional platform.				
Blind Drop Zones (Natural radar targets only or radar beacon/zone marker on the DZ)				
Personnel	600x600 yd 550x550 m	600x600 yd 550x550 m	600x600 yd 550x550 m	600x600 yd 550x550 m
Add 75 yd (69 m) to the length for each additional parachutist.				
CDS/CRS	400x400 yd 365x365 m	400x400 yd 365x365 m	400x400 yd 365x365 m	450x590 yd 410x540 m
Add 50 yd (45 m) to the DZ length for each additional container.				
HSLLADS	400x600 yd 365x550 m	NA	NA	NA
Recovery Kit	400x400 yd 365x366 m	400x400 yd	400x400 yd 365x365 m	NA 365x365 m
Heavy Equipment	600x1,000 yd 550x915 m	600x1,000 yd 550x915 m	600x1,000 yd 550x915 m	600x1,000 yd 550x915 m
For all except C-141, add 400 yd (366 m) to DZ length for each additional platform. For C-141, add 500 yd (457 m) to DZ length for each additional platform.				
NOTES: 1. For all blind drops, add 30 yd/27 m to each side and 30 yd/27 m to each end of the DZ for each 100-ft increase in altitude above the minimum drop altitude for the load being dropped. 2. C-141 aircraft require an SKE zone marker for blind drops.				

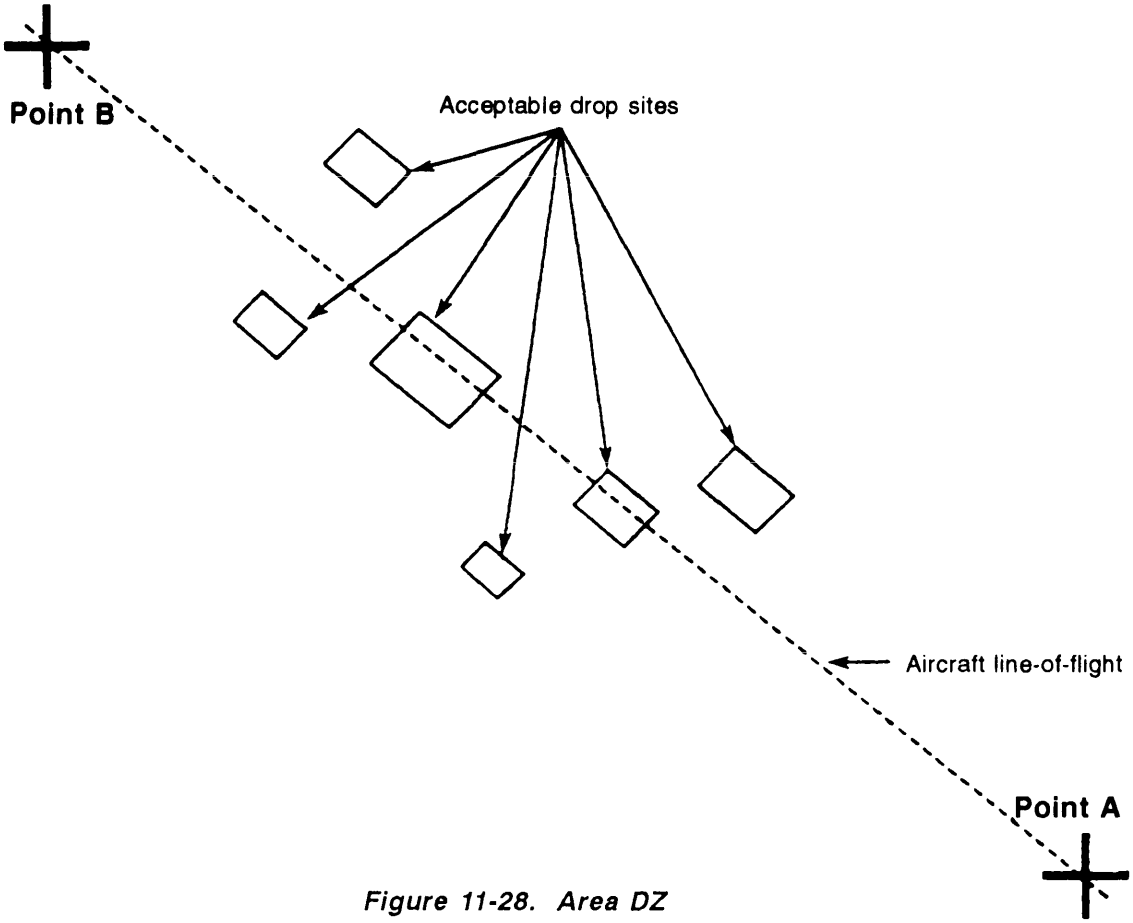


Figure 11-28. Area DZ

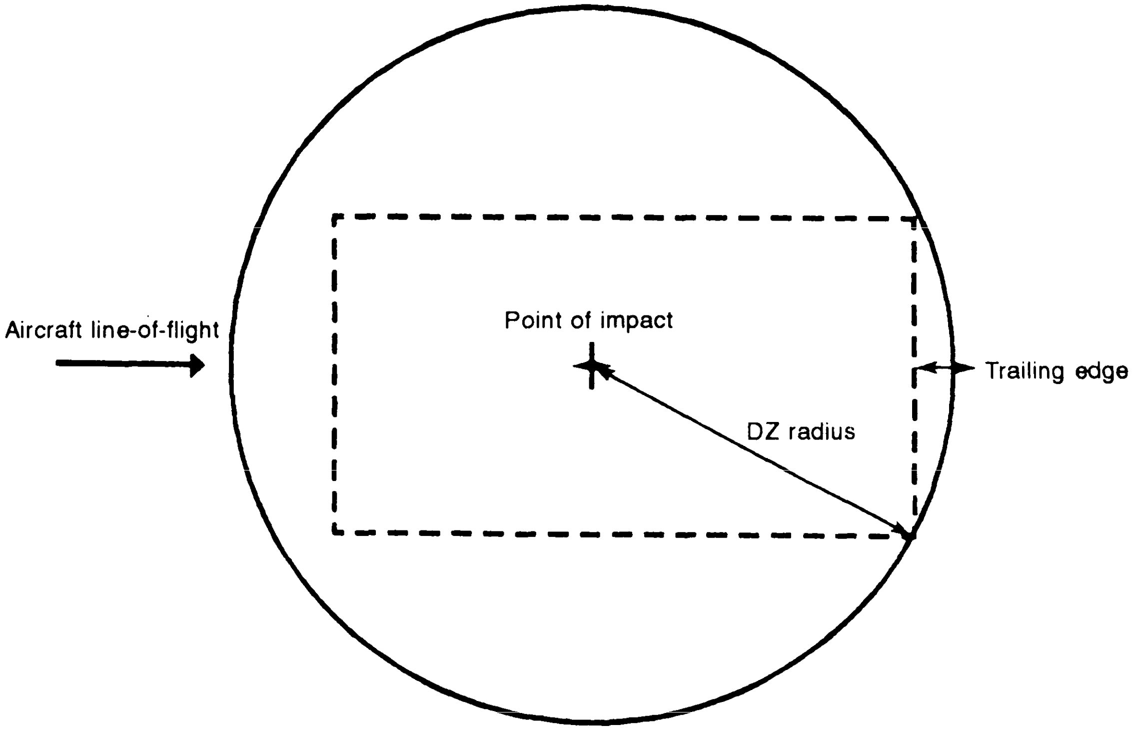


Figure 11-29. Circular DZ dimensions

minimum for C-141) on either side of the centerline (see Figure 11-30).

POI. See Table 11-15, page 11-56, for normal POI location. When mission requirements dictate, the random POI placement option may be used. In this option, the mission commander will notify the drop zone control (DZC) unit that random POI placement is to be used at least 24 hours in advance. When the DZ is set up, the DZC randomly selects a point on the DZ and establishes that point as the POI for The DZC ensures DZ minimum

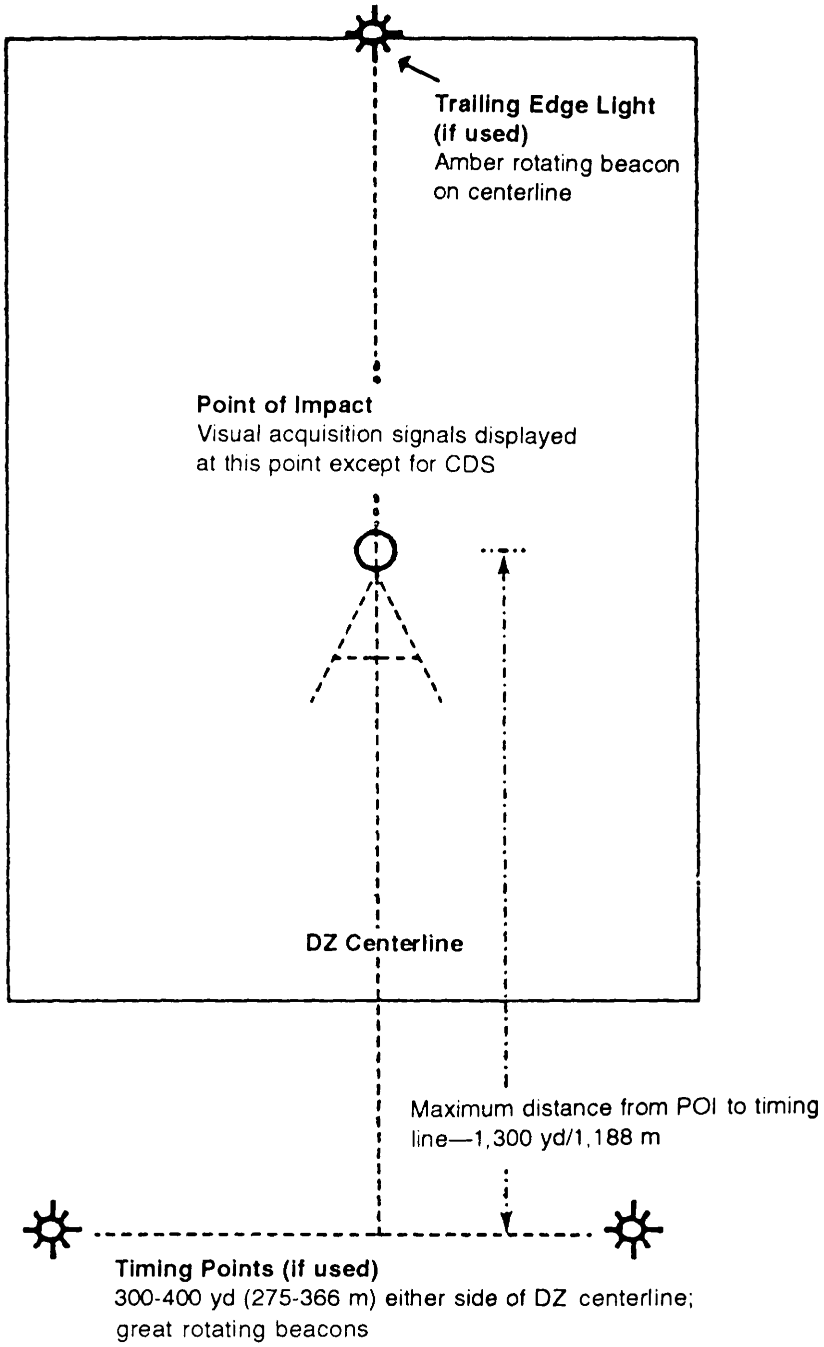


Figure 11-30. DZ markings

Table 11-15. DZ POI placement minimums

Type Drop	Type Aircraft	Distance From Approach End[2] (yards/meters)		Distance from DZ Sides (yards/meters)	
		Day	Night	Day	Night
Single Aircraft[1]					
CDS[1]	C-130	200/185	250/230	200/185	250/230
CDS[1]	C-141	225/205	275/250	225/205	250/230
Personnel	All	300/275	350/320	300/275	350/320
Equipment	All	500/455	550/500	300/275	350/320
Multiple Aircraft[1]					
CDS[3]	C-130	NA	NA	NA	NA
CDS[3]	C-141	NA	NA	NA	NA
Personnel	All	300/275	350/320	350/320	400/365
Equipment	All	500/455	550/500	350/320	400/365

NOTES:

1. For INS/SKE/ZM or AWADS use, day POI placement criteria for both day and night drops.
2. POI location may be adjusted for special operations or to meet specific mission requirements. All participants will be briefed.
3. POI location may be adjusted for aircrew POI acquisition training. The POI may be located anywhere within the surveyed DZ boundaries as long as the minimum required DZ size for that drop fits within the boundaries. All participants must be briefed when using this option.

size requirements are met for the load being dropped and that the entire DZ falls within the surveyed boundaries. The mission commander or supported force commander also may request the DZ be set up with the POI at a specific point on the DZ. These requests also must be made at least 24 hours in advance. The requester either ensures the minimum DZ size requirements remain on the surveyed DZ or accepts responsibility for the drop if they do not. Both these procedures are used only during VFR operations. Aircrew schedulers ensure requests for these type operations are consolidated to prevent more than two POI location changes on one DZ during a mission or operation.

Unless otherwise coordinated with the aircrew, the POI is normally marked with a RAM (day operations) or a block letter (night operations).

- The RAM is aligned into the aircraft line of flight with the base on the actual intended landing point. If required for additional identification or authentication colored panels (placed flat on the surface in a block letter or other prebriefed symbol) may be added.
- Block letters are at least 35 feet by 35 feet. They consist of at least nine white/IR, omnidirectional lights for night (if the tactical environment permits). Letters authorized for POI markings are A, C, J, R, and S. The letters H and O may be used for circular DZSs If used for day operations, the letter will consist of at least nine marker panels.

If used, smoke is displayed next to and downwind of the POI for other than Container Delivery System (CDS) drops. For CDS, visual acquisition signals are normally displayed on the DZ centerline, 200 yards/180 meters short of the intended POI.

On small CDS (resupply) DZs where obstacles may prevent timely visual acquisition by the aircrew, visual signals may be displayed at the trailing edge of the DZ on the centerline or at another location on the DZ. If this option is exercised, the DZC must ensure all participating aircrews have been thoroughly briefed on the change in location.

Trailing edge. For night airdrops, the trailing edge marker (if used) will be an amber, rotating beacon (or other briefed light) placed at the trailing edge of the minimum size DZ (for the type airdrop being done) on the DZ centerline.

No-drop signals. A scrambled block letter, a block letter X, markings removed, red smoke, red flares, a red beam from a B-2 light gun, or any other precoordinated signal on the DZ indicates a no-drop condition. Temporary closing of the DZ or temporary delay of the airdrop is shown by forming the letter identifier into two parallel bars, placed perpendicular to the line of flight. These visual signals may be confirmed by radio communication to the aircraft if communications security permits.

Visual clearance. Unless radio communications are specifically required, any precoordinated marking (other than red smoke, flares, or lights) displayed on the DZ indicates clearance to drop.

Special-Use Drop-Zone Markings

Marked special operations drop zone. This is an authenticated drop zone, which has the POI or release point marked with a precoordinated signal. This marking may be either overt (block letter, flares, smoke, mirror, or RAM) or covert (IR strobe, RACON, or zone marker). No other markings are required. Unless radio communications are specifically required, any precoordinated marking (other than red smoke, flares, or lights) displayed on the DZ indicates clearance to drop. For personnel drops, the DZ will be visually marked to identify it as a hazard to parachutists.

RACONs. Tactical airlift airdrops using RACONs require the use of a collocated pair of tuned I-band (SST-181) beacons. MC-130 aircraft can use a single I-band beacon or other type radar beacons. The TACAN is not normally placed on a DZ as an airdrop aid.

For special operation airdrops, NAVAIDs are placed as directed by the mission commander. They are normally located on the release point or on the POI.

EXTRACTION ZONES

EZs are areas used for delivering supplies and equipment by aircraft without actually landing. At an EZ, the load is removed from the aircraft by a deployed parachute. As the aircraft flies by, the parachute pulls the load from the aircraft. This is called a LAPES. Figure 11-31 shows a typical

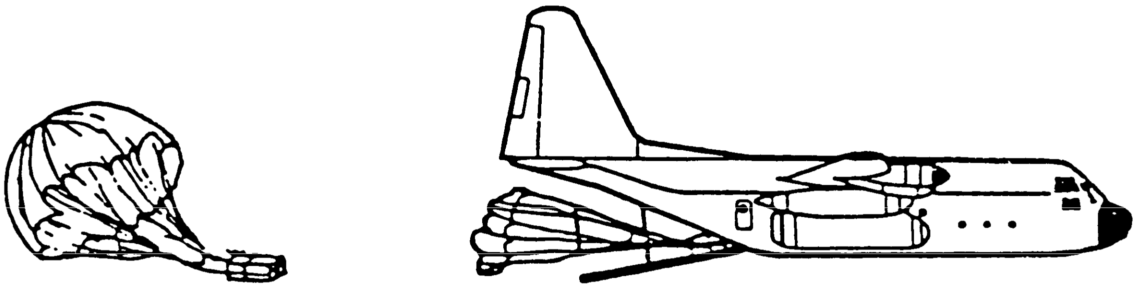


Figure 11-31. Low-Altitude Parachute-Extraction System

LAPES deployment from a C-130 aircraft. Specific details on EZs are contained in AMC Reg 55-60.

The LAPES, as described in the previous paragraph, is a low-altitude method of aerial delivery. This system employs a 15-foot drogue parachute deployed behind the aircraft and attached to a tow plate on the aircraft ramp. At the release point, the parachute forces are transferred from the tow plate to the ring slot or ribbon main extraction parachute(s) that then extract single or tandem platforms from the aircraft. Ground friction decelerates the load. Loads up to 42,000 pounds may be delivered into small areas using LAPES and tandem platforms. The total distance from release to stopping point of the load depends on ground speed, size, number of extraction parachutes, weight of the load(s), and type of terrain.

General EZ Criteria

Since proper site selection for the EZ depends on a variety of conditions, there are specific criteria that must be used to ensure a safe operation when physically locating the EZ. These criteria are shown in Figure 11-32.

Approach zones. The complete approach path for LAPES consists of the *initial* and *final* approach zones. These two zones overlap and use different glide slope ratios for obstacle clearance.

The initial approach zone is 10,500 feet long, and starts 11,000 feet and ends 500 feet (at the release panels) from the leading edge of the impact/slide-out zone. The recommended glide-slope ratio for obstacle clearance within this zone is 35:1.

For day operations, the final approach zone on the leading edge of the impact/slide-out zone should consist of two 400-foot zones (800 feet in total length). The inner 400-foot zone (nearest the impact/slide-out zone) may be a graduated slope with obstacles limited to a maximum of 1 foot at the leading edge of the impact/slide-out zone and 12 feet at the farthest edge from the impact/slide-out zone. The outer 400-foot zone may be a graduated slope with obstacles limited to a maximum of 12 feet at the inner edge and a maximum of 50 feet at the outer edge. The inner zone of the final approach zone must be sufficiently clear to make the impact panels clearly visible (because of the steep aircraft approach, the approach-zone slope must not exceed a 15:1 ratio).

For night operations, the final approach zone on the leading edge of the impact/slide-out zone should consist of two zones–one 600 feet long and the other 1,000 feet long (1,600 feet total length). The 600-foot zone nearest the impact/slide-out zone should be a level area with no obstacles over 1 foot high. The next 1,000-foot zone may be a graduated slope with obstacles limited to a maximum of 1 foot at the inner edge and a maximum of 12 feet at the outer edge. The entire portion of the final approach zone must be clear to make the approach zone and impact area lights clearly visible to the aircraft.

The *impact/slide-out zone* should be clear of obstructions and relatively flat. It may contain grass: dirt: sand: short, light brush; or snow.

The *clear area* may be a graduated slope with obstacles limited to a maximum of 1 foot high adjacent to the impact/slide-out zone and 2 feet at the outer edge.

The *lateral safety zone* may be a graduated slope with obstacles limited to a maximum of 2 feet at the inner edge and 12 feet at the outer edge.

The *climb-out zone* should contain no obstructions that would prevent a loaded aircraft from maintaining a normal obstacle clearance climb rate after an inadvertent touchdown, delivery abort, or extraction malfunction.

Multiple LAPES. Extraction lanes are designated in numerical sequence from left to right. The left lane in the direction of flight

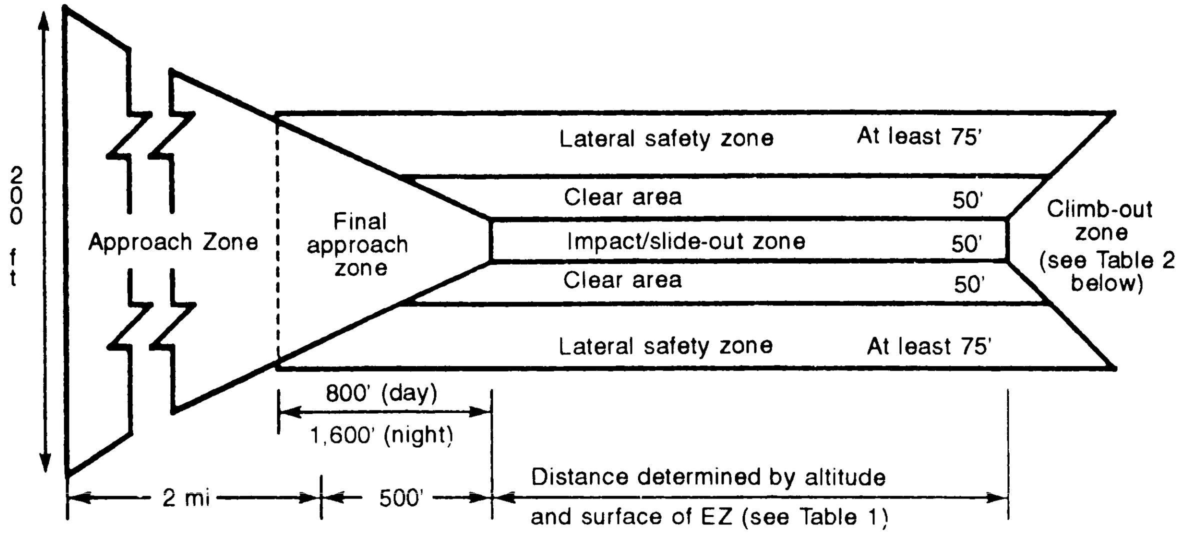


Table 1. Impact/slide-out Zone length

EZ ELEVATION	Type surface				
	Dirt/ sand	Clay	Grass/ gravel	Snow	Ice
Sea level to 999'	850'	900'	1,000'	1,300'	2,000'
1,000 'TO 1,999'	900'	950'	1,050'	1,350'	2,080'
2,000' TO 2,999'	950'	1,000'	1,100'	1,400'	2,160'
3,000' TO 3,999'	1,000'	1,050'	1,150'	1,450'	2,240'
4,000' TO 4,999'	1,050'	1,100'	1,200'	1,500'	2,320'
5,000' TO 5,999'	1,100'	1,150'	1.250'	1,550'	2,400'
6,000' TO 6,999'	1,150'	1,200'	1,300'	1,600'	2,480'
7,000' TO 7,999'	1,200'	1.250'	1,350'	1,650'	2,560'
8,000' TO 8,999'	1.250'	1,300'	1,400'	1,700'	2,640'
9,000 TO 9,999'	1,300'	1,350'	1,450'	1,750'	2,720'
10,000 AND ABOVE	1,350'	1,400'	1,500'	1,800'	2,800'

Note: Add 250' to impact/slide-out zone length for asphalt, PSP, or AM-2 matting surfaces.

Table 2. Climb-out Zone length

PRESSURE ALTITUDE	Obstacle distance from impact/slide-out zone					
	50' Obstacle			200' Obstacle		
	Cold	Warm	Hot	Cold	Warm	Hot
Sea level	450'	550'	650'	1,200'	2,100'	2,650'
2,500'	500'	600'	800'	2,000'	2,400'	3,100'
5,000'	600'	700'	900'	2,250'	2,800'	3,600'
10,000'	850'	1,100'	1,550'	3,350'	4,350'	6,000'

Figure 11-32. EZ criteria

will be designated as lane one. The lead aircraft will extract on the downwind lane. Lane dimensions are the same as for single LAPES operations. When establishing two or more lanes, both sides of each lane are marked. If available, place radar reflectors at the trailing edge of the first and last lanes as shown in Figure 11-33. When possible, additional lanes are staggered 100 feet down from lane one. However, additional lanes are established side by side, beginning at the same parallel starting point. In all cases, there is 150 feet between lane centerlines. Minimum aircraft spacing is 10 seconds.

EZ marking equipment. EZs are normally marked with VS-17 marker panels, omnidirectional visible lighting systems, and if required, strobe lights, but virtually any type overt lighting or marking system is acceptable if all participating units are briefed.

EZ markings and identification. This information will be a special subject at the final briefing to ensure all required ground and aircrew members thoroughly understand the EZ recognition and identification procedures. EZ markings for day operations will be IAW Figure 11-34. EZ markings for night operations will be IAW Figure 11-35.

Control point. The control point for the EZ will be established at the direction of the extraction zone control (EZC). The EZC must take into account pertinent factors such as an unobstructed line of sight, winds, positive control of the EZ and surrounding airspace, and security requirements. The entire length of the extraction area(s) should be in full view of the EZC. It should, whenever possible, be upwind of the extraction area(s) so the dust and debris that rise from the EZ will not obscure the vision of the EZC.

Marking considerations. The EZ markings must be clearly visible to the pilot as early on the approach as possible. As a security precaution, night EZ markings should be visible only from the direction of the aircraft's approach. If flashlights are used, they may be equipped with simple hoods or shields and aimed toward the approaching aircraft. Fires or improvised flares may be screened on three sides or placed in pits with sides sloping toward the direction of approach. During daylight extractions, the marker panels should be slanted at a 45-degree angle from the surface toward the aircraft approach to increase the pilot's ability to see them.

SPECIAL OPERATIONS FORCES

Minimum airfield criteria for SOF are noted in Table 11-16, page 11-62. Runway marking patterns for SOF airfields are shown in Figures 11-36 and 11-37, pages 11-63 and 11-64. Further detailed information on SOF airfields is contained in AMC Reg 55-60.

BLACKED-OUT OPERATIONS

Airfields operating under blacked-out conditions are normally used by SOFs or special mission aircraft where aircrews use night vision goggles (NVG). For MC-130 aircraft used by SOFs, the minimum airfield criteria are noted in Table 11-16. Airfield marking patterns use no visual markings and are detailed in AMC Reg 55-60. For additional information on airfields where NVG are used, see Training Circular (TC) 1-204.

UNMANNED AERIAL VEHICLES AIRFIELD

UAV air-fields are used for UAV operations by military intelligence units for reconnaissance missions. Because of the limited geometric dimensions (1,800 feet long by 60 feet wide), a local asphalt or concrete road is normally used for the runway. However when a paved surface is not available, an airfield must be constructed. Because UAV operations must be mobile, the airfield is normally constructed of M-19 or AM-Z matting rather than asphalt or concrete.

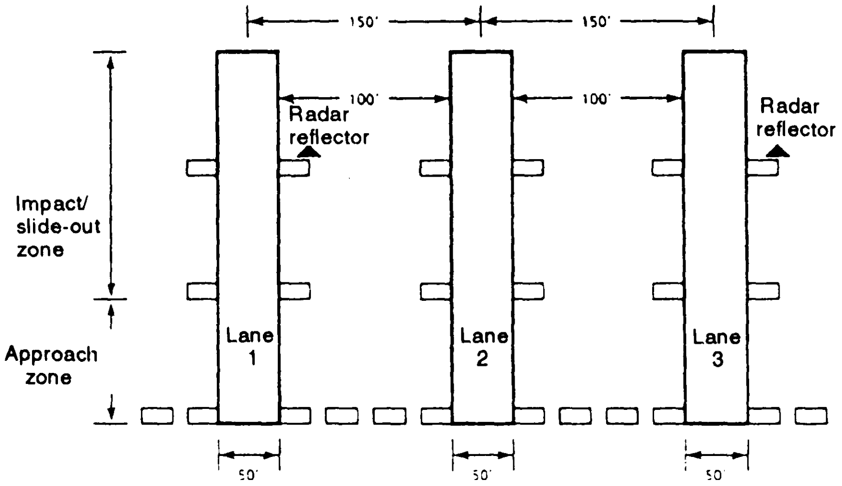


Figure 11-33. Multiple LAPES zones configuration and marking

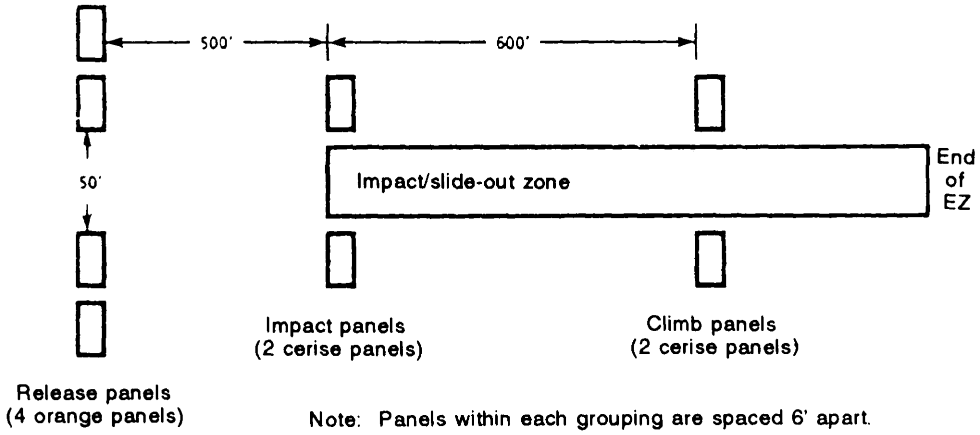
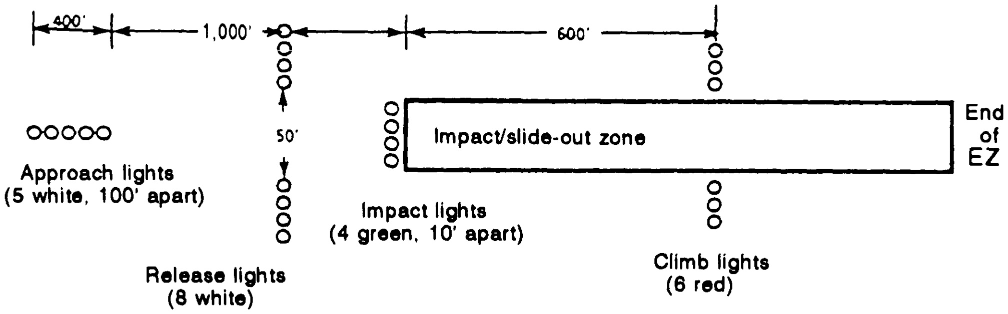


Figure 11-34. Day EZ markings



NOTE: Lights within each grouping are spaced 10' apart.

Figure 11-35. Night EZ markings

Table 11-16. Minimum airfield criteria (SOF)

Type LZ	Length[1] (feet)	Width[1] (feet)		
		Qualified Crews	Unqualified Crews	108° Turn (On Runway)
C-130 SOLL I	3,000[2]	60	60	60
C-130 SOLL II	4,000	60	75	75
C-141 SOLL I	5,000	98	98	138
C-141 SOLL II	5,000	98	98	150
Blacked Out (MC-130)	4,000	60	75	75

NOTES:

1. Minimum operational criteria without a waiver during peacetime operations.
2. The length used for routine training is 3,500 feet.
3. Specific criteria for runway gradients are located in Table 11-3, page 11-4.

LOGISTICAL DATA ON PETROLEUM, OILS, AND LUBRICANTS FACILITIES

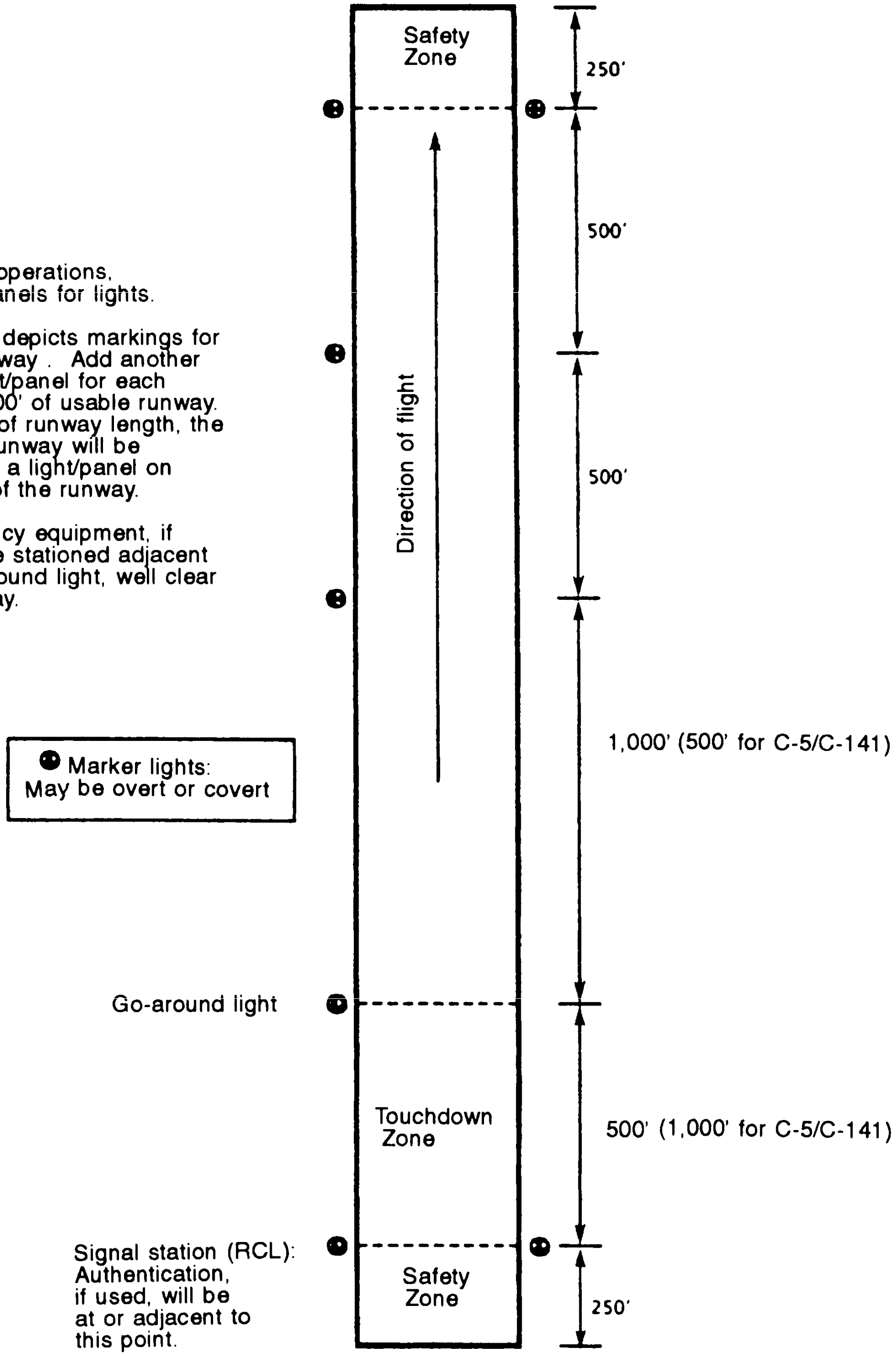
The storage requirements for aviation fuels depend on the type and grade of fuel to be stored; the number and range of sorties to be flown; the type of aircraft used; the prestrike and poststrike refueling missions; and the support, transport, anti transient aircraft to be supported. The daily consumption of aviation fuels is a function of all these factors, and all factors should be considered when computing fuel consumption. The theater commander is responsible for establishing storage policy and requirements. Normally, facilities should provide storage for a 15-day operating supply. For planning storage facilities, lubricant requirements may be estimated as 1.304 percent of fuel requirements for reciprocating engines and 0.032 percent for jet engines.

The per-person/per-day method of estimating ground fuel and lubricant requirements described in FM 101-10-1 may be used to guide the early planning stages when definite information about the number and types of vehicles is not available. However, this method is not a substitute for more exacting computations. The theater commander is responsible for establishing the storage policy and requirements.

Types of Storage Facilities

Aviation and ground fuels are normally stored in drums; collapsible containers; or welded or bolted, above-ground storage tanks. Underground or revetted storage tanks may be required. This requirement is determined by the air or ground threat to the base and must be consistent with the overall vulnerability reduction program. Lubricants are only stored and distributed in drums. Recommended types of storage for different construction types follow:

- Initial. Drums, collapsible containers, or fabric bags.
- Temporary. Welded or bolted, steel tanks.



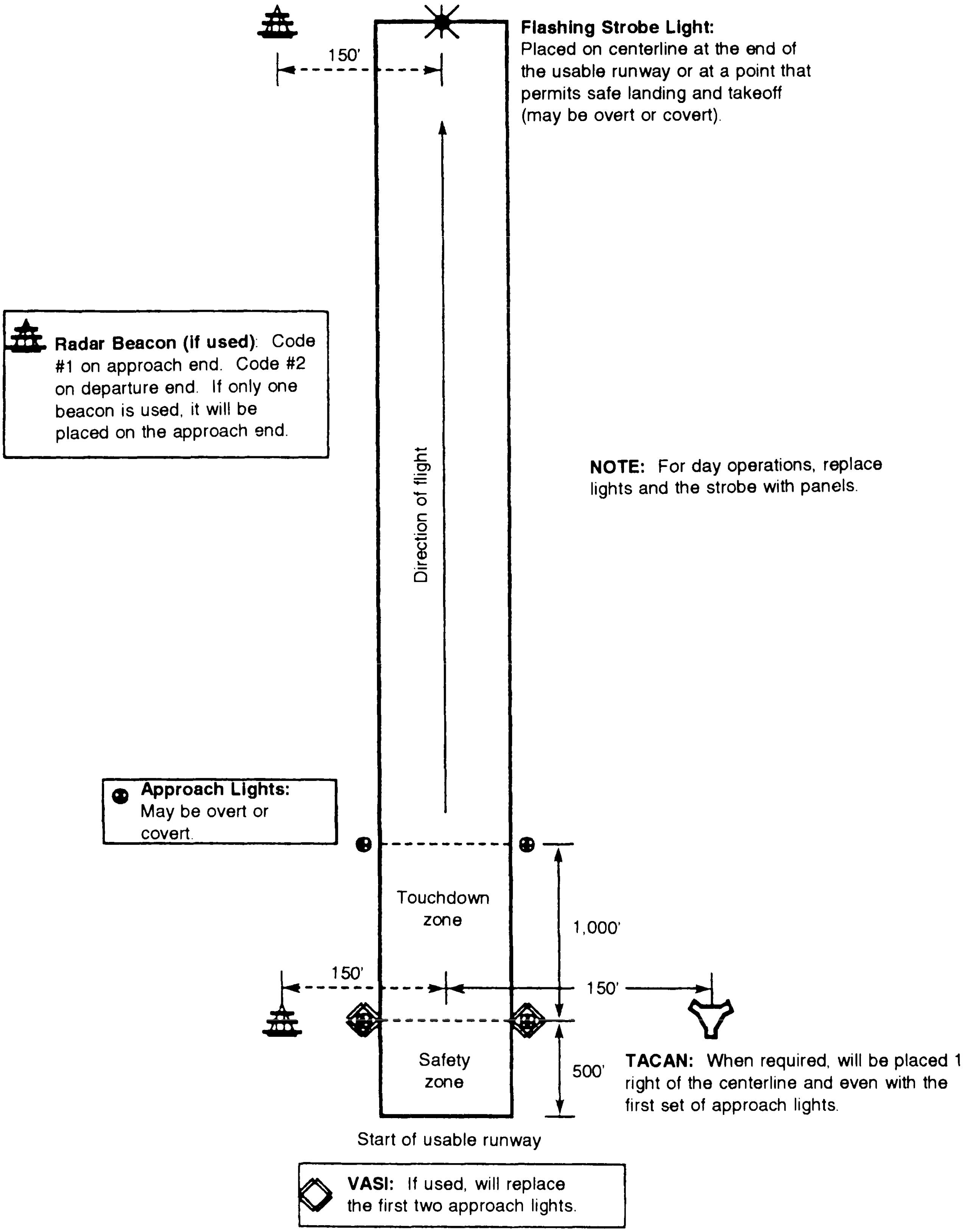
NOTES:

1. For day operations, substitute panels for lights.

2. Diagram depicts markings for a 2,500' runway . Add another left side light/panel for each additional 500' of usable runway. Regardless of runway length, the end of the runway will be marked with a light/panel on either side of the runway.

3. Emergency equipment, if used, will be stationed adjacent to the go-around light, well clear of the runway.

Figure 11-36. Runway marking pattern (SOF airfields)



Flashing Strobe Light: Placed on centerline at the end of the usable runway or at a point that permits safe landing and takeoff (may be overt or covert).

Radar Beacon (if used): Code #1 on approach end. Code #2 on departure end. If only one beacon is used, it will be placed on the approach end.

NOTE: For day operations, replace lights and the strobe with panels.

Approach Lights: May be overt or covert.

TACAN: When required, will be placed 1 right of the centerline and even with the first set of approach lights.

VASI: If used, will replace the first two approach lights.

Figure 11-37. Runway marking pattern (SOF airfields)

Construction Standards

The storage and distribution of aviation fuels and lubricants are direct-support operational functions, and construction is high priority. Initial construction is authorized under construction combinations A and B (Table 10-1, page 10-13). Temporary construction is authorized under combinations C, D, E, and F (Table 10-1).

Ground Fuels and Lubricants

The storage and distribution of ground fuels and lubricants is an indirect-support function, and construction is priority 2. Initial construction is authorized under construction combinations A, B, and C (Table 10-1). Temporary construction is authorized under combinations D, E, and F (Table 10-1).

Other Criteria

Information on fuel dispensing and distributing systems, TO pipeline systems, and tank-farm installations is given in FM 5-482 and TM 5-302-2. Petroleum handling operations are discussed in FM 10-69. Fuel storage requirements for Air Force airfields are discussed in Chapter 10.

LOGISTICAL DATA ON AMMUNITION STORAGE

Detailed computations of ammunition requirements and the consequent storage requirements depend on the mission, type and number of planes, number of sorties, takeoff load, and estimated ammunition expenditure rate. Calculate the requirements using information furnished by the theater commander. As a guide for temporary construction planning purposes, use the requirements in Table 11-17.

Temporary construction uses covered revetments, and initial construction uses unrevetted stacks. The layout of an explosive storage area is IAW TM 9-1300-206 and AFM 127-100.

LOGISTICAL DATA ON STRUCTURES

Detailed information about space requirements and criteria for maintenance, supply, and administrative facilities is contained in Chapter 10. The AFCS, which is described in three manuals (TM 5-301, TM 5-302-series, and TM 5-304), allows the military planner and logistician to determine the Class IV materials required for engineer support of Army requirements.

VEHICLE PARKING AREA

Provide all-weather vehicle parks for squadron bomb trucks and fuel units, flight-control vehicles, engineer fire-fighting equipment, service-team vehicles, and squadron and group headquarter motor transport. Except for the area for fuel units and bomb trucks, locate vehicle parks away from the taxiway system.

ACCESS AND SERVICE ROADS

At least one access road connecting the airfield site with the existing road net or

Table 11-17. Ammunition storage area requirements

Type/No Aircraft	Base Segregated Magazine (sq ft)	Base Small-Arms Ammo (sq ft)	General Ammo and Explosives (sq ft)
Sqdn F-111	545	5,000	30,000
Wg F-11	545	10,000	75,000
Sqdn F-4C	545	5,000	35,000
Wg F-4C	545	10,000	80,000

adjacent railhead or port area is required. An installation containing operations and service facilities on both sides of a runway should have a perimeter road connected to the access road. Provide service roads with connections to hardstands, the control tower, service areas, fuel storage and dispensing areas, bomb and ammunition storage areas, and bivouac areas.

BIVOUAC SITES

Where existing shelter is inadequate, provide tentage for initial construction. As construction progresses, portable, prefab housing or frame TO structures may be constructed. Do not locate bivouac areas in runway approach zones. Housing, administrative, and housekeeping facilities for officers and enlisted personnel may be dispersed or concentrated IAW the base dispersal policy.

The efficiency of an installation can be greatly increased by careful placement of bivouacs to minimize the distance traveled by personnel to and from duty stations, even though such facilities are not placed within the operational perimeter of the airfield.

AIR-BASE DAMAGE REPAIR

Conduct air-base damage repair (ADR) operations, including emergency or rapid runway repair (RRR), as outlined in Chapter 8, FM 5-430-1/AFPAM 32-8013, Vol 1. Further detailed information can be found in Department of Defense (DOD) Directive 1315.6, TC 5-340, AFR 93-2, and AFP 93-12.

AIRFIELD PAVEMENT DESIGN

CHAPTER 12

This chapter provides information to help select design, and construct airfield structures and landing facilites. Close battle support, and rear area TO air-fields are designed according to specific aircraft characteristics and requirements governing thickness, strength, and quality of materials. Airfield location and soil strength determine the different minimum pavement thicknesses and design procedures. The proper placement of the base, subbase, and subgrade determine the effectiveness of the airfield under all climatic and seasonal conditions.

AIRFIELD STRUCTURE TYPE

Airfield structures fall into three categories: expedient-surfaced, aggregate-surfaced, and flexible-pavement. Expedient-surfaced and aggregate-surfaced airfields are used primarily in the close battle and support areas. Flexible-pavement airfields are primarily constructed in the rear area.

PRELIMINARY INFORMATION

Field condition, soil strength, and soil behavior are the three most important pieces of information used to determine the feasibility of constructing an airfield at a particular location.

Field Condition

Knowledge of the current field condition is important when designing and constructing an airfield. A proper description of the field condition at a proposed construction site includes the following elements:

- Ground cover (vegetation).
- Natural slopes.
- Soil density.
- Moisture content.
- Soil consistency (soft or hard).
- Existing drainage.
- Natural soil strength (in terms of California Bearing Ratio (CBR)).

Information about the kind and distribution of ground cover, slopes, moisture content, and natural strength is used to estimate the construction effort required for a specific type of airfield. The surface condition and the soil type must be known to predict potential dust problems at the site. Moisture content data is required to determine the effect of traffic on soil strength and to estimate water needs during construction. Soil strength data is needed to determine the surfacing requirements as well as the thickness design.

Soil Strength

From an engineering viewpoint, shearing resistance (or shear strength) is one of the most important properties that a soil possesses. A soil’s shearing resistance under given conditions is related to its ability to withstand a load. The shearing resistance is especially important in its relation to the supporting strength or bearing capacity of a soil used as a base or subgrade beneath a road, runway, or other structure. For most military pavement applications, the CBR value of a soil is used as an empirical measure of shear strength. The CBR is determined by a standardized penetration shear test and is used with empirical curves for designing and evaluating unsurfaced aggregate-surfaced, and flexible pave ments for military airfields. The CBR test is usually performed on laboratory compacted test specimens when used in pavement design. When used in pavement evaluations, destructive test pits are usually dug to determine pavement layer thicknesses, and in-place field CBR tests are conducted on the base course, subbase, and subgrade materials. In-place CBR tests are time-consuming to run and are usually impractical for use in the TO.

For expedient-surfaced airfields in the close battle and support areas, the laboratory CBR test (which usually takes about four days to complete) is inappropriate due to time and equipment constraints. Therefore, several field-expedient methods of determining CBR are available in the TO.

The Unified Soil Classification System (USCS) correlation is the quickest means available for estimating CBR. For each soil classification, empirical studies have determined a range of CBR values. These ranges can be found in FM 5-410 (Table 5-3, page 5-11). Since the CBR ranges are only estimates, use the lowest CBR value in the range. The soil type usually varies across the entire airfield.

A better method for determining the CBR for in-place soils is with a penertrometer. There are currently three types of penetrometers available for airfields: the airfield cone penetrometer, the trafficability penetrometer, and the dual-mass dynamic cone penetrometer (DCP).

The airfield cone penetrometer described in Appendix I is used to determine an index of soil strengths (Fenwick 1965) for various military load applications. The airfield penetrometer consists of a 30-degree cone with a 0.2-square-inch base area. The force required to penetrate to various depths in the soil is measured by a spring, and the airfield index (AI) is read directly from the penetrometer. The airfield cone penetrometer has a range of 0 to 15 (CBR value of 0 to approximately 18). (The AI-CBR correlation is shown in Figure 12-1.) The airfield cone penetrometer is compact and sturdy. Its operation is simple enough that inexperienced military personnel can use it to determine soil strength. A major drawback to the airfield cone penetrometer is that it will not penetrate many crusts, thin base course, or gravel layers that may lie over soft layers. Relying only on the surface AI test results could cause the loss of vehicles or aircraft.

The airfield cone penetrometer must not be confused with the trafficability penetrometer, a standard military item in the soil test set. The trafficability penetrometer has a dial-type load indicator (0 to 300 range) and is equipped with two cones: one is 1/2 inch in diameter with a cross-sectional area of 0.2 square inch, and the other is 0.8

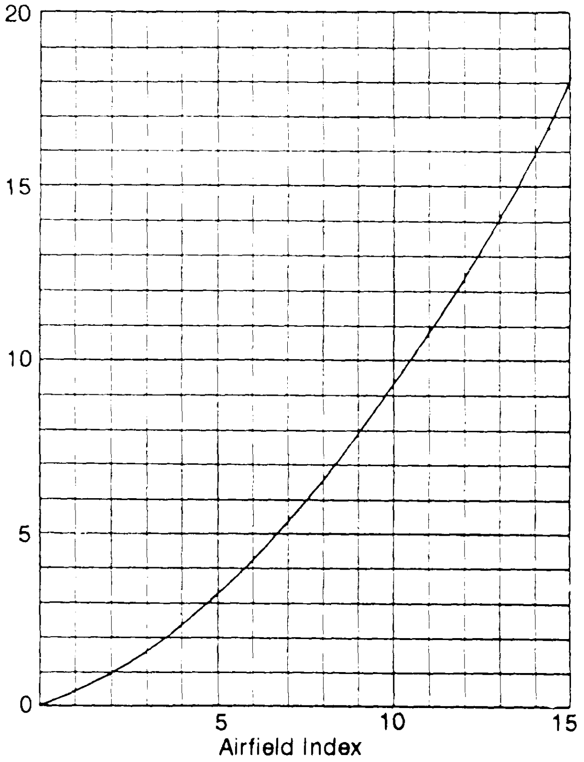


Figure 12-1. Correlation of CBR and AI

inch in diameter with a cross-sectional area of 0.5 square inch. It also will not penetrate gravelly soils or aggregate layers, but it may be useful for subgrades. If the trafficability penetrometer is used to measure AI, the readings obtained with the 0.2-square-inch cone must be divided by 20; the reading with the 0,5-square-inch cone must be divided by 50. Use the same testing procedures as discussed in Appendix I for the airfield cone penetrometer.

The dual-mass DCP described in Appendix J will overcome some of the shortfalls associated with traffic ability and airfield cone penetrometers. The DCP was originally designed and used for determining the strength profile of flexible-pavement structures. It will penetrate soil layers having CBR strengths in excess of 100 and will also measure soil strengths less than 1 CBR. The DCP is a powerful, relatively compact, sturdy device that can be used by inexperienced military personnel to determine soil strength. The DCP relation to CBR is shown in Figure 12-2. Presently, the DCP is not in the Army inventory. It was recently modified and studied by the United States Army Engineer (USAE) Waterways Experiment Station (WES). Information on procurement and use of the DCP should be directed to USAE WES, Pavement Systems Division, Geotechnical Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

Soil Behavior

Soil is compacted to improve its load-carrying capacity and to prevent differential settlement (rutting) under aircraft traffic loads. High soil strength is usually associated with a high degree of compaction. However, attaining and maintaining a desired strength in soils is contingent upon the water content at the time of construction and throughout the period of use. Some

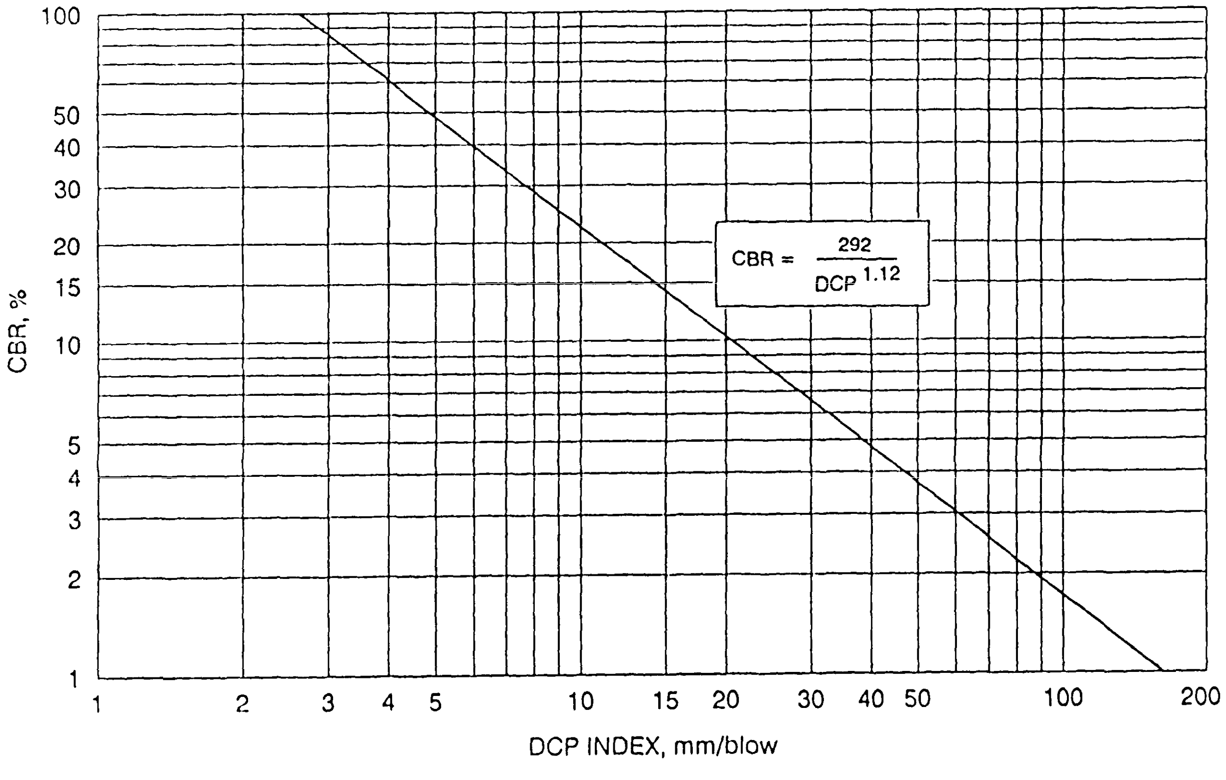


Figure 12-2. Correlation plot of CBR versus DCP index

basic moisture content-density relations for cohesive and cohesionless soils are discussed in FM 5-410. Generally, it is desirable for the soil to be compacted to American Society of Test Materials (ASTM) 1557 or to compactive effort, 55 blows per layer (CE 55), while it is within the desired moisture content range. The 4 percent moisture range and the 5 percent density range are derived from initial soil tests, and they make up the specification block. Soils are treated to improve their strength or to reduce the effects of plasticity and high liquid limits. Stabilizing a soil can also provide dust control and waterproofing. During construction, the type of soil treatment is determined by the soil characteristics and availability of stabilizing materials. (See FM 5-410 for additional information.)

DESIGN CONSIDERATIONS

The design of airfield structures is based on—

- Airfield location/mission.
- Using aircraft and associated gross weight.
- Strength of subgrade and available construction materials.
- Susceptibility of geographic area and construction materials to frost action.
- Traffic areas.
- Expected number of passes of aircraft.

Airfield Location/Mission

The location of the airfield within the TO is broken down into three major areas, as described in Chapters 10 and 11:

- Close battle area.
- Support area.
- Rear area.

These areas are designated by the mission of the airfield.

Design Aircraft and Associated Gross Weight

In TO airfield design, the design aircraft is based solely on the airfield location, as shown in Table 12-1. The gross weight is the maximum allowable weight during takeoff (worst case) and is the basis for the thickness design. Of the aircraft listed in Tables 11-1 and 11-2, pages 11-2 and 11-3, that can possibly use the airfield, the design aircraft is the one that presets the most extreme load distribution characteristics.

Expected Number of Passes

For a runway, passes are determined by the number of aircraft movements across an imaginary traverse line placed within 500 feet of the end of the runway. More simply, a pass on a runway is equivalent to a takeoff and landing of an aircraft similar in weight to the design aircraft. For taxiways and aprons, passes are determined by the number of aircraft cycles across a line on the primary taxiway that connects the

Table 12-1. Design aircraft

Airfield Location	Design Aircraft (Thickness Design)		Gross Weight (kips)	
Close battle	C-130E	C-17A	130	430
Support	C-130E	C-17A	130	430
Rear	C-141A		345	
The C-17 is the design aircraft when both aircraft are anticipated on the airfield.				

NOTE: These design aircraft should not be confused with constraining aircraft for TGR, which is mentioned in Chapter 11.

runway and parking apron. At single runway airfields, the pass level of the runway, taxiway, and apron should be the same.

For expedient-surfaced airfields, the in-place soil strength determines the number of passes. If the mission requires a longer service life, the designer must adjust the design so measures are taken to improve the in-place soil. When designing aggregate and flexible-pavement surfaces, there is a direct correlation between the number of passes and the thickness of the design.

Traffic Areas

On expedient-surfaced airfields in the close battle and support areas, traffic areas are Type A. The airfield is capable of supporting missions as soon as the runway is constructed. The layout of the runway and hammerhead turnaround areas are shown in Figure 12-3. Specific dimensions for the entire runway are shown in Chapter 11. The 63-foot turnaround area is required for the design aircraft (C-130). When C-17s are anticipated, the turnaround area does not increase the airfield width, which is 90 feet. Ensure that an extra 90-foot section is added to both ends of the runway because turnaround procedures can be detrimental to an airfield surface. Taxiways and aprons should then be continually developed to support continuous traffic.

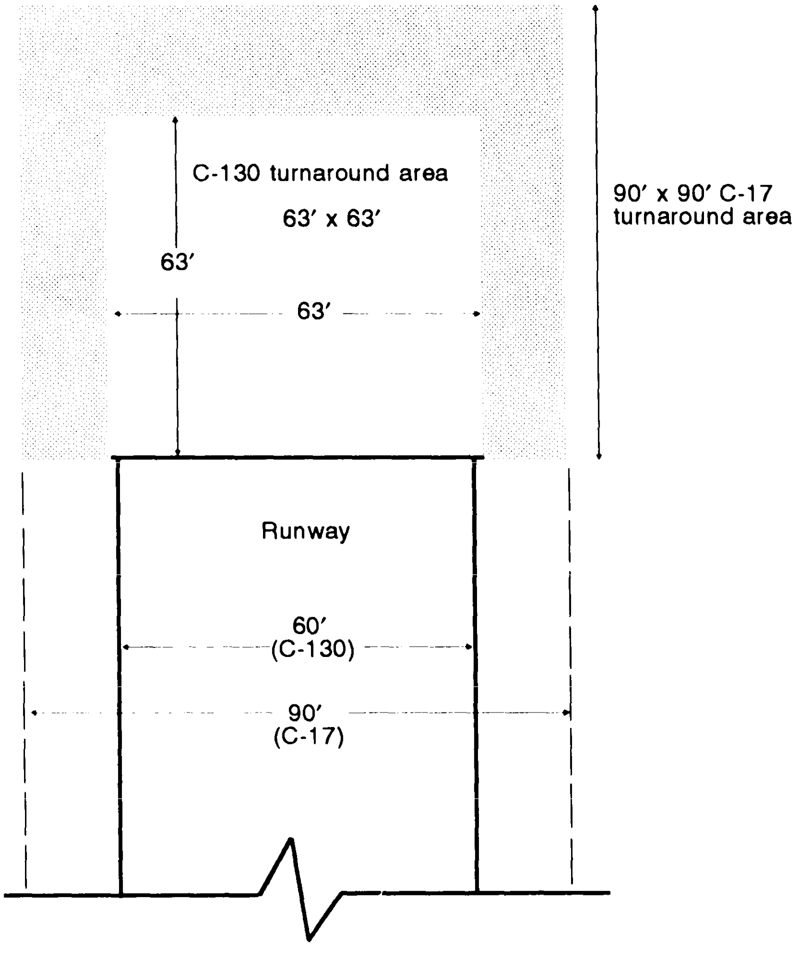


Figure 12-3. Typical layout for expedient-surfaced airfield in close battle and support areas

On aggregate-surfaced airfields in the support area, traffic areas are designated as shown in Figure 12-4. Type A areas include primary taxiways, parking aprons, washrack areas, power check pads, and 1,000 feet on both ends of the runway. The interior portion of the runway and the ladder taxiway are considered Type C areas. Since the lift on the wings accounts for some of the aircraft load, Type C areas are designed for only 75 percent of the total load.

On pavement airfields in the rear area, pavements can be grouped into four traffic areas designated as Types A, B, C, and D. They are defined below and shown in Figure 12-5.

Type A traffic areas include all primary taxiways, including straight sections, turns, and intersections. The ends (1,000 feet) are also considered Type A since the aircraft load is still fully transferred to the pavement. Although traffic tends to channelize

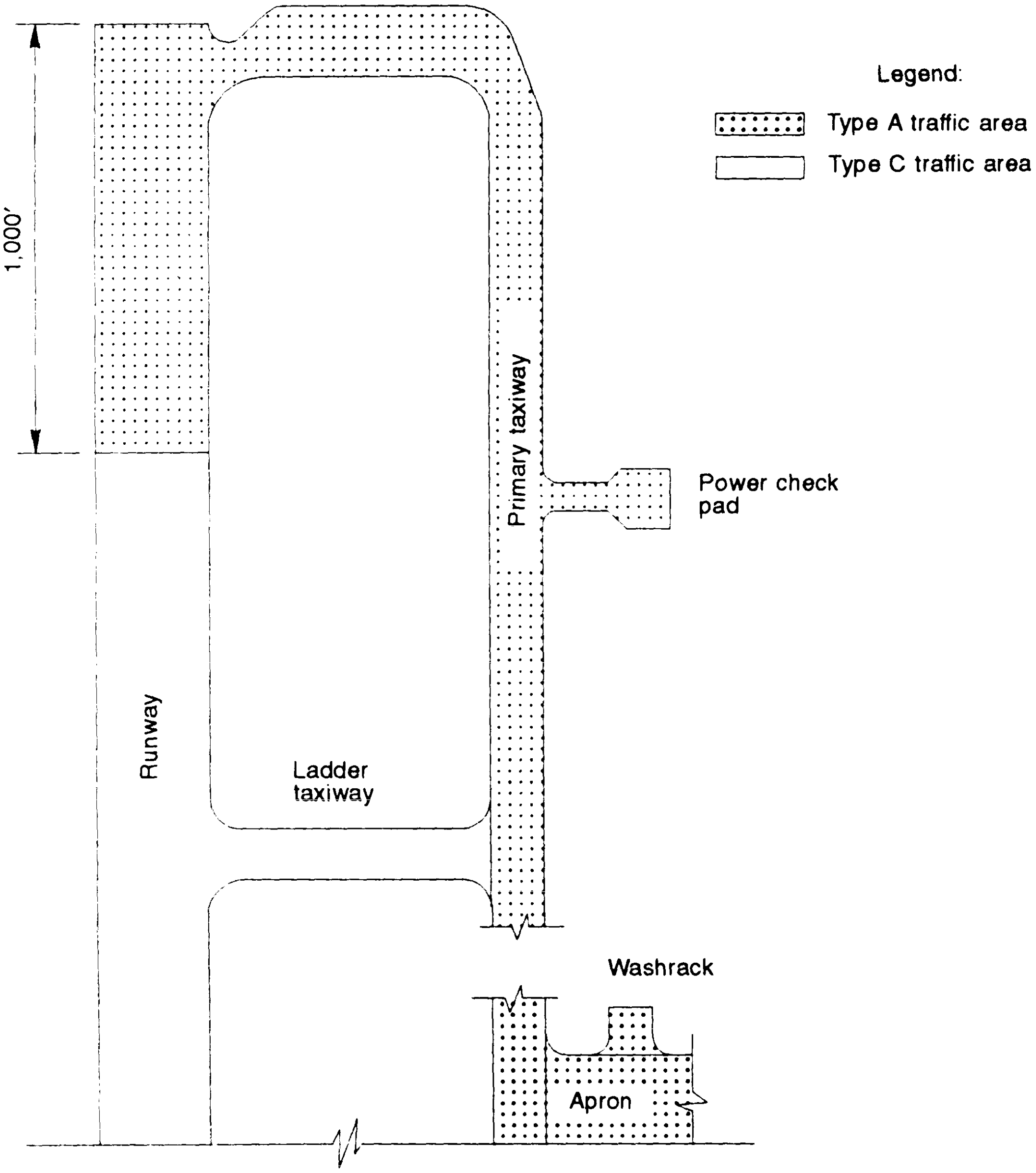


Figure 12-4. Typical layout of aggregate-surfaced airfields in the support area

in the center lane on long, straight taxiway sections, it is not practical in the TO to construct pavement sections of varying thicknesses. Type B areas include all aprons and hardstands. Type C areas include the center, 75-foot width of runway interior between the 1,000-foot runway ends and at the runway edges adjacent to intersections with ladder taxiways. Washrack pavements are also included in Type C areas. Type D areas include those areas where traffic volume is extremely low, and/or the applied weight of the operating aircraft is much lower than the design weight. Type D areas include the edges of the entire runway except for the approach and exit areas at taxiway intersections.

In designing flexible-pavement structures, the area type determines the actual load on the pavement. Type A and B areas support the entire design weight, while Types C and D should be designed for only 75 percent of the design weight.

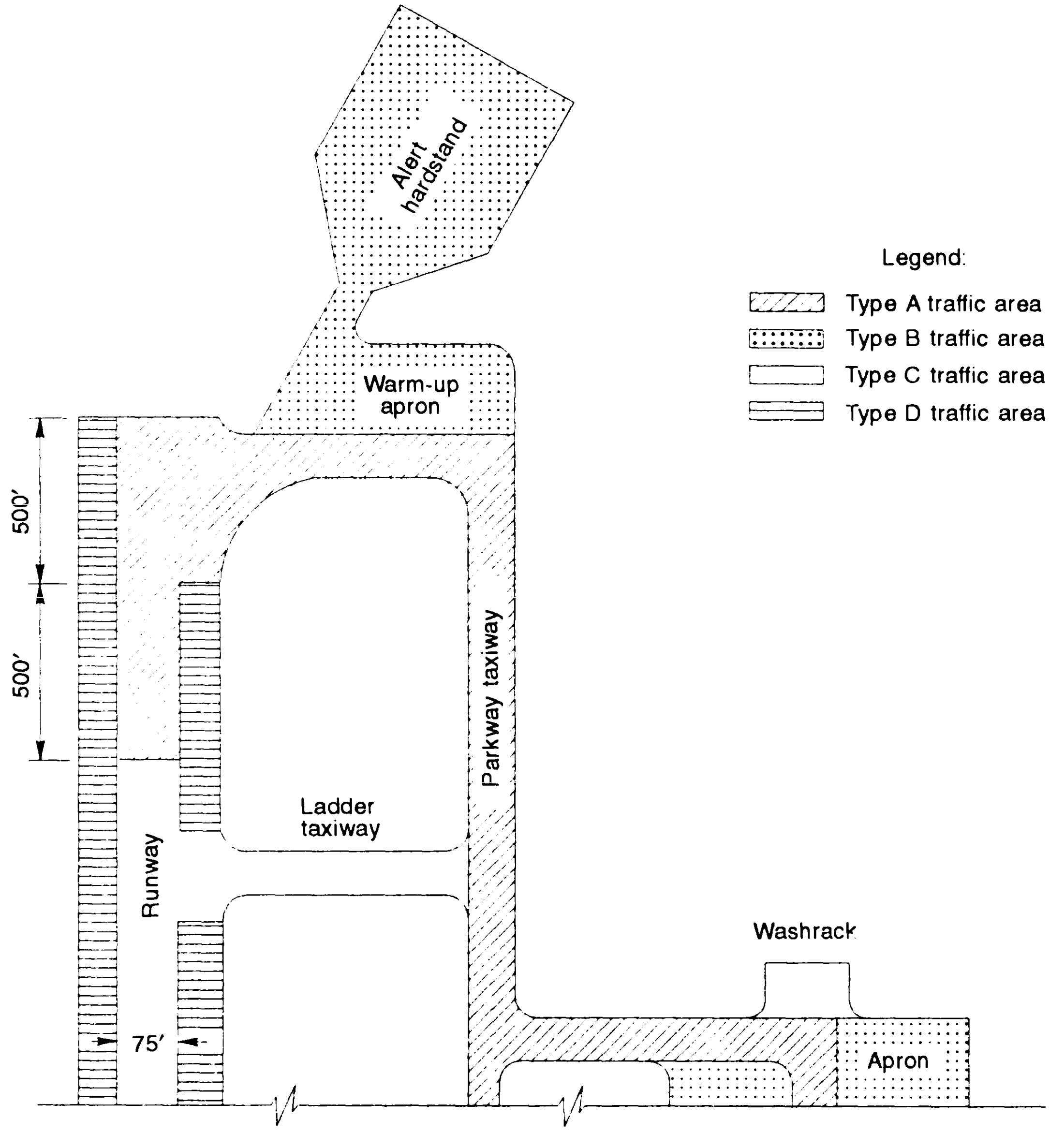


Figure 12-5. Typical layout of flexible-pavement airfields in the rear area

Soil Strength

The strength of construction materials can be determined in terms of CBR by using the laboratory CBR test, airfield cone penetrometer, trafficability penetrometer, or DCP, as discussed earlier in this chapter. The strength of both the subgrade and available construction materials can be determined in terms of CBR based on procedures outlined in Chapter 5, FM 5-430-00-1/AFPAM 32-8013, Vol 1. Strength of the in-place soil or subgrade will determine the type of surface and the number of passes for expedient-surfaced airfields. It also will determine the total thickness design in aggregate and flexible-pavement surfaces.

Frost Action

In regions subject to frost action, the design of aggregate-surfaced and flexible-pavement airfields must give consideration to measures that will prevent serious damage from frost action. Three conditions must exist simultaneously for detrimental frost action to occur: (1) soil must be frost-susceptible, (2) temperature must remain below freezing for a considerable period time, and (3) ample supply of groundwater must be available. Precise methods for estimating the depth of freeze and thaw in soils are contained in AFR 88-19, Vol 1. In addition, Chapter 4, Air Force Manual (AFM) 88-6 (TM 5-818-2), contains the criteria and procedures for design and construction of pavements subject to seasonal frost action.

Specific design procedures for frost are discussed in detail in aggregate-surfaced and flexible-pavement airfield design sections, pages 12-22 and 12-35, respectively.

EXPEDIENT-SURFACED AIRFIELDS

Unsurfaced deserts, dry lake beds, and flat valley floors serve as possible airfield sites. Normally, expedient-surfaced airfields are used for very short periods of time (zero to six months) and support C-130s, C-17s, and Army aircraft operations. Although expedient-surfaced airfields require very little initial construction, they may require extensive daily maintenance.

Expedient-surfaced airfields are primarily used for the movement of troops and supplies in the close battle and support areas. Only those Army and Air Force aircraft configured for expedient surfaces will be allowed to use the airfields. The C-130 has been the primary aircraft for missions in the close battle area because it can land on unpaved or semiprepared surfaces. The C-17, which is used primarily for strategic mobility, can also land on austere airfields. Therefore, expedient-surfaced airfields are designed for the C-130 or the C-17.

Since the close battle area is expected to change quickly, minimal resources should be committed to airfields in this area. Although the design life of expedient surfaces ranges from zero to six months (initial construction), the airfield is usually only required from zero to two weeks, unless it is upgraded to a support area. If a soil will support an unsurfaced airfield for the design aircraft, do not surface the airfield with matting unless the service life becomes significant. Use the following design procedure to determine the expedient surface type and its expected service life:

DESIGN STEPS

1. Determine the airfield location.
2. Determine the design aircraft and associated gross weight.
3. Determine the in-place soil strength.
4. Determine the required number of passes (service life).
5. Determine the allowable number of passes and surface type.
6. Outline corrective actions to increase service life as necessary.

STEP 1. DETERMINE THE AIRFIELD LOCATION

The general area (close battle, support area) will be given in the mission statement. In this case, expedient-surfaced airfields only occur in the close battle and support areas. Determining the best location should be based on a thorough reconnaissance of the area, if possible.

Site Reconnaissance

Potential LZ areas fall into three basic categories:

- *Existing.* Roads, highways, and other paved surfaces that can be used for cargo aircraft (beyond the scope of this chapter).
- *Unsurfaced.* Natural areas such as deserts, dry lake beds, and flat valley floors that may or may not include a membrane (geosynthetic covering that does not contribute strength).
- *Surfaced.* Unsurfaced airfields requiring a matting or membrane surface because of the in-place soil or to increase the service life of the airfield.

USAF combat control teams (CCTs) are trained to perform airfield surveys in support of C-130 and C-17 aircraft operations. CCTs gather all available data on the airfield and perform site visits to evaluate approach-zone obstruction clearances and weight bearing. CCTs are equipped with hand-held pocket transits, clinometers, and levels to check approach-zone clearance. Airfield and DCPs are used to check weight bearing of unsurfaced LZs. CCTs are not qualified to evaluate deteriorating existing pavements for traffic cycles and weight bearing.

CCTs gather data from an on-site survey, present an LZ survey package, and recommend approval/disapproval for use of a proposed airfield. Airlift force commanders at the Numbered Air Force/Airlift Control Center/Air Force Special Operations Base make the final decision. Airfields that require precise determination of gradients should be surveyed by Army engineering teams using theodolites, auto levels, and Philadelphia rods.

After a potential airfield site has been selected, it must be tested to ensure its suitability. The reconnaissance leader must first determine the alignment of the airfield and the location of the runway, hammerhead turnaround, taxiway, and parking apron (if any). Airfield approach zones also must be evaluated for satisfactory glide angles. (See Chapter 2, FM 5-430-00-1/AFPAM 32-8013, Vol 1.) The criteria may dictate the airfield alignment even before soil testing begins.

STEP 2. DETERMINE THE DESIGN AIRCRAFT

Design aircraft, as discussed previously, are merely a function of the area, which is determined by the mission. The design aircraft for expedient surfaces is the C-130 or C-17. When a C-17 is expected, it will become the design aircraft. The C-17 has a greater load capacity in the close battle and support areas. The gross weights for both aircraft are shown in Table 12-1, page 12-4.

STEP 3. DETERMINE THE IN-PLACE SOIL STRENGTH

This design step is significant in determining the thickness design and the service life. Therefore, it is important that accurate readings are taken from one of the expedient CBR methods. Use these procedures for determining soil strength for a uniform soil, which has equivalent CBR readings and soil characteristics (Atterberg limits, gradation) to a depth of 24 inches after organics and loose granular soil have been removed. Special cases of varying subgrades are discussed later in this chapter.

Potentially soft or dangerous areas should be tested first. Areas with poor drainage, with moist or discolored soil, or where vegetation is growing well may indicate a problem. Additionally, animal burrow holes, areas prone to flash flooding, previously forested areas, and dry lake beds may all pose potential problems. The airfield may need to be realigned, taking into consideration an area that will not lend itself to traffic.

Once the initial alignment of the airfield has been decided, determine critical CBR for the sites. To do this, test each aspect of the airfield to ensure accurate coverage in locating potential problem area. (Appendices I and J detail the recommended testing intervals for the airfield cone penetrometer and DCP, respectively.) Many soils may not be a uniform classification throughout the depth concerned (usually 24 inches.) Cases where specific layers have different CBRs pose special concerns in determining the critical CBR These cases are discussed in detail in following sections.

STEP 4. DETERMINE THE REQUIRED NUMBER OF PASSES

From the mission statement or an estimate of the situation, determine the minimum number of design aircraft passes that will accomplish the mission. Remember, a pass is considered one takeoff and one landing. Given the design aircraft, the in-place soil CBR, and the number of required aircraft passes, you can determine the airfield surface type needed. While unsurfaced airfields are favorable in minimizing resources involved in construction, some soils in their natural state cannot support traffic without a surface. For more information about specific mats and membranes, see Appendix N.

STEP 5. DETERMINE THE ALLOWABLE NUMBER OF PASSES AND SURFACE TYPE

The service life is a function of taking the design aircraft and the in-place soil CBR entering into Figure 12-6 and determining the number of allowable passes. The surface type (unsurfaced, light-duty mat, or medium-duty mat) is also a variable in determining the allowable number of passes. It does not directly increase the strength of the soil, but a surface does increase a soil's service life. Determine the surface type by checking the least resource-intensive method first. For example, if the intersection of the soil CBR and the unsurfaced curve does not meet the required number of passes, use the light-duty mat curve. Use a medium-duty mat if the number of required passes is still not met. If the soil CBR cannot support the required number of passes for any surface type, go to Step 6.

STEP 6. OUTLINE CORRECTIVE ACTIONS TO INCREASE SERVICE LIFE

After determining the allowable number of passes, compare it to the number of passes required by the mission or construction directive. There are certain courses of action available to increase the allowable number of passes. Each course of action involves increasing the strength of the in-place soil: (1) compact the in-place soil, (2) stabilize the in-place soil using mechanical, chemical, or geosynthetic stabilization, or (3) add a base course. Each of these methods is discussed in more detail later in this chapter.

DESIGN EXAMPLES

Example 1

Design an airfield for 200 passes in the close battle area given an in-place soil with AI=13. No C-17s are expected to use the airfield.

NOTE: Multiply the number of required passes by two to account for the aircraft taxiing down the runway to take off or unload.

Solution 1

Step 1. The airfield location is the close battle area.

Step 2. From Table 12-1, page 12-4, the design aircraft is a C-130, which has a gross weight of 130 kips.

Step 3. The soil strength is given as an AI. It can be converted to a CBR value through Figure 12-1, page 12-2. AI = 13 is equivalent to CBR = 14.1.

Step 4. The required number of passes is 200.

Step 5. Determine the allowable passes from Figure 12-6. Enter the chart with CBR = 14.1. Read the number of passes on the horizontal axis where the CBR intersects the C-130 curve for the appropriate

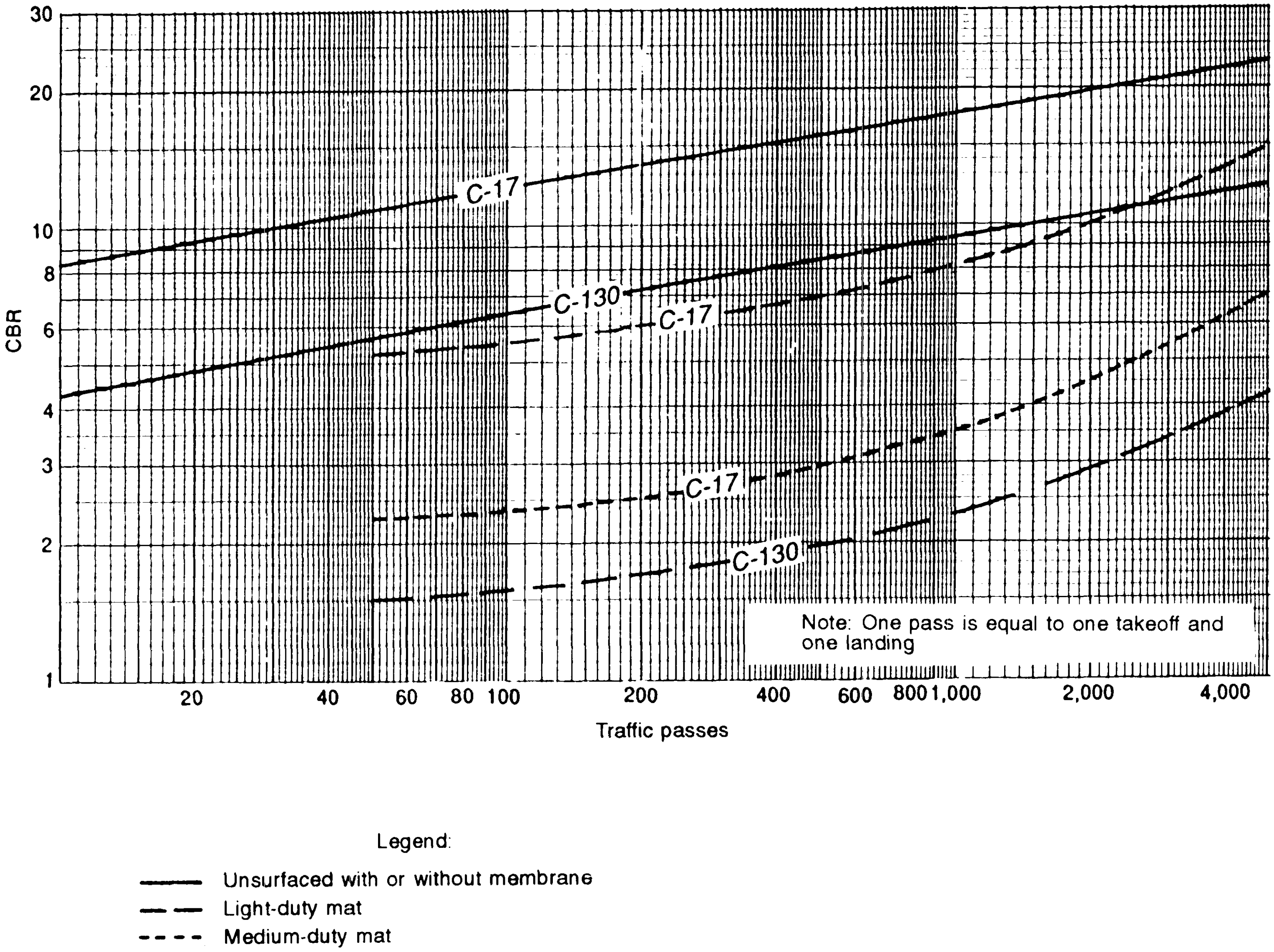


Figure 12-6. Subgrade strength requirements for C-130 and C-17

surface. In this case, the unsurfaced curve exceeds the required number of passes for a CBR = 14.1 soil; therefore, the soil will carry the 200 required passes.

Example 2

Design an airfield for logistics missions of a C-17 in the support area. The in-place soil has a DCP index of 60. The division Air Force liaison estimates the need for 600 passes.

Solution 2

Step 1. The airfield is located in the support area (given).

Step 2. Design aircraft is a C-17, which has a gross weight of 430 kips in the support area (Table 12-1, page 12-4).

Step 3. DCP index is 60. From Figure 12-2, page 2-3, CBR = 3.

Step 4. The required number of passes is 600.

Step 5. From Figure 12-6, page 12-11, the intersection of the unsurfaced curve and the soil CBR yeilds zero passes. The only surface available for this low CBR is a medium-duty mat. The allowable number of passes for a C-17 weighing 430 kips on a medium-duty treat is 540. Since the allowable number of passes exceeds the required number, proceed to Step 6.

Step 6. Outline corrective actions to increase service life. Since the DCP index reflects the soil strength in an undisturbed state, first determine the DCP index after several passes with a roller suitable to the soil type. If you improve the index only slightly, then you can meet the service life with compaction only. Consider stabilization or adding a base course as other methods if compaction alone is not enough.

EXPEDIENT AIRFIELD DESIGN—SPECIAL CASES

The previous discussion of soil-strength determination was adequate for a soil that has a uniform CBR and soil characteristics (Atterberg criteria, gradation) to a depth of 24 inches after organics and any loose, granular soil is moved aside. It is possible to determine a critical CBR for soils with varying strengths by evaluating each case separately. This changes the method of determining the in-place CBR but not the actual design procedure.

Soil-Strength Profile-Increasing with Depth

If a soil-strength profile increases with depth, the critical CBR is the average CBR for the upper 12 inches. Soil strength usually increases with depth so the weakest 12 inches are considered critical, and they control the evaluation. If the average CBR of the top 12-inch layer yields a CBR that does not meet any surfacing requirement in Figure 12-6, consider stabilizing the subgrade. (See Chapter 9, FM 5-410, for details on the type and depth of stabilization.)

Example 3

Determine the number of allowable traffic passes for a C-130 aircraft in the close battle area. Gross weight is 130 kips. The soil-strength profile is shown below.

Depth (in)	CBR
0	--
1.0	3
2.2	4
4.9	4
6.9	5
8.1	7
9.1	7
11.0	7
12.2	7
13.4	8
15.2	8
16.4	8
18.6	7
20.1	8
21.8	9
23.0	9
24.5	9

Solution 3

Step 1. Airfield location is the close battle area.

Step 2. Design aircraft is the C-130, gross weight = 130 kips.

Step 3. From the soil profile, the CBR increases with depth. The critical CBR is an average of the top 12 inches; therefore, CBR = 5.5.

Step 4. The required number of passes is not given in the mission statement, so go to Step 5.

Step 5. While the required number of passes is not given, use Figure 12-6, page 12-11, to determine the surface type and allowable number of passes. For a CBR = 5.5, an unsurfaced airfield allows only 42 passes. If a light-duty mat is used, however, the service life increases to 5,000 passes (use the largest number if it runs off the scale). Either surface would be correct, depending on the tactical situation; but if time and resources exist, use the light-duty mat.

Soil-Strength Profile-Very Soft Layer on a Hard Layer

Determining the critical CBR on a soil with a very soft layer over a hard layer can be subjective, depending on the AI or CBR value and design aircraft weight. A soft layer can be a thin layer in which there is an extreme contrast between the upper few inches and the lower level.

If a very soft layer is 4 inches thick or less, discard the CBR values from the soft layer, and determine the critical CBR from the 12-inch layer below the soft layer. For unsurfaced airfields, the allowable number of traffic passes may be reduced due to rutting in the top 6 inches, which causes excessive drag on aircraft during takeoff. This must be carefully monitored by airfield personnel. The maximum rutting depths (Table 12-2) are based on the orientation of the ruts as well as the soil strength.

Table 12-2. Maximum rutting depth

CBR	Orientation	Depth
Less than 15	Parallel or not more than a 5-degree angle off runway centerline	3 in
Less than 15	More than a 5-degree angle off runway centerline	3 in
15 or more	Any	3 in

NOTE: The aircraft cannot traffic on the surface if maximum ruts are exceeded.

If the very soft layer is more than 4 inches thick, the soft layer should be reduced by grading to at least 4 inches. If you cannot reduce the depth of the soft layer because of time or equipment constraints, determine the critical CBR as an average of the top 12 inches. The resulting low CBR will prescribe matting, which reduces the effects of rutting. Generally, the area will not be suitable as an airfield without placing matting on the traffic area or blading the soft material off and waste it, if the equipment is available.

Example 4

Determine the surface type needed to support 2,000 passes of a C-130 aircraft in the support area. Gross weight is 130 kips; soil-strength profile is indicated below.

Depth (in)	AI
0	--
2.2	0.5
4.0	0.4
6.2	6
8.0	6
9.6	7
11.2	7
13.3	7
14.9	8
16.7	8
18.0	8
20.1	7
22.4	8
23.8	8

Solution 4

Step 1. Airfield location = support area.

Step 2. Design aircraft = C-130; gross weight = 130 kips.

Step 3. The soil profile shows a soft layer that is roughly 4 inches deep. It is followed by a hard layer. Discard the data from the soft layer since the critical AI is an average of the 12-inch layer below the soft layer. The average AI from the 6.2-inch depth to the 16.7-inch depth is 7. The equivalent CBR from Figure 12-1, page 12-2, is 5.4.

Step 4. The required number of passes is 2,000.

Step 5. The surface type is a light-duty mat, capable of supporting 5,000 passes (Figure 12-6, page 12-11).

NOTE: If the CBR was high enough to justify an unsurfaced airfield, check Table 12-2, page 12-13, for maximum rutting depth. Airfield personnel should carefully monitor the runway to ensure ruts do not exceed the maximum.

Hard Layer Over a Softer Layer

Some soils may yield a profile that shows a hard layer over a soft layer. This type profile is generally exhibited by a soil that has a gravel surface over a natural or fill soil, or by a natural soil that has a hard crust in the upper layer. If the top layer of soil is adequate to support the desired aircraft passes, then the strength of the weaker soil layers beneath the top layer is used to check for the critical CBR.

The airfield cone penetrometer cannot be used to determine soil strength in a gravelly soil, but the DCP can be used. If the DCP is not available, dig a test hole or test pit to determine the thickness of the hard layer.

If the hard layer is less than 4 inches thick, the hard layer is discarded, and the critical CBR is determined by the average CBR of the 12-inch layer profile below the hard layer. The number of traffic passes is determined as before (Figure 12-6).

If the hard layer is greater than 4 inches thick, the critical layer is the 12 inches directly beneath the hard layer. If the hard layer is greater than 12 inches, simply average the CBR values of the 12- and 24-inch layers.

Example 5

Determine the surface type and the number of allowable traffic passes for a C-130 aircraft in the close battle area. Gross weight is 130 kips. The soil-strength profile yields 5 inches of gravel, and the 12-inch soil profile below the gravel layer has an average CBR = 6. The commander indicated that he needed 60 passes to accomplish the mission.

Solution 5

Steps 1-3. Close battle area; C-130 (130 kips); CBR = 6 (given).

Step 4. The required number of passes is 60 (given).

Step 5. Allowable passes = 70 (Figure 12-6) for an unsurfaced airfield.

Example 6

Design an airfield in the support area for use by both C-130s (130 kips) and C-17s (430 kips) for 1,000 passes. The soil analysts used a DCP to determine the soil strength profile below.

Depth (in)	AI
0	--
1.6	19
3.2	19
5.6	19
7.9	18
9.0	18
10.8	18
12.4	19
14.6	18
16.6	17
18.9	10
20.5	9
22.9	8
24.3	6

Solution 6

Step 1. Airfield location = close battle area (given).

Step 2. Although both aircraft will use the airfield, the C-17 is the design aircraft when both are present.

Step 3. The soil profile above shows that a soft layer exists under a hard layer. The AIs are consistently above 17 until the 18-inch depth, when they drop significantly to 10. Since the hard layer is greater than 12 inches and the soil is only evaluated to 24 inches, calculate the average of the bottom 12 inches or the 12.4-inch to the 24.3-inch layer:

$$\frac{6+8+9+10+17+18+19}{7} = 12.4$$

The critical AI is 12.4, which yields a CBR = 13 (Figure 12-1, page 12-2).

Step 4. The required number of passes is 1,000 (given).

Step 5. From Figure 12-6, page 12-11, an unsurfaced airfield allows 130 passes for a soil CBR = 13. Since this does not meet the commander's guidance, check other surfaces. A light- or a medium-duty mat can be used in this situation.

A hard soil layer over a soft layer can usually be found in dry lake beds having a high evaporation rate and a high water table. The upper crust is often 2 to 6 inches thick, and the soil beneath it generally cannot support an aircraft.

Soil-Strength Profile Decreasing with Depth

This type profile is similar to a hard layer over a soft layer. Generally, the soil exhibits a weakening with depth without a very strong surface layer. This type profile can readily be seen in areas of dry lake beds or where the groundwater can be found close to the surface. Areas such as these also may be subjected to seasonal fluctuation if the water table causes the soil profile to change.

Determine the critical CBR for this type profile by evaluating various layers to a depth of 24 inches. Determine the profile's critical CBR by choosing the lowest average CBR from the following layers: 6-18 inches, 8-20 inches, 10-22 inches, and 12-24 inches.

Example 7

Determine the number of allowable C-130 traffic passes on an airfield in the close battle area, gross weight 130 kip-pounds, and a soil strength profile shown below:

Depth (in)	AI
0	--
2.2	2
4.0	3.5
6.0	10.5
8.4	10.5
9.1	9
11.5	8.5
13.3	8
15.3	8
16.9	8
18.6	7
20.1	6
22.4	6.5
24.0	7

Solution 7

Step 1. Airfield location = close battle area (given).

Step 2. Design aircraft = C-130; gross weight = 130 kips.

Step 3. Determine the in-place soil strength by calculating averages for the following layers:

$$\text{6-18 inch: } \frac{10.5+10.5+9+8.5+8+8+8}{7} = 8.9$$

$$\text{8-20 inch: } \frac{10.5+9+8.5+8+8+8+7}{7} = 8.4$$

$$\text{10-22 inch: } \frac{8.5+8+8+8+7+6}{6} = 7.6$$

$$\text{12-24 inch: } \frac{8+8+8+7+6+6.5+7}{7} = 7.2$$

Since the lowest average CBR for the different layers is 7.2, it is the critical CBR.

Step 4. The required number of passes is not specified.

Step 5. From Figure 12-6, page 12-11, the allowable number of passes = 180 (unsurfaced) and 5,000 (light-duty mat).

SMOOTHNESS REQUIREMENTS FOR UNSURFACED AIRFIELDS

While unsurfaced airfields require little preparation, both the C-130 and the C-17 require relatively smooth surfaces for take-off and landing. The overall grades, grade changes, and slopes must be within the limits indicated in Table 11-3, page 11-4. The random surface deviations and obstacles allowed depend on the strength, hardness, and size of items that cause roughness. They should not exceed the following limits:

- Rocks in traffic areas must be removed, embedded, or interlocked in a manner that will preclude displacement when traversed by aircraft. Tree stumps must be cut to within 2 inches of the ground.
- Dried, cohesive dirt clods (clay excluded) and soil balls (as much as 6 inches in diameter) that will burst upon tire impact are allowed. Because hardened clay clods may have characteristics similar to those of rocks, they must be pulverized or removed from traffic areas.
- Contours of dirt patterns are allowed when they result from plowing to reduce erosion, aid water drain off, and prepare the soil for planting. These contours contain a soft core that does not require removal.
- Limitations on rutting are a function of the orientation, depth of ruts, and soil bearing strength. Maximum ruts that can be traversed safely are shown in Table 12-2, page 12-13.
- Potholes must be filled if they exceed 15 inches across their widest point and 6 inches deep. Potholes are circular or oval and are distinguished from depressions by their smaller size and sharp-angled corners. Distance between repairs should be at least 20 feet apart.
- Ditches more than 6 inches deep must be eliminated from traffic areas. When ditches are filled, the bearing strength must approximate that of the surrounding soil.

If it is decided (after final analysis of the subgrade strength) to change the alignment of the airfields, test the new area as required.

Remember, these evaluations do not guarantee risk-free operation; and evaluations are affected by airfield condition, weather, and aircraft use. The commander must keep these risks in mind when making decisions on airfield use.

DESIGN REQUIREMENTS FOR MEMBRANE- AND MAT-SURFACED AIRFIELDS

Many high-performance Air Force aircraft cannot operate on the degree of surface roughness permitted by unsurfaced criteria. Heavy cargo aircraft will rarely operate on unsurfaced airfields because of their sensitivity to foreign object damage and soil strength requirements. Matting and membranes can alleviate some of these problems. A thorough discussion on membranes and matting placement is contained in Appendices L, M, and N.

Smoothness Requirement for Mats and Membrane Airfields

Membrane-surfaced airfields. Membrane coverings are impermeable nylon fabrics that protect an airfield from harmful drainage effects and act as a rustproofing agent. Membranes are used on both types of expedient surfaces (unsurfaced and surfaced) with a light- or medium-duty mat. Although the membranes do not increase the strength of in-place soil, they may increase the service life in many geographic areas. The surface smoothness requirements for this airfield category apply to the subgrade surface before placement of membrane or to an existing unsurfaced airfield where sustained operations of the C-130 are expected. Smooth grade the runway and taxiway to a crown or transverse slope that meets design standards. The overall grades and slopes will not exceed that required for the unsurfaced airfield either longitudinally or transversely at any location on the surface of the runway, taxiway. or apron.

Mat-surfaced airfields. Mat surfacing provides a very smooth, well-drained, fine-graded surface free of local depressions or potholes. Surface smoothness requirements for this air-field category apply to the surface of subgrade before placement of membrane and landing mat. For satisfactory performance, the landing mat must be supported by the subgrade and must not be required to bridge over depressions or potholes. Prepare a satisfactory surface for the landing mat by compacting and fine grading to a predetermined grade. Tables 12-3 and 12-4, page 12-18, list some mat characteristics.

Grade runways and the taxiway to provide a crown section or transverse slope that meets the design standards. Overall grades and slopes must be within the limits given in Table 11-3, page 11-4. Random surface deviations in grade will not exceed 1 inch either longitudinally or transversely from a 12-foot straightedge or string line placed at any location on the surface of the taxiway, runways, or aprons.

Table 12-3. Characteristics of M19 and ancillary items

Item	NSN	Quantity of Items Per Bundle	Bundle Weight (lb)	Outside Bundle Dimensions			Bundle Volume (cu ft)
				Length (in)	Width (in)	Depth (in)	
M19 full mat	5680-930-1524	32	2,484	51 3/4	51	55	84.0
M19 half mat	5680-930-1525	32	1,480	51 3/4	51	30	45.8
M19 repair mat	5680-089-5919	16	1,555	51 3/4	51	30	45.8
Special surf mat	None	16	1,480	51 3/4	51	31	47.3
Starter connector	5680-933-3122	15	305	51	15	9	4.0
Access adapter	5680-089-5924	25	382	51	12	11	3.9
Overlap/D1 adapter	None	30	331	50	11	12	3.9
Underlap/D1 adapter	None	30	331	50	11	12	3.9
Turn adapters							
Male/underlap	5680-933-3120	15	167	50	11	8	2.5
Male/overlap	5680-089-5925	15	167	50	11	8	2.5
Female/underlap	5680-933-3121	15	167	50	11	8	2.5
Female/overlap	5680-089-5928	15	156	50	11	8	2.5
Turndown adapter	5680-933-3119	15	181	50	11	10	3.2
Anchor	5680-089-5934	250	1,225	42	36	36	31.5
Anchor attachment							
Female	5680-089-5929	125	262	27	30	12	5.7
Male	5680-089-5930	125	262	27	30	12	5.7
Locking bar	5680-930-1526	NA	NA	48 1/2	5/8	1/16	ea

Table 12-4. Mat dimensions

	M8A1	AM2	Standard Medium Duty M19
Bundle dimensions (W x L x D), ft	1.896 x 12.021 x 1.083	2.28 x 12.58 x 2.16	4.29 x 4.25 x 4.67
Volume of bundle, cu ft	24.7	62	85.1
Placing area in bundle, sq ft	268.8	288	534.4
Area covered, sq ft, per cubic foot of cargo space	10.88	4.64	6.28
Gross weight of bundle, lb	2,036	1,980	2.484
Number of panels in bundle	13	11	32
Number of half-panels in bundle	2	2	32*
Panel placing dimensions (W x L), ft	1.625 x 11.8125	2.0 x 12.0	4.008 x 4.16
Panel depth (D), in	1.125	1.500	1.500
Panel weight, lb	144	140	71
Placing area per panel, sq ft	19.2	24.0	16.7
Weight per sq ft in place, lb	7.5	5.8	4.25
Placing rate, sq ft per man-hour: On 1 1/2% crown On 3% crown	 240 200	 163 112	 352 350

*Separate bundle of half-panels

DESIGN IMPROVEMENTS FOR EXPEDIENT-SURFACED AIRFIELDS

When suitable in-place soils cannot be found to support expedient-surfaced airfields, improve the in-place soil of the desired location as a last resort. The extra time and resources involved in improving in-place soil is minimal when compared to reconfiguring missions based on finding a suitable subgrade.

The easiest way to increase the allowable number of passes is by compacting the in-place soil or subgrade. Through compaction, soil particles orient themselves in a denser formation, which increases the soil CBR. Compaction will only be effective if done for the entire critical layer. For uniformly distributed soil profiles, that means the top 12 inches. Since most rollers only compact to a depth of 6 to 8 inches, scarify and windrow the top 6 inches to the side in order to compact the bottom 6-inch layer. Specific guidelines for the type of roller to use can be found in FM 5-410. After you increase the soil CBR, go back through the design steps to determine the new allowable number of passes. Depending on the uncompacted CBR and the amount that it changed by compaction, the surface type or the need for a surface altogether also may have changed.

Normally, compaction will improve the strength of soils. However, there are some special cases where working a soil may actually decrease its strength. Specifically, the fine-grained soils, types CH and OH, can have high strengths in an undisturbed condition; but scarifying, grading, and compacting may reduce their shearing resistance. For more information on these soils, see Chapter 8, FM 5-410.

Another way to increase the strength of the subgrade is through soil stabilization. There are many methods of stabilization available to increase soil CBR. The three major types of stabilization are stabilization expedients (or geosynthetics), mechanical stabilization, and chemical stabilization. Choosing the best one depends on the soil characteristics as well as available resources. Specific information on each type of stabilizer can be found in Chapter 9, FM 5-410. Stabilizing an in-place soil is most commonly done to increase the soil's CBR, but it can also be used to negate the harmful effects of dust and water. Table 12-5 summarizes the possible functions of stabilizers in traffic and nontraffic areas on expedient surfaces.

Dust Control and Waterproofing

Much information needs to be developed to form comprehensive criteria for selecting and using dust-control agents and soil waterproofers on expedient airfields. There are many possible choices. Until one or two vastly superior dust-control agents or soil waterproofers are developed, the engineer should be aware of the potentially acceptable systems and some of their characteristics.

Dust Control. The presence of dust-sized particles in a soil surface may not indicate a dust problem. An external force imposed on a ground surface will generate dust. Dust may be generated as a result of erosion by an aircraft's propeller wash, engine exhaust blast, jet-blast impingement, or the draft of moving aircraft. The kneading and abrading action of tires can loosen particles from the ground surface. These particles may become airborne as dust.

On unsurfaced airfields, the source of dust may be the runway, taxiways, shoulders, overruns, or parking areas. In areas of open terrain and prevailing winds, soil particles may be blown in from distant locations and deposited on an airfield. This can contribute to dust potential despite adequate initial control measures of the soil within the construction area. Where blowing dust is a problem, it may be necessary to apply additional dust-control agents to an airfield.

The primary objective of a dust-control agent is to prevent soil particles from becoming airborne. These agents may be needed on traffic and nontraffic areas. If prefabricated landing mat, membrane, or conventional pavement surfacing is used in the traffic areas of an airfield, dust-control agents are needed only on nontraffic areas. The substance used in these areas must resist the maximum intensity of air blast impingement of aircraft.

Dust-control agents used for traffic areas must withstand the abrasion of wheels and blast impingement. Although dust-control agents may provide resistance against air impingement, they may be unsuitable as a wearing surface. An important factor

Table 12-5. Stabilization functions

Airfield Type	Possible Functions of Stabilization for Indicated Areas					
	Traffic Areas[a]			Nontraffic Areas[b]		
	Strength Improvement	Dust Control	Soil Waterproofing	Strength Improvement	Dust Control	Soil Waterproofing
Close Battle Area						
No mat	X	X	X		X	
With LM					X	
Support Area						
No mat				X	X	X
With LM	X			(X)	(X)	(X)
With MM				(X)	(X)	(X)

NOTES:

1. References to the use or no use of mat for a particular airfield apply only to their use in traffic areas.
2. X = functions for which stabilization may be considered; blank space = no function for stabilization; (X) = function will exist only if landing mat is not used in nontraffic areas.

[a] Traffic areas include runway, taxiways, and aprons.

[b] Nontraffic areas include overruns, shoulders, and peripheral zones which receive little or no traffic.

limiting the applicability of a dust-control agent in traffic areas is the extent of surface rutting that occurs under traffic. Under these conditions, the effectiveness of a shallow dust-control treatment could be destroyed rapidly by breakup and subsequent stripping from the ground surface. Some dust-control agents will tolerate deformations better than others. Normally, ruts in excess of 1/2 inch will result in the destruction of any thin layer or shallow dust-control treatment.

Waterproofing. Water may enter a soil by the (1) leaching of precipitation or ponded surface water, (2) capillary action of underlying groundwater, (3) a rise in the water table, or (4) condensation of water vapor and the accumulation of moisture under a vapor-impermeable surface.

As a general rule, areas with an existing shallow water table will have a low soil bearing strength and should be avoided whenever possible.

The objective of a soil surface waterproofer is to protect soil against water and preserve its strength during wet-weather operations. The use of soil waterproofers is limited to traffic areas except where excessive softening of nontraffic or limited traffic areas such as shoulders or overruns must be prevented.

Soil waterproofer may prevent soil erosion resulting from surface-water runoff. Like dust-control agents, a thin or shallow soil waterproofing treatment loses its effectiveness when damaged by excessive rutting. These treatments can be used efficiently only in areas that are initially firm.

Many soil waterproofers also function well as dust-control agents. A single material may be used as a treatment in areas with both wet- and dry-soil surface conditions.

Materials. Many materials for dust control and soil waterproofing are available. No one choice, however, can be singled out as acceptable for all problem situations. To simplify the discussion, materials are grouped into five general classifications: Group I, bituminous materials: Group II, cementing materials: Group III, resinous and latex systems; Group IV, salts; and Group V, miscellaneous materials.

A summary of the various materials and a guide to their applications as a dust-control agent or soil waterproofer are given in Table 12-6. This summary is the best estimate of the applicability of the materials based on existing information. Two materials in the table (asphalt penetrative soil binder (APSB) (Peneprime) and polyvinyl acetate dust-control agent (DCA 1295) warrant special mention.

- APSB (Peneprime) is a special cutback asphalt having good penetration capability and rapid curing characteristics. This material is effective in sand, gravel, silt, and lean clay. It is not effective in heavy clay or clay with excessive shrinkage or swelling characteristics. Surface application assures good penetration in granular soils. In clay, silt, and granular soils that are highly compacted, the surface should be scarified to a shallow depth before the material is applied.

  Compaction should be initiated when penetration is complete. In traffic areas, compaction can be accomplished by normal traffic. These materials are effective in traffic and nontraffic. When the material is applied on unscarified areas of well-compacted soil, reapplication may be necessary if the traffic is moderate to heavy.

- Polyvinyl acetate (DCA 1295) is an emulsion that is applied to the surface using a fiberglass scrim (screen) fabric to reinforce it. This material can be used on all types of soil, and it cures in four hours or less. This system is applicable to shoulders and overruns and is effective as a waterproofing agent. It will not support heavy fixed-wing aircraft traffic.

The following information is provided in Table 12-6:

Table 12-6. Dust-control and waterproofing applications

Material	Form of material	Acceptable application method(s)	Applicable soil range	Primary function, area of application, and degree of effectiveness[a]			Quantity requirements[b]		Minimum curing time requirements	Remarks
				Dust palliative		Waterproofer (traffic or limited traffic areas only)	gallons per square yard	pounds per square yard		
				Traffic	Nontraffic or limited traffic					
Group I: Bituminous Materials										
Cutback asphalts										
RC-70 to RC-250	Liquid	Admix	Gravel to sand	M	V	M	0.18-0.25	1.5-2.0	12-24 hours	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 hours	
MC-70 to MC-250	Liquid	Admix	Sand to silt	M	V	M	0.25-0.55	2.0-4.5	>24 hours	
MC-30 to MC-250	Liquid	Penetration	Gravel to silty sand	M	V	X	0.25-0.50	2.1-4.0	>24 hours	
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 hours	
		Penetration	Gravel to silty sand	M	V	X	0.25-0.50	2.1-4.0	>24 hours	
Road tars										
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.
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										
SS-1 or SS-1h (Anionic)	Liquid	Admix	Gravel to silty sand	X	X	X	0.10-0.50	0.8-4.0	Several hours	Requires water for dilution and requires careful control 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 hours	
Special asphalts										
APSB (Peneprime)[c]	Liquid	Penetration	Gravel to clay of moderate plasticity	M	V	M	0.25-0.5	2.1-4.0	4-8 hours	Excellent penetration ability; required heating.
Lion Prime	Liquid	Penetration	Gravel to clay of moderate plasticity	M	V	M	0.25-0.5	2.1-4.0	4-8 hours	Excellent penetration ability; required heating for spraying.
Group II: Cementing Material										
Portland cement	Powder	Admix	All	S	S	S	--	1.5-4.0	12-24 hours	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 high plasticity	S	S	S	--	1.5-4.0	12-24 hours	Same as cement above.
Group III: Resinous or Latex Systems										
Lignin	Liquid or powder	Admix	Sand to clay of low plasticity	S	S	S	--	4.0-8.0	12-24 hours	Benefits may be only temporary since resin is water soluble.
Membrane, liquid form (Polyvinyl acetate DCA 1295)	Liquid	Surface application	All	S	V	S	--	3.0-7.0	4 hours	Use with reinforced fiberglass screen.
Concrete curing compound (with paraffin base resin)	Liquid	Penetration	Sand to silty sand	X	X	X	0.50-1.0	4.0-8.0	2-6 hours	Fairly viscuous; requires special spray nozzels, forms thin, moderately flexible film on surface when cured; curing depends on temperature and humidity.
		Penetration	Silts to clays	S	M	X	0.1-0.2	1.0-2.0	2 hours	
Group IV: Salts										
Sodium chloride	Granular	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	
Magnesium chloride	Liquid	Penetration	Gravel and sand	M	V	--	0.5	--	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 n	--	0	Temporary measure only.
Various oils	Liquid	Penetration	All	S	X	--	0.5-1.0	--	0	Temporary measure only; may require frequent application.

[a] Relative degree of effectiveness as follows: S = slightly; M = moderately; V = very; X = applicable, but effectiveness unknown; blank = not applicable.
[b] For all admixture treatments, the quantities indicated are for a 1-inch depth of treatment and assume a compacted dry density of 100 pcf.
[c] Proprietary material.

- Column 1 identifies the material.
- Column 2 indicates the usual form in which the material is supplied.
- Column 3 indicates the most 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 shows applicable soil ranges. The range of soils indicated will normally result in reasonably satisfactory results with the particular material. Sometimes the materials may be used outside this range with decreased effectiveness. In general, granular 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 (such as dune or windblown sands) will probably require a dust-control treatment but will not need to be waterproofed. Soils ranging from silty sand to highly plastic clay may require a dust-control agent or a soil waterproofer.
- Columns 5, 6, and 7 show the primary function of the materials as either a dust-control agent or soil waterproofer, and where known, the relative degree of effectiveness that can be expected. Rarely will nontraffic areas require waterproofing because there is usually no need to maintain soil strength in nontraffic areas. If such a requirement exists, materials suitable for traffic areas can be considered acceptable for use in nontraffic areas.
- Columns 8 and 9 reflect the quantity requirements applicable to the soil range indicated in column 4. The lower quantity of the range generally is suitable for coarse soils, and the greater quantity is needed for fine soils. These quantity requirements are given only as a general guide, and in some cases, effective results may be achieved with lesser or greater amounts than those given in the table. (Detailed information on dust control is in TM 5-830-3.)
- Column 10 indicates the minimum curing time requirements.

AGGREGATE-SURFACED AIRFIELDS

While time and resources are limited in the close battle area, it may be possible to commit resources in the support area to aggregate-surfaced airfields. Most airfields in the support area initially have expedient surfaces, which may be upgraded to aggregate surfaces for sustained operations. Sometimes a former close battle area is redesignated as a support area and upgraded to an aggregate surface for ensuing operations.

The design of aggregate-surfaced airfields is similar to the design of expedient-surfaced airfields. In aggregate-surfaced airfields, however, a layer of high-quality material is placed on the compacted subgrade to improve its strength. The thickness design is a function of the CBR of the in-place soil and the design aircraft. Instead of determining the number of allowable passes based on the CBR, use the required number of passes to determine the total thickness design. For a given CBR, the thickness design increases with increased number of passes. Normally, aggregate-surfaced airfields are used from one to six months and support C-17 and C- 130 sorties.

Design the layout of aggregate-surfaced airfields like expedient-surfaced airfields. The runway with turnarounds should be constructed first as shown in Figure 12-3, page

12-5. As time permits, complete the airfield layout according to Figure 12-4, page 12-6.

MATERIALS

Materials used in aggregate airfields must meet the requirements stated in Chapter 5, FM 5-430-00-1/AFPAM 32-8013, Vol l, and in the following paragraphs. The materials should have greater strength than the subgrade and should be placed so the higher quality material is on top of the lower quality material. All layers in an airfield design require a minimum layer thickness of 6 inches and should conform to the CBR and compaction criteria shown in Table 12-7.

Table 12-7. Compaction criteria and CBR requirements for aggregate-surfaced airfields (MIL STD 621 method 100 CE 55)

CBR Requirements	Layer	Compaction Requirements
80-100	Base course	Asphalt: 98-100% @ CE 55 Soil: 100-105% @ CE 55
20-50	Subbase course	100-105% @ CE 55
0-20	Select material	Cohesive: 90-95% @ CE 55 Cohesionless: 95-100% @ CE 55
	Compacted subgrade	Cohesive: 90-95% @ CE 55 Cohesionless: 95-100% @ CE 55
	Uncompacted subgrade	

Subgrade

The in-place soil or subgrade requires more attention in aggregate-surfaced airfield structures. Before developing the thickness design, determine the compacted CBR of the subgrade. Since laboratory CBR tests are impractical for initial construction, use the penetrometers discussed earlier.

Determine the soil's CBR profile as discussed previously for expedient surfaces. Like road design, the CBR of the subgrade determines the thickness of the whole design. If you can improve the CBR through compaction, the thickness of the aggregate airfield structure will decrease. The depth to which an in-place soil should be compacted is normally 6 inches, but the depth is determined in the design procedure.

Select and Subbase Materials

Select and subbase materials used in aggregate airfields provide granular fill to meet the thickness design based on the subgrade CBR. Select materials and subbase courses must meet the Atterberg limits and gradation requirements of Table 12-8, which are the same criteria used for roads.

Base Course

Only good quality materials should be used in base courses of aggregate airfields. Since the base course is also the surface course, it must meet specifications for both strength anti gradation. The minimum CBR

Table 12-8. Maximum permissible values for subbases and select materials

Material	Maximum Permissible Value					
	Maximum Design CBR	Size (inch)	Gradation Requirements Percent Passing		Liquid Limit*	Plasticity Index*
			No. 10 Sieve	No. 200 Sieve		
Subbase	50	2	50	15	25	5
Subbase	40	2	80	15	25	5
Subbase	30	2	100	15	25	5
Select material	20	3	--	--	35	12

*Determination of these values will be made in accordance with ASTM D 4318.

for an airfield base course is 80 (Table 12-7, page 12-23). Since CBR tests require time, use one of the base-course materials shown in Table 12-9, if possible. They are materials of known strength. If a material not listed is more easily obtained, use a test strip to determine its compacted CBR with a DCP.

Gradation requirements for aggregate-surfaced layers are given in Table 12-10, where the specifications depend on the maximum size aggregate (MSA). These are the same gradation requirements as given in Chapter 5, FM 5-430-00-1/AFPAM 32-8013, Vol 1, for base courses for aggregate-surfaced roads.

FROST CONSIDERATIONS

Aggregate-surfaced airfields, unlike roads or expedient surfaces, require much more restrictive tolerances in construction and general maintenance. For this reason and the potential for catastrophic accidents in the case of structural failure, frost must be considered in the design of aggregate airfields. The specific areas where frost has an impact on the design are discussed in the following paragraphs:

Table 12-9. Assigned'CBR ratings for base-course materials

Number	Type	Design CBR
1	Graded, crushed aggregate	100
2	Water-bound macadam	100
3	Dry-bound macadam	100
4	Bituminous base course, central plant, hot mix	100
5	Limerock	80
6	Bituminous macadam	80
7	Stabilized aggregate	80
8	Soil cement	80
9	Sand shell or shell	80

Table 12-10. Desirable gradation for crushed rock or slag, and uncrushed sand and gravel aggregates for nonmacadam base courses

Sieve Designations	Percent Passing Each Sieve (Square Openings) by Weight			
	Maximum Aggregate Size			
	2-Inch	1 1/2-Inch	1-Inch	1-Inch Sand Clay
2-inch	100			
1 1/2-inch	70-100	100		
1-inch	55-85	75-100	100	100
3/4-inch	50-80	60-90	70-100	
3/8-inch	30-60	45-75	50-80	
No. 4	20-50	30-60	35-65	
No. 10	15-40	20-50	20-50	65-90
No. 40	5-25	10-30	15-30	33-70
No. 200	0-10	5-15	5-15	8-25

As discussed earlier, three conditions must exist for detrimental frost action to occur: (1) the subgrade must be frost susceptible, (2) the temperature must remain below freezing for a considerable amount of time, and (3) an ample supply of groundwater must be available. Since aggregate-surfaced airfields have a design life up to six months, the effects of frost may not be relevant because of the time of year. In any case, evaluate the frost effects during the design process in the event the airfield is needed for sustained operations.

In general, frost-susceptible soils are those with considerable amount of fines or with at least 6 percent of materials finer than 0.02-millimeter grain size by weight. You do not have to relocate or find another soil when faced with one of these situations; however, you need to adjust the thickness design to account for the frost action. When water in a subgrade freezes, additional water travels by capillary rise and increases the ice lense. The ice lenses can disturb the compacted layers enough to create large voids during the next thaw cycle.

THICKNESS DESIGN PROCEDURE

The design procedure for aggregate-surfaced airfields in the support area is very similar to expedient-surfaced airfields. The major difference is that the outcome is the thickness of the aggregate structure, which is a function of the subgrade CBR, the design CBR, and the number of passes.

DESIGN STEPS

1. Determine the airfield location.
2. Determine the design aircraft and gross weight.
3. Check soils and construction aggregates.
4. Determine the number of passes required.
5. Determine the total surface thickness and cover requirements.
6. Complete the temperate thickness design.
7. Adjust thickness design for frost susceptibility.
8. Determine compaction requirements and subgrade depth.
9. Draw the final design profile.

Step 1. Determine the Airfield Location

The airfield location is always the support area. While aggregate-surfaced airfields are too resource intensive for the close battle area (unless they are existing airfields), they do meet the surface requirements for the rear area.

Step 2. Determine the Design Aircraft and Gross Weight

The C-17 and C-130 are the only possibilities for design aircraft in the support area. Aggregate surfaces are considered a semi-prepared surface where only the C-17 and C-130 can land. Since the support area is primarily a connector of the rear and close battle areas, it is logical that the design aircraft be able to land in all three areas. The aircraft also have the same design weights for the support and close battle areas as shown in Table 12-1, page 12-4.

Step 3. Check Soils and Construction Aggregates

This design step has three parts: (1) check the local area for possible borrow sites to be used as select materials and subbases, (2) check the strength and gradation of a possible base course, and (3) check the frost susceptibility of all materials, if necessary.

- Check construction aggregates for use as select and subbase materials. This is similar to road design discussed in Chapter 9, FM 5-430-00-1/AFPAM 32-8013, Vol 1. Conduct soil tests on any borrow sites to determine the soil's CBR, gradation, and liquid and plastic limits. Compare these values to Table 12-8, page 12-23, to determine if the borrow material can be used in a layer of the design.
- Check the strength and gradation of the base course. The base course must have a CBR = 80 or higher and meet the gradation criteria of Table 12-10.
- Check frost susceptibility of materials. If detrimental frost action (as defined earlier) is a concern, evaluate each layer soil below the base course for frost susceptibility. A soil is frost susceptible if it has 6 percent fines and/or 6 percent (by weight) 0.02 millimeter grain size.

For frost design purposes, soils have been divided into seven groups (Table 12-11, page 12-26). Only the nonfrost-susceptible (NFS) group is suitable for base course. Soils are listed in approximate order of decreasing bearing capability during periods of thaw.

The percentage of fines should be restricted in all the layers to facilitate drainage and reduce the loss of stability and strength during thaw periods.

Do not use a soil above the compacted subgrade if it is frost susceptible. For example, a borrow material that meets the criteria for a subbase should not be used in the design if it has more than 6 percent finer than 0.02 millimeter by weight.

Table 12-11. Soil classification for frost design

Frost Group	Type of Soil	% By Weight < 0.02 mm	Typical Soil Types Under the USCS
NFS	(a) Gravels (e ≥ 0.25)	0 - 3	GW, GP
	Crushed stone	0 - 3	GW, GP
	Crushed rock	0 - 3	GW, GP
	(b) Sands (e ≤ 0.30)	0 - 3	SW, SP
	(c) Sands (e > 0.30)	3 - 10	SP
S1	(a) Gravels (e < 0.25)	0 - 3	GW, GP
	Crushed stone	0 - 3	GW, GP
	Crushed rock	0 - 3	GW, GP
	(b) Gravelly soils	3 - 6	GW, GP, GW-GM, GP-GM, GW-GC, GP-GC
S2	Sandy soils (e ≤ 0.30)	3 - 6	SW, SP, SW-SM, SP-SM, SW-SC, SP-SC
F1	Gravelly soils	6 - 10	GW-GM, GP-GM, GW-GC, GP-GC
F2	(a) Gravelly soils	10 - 20	GM, GC, GM-GC
	(b) Sands	6 - 15	SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, SM-SC
F3	(a) Gravelly soils	> 20	GM, GC, GM-GC
	(b) Sands, except very fine silty sands	> 15	SM, SC, SM-SC
	(c) Clays (PI > 12)	-	CL, CH, ML-CL
F4	(a) Silts	-	ML, MH, ML-CL
	(b) Very fine sands	> 15	SM, SC, SM-SC
	(c) Clays (PI < 12)	-	CL, ML-CL
	(d) Varved clays and other fine-grained, banded sediments	-	CL or CH layered with ML, MH, SM, SC, SM-SC, or ML-CL

NOTE: e = void ratio.

If a subgrade is frost susceptible, determine its frost group from Table 12-11, and find the frost area soil support index from Table 12-12. This value is needed to adjust the thickness design in Step 8.

Table 12-12. Frost area soil support index

Frost Group of Soils	Frost Area Soil Support Index
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

Step 4. Determine the Number of Passes Required

Unlike design for expedient surfaces, you can control the thickness design by the number of passes required. As the number of passes increases, so does the thickness design and, consequently, the construction effort. You may be given the required number of passes in a mission statement or you can adjust it based on the thickness design.

Step 5. Determine the Total Surface Thickness and Cover Requirements

The total thickness of the aggregate structure is a function of the subgrade CBR, the design aircraft, and the number of passes. Since the thickness design is usually greater than 6 inches (the minimum layer thickness), multiple soil layers are used. For example, if the thickness required over a subgrade was 18 inches, it would be expensive and wasteful to fill the entire 18 inches with a high-quality base course. Instead, use borrow materials to fill all but the top 6 inches. The CBR of each soil used in the design determines the required cover.

After evaluating the available soils and determining the number of passes, enter Figure 12-7 or 12-8, page 12-28, with the subgrade CBR until it intersects the gross weight of the design aircraft. Trace a line horizontally until you intersect the desired number of passes and determine the minimum cover required over the subgrade from the horizontal axis. Determine the minimum cover required over each soil that could be used in the design.

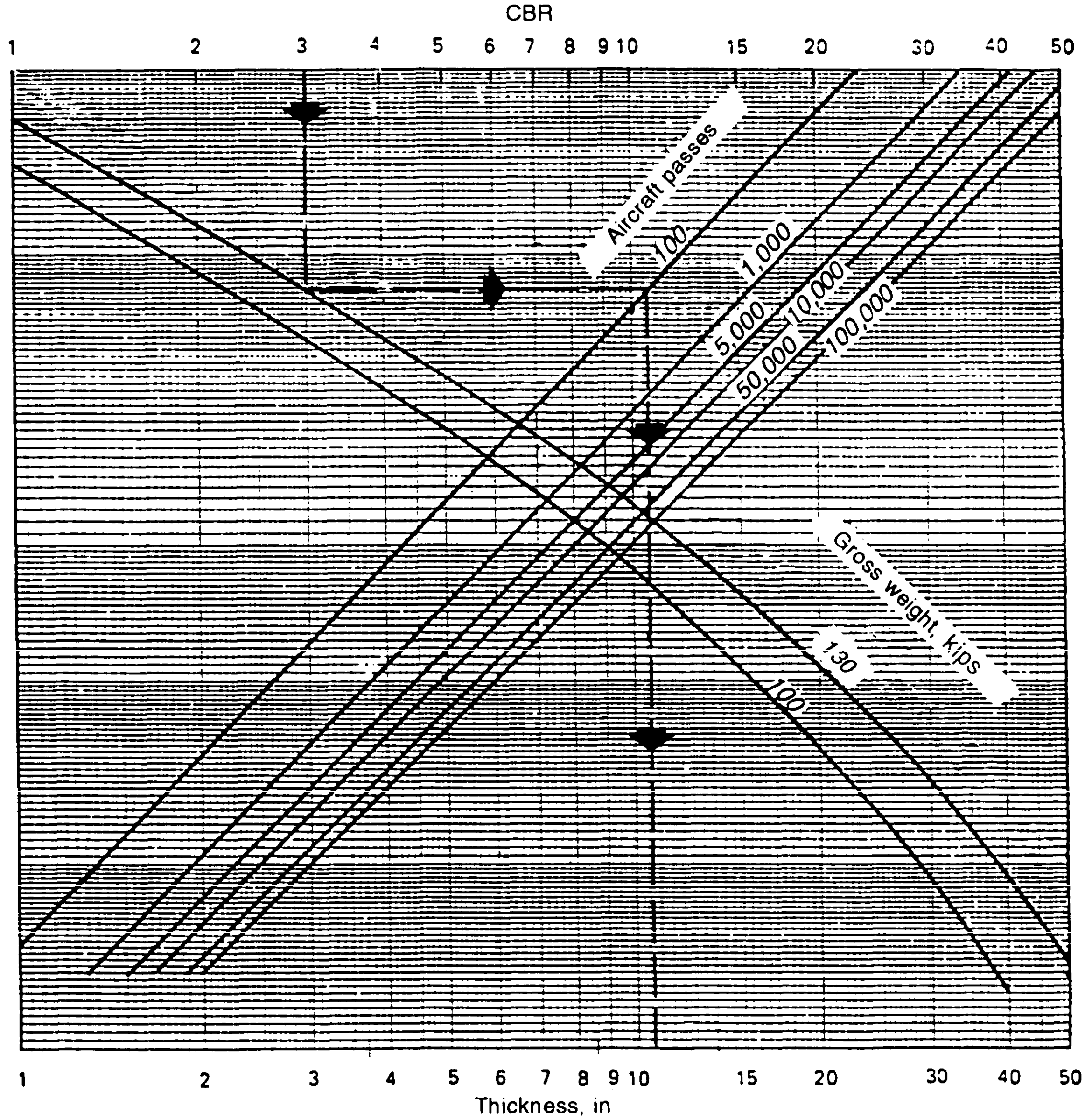


Figure 12-7. C-130 design curves for gravel-surfaced airfields

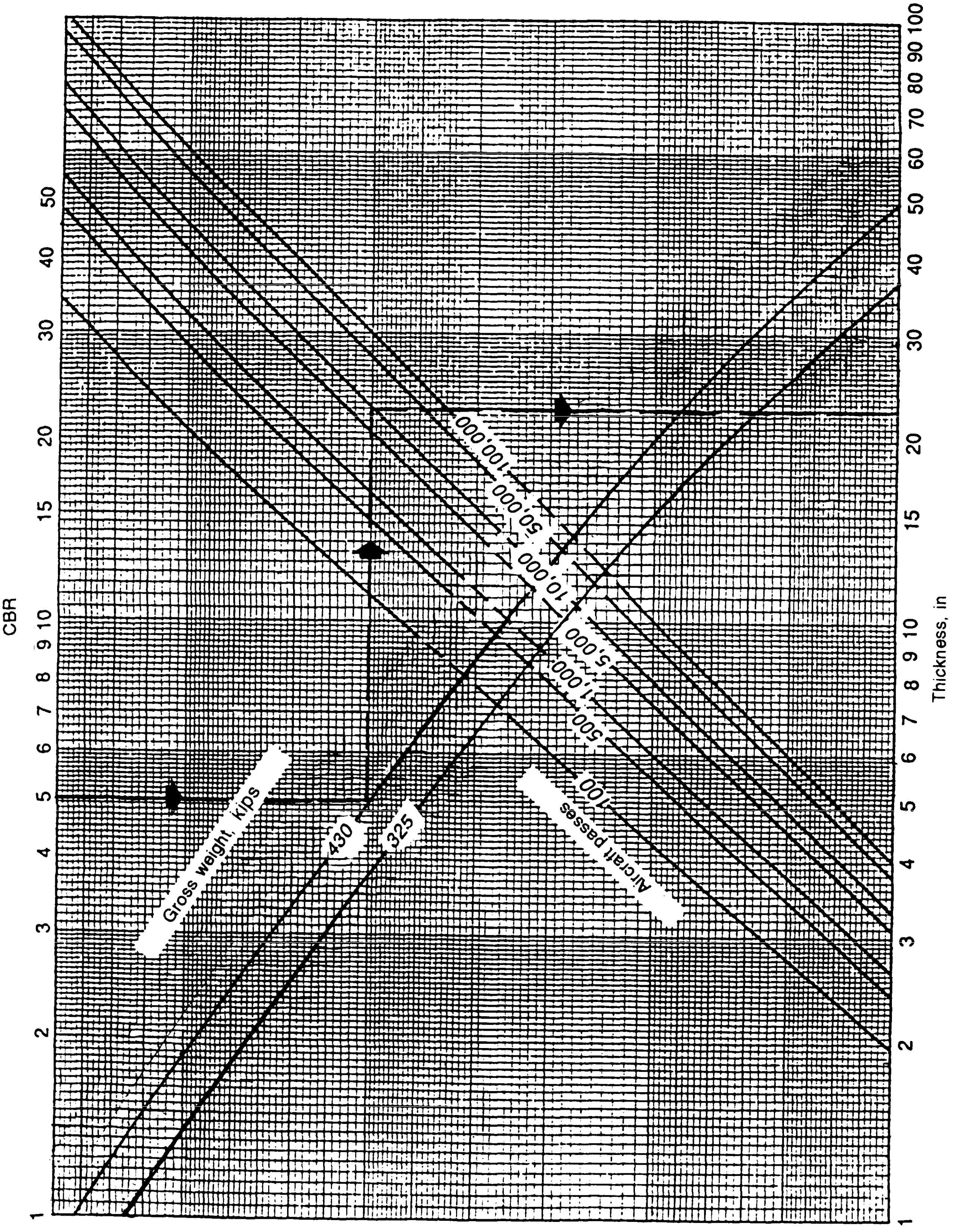


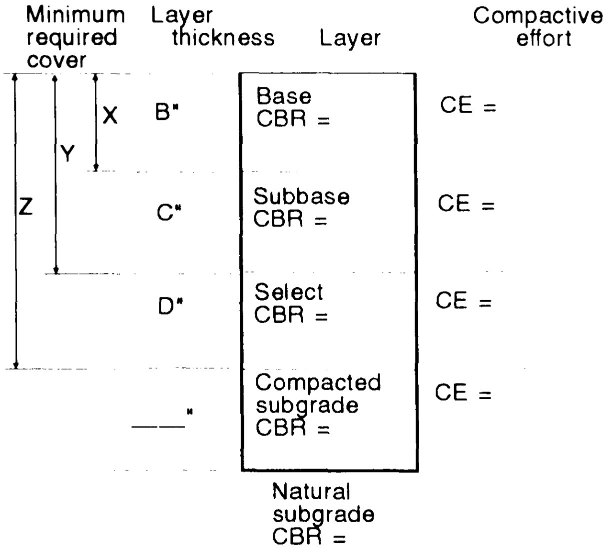
Figure 12-8. C-17 design curves for gravel-surfaced airfields

Step 6. Complete the Temperate Thickness Design

After finding the cover requirements, you can complete the thickness design without considering the effects of frost. The method is similar to road design in that you determine the layer thicknesses that satisfy the minimum cover requirements for each layer. Remember that each layer must be a minimum of 6 inches thick. Also, do not use soil layers in the design if they are not necessary to satisfy the cover requirements. For example, if a subgrade only requires 5 inches of granular fill, then the base course is the only aggregate layer required. Even though you may have determined that subbases and select materials are readily available nearby, they are not necessary for the airfield design. Figure 12-9 illustrates the relationship between minimum cover and layer thickness.

Step 7. Adjust Thickness Design for Frost Susceptibility

If you are not designing in a frost area or if the subgrade in a frost area is not frost susceptible (see Step 1), go to Step 9.



B = X
C = Y - B
D = Z - B - C

X = Minimum cover over subbase (Figure 9-54, Page 9-72, FM 5-430-00-1/AFPAM 32-8013 Vol 1)
Y = Minimum cover over select (Figure 9-54)
Z = Minimum cover over compacted subgrade (Figure 9-54)

Figure 12-9. Thickness design procedure

Since the freeze-thaw cycles associated with frost areas weaken soils, you now have to consider frost and how it will affect the thickness design. Since the subgrade is the only frost-susceptible material at this point, retrieve the subgrade information from Step 1.

Determine the frost-area soil-support index from Table 12-12, page 12-26. Use the index to enter Figure 12-7, page 12-27, or Figure 12-8 instead of the compacted CBR.

For example, for a C-130 airfield, if the compacted subgrade CBR was found to have CBR = 8 and the subgrade was found to be an F2 type soil, enter Figure 12-7 with CBR = 6.5 instead of 8. Since the lower value increases the thickness design for the same number of passes, choose the thicker of the two designs.

The frost design will not always increase the thickness design. For instance, if Step 7 indicates a total thickness design of 14 inches over a subgrade with a CBR = 3 and the soil is an F3 soil, use Table 12-12, page 12-26, to determine the soil support index of 3.5. Since 3.5 is greater than 3, it requires thinner design (determined by Figure 12-7).

After choosing the thicker of the two designs, you must add a frost filter to the design and adjust the layer thicknesses. A frost filter is sand or a uniformly graded, cohesionless material that allows the lateral movement of water. Place a 4-inch layer directly on the compacted subgrade and compact it to the specifications outlined in Step 8.

Geotextiles may be used over F3 and F4 subgrade materials in seasonal frost areas to help prevent intrusion of fines into base layers during periods of thaw. The geotextile should provide at least 110 pounds at 10 percent strain when the material is tested by the Grab Strength Test (ASTM D-5034 and D-5035). If the material exhibits different strengths in perpendicular directions, the lowest value is used. If longitudinal seams are required, they must meet the requirements in ASTM D-1683. End overlap at transverse joints should be a minimum of 2 feet. The fabric will be placed directly on the subgrade and must extend laterally to within 1 foot of the toe of slope on each side. A frost-filter layer is not required when a geotextile is placed directly on the compacted subgrade.

Step 8. Determine Subgrade Depth and Compaction Requirements

The layer thickness of an in-place soil is the depth to which you must ensure adequate compaction. Determine the depth by entering Table 12-13 with the appropriate traffic area and soil information.

The actual depth of subgrade compaction is the difference between the total thickness above the subgrade and the value from Table 12-13 or 6 inches, whichever is greater. For example, if the thickness above the cohesive subgrade (Type B traffic area) is 16 inches, then the depth of subgrade compaction is 21 inches (Table 12- 13) - 16 inches = 5 inches. However, since 5 inches is less than 6 inches, compact to a depth of 6 inches. Since the equipment effort for compaction is about the same for depths of 1 to 6 inches, the minimum depth of subgrade compaction is 6 inches.

Because most road construction missions require cut-and-fill operations, the subgrade depth requirement is only significant in cut sections since the soil in fill sections is placed and compacted in lifts (usually 6 inches). In cut sections, however, the subgrade must be scarified and compacted in place to the depth required after the cut is made.

Table 12-13. Depth of compaction required for subgrades

Traffic Area	Minimum Compacted Depth Below Surface (inches)	
	Cohesive Soils	Cohesionless Soils
B	21	25
C	17	21

Compaction requirements for subgrade and granular layers are expressed as a percent of maximum CE 55 density as determined by using Military Standard (MIL-STD) 621 Test Method 100 (ASTM 1557). The specifications for each layer in the design are listed in Table 12-7, page 12-23.

Remember, there are special cases for subgrades that lose strength when being remolded. These are generally soil types CH and OH. See Chapter 8, FM 5-410, for more information on these soils.

Step 9. Draw the Final Design Profile

This step is a culmination of the previous eight steps into a picture that the builder can understand. It shows the layer thicknesses, soil CBRs, and compaction requirements. It also shows the compactive effort of any fill sections, which is the same soil as the subgrade. Figure 12-10 shows the specific detail included in the profile.

______" Base course CBR @ 100-105% CE 55

______" Subbase[1] CBR ___ @ 100-105% CE 55

______" Select Mat'l[1] CBR ___ @ __%-__% CE 55

______" SCIP[2] CBR ___ @ __%-__% CE 55

TDF[3] @ ___%-___% CE 55

1 These are optional layers depending on the materials available and the thickness design.
2 Scarifiy and compact in place.
3 Total depth of fill.

Figure 12-10. Final design profile

Example 8

Design the taxiways and ends of the runway (Type B area) for an aggregate-surfaced airfield in the support area (Honduras) for 1,000 passes of a C-130. The in-place soil is a well-graded, sandy clay with a PI = 6, and has 7 percent finer than 0.02 millimeter by weight. Your soils analyst reports a uniform CBR = 5. After he set up a test strip, he found that the CBR increased to 7 with compaction. From the reconnaissance teams, you have one potential borrow site with the following soil characteristics:

> Borrow A: GP-GC; CBR = 35, PI = 8, LL = 28; 60 percent passes Number 10 sieve; 15 percent passes Number 200 sieve.
>
> Base course: Nearby civilian batch plant has been leased by the US; well-graded, crushed limestone available with the following gradation specifications:

Sieve	Percent Passing
2"	100
1.5"	93
1"	63
3/4"	54
No. 4	42
No. 10	18
No. 200	6

Solution 8

Step 1. Airfield location = support area (given).

Step 2. Design aircraft = C- 130/130 kips (given).

Step 3. Check construction aggregates.

a. Check materials for use as select/subbase. Since there is only one potential source, check it according to Table 12-9, page 12-24. Since PI = 6, the soil does not meet the Atterberg criteria for a subbase. Therefore, determine whether it meets select material criteria. Since its LL < 25 and the PI < 12, it can be used as a select material CBR = 20.

b. Determine the base course CBR. From Table 12-10, page 12-24, since the base course material is a well-graded, crushed aggregate (limestone), the CBR = 100.

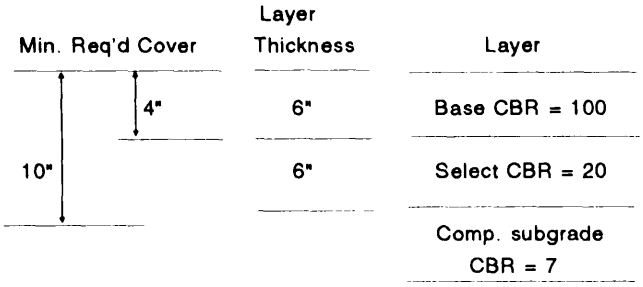
c. Check materials for frost susceptibility. Since the location of the airfield is Honduras, frost is not a concern.

Step 4. Determine the number of passes required. Passes required = 1,000 (given).

Step 5. Determine the total surface thickness and cover requirements. Using CBRs for each soil layer that requires cover, enter Figure 12-7, page 12-27, to determine the cover requirements.

Material	Minimum Required Cover
Compacted subgrade CBR 7	9.1" ♂ 10"
Select material CBR 20	3.9" ♂ 4"

Step 6. Complete the temperate thickness design. Draw a figure to determine the layer thicknesses based on the cover requirements.



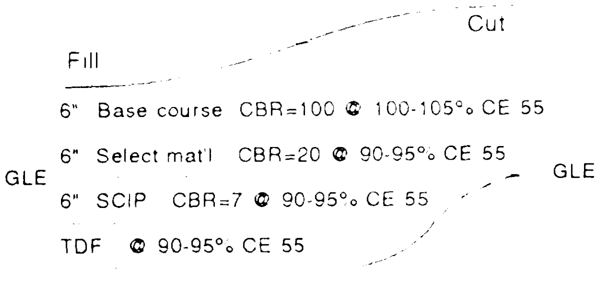
Calculate the layer thicknesses from the surface down. First, look at the cover required above the select layer. It requires a minimum of 4 inches above it. The base course has a layer thickness of 6 inches because the minimum layer thickness in an airfield is 6 inches. Next, look at the cover required above the CBR = 7 subgrade. While 10 inches are required, you already have 6 inches in the base. Therefore, the subgrade requires an additional 4 inches of cover. Again, since the minimum layer. thickness is 6 inches, round the select layer thickness up to 6 inches.

Step 7. Not applicable since the airfield is located in a nonfrost area.

Step 8. Determine the subgrade depth and compaction requirements. (See Table 12-13, page 12-30, to find the minimum depth of compaction below the surface.) Because the subgrade soil has a PI = 6, it is a cohesive soil. For a cohesive soil in a Type C area, the required depth of compaction is 17 inches below the surface. Since the total thickness design is 12 inches, the actual depth of subgrade compaction is 17 - 12 = 5 (rounded up to 6 inches.) The compaction requirements (from Table 12-7, page 12-23) for the three layers is shown below:

Layer	Compaction Requirement
Compacted subgrade	90-95% CE 55
Select material	90-95% CE 55
Base course	100-105% CE 55

Step 9. Draw the final design profile.



Example 9

Design a Type B area for an aggregate-surfaced airfield in northeastern Turkey that can withstand 10,000 passes of a C-17 (gross weight = 430 kips). The area is subjected to seasonal frost conditions (assume that seasonal frost will occur during the airfield service life). Below is a summary of soil and construction aggregate data.

- Subgrade: CL: PI = 14: natural CBR = 3: compacted CBR = 5: 7 percent finer than 0.02 millimeter by weight.
- Borrow A: GP: CBR = 35: PI = 8; LL = 28: 10 percent pass Number 80 sieve; 5 percent pass Number 200 sieve; NFS.
- Borrow B: GW-GC; CBR = 45; PI = 5; LL = 23; 65 percent pass Number 10 sieve; 12 percent pass Number 200 sieve; NFS.
- Base course: Limestone; meets gradation limits for 2-inch MAS (Table 12-10, page 12-24).

Solution 9

Steps 1 and 2. Support area is the only choice for aggregate-surfaced airfields; C-17 (430 kips) is the design aircraft.

Step 3. Check soils and construction aggregates.

a. Check possible subbases and select materials.

- Borrow A: Fails as a subbase due to Atterberg criteria, but meets select material criteria. Therefore, it can be used as a select material CBR = 20.
- Borrow B: Meets criteria for a subbase CBR = 50; therefore, use it as a subbase CBR = 45.

b. Check strength and gradation of the base course. Since the base course is limestone, the CBR = 80 (Table 12-9, page 12-24). The soils analyst already checked the gradation information and said it met the specifications.

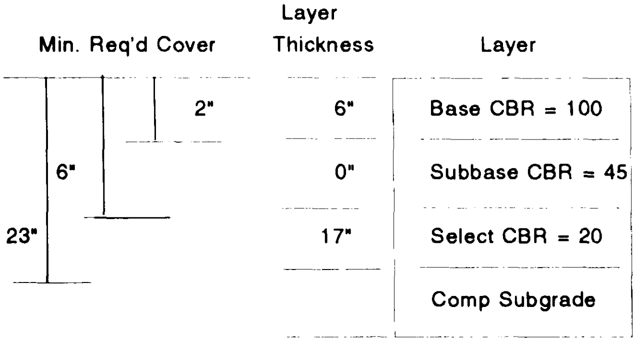
c. Check for frost susceptibility. No materials above the compacted subgrade are frost susceptible. Since the subgrade has greater than 6 percent finer than 0.02 millimeter by weight, it is frost susceptible. From Table 12-11, page 12-26, the soil falls into frost group F3. The soil support index from Table 12-12, page 12-26, is 3.5.

Step 4. The number of passes required is 10,000 (given).

Step 5. Determine the cover requirements from Figure 12-8, page 12-28.

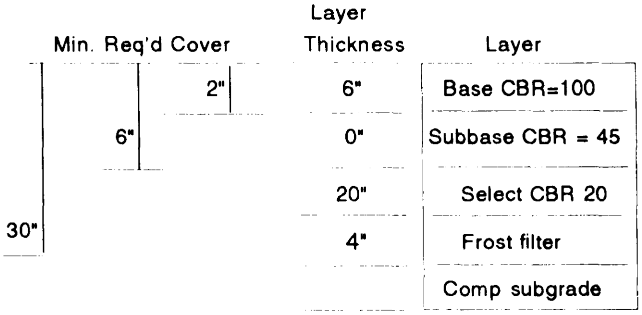
Layer	Minimum Required Cover
Compacted subgrade CBR 5	22.5" ♂ 23"
Select material CBR 20	5.9" ♂ 6"
Subbase CBR 45	1.7" ♂ 2"

Step 6. Complete the temperate thickness design.



The required cover above the select material CBR=20 is only 6 inches. Since the base course already has a layer thickness of 6 inches, the select's cover requirement is satisfied. Therefore, there is no need for the subbase layer. The cover required over the subgrade is 23 inches; consequently, the select material must be 23 - 6 = 17 inches. This is the most cost-effective design under normal conditions because there are fewer restrictions on select materials than on subbases. Keeping a subbase layer would be acceptable if the material is readily available and usable in its borrowed or quarried state.

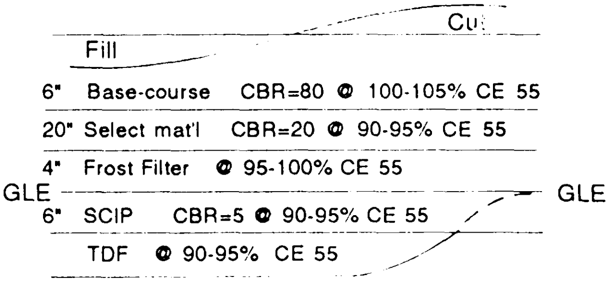
Step 7. Adjust thickness design for frost. Since the subgrade is a frost-susceptible soil (frost group F3) and the area is subjected to frost, the total thickness design must be derived from the soil-support index, which is 3.5 (Table 12-12, page 12-26). Entering Figure 12-8 with 3.5 yields a minimum required cover of 29.2 inches (rounded up to 30 inches.) Since this thickness is greater than the 23 inches required for the temperate design, use this design for the airfield. Also, you must add a 4-inch frost filter. This changes the thickness design shown below.



Step 8. Determine subgrade depth and compaction requirements. From Table 12-13, page 12-30, the required depth of compaction below the surface is 21 inches. Since the actual thickness design is greater than 21 inches, use the minimum depth of subgrade compaction = 6 inches. To find the compaction requirements for the soil layers, see Table 12-7, page 12-23.

Material	Minimum Required Cover
Compacted subgrade CBR 7	9.1" ♂ 10"
Select material CBR 20	3.9" ♂ 4"

Step 9. Draw the final design profile.



SPECIAL DESIGN CONSIDERATIONS

Stabilized Soil Design

The use of stabilized soil layers for aggregate-surfaced pavement structures (as described in Chapter 5, FM 5-430-00-1/AFPAM

32-8013, Vol 1, and FM 5-410) provides the opportunity to reduce the overall thickness required to support a given load. Designing an airfield with stabilized soil layers requires the application of equivalency factors to a layer or layers of a conventionally designed structure.

To qualify for the application of equivalency factors, the stabilized layer must meet appropriate strength and durability requirements. An equivalency factor represents the number of inches of a conventional base or subbase that can be replaced by 1 inch of stabilized material. Equivalency factors are determined as shown in Table 9-21, page 9-76, FM 5-430-00-l/AFPAM 32-8013, Vol 1, for bituminous-stabilized materials and in Figures 9-55 and 9-56, page 9-76, FM 5-430-00-1/AFPAM 32-8013, Vol 1, for materials stabilized with cement, lime, or fly ash mixed with cement or lime. Selecting an equivalency factor from the tabulation depends on the classification of the soil to be stabilized. Selecting an equivalency factor from Figures 9-55 and 9-56 requires the unconfined compressive strength (as determined by ASTM D 1633) be known. Figure 9-55 shows equivalency factors for subbase materials, and Figure 9-56 shows equivalency factors for base materials.

Minimum thickness. The minimum thickness requirement for a stabilized base or subbase is 6 inches.

Application of equivalency factors. The use of equivalency factors requires that a road or airfield be designed to support the design load conditions. If a stabilized base or subbase course is desired, the thickness of a conventional base or subbase is divided by the equivalency factor for the applicable stabilized soil. (See page 9-77, FM 5-430-00-1/AFPAM 32-8013, Vol 1, for examples of applying equivalency factors to base and subbase thicknesses.)

Drainage Requirements

Adequate surface drainage should be provided in order to minimize moisture damage. Expeditiously removing surface water reduces the potential for absorption and ensures more consistent strength and reduced maintenance. Drainage, however, must be provided in a manner to preclude damage to the aggregate-surfaced airfield from erosion of fines or the entire surface layer. Also, ensure the change in the overall drainage regime, as a result of construction, can be accommodated by the surrounding topography without damage to the environment or to the newly constructed airfield.

The surface geometry of an airfield should be designed to provide drainage at all points. Depending on surrounding terrain, surface drainage of the roadway can be achieved by a continual cross slope or by a series of two or more interconnecting cross slopes. Judgment is required to arrange the cross slopes in a manner to remove water from the airfield at the nearest possible points while taking advantage of the natural surface geometry.

It is also essential to provide adequate drainage outside the airfield area to accommodate maximum flow from the area to be drained. One or more such provisions will be required if they do not already exist. Additionally, adjacent areas and their drainage provisions should be evaluated to determine if rerouting is needed to prevent water from other areas flowing across the airfield.

Drainage should be considered a critical factor in aggregate-surface airfield design, construction, and maintenance. Therefore, drainage should be considered before construction and, when necessary, serve as a basis for site selection.

Maintenance Requirements

Environment and surface migration of materials as the result of traffic are the primary reasons that an aggregate surface requires frequent maintenance. Also, rainfall and water running over the aggregate surface tend to reduce cohesiveness by washing the fines from the surface course. Maintenance should be performed at least weekly and, if required, more frequently. Experience with aggregate surfaces indicates that the frequency of maintenance is initially high, but it will decrease over time to a constant value. Although the design life of an aggregate-surfaced airfield is only 6 months, the decreasing maintenance allows the design life to be easily increased for sustained operations in the support area. Most maintenance consists of replacing fines and grading periodically to remove ruts and potholes created by passing traffic and the environment. During the lifetime of the airfield, occasionally scarifying the surface layer might be required to bring fines back to the surface. Additional aggregate must be added to restore the thickness, and the wearing surface must be recompacted to the specified density. Additional maintenance information is provided in Chapter 8, FM 5-430-00-1/AFPAM 32-8013, Vol 1.

Dust Control

The primary objective of a dust palliative is to prevent soil particles from becoming airborne as a result of wind or traffic. Where dust palliative are considered for traffic areas, they must withstand the abrasion of wheels and tracks. An important factor limiting the applicability of the dust palliative in traffic areas is the extent of surface rutting or abrasion that occurs under traffic. Some palliative tolerate deformations better than others, but normally ruts in excess of 1/2 inch will result in the virtual destruction of any thin layer or shallow penetration dust-palliative treatment. The abrasive action of aircraft landing gear may be too severe for the use of some dust palliative in a traffic area.

A wide selection of materials for dust control is available to the engineer. No one choice, however, can be singled out as being the most universally acceptable for all problem situations that may be encountered. However, several materials have been recommended for use and are discussed in TM 5-830-3.

FLEXIBLE-PAVEMENT AIRFIELDS

Bituminous (flexible)-pavement designs permit the maximum use of readily available local construction materials. They are easier to construct and upgrade than rigid-pavement designs. Thus, they permit greater flexibility in responding to changes in the tactical situation.

Each type airfield in the basic airfield complex has a specific purpose. The type, volume, composition, and character of anticipated traffic is much greater in the rear area than in the close battle or support areas. Therefore, a different pavement structure and a resilient, waterproof, load-distributing medium that protects the base course from detrimental effects of water and the abrasive action of traffic may be required in the rear area. In designing a flexible-pavement structure, the design values for various layers are determined and applied to the curves and criteria in this chapter to determine the best structure. Generally, several designs are possible for a specific site. Only the most economical, practical design should be selected. Because the decision may be largely a matter of judgment, full details regarding the selection of the final design should be included in the analysis.

Circumstances may warrant the evaluation of an airfield pavement for aircraft other than the controlling aircraft. In this case, the design evaluation curves in Appendix M may be used for the pass level required. These evaluation curves can be used for design by entering them in reverse order and may be used when estimating the number of passes for unknown (captured) airfields. Evaluation of pavements is discussed later in this chapter.

Pavement Types and Uses

The descriptions, uses, advantages, and disadvantages of bituminous pavements and surfaces presented in TM 5-337 are applicable to TO construction except as modified in the following paragraphs:

Hot-mix bituminous-concrete pavements. Dense-graded, hot-mix bituminous-concrete mixtures are suited for paving airfields with volumes of 1,000 or more aircraft passes. Where conditions warrant, use these mixtures to pave airfields having traffic volumes of less than 1,000 aircraft passes. Select exact percentages of bituminous materials on the basis of design tests described in TM 5-337 and Chapter 9, TM 5-822-8/AFM 88-6.

Cold-laid bituminous-concrete plant mix. Where hot-mix bituminous-concrete mixtures are not available, use cold-plant bituminous concrete to pave areas subject to pneumatic-tired traffic only.

Bituminous road mix. Use road mix as a wearing course for TO roads or as the first step in stage construction for airfields. When the existing subgrade soil is suitable or satisfactory aggregates are nearby, road mixing saves time in handling and transporting aggregates as compared with plant mixing. When properly designed and constructed, the quality of road mix approaches that of cold-laid plant mix.

Flexible-Pavement Structure

A typical flexible-pavement structure is shown in Figure 9-32, page 9-34, FM 5-430-00-1/AFPAM 32-8013, Vol 1, and illustrates the terms used to refer to the various layers.

A bituminous pavement may consist of one or more courses depending on stage construction features, job conditions, and economical use of materials. The pavement should consist of a surface course, an intermediate (binder) course, and when needed, a leveling course. These courses should be thick enough to (1) prevent displacement of the base course because of shear deformation, (2) provide long life by resisting the effects of wear and traffic abrasion and acting as a waterproofing agent, and (3) minimize differential settlements.

Sources of Supply

If time and conditions permit, investigate subgrade conditions, borrow areas, and all sources of select materials, subbase, base, and paving aggregates before designing the pavement. When determining subgrade conditions in cut sections of roads, conduct test borings deeper than the frost penetration depth. The minimum boring should never be less than 4 feet below the final grade.

NOTE: Not all layers and coats are present in every flexible-pavement structure. Intermediate courses may be placed in one or more lifts. Tack coats may be required on the surface of each intermediate course while a prime coat may be required on the uppermost aggregate course.

MATERIALS

Select Materials and Subbases

The criteria for aggregate layers in a flexible-pavement structure are the same as previously discussed for aggregate-surfaced airfields. Local materials used to satisfy the subgrade's minimum required cover must satisfy all the requirements for a given layer that are listed in Tables 12-8 and 12-9, pages 12-23 and 12-24. (See Chapter 5, FM 5-430-00-1/AFPAM 32-8013, Vol 1, for more specific information.)

Base Courses

Although a base course can be either bituminous or aggregate, the latter is more common because of its availability and the resources involved to work with it. The specifications for an aggregate base course in a flexible-pavement structure are the same as the base course in an aggregate-surfaced airfield. Since a flexible pavement transfers most of any load to the underlying base course, aggregate strength, gradation and compaction are essential. The CBR strength of a base course can be determined by the material type in Table 12-10, page 12-24; gradation specifications are listed in Table 12-11, page 12-26. (See Chapter 5, FM 5-430-00-1, AFPAM 32-8013, Vol 1, for more information.)

Bituminous Pavements

Bituminous pavements may be made up of one or more courses, depending on the total pavement thickness, economic use of materials, stage construction features. availability of equipment, and job conditions. Usually, flexible-pavement airfields in the TO resemble aggregate structures with an asphaltic concrete (AC) wear surface. For most aircraft in the rear area, an aggregate structure is suitable only when it has a smooth, water-shedding surface like AC.

If time and resources exist, a flexible pavement with a surface course and one or more intermediate courses is preferred. Once the total thickness is known, you can design for intermediate courses based on Table 12-14. Table 12-15 shows the recommended pavement thicknesses based on the traffic area and the strength of the base course.

- Generally, if the thickness of the bituminous layer is greater than 2 inches, it should be placed in two lifts to ensure that each is properly compacted. Compacting a lift greater than 2 inches may result in the asphalt cooling before it is compacted to the required density. The compaction requirement for AC is 98-100 percent CE 55. After the pavement meets the required density, it must be proof rolled. A proof roller is a heavy, rubber-tired roller having four tires, each loaded with 30,000 pounds or more and inflated to at least 150 pounds per square inch (psi). Type A and Type C areas require a proof roller to make at least 30 coverages, where a single coverage is the application of one tire print over each point on the surface.

Designing the actual bituminous pavement mix consists of (1) selecting the bitumen and aggregate gradation, (2) blending aggregates to conform to the selected gradation, (3) determining the optimum AC content, and (4) calculating the job mix formula. Mix design is further discussed in Chapter 4, TM 5-337, and Chapter 9, TM 5-822-8/AFM 88-6.

TRAFFIC AREAS

For previous airfield designs, only Types B and C were considered. Since rear area airfields have a design life up to two years, it is practical to consider all traffic areas of a full-service airfield. (See Figure 12-5, page 12-7, for the following descriptions.)

- *Type A.* Primary taxiways, through taxi lanes, and portions of the 1,000-foot ends of the runway are all Type A areas and are designed for the full gross weight of the design aircraft. Although the effects of channelization are evident in the center lane of taxiways, it is impractical in temporary construction to construct pavements of alternating variable thicknesses.
- *Type B.* These areas are also designed for the gross weight of the design aircraft, but the repetition of such stress is less than Type A areas. Essentially, all aprons and hardstands are considered Type B.
- *Type C.* These areas are characterized by a low volume of traffic or a decrease in the applied weight of the operating aircraft due to lift on the wings. The 75-foot width of the interior portion of the runway (excluding 1,000-foot end sections), ladder taxiways, hangar access aprons and floors, and washrack pave-

Table 12-14. Intermediate asphalt courses

Pavement Thickness (in)	Intermediate (Binder) Course Thickness (in)	Surface Course Thickness (in)
2	--	2
3	1 1/2	1 1/2
4	2 1/2	1 1/2
5	2 + 1 1/2*	1 1/2
6	2 1/2 + 2*	1 1/2

*This intermediate course is placed in two lifts.

Table 12-15. Minimum thicknesses, pavement and base course

Traffic Area	Minimum Thicknesses (in)			
	100-CBR Base		80-CBR Base	
	Pavement	Base	Pavement	Base
A	4	6	5	6
B	3	6	4	6
C	3	6	4	6

ments are all Type C areas. Decrease the design gross weight by 25 percent when designing a Type C area.

- *Type D.* The outside edges of the entire length of runway except for the approach and exit areas at taxiway intersections are Type D areas. Expected traffic volume in these areas is extremely low, or the applied weight of the aircraft is considerably less. Therefore, like Type C areas, decrease the design gross weight by 25 percent when designing these structures.
- *Overruns.* Overruns are generally surfaced with a multiple surface treatment. The thickness design is usually the same as the runway design, but it may be decreased based on design loading. If the airfield is designed for jet aircraft, an overrun blast area may be desirable. This 150-foot strip of overrun is immediately adjacent to the runway and is for the full width of the runway, excluding shoulders. Surface this area with 2 inches of hot-mix AC.
- *Shoulders.* The thickness of the shoulders is determined by Figure 12-11, which is valid for all design aircraft. Enter the figure with the compacted CBR of the subgrade and insect the curve. From the intersection point, draw a line to the left-hand side of the figure. The result will be the thickness of the shoulder after compaction.

THICKNESS DESIGN PROCEDURE

The design procedure for flexible-pavement surfaces is almost identical to that of aggregate surface. Since flexible pavements exist only in the rear area, however, they are subjected to fighter and cargo aircraft. While some of the curves and specifications may be different, the design steps are exactly the same.

DESIGN STEPS

1. Determine the airfield location.
2. Determine the design aircraft and gross weight.
3. Check soils and construction aggregates.
4. Determine the number of passes required.
5. Determine the total surface thickness and cover requirements.
6. Complete the temperate thickness design.
7. Adjust thickness design for frost susceptibility
8. Determine compaction requirements and subgrade depth.
9. Draw the final design profile.

Step 1. Determine the Airfield Location

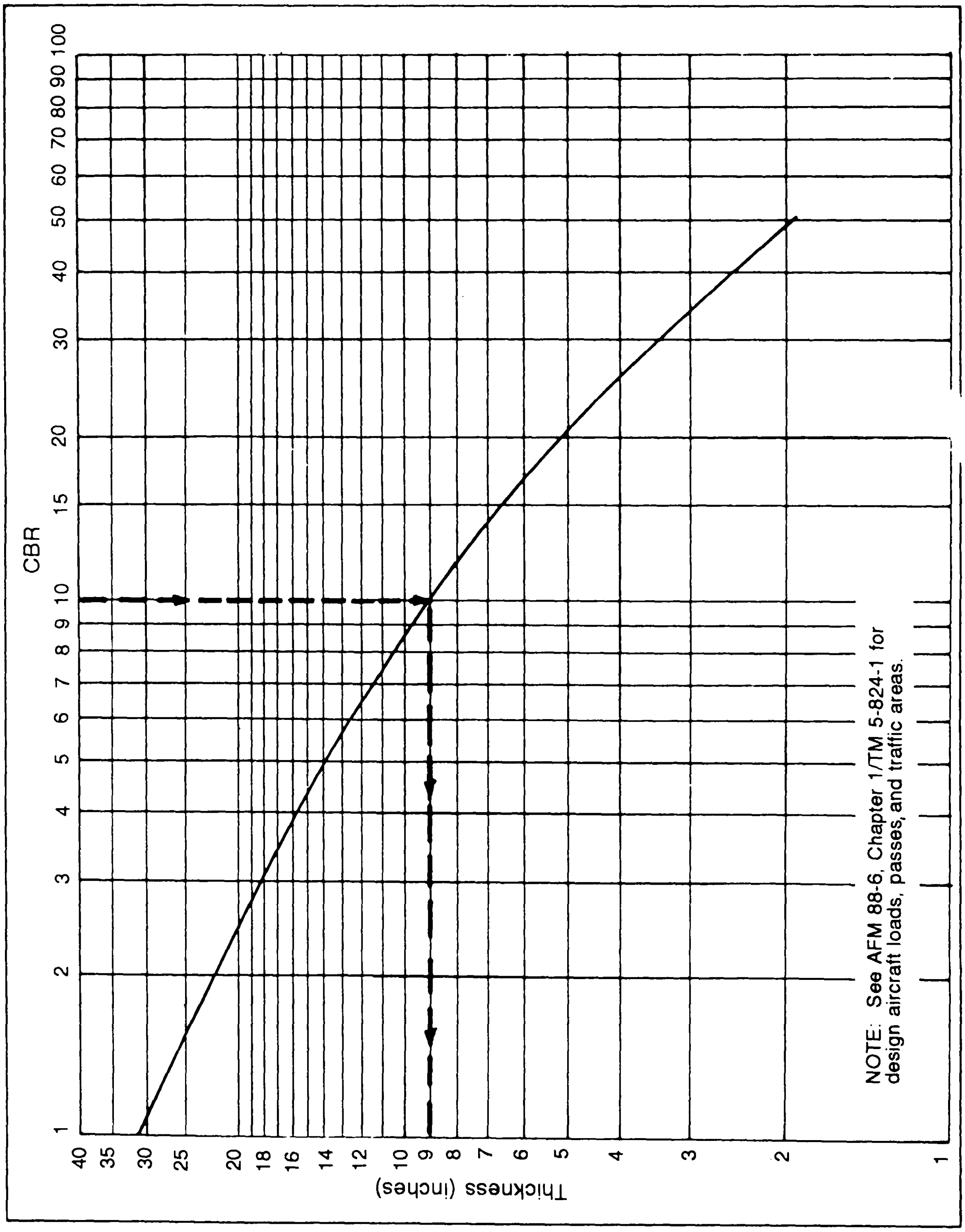
Flexible pavements are only constructed in the rear area. While existing airfields may provide flexible-pavement surfaces in the support or even close battle areas, the rear area requires a flexible-pavement surface to support fighter aircraft as well as large cargo aircraft.

Step 2. Determine the Design Aircraft and Gross Weight

While previous airfield types limited aircraft based on their landing capability, the rear area has no constraints about the type of aircraft that can land. Flexible-pavement structures have the capability to support large cargo aircraft with tremendous gross weights as well as small fighter aircraft with large tire pressures. Because of the rear area's diverse mission and the service life (six months to two years), it is logical to design the airfield for only the most constraining aircraft, the C-141 Starlifter. While it is not the heaviest aircraft in the rear area, its gross weight (345 kips) is not distributed like that of the C-5 or C-17.

Step 3. Check Soils and Construction Aggregates

The procedure for evaluating materials for flexible-pavement structures is the same as for aggregate-surfaced airfield structures. First, locate borrow sites and evaluate them for suitability as select and subbase courses. Use Table 12-8, page 12-23, to check soil characteristics and strength against the specifications for each layer. Second, check the strength and gradation of the base course. The strength of a known material is determined from Table 12-9, page 12-24, while the gradation of a soil must meet the specifications in Table 12-10, page 12-24, based on the MSA. Third, check the materials for frost susceptibility. Any frost-susceptible borrow materials cannot be used in the design. If the subgrade is frost susceptible, determine the frost group and soil support index from Tables 12-11 and 12-12, page 12-26.



NOTE: See AFM 88-6, Chapter 1/TM 5-824-1 for design aircraft loads, passes, and traffic areas.

Figure 12-11. Flexible-pavement design curves for shoulder pavement

Step 4. Determine the Number of Passes Required

Since the rear area is considered temporary construction (6 to 24 months), design flexible-pavement airfields to sustain an appropriate number of passes.

Step 5. Determine the Total Surface Thickness and Cover Requirements

The procedure for designing the total thickness for flexible pavements differs in two ways. First, since the design aircraft is different, you must use a different curve. Enter the curve for the appropriate traffic area with the soil CBR and number of required passes. The thickness design curve for the C-141 is found in Figure 12-12. The resulting thickness is the cover required above that particular soil layer to protect it from shear failure. Second, the asphalt thickness is a function of the traffic area and the strength of the base course, and it can be determined from Table 12-15, page 12-37.

Steps 6 and 7. These design steps are the same as previously discussed for aggregate-surfaced airfields. See pages 12-25 through 12-30 for a review.

Step 8. Determine the Compaction Requirements and Subgrade Depth

While compaction requirements are the same as previously discussed, the required depth of subgrade compaction changes because of the significant loads in the rear area. Table 12-16 shows the depth of required compaction below the surface of the pavement. Choose the depth for the type subgrade or 6 inches, whichever is greater.

Step 9. Draw the Final Design Profile

Draw the final design profile as previously shown for aggregate airfields.

Example 10

Design a rear area airfield in Central America, Type B traffic area, capable of handling 100,000 passes of a C-141 aircraft. Soil layers have already been determined by the soils analyst, as follows:

Table 12-16. Depth (inches) of required subgrade compaction below the surface of rear area flexible-pavement airfields

Traffic Area	Minimum Compacted Depth Below Surface (inches)	
	Cohesive Soils	Cohesionless Soils
A	48	54
B	42	48
C	36	42
D	24	30

- Subgrade: Clay, PI = 12, LL = 20, natural CBR = 4, compacted CBR = 5.
- Borrow A: Select material CBR = 15, PI = 7.
- Borrow B: Subbase material CBR = 40, PI = 4.
- Base course (limestone): CBR = 80, PI = 4. Meets gradation specifications for 2-inch MSA (Table 12-11, page 12-26).

Solution 10

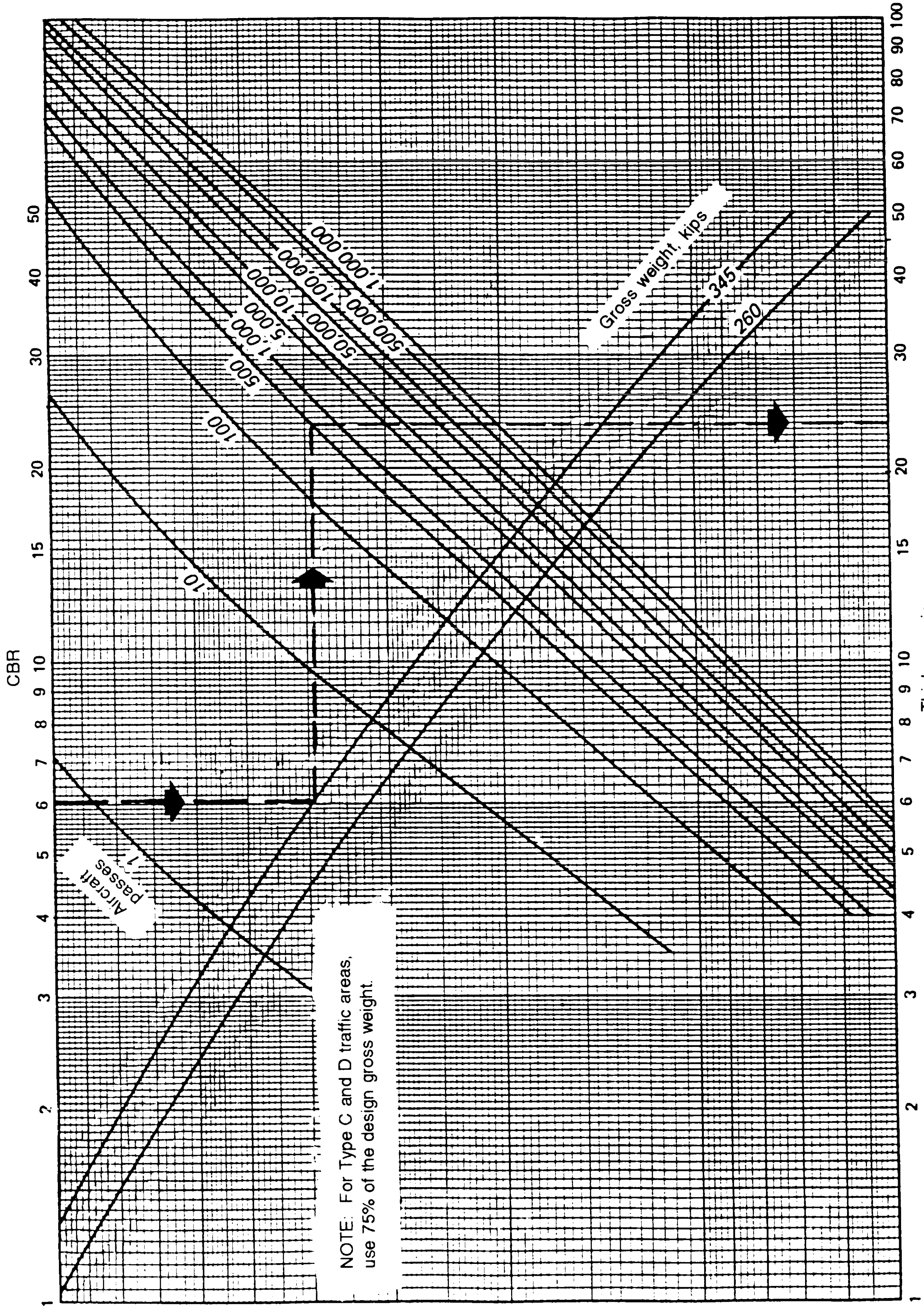
Step 1. Airfield location (given) = rear area/Type B traffic area.

Step 2. Design aircraft (always) = C-141/345 kips.

Step 3. Check soils and construction aggregates:

- Select and subbase (given): Borrow A, select material CBR = 15: borrow B, subbase CBR = 40.
- Base course: Limestone, CBR = 80; meets gradation.
- Frost is not a concern in Central America.

Step 4. Number of passes (given) = 100,000.



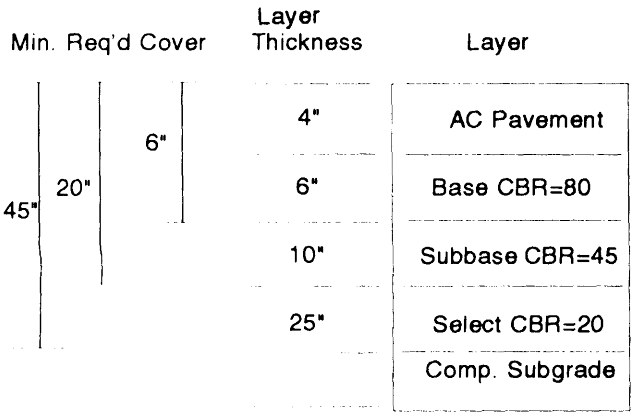
NOTE: For Type C and D traffic areas, use 75% of the design gross weight.

Figure 12-12. Flexible-pavement design curves for C-141 aircraft runway > 5,000 feet.

Step 5. Determine the thickness requirements from Figure 12-11, page 12-39 (Type B traffic area):

Material	Minimum Required Cover
Compacted subgrade CBR 5	45"
Select material CBR 15	19.7" ♂ 20"
Subbase CBR 40	6"

Step 6. Complete the temperate thickness design.



See Table 12-15, page 12-37, with the traffic area (B) and the base course CBR (80) to find that the thickness of the AC pavement = 4 inches. See Table 12-14, page 12-37, for a further breakdown of the specific course in the pavement design. Next, from Step 4, calculate the layer thicknesses. For instance, the cover required over the select material is 20 inches. With the base course and the AC pavement combined, the thickness is already 10 inches. To meet the cover requirement over the select material, the thickness of the subbase must be at least 10 inches.

Step 7. Frost adjustment not applicable.

Step 8. Determine subgrade depth and compaction requirements. From Table 12-16, page 12-40, determine the required depth of subgrade compaction. Since the subgrade is cohesive (P = 15) and the traffic area is a Type B, the depth required = 42 inches. The total design thickness is 45 inches; therefore, the depth of subgrade compaction is 6 inches since 6 inches >3 inches. Next, determine the compaction requirements for each layer from Table 12-17.

Layer	Compaction Requirement
Compacted subgrade	90-95% CE 55
Select material	90-95% CE 55
Subbase	100-105% CE 55
Base course	100-105% CE 55
AC pavement	98-100% CE 55

Table 12-17. Compaction criteria and CBR requirements for a flexible-pavement structure

CBR Requirements	Layer	Compaction Requirements
	Pavement	98-100%
80-100	Base course	Asphalt 98-100% Soil: 100-105%
20-50	Subbase course	100-105%
0-20	Select material	Cohesive: 90-95% Cohesionless: 95-100%
	Design subgrade (SCIP)	Cohesive: 90-95% Cohesionless: 95-100%
	Uncompacted subgrade	

NOTES:

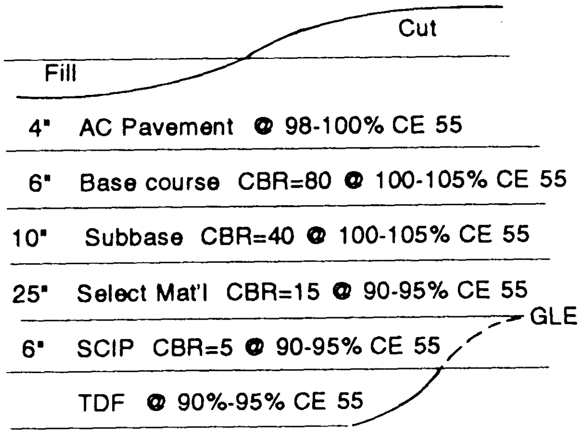
1. All lifts (excluding the pavement) in an airfield must be at least 6 inches.

2. A cohesive soil is one with a PI above 5.

3. A cohesionless soil is one with a PI of 5 or less.

4. Percent compaction is compared to CE 55 compactive effort.

Step 9. Draw the final design profile.



SPECIAL DESIGN CONSIDERATIONS

STABILIZED SOIL DESIGN

The use of stabilized soil layers within a flexible-pavement airfield structure provides the opportunity to reduce the overall thickness required to support a given level. The section on stabilized soil design (described in detail in Chapter 9, FM 5-430-00-1/AFPAM 32-8013, Vol 1) pertains to airfield flexible pavements as well. As such, only examples of procedural applications for flexible-pavement airfields are discussed below:

Design Example

Assume a conventional flexible-pavement airfield has been designed that requires a total thickness of 10 inches above the subgrade. The minimum thicknesses of AC and base are 2 and 6 inches, respectively. The thickness of the subbase is 6 inches, the minimum layer thickness. Replace the base and subbase with a cement-stabilized, gravelly soil having an unconfined compressive strength of 890 psi. From Figure 9-55, page 9-76, FM 5-430-00-l/AFPAM 32-8013, Vol 1, the equivalency factor for a subbase having an unconfined compressive strength of 890 is 2; and from Figure 9-56, page 9-76, FM 5-430-00-l/AFPAM 32-8013, Vol 1, the equivalency factor for the base is 1.

Therefore, the thickness of the stabilized subbase is 6 inches/2 = 3 inches, and the thickness of the stabilized base course is 6 inches/ 1 = 6 inches. The final section would be 2 inches of AC and 9 inches of cement-stabilized, gravelly soil. The subgrade still has an equivalent cover of 11 inches within the newly designed 2 inches of AC and 9 inches of cement-stabilized, gravelly soil. The savings of 3 inches of aggregate may prove to be more economical and efficient, depending on material, equipment, and time constraints.

The other alternative would be to increase the base course thickness to 9 inches. If material and resources are available, this may be the most efficient method. However, if the base course material is coming from a batch plant or leased contractor, you may save time by stabilizing a soil and using equivalency factors to reduce the thickness design.

FROST REGIONS

Pavements frequently break up or are severely damaged when subgrades and materials within the flexible-pavement structure freeze in the winter and thaw in the spring. Besides the physical damage suffered by pavements during periods of freezing and thawing and the high cost of time, equipment, and personnel required in maintenance, the military loss to the using agency may be very great (or intolerable) from the strategy standpoint. The design engineer for TO rear area airfields must decide whether to design for frost, given the increased thickness and material quality requirements.

Investigational Procedures for Frost Action

Field and laboratory investigations conducted in accordance with FM 5-410 usually provide sufficient information to determine whether a given combination of soil and water conditions beneath the pavement will be conducive to frost action. The procedures for determining whether the conditions necessary for ice segregation are present at a proposed site are described in the following paragraphs:

Soil. Inorganic soils containing 6 percent or more (in the TO) by weight of grains finer than 0.02 millimeter are generally considered susceptible to ice segregation. Thus, examination of the fines portion of the gradation curves obtained from hydrometer analysis or recantation process for these materials indicates whether they are frost susceptible. In borderline cases or where unusual materials are involved, slow laboratory freezing tests may be performed to measure the relative frost susceptibility.

Depth of frost penetration. The depth to which freezing temperatures penetrate below the surface of a pavement kept cleared of snow and ice depends principally on the magnitude and duration of below-freezing air temperatures, the properties of the underlying materials, and the amount of water that becomes frozen. Methods are described in Engineering Manual (EM) 1110-3-138 and TM 5-818-2.

Water. A potentially troublesome water supply for ice segregation is present if the highest groundwater at anytime of the year is within 5 feet of the proposed subgrade surface or the top of any frost-susceptible base materials. When the depth to the uppermost water table measured from the subgrade surface is in excess of 10 feet throughout the year, a source of water for substantial ice segregation is usually not present. In silts or homogeneous clay soils, the water content of the subgrade under pavement is usually sufficient to provide water for ice segregation even with a remote water table. Additional water may enter a frost-susceptible subgrade by surface infiltration through pavement and shoulder areas.

Consider all reliable information concerning past frost heaving and performance during the frost-melting period of airfield pavements previously constructed in the area. Place emphasis toward modifying or increasing frost design requirements.

Counteractive Techniques for Frost Action

The military engineer cannot prevent the basic condition of temperature affecting frost action. If a runway is constructed in a climate where freezing temperatures occur, in all probability the soil beneath the pavement will freeze unless the period of lowered temperature is very short. There are, however, several construction techniques that may be applied to counteract the presence of water and frost-susceptible soil.

Lowering water table. Try to lower the groundwater table in relation to the elevation of the runway. This may be accomplished by installing subsurface drains or opening side ditches if suitable outlets are available and the subgrade soil drains. (See Chapter 5, FM 5-430-00-l/AFPAM 32-8013, Vol 1.) It also may be accomplished by raising the grade line in relation to the water table. Whatever means are employed, the distance from the top of the proposed subgrade surface to the highest probable elevation of the water table should not be less than 5 feet. Distances greater than 5 feet are desirable if they can be obtained at reasonable cost.

Preventing upward water movement. In many cases, it may not be practical to lower the water table. In swampy areas, for example, an outlet for subsurface drains may not be present. Treatments that successfully prevent the rise of water include placing a 4- to 6-inch layer of pervious, coarse-grained soil between the maximum expected frost depth and the water table. This layer must be designed as a filter to prevent clogging the pores with fine material. If the depth of frost penetration is not too great, it may be cheaper to backfill with granular material.

Another method (successful, though expensive) is to excavate to the frost line, lay prefabricated bituminous surfacing (PBS), and backfill with granular material. In some cases, soil-cement and asphalt-stabilized mixtures, 6 inches thick, have been used effectively to cut off the upward movement of water. Waterproof membranes also may be used.

Removing frost-susceptible soil. Even though the site selected may be on ideal soil, long or wide expanses of runways probably will have localized areas containing frost-susceptible soils. These must be identified, removed, and replaced with select granular material. Unless this procedure is meticulously carried out, differential heaving or frost boils may result.

Insulating subgrade against frost. The most widely accepted method of preventing pavement failure due to frost action is to provide adequate thickness of pavement, base, and subbase over the subgrade. This prevents excessive frost heave and provides necessary load-carrying capacity during thawing periods. Extruded polystyrene thermal insulation has been successfully used to replace a substantial portion of the base and subbase.

Snow removal. During freezing weather, if the wearing surface is cleared of snow, it is important that the shoulders also be kept free of snow. When this precaution is not followed, freezing will set in first beneath the wearing surface. This permits water to be drawn into and accumulated in the subgrade from the unfrozen shoulder area, which is protected by the insulating snow.

If both areas are free of snow, freezing will begin in the shoulder area because it is not protected by pavement. Under this condition, water is drawn from the subgrade to the shoulder area. As freezing progresses to include the subgrade, there will be little frost action unless more water is available from groundwater or seepage.

Base Composition Requirements for Preventing Frost Action In Flexible Pavements

Base courses may be made of granular, unbound materials; bound materials; or a combination of both. However, an unbound base course will not be placed between two impervious, bound layers. If the combined thickness, in inches, of pavement and contiguous, bound base course is less than 0.09 multiplied by the design freezing index, and the pavement is expected to have a life exceeding one year, not less than 4 inches of free-draining material should be placed directly beneath the lower layer of bound base. If there is no bound base, material should be placed directly beneath the pavement slab or surface course.

Frost filter. The free-draining material should contain 2 percent or less, by weight, of grains that can pass the Number 200 sieve. To meet this requirement, the material probably will need to be screened and washed. The material in the 4-inch layer also must conform to the filter requirements prescribed in the following paragraphs. If the structural criteria for design of the pavement does not require granular, unbound base other than the 4 inches of free-draining material, the material in the 4-inch layer must be checked for conformance with the filter requirements. If it fails the test of conformance, an additional layer meeting those requirements must be provided.

Other granular unbound base course. If the structural criteria for design of the pavement requires more granular, unbound base than the 4 inches of free-draining material, the material should meet the applicable requirements of current guide specifications for base and subbase materials. In addition, the top 50 percent of the total thickness of granular unbound base must be NFS and must contain not more than 5 percent, by weight, of particles passing a Number 200 sieve. The lower 50 percent of the total thickness of granular, unbound base may be NFS or partially frost-susceptible (PFS) material (S1 or S2). (See Table 12-11, page 12-26.) If the subgrade soil is PFS material meeting the requirements of current guide specifications for base or subbase, the lower 50 percent of granular base will be omitted. If subgrade freezing will occur, an additional requirement is that either the bottom 4-inch layer in contact with the subgrade must meet the filter requirements, or a geotextile fabric meeting the filter requirements must be placed in contact with the subgrade. The dimensions and permeability of the base should satisfy the base course drainage criteria given in Chapter 2, TM 5-820-2/AFM 88-5, and the thickness requirements for frost design. If necessary, thicknesses indicated by frost criteria should be increased to meet subsurface drainage criteria. Base course materials of borderline quality should be tested frequently after compaction to ensure they meet these design criteria. Subbase and base materials must meet applicable compaction requirements.

Use of F1 and F2 Soils for Base Courses in Roads and Airfields with Short Life spans

A further alternative is the use of PFS base materials permitted for all roads and airfields with short life spans (less than one year).

Materials of frost groups F1 and F2 may be used in the lower part of the base over F3 and F4 subgrade soils. F1 materials may be used in the lower part of the base over F2 subgrades. The thickness of F2 base material should not exceed the difference between the reduced subgrade strength thickness requirements over F2 and F3 subgrades. The thickness of F1 base should not exceed the difference between the thickness requirements over F1 and F2 subgrades. Any F1 or F2 material used in the base must meet the applicable requirements of the guide specifications for base, subbase, or select materials. The thickness of the F1 and F2 materials and the thickness of pavement and base above the F1 and F2 materials must meet the nonfrost criteria.

Filter Over Subgrade

Granular filters. For both flexible and rigid pavements where subgrade freezing will occur, at least the bottom 4 inches of granular unbound base should consist of sand, gravelly sand, screenings, or similar material. It should be designed as a filter between the subgrade soil and overlying base course material to prevent mixing of the frost-susceptible subgrade with the base during and immediately following the frost-melting period. This filter is not intended to serve as a drainage course. The gradation of this filter material should be determined in accordance with the following criteria to prevent movement of particles of the protected soil into or through the filter(s):

$$\frac{\text{15 percent size of filter material}}{\text{85 percent size of protected soil}} \le 5$$

and

$$\frac{\text{50 percent size of filter material}}{\text{50 percent size of protected soil}} \le 25$$

The percent size in these equations is used to determine a particle size. For example, the 15 percent size refers to a grain size in millimeters at which 15 percent passes on a Grain Size Distribution Graph.

To offset the tendency of segregation of the filter material, a coefficient of uniformity of not more than 20 will be required.

The filter material must be NFS or PFS. Experience shows that a fine-grained subgrade soil will work up into a coarse, open-graded overlying gravel or crushed stone base course under the kneading action of traffic during the frost-melting period if a filter course is not provided between the subgrade and the overlying material. Experience and tests indicate that well-graded sand is especially suitable for this filter course. The 4-inch minimum filter thickness is dictated primarily by construction requirements and limitations. Greater thicknesses should be specified when required to suit field conditions. Over weak subgrades, a 6-inch or greater thickness may be necessary to support construction equipment and to provide a working platform for placement and compaction of the base course.

Geotextile fabric filters. The use of geotextile filters in lieu of a granular filter is encouraged. No structural advantage will be attained in the design when a geotextile fabric is used; it serves as a separation layer only. Filter criteria for geotextile filters found in Chapter 2, AFM 88-5, is as follows:

$$\frac{\text{85 percent size of material adjacent to fabric}}{\text{equivalent size of fabric openings}} \ge 1$$

DESIGN OF PAVEMENTS FOR FROST ACTION

In the reduced subgrade strength method of design, the design curves for the C-141 (Figure 12-12, page 12-41) should be used to determine the combined thickness of flexible pavement and base required for aircraft loads. The curves should not be entered with subgrade CBR values determined by tests or estimates but with one of the applicable frost area soil support indexes shown in Table 12-11, page 12-26.

The soil support index for PFS soils meeting current specifications for base and subbase will be determined by conventional CBR tests in the unfrozen state.

FIELD CONTROL FOR FROST CONDITIONS

Inspection of airfield and road pavement construction in areas of seasonal freezing and thawing should emphasize looking for conditions and materials that promote detrimental frost action. Remove unsuitable materials where such conditions exist. Personnel assigned to quality control must be able to recognize unsuitable materials.

Subgrade Preparation

Where laboratory and field investigations indicate that the soil and groundwater conditions will not result in ice segregation in the subgrade soils, the pavement design is based on the assumption that the inspection personnel must check the validity of the design assumptions and take corrective action if pockets of frost-susceptible material and wet subgrade conditions are revealed.

The subgrade is to be excavated and scarified to a predetermined depth, windrowed, and bladed successively to achieve adequate blending. It is then relaid and compacted. The purpose of this work is to achieve a high degree of uniformity of the soil conditions by mixing stratified soils, eliminating isolated pockets of soil of higher or lower frost susceptibility, and blending the various types of soils into a single, homogeneous mass. It is not intended to eliminate soils from the subgrade in which detrimental frost action will occur, but it is intended to produce a subgrade of uniform frost susceptibility and thus create conditions tending to make both surface heave and subgrade thaw weakening as uniform as possible over the paved area.

The depth of subgrade preparation, measured downward from the top of the subgrade, should be the lesser of the following:

- 24 inches.
- 72 inches, less the actual combined thickness of pavement, base, and subbase.

Prepared subgrade must meet the compaction requirements stated in Step 8 of the flexible-pavement airfield design procedure, page 12-40. At transitions from cut to fill, the subgrade in the cut section should be undercut and backfilled with the same material as the adjacent fill. (See TM 5-818-2.)

Exceptions to the basic requirement for subgrade preparation in the preceding paragraph are limited to the following:

- Subgrades known to be NFS to the depth prescribed for subgrade preparation and known to contain no frost-susceptible layers or lenses, as demonstrated and verified by extensive and thorough subsurface investigations and by the performance of nearby existing pavements.
- Fine-grained subgrades containing moisture well in excess of the optimum for compaction, with no feasible means of drainage nor of otherwise reducing water content. Consequently, it is not feasible to scarify and recompact the subgrade. If wet, fine-grained soils exist at the site, it is necessary to achieve equivalent frost protection with fill material. This may be done by raising the grade by an amount equal to the depth of subgrade preparation that would otherwise be prescribed, or by undercutting and replacing the wet, fine-grained subgrade to the same depth. In either case, the fill or backfill material may be NFS or frost-susceptible material meeting specified requirements. If the fill or backfill material is frost-susceptible, it should be subjected to the same subgrade preparation procedures prescribed above.

Correction for gradation changes. Perform gradation tests on all questionable materials found during grading operations. In an otherwise NFS subgrade, remove all pockets of frost-susceptible soils to the full depth of frost penetration. Replace frost-susceptible soils with NFS material when possible.

Wherever the design indicates that frost action may be a problem, the construction engineer must ensure that special frost protection measures are adequate and provisions in this chapter for base composition design are strictly followed.

Correction for special subgrade conditions. Besides abrupt variations in soil characteristics, frequent sources of trouble include sudden changes in groundwater conditions; changes from cut to fill; and location of under-pavement pipes, drains, or culverts. The top soil and humus materials at the transition between cut-and-fill sections should be completely removed for the full depth of frost penetration in otherwise NFS materials, even though the specifications may not require stripping of the subgrade in fill areas.

Carefully check wet areas in the subgrade. and install special drainage facilities as required. The most frequent special need in airfield construction is to provide intercepting drains. These drains prevent infiltration of water into the subgrade from higher ground adjacent to the road.

Preparation of rock subgrades. In areas where rock excavation is required, examine the character of the rock and seepage conditions. The excavation should always provide transverse drainage to ensure no pockets are left in the rock surface that permit pending of water within the maximum depth of freezing. The irregular presence of groundwater may result in heaving of the pavement surface under freezing conditions. It may be necessary to fill drainage pockets with lean concrete. Stones larger that 12 inches in diameter should be removed from frost-susceptible subgrades to prevent boulder heaves from damaging the pavement. This boulder removal must be accomplished to the depth of subgrade preparation outlined in the preceding paragraphs.

Where seepage is great, cover the rock subgrade with a high pervious gravel material so water can escape. Fractures and joints in the rock surface frequently contain frost-susceptible soils. Clean these soils out of the joints to the depth of frost penetration and replace them with NFS material. If this is impractical, it may be necessary to remove the rock to the full depth of frost penetration. Blasting the rock in place to provide additional cracks for the downward and lateral movement of water has also been successful. If blasting is used, rock should be broken to the full depth of frost penetration.

Base-Course Construction

Where available, base-course materials (including any select and subbase layers) are clearly NFS; base-course construction control should be in accordance with normal practices. When the selected base-course material is borderline frost susceptibility (usually having as much as 3 percent by weight of grains finer than 0.02 millimeter), make frequent gradation checks to ensure materials meet design criteria.

If pit selection of base material is required, inspect the materials at the pit. It is easier to reject unsuitable material at the source when large volumes of base course are being placed.

It is frequently desirable to check the gradation of materials taken from the base after compaction; for example, check gradations on density test materials. This procedure determines whether fines are being manufactured in the base under the passage of the base course compaction equipment.

Avoid mixing base-course materials with frost-susceptible subgrades by ensuring the subgrade is properly graded and compacted before placing the base course. Also, ensure the first layer of base course or subbase is thick enough and provides sufficient filter action to prevent penetration of subgrade fines under compaction. Excess wetting by hauling equipment may cause mixing of subgrade and base materials. This can be greatly reduced by frequently rerouting hauling equipment.

After completing each layer of the aggregate course, carefully inspect them before permitting placement of additional material. This ensures there are no areas with a high percentage of fines. These areas may frequently be recognized by visual examination of the materials and by observation of their action under compaction equipment, particularly when the materials are wet.

Remove materials that do not meet the requirements or specifications and replace them with suitable material.

FROST DESIGN FOR STABILIZED RUNWAY OVERRUNS

A runway overrun pavement must be designed to withstand occasional short landings, aborted takeoffs, long landings, and possible barrier engagements. The pavement also must give service under the traffic of various maintenance vehicles such as crash trucks and snowplow equipment.

Frost Condition Requirements

The design of an overrun must provide for the following frost conditions:

- Adequate structure for infrequent aircraft loading during the frost-melting period.
- Adequate structure for normal traffic of snow-removal equipment and other maintenance vehicles during frost-melting periods.
- Sufficient thickness of frost-free, base- or subbase-course materials to protect against objectionable heave during freezing periods.

Frost Design Criteria

To provide adequate strength during frost-melting periods, the combined thickness of flexible pavement and NFS base and subbase course must be equal to 75 percent of the thickness required for normal frost design, based on reduced subgrade strength. The thickness established by this procedure will not be less than that required for conventional flexible-pavement design.

Arid regions. In regions where the annual precipitation is less than 15 inches and the water table (including perched water table) is at least 15 feet below the finished pavement surface, the danger of high moisture content in the subgrade is reduced. Where information on existing structures in these regions indicates that the water content of the subgrade will not increase above optimum (as determined by the CE 55 compaction test), the total thickness above the subgrade (as determined by CBR tests on soaked samples) may be reduced by 20 percent. The reduction is made in the select material or in the subbase courses having the lowest CBR value. The reduction applies to the total thickness dictated by the subgrade CBR.

If only limited rainfall records are available or the annual precipitation is near the 15-inch criterion, before any reduction in thickness is made, carefully consider such factors as the number of consecutive years in which the annual precipitation exceeds 15 inches and the sensitivity of the subgrade to small increases in moisture content.

Arctic regions. Airfield construction in arctic regions will be a rare occurrence. When construction is called for, engineer units will find construction in extreme environmental conditions difficult at best. Snow pavements requiring strength characteristics above CBR = 40 are difficult to produce with practical construction methods. With specialized equipment, the strength of snow pavement can be achieved with dry-processing methods (milled or mixed snow, compacted with tractor tracks, vibrators, and rollers) if temperatures during construction are in the -12° to -1° Celsius (C) range. As the temperature decreases, particularly below -18°C, the compaction effectiveness decreases, the rate of age hardening (or sintering) decreases, and equipment operational problems increase.

Due to the low rate of the age-hardening process in arctic temperature conditions, a one-year waiting period after construction may be required before C-141 aircraft operations could be considered. That is, if runway construction can be successfully completed during one season, the hardening process may require a full season to progress to a stage where the snow strength approaches that required for C-141 aircraft. A design-and-testing manual for the construction of compressed-snow runway pavement can be found in Appendix B of the Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 89-10, April 1989. Appendix C contains a construction manual for compacted snow runways. The report is available from the US Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755-1290.

Airfields also can be constructed on glacial ice. Unlike cold, dry snow, blue ice (typical of most ice found on Antarctica) has sufficient bearing capacity to support heavy wheel loads without rutting, even at the highest imaginable inflation pressures for aircraft tires. Blue ice is solid glacier ice. It is usually hundreds of meters thick and rests on solid rock (on an ice shelf, it may be afloat). By contrast, typical sea ice is a thin (<3 meters), viscoelastic plate floating freely on a liquid foundation and should not be considered for airfield construction. If blue ice is smooth and level over a sufficient distance and approaches are unobstructed by high terrain, then it is highly suitable for use as an airfield. Unfortunately, there are few blue-ice ablation areas in arctic regions. Most of the existing areas are unsuitable for use as airfields because they are not smooth, level, and unobstructed.

EVALUATION OF AIRFIELD PAVEMENTS

The design of airfield pavement is based on covering a subgrade of given strength with adequate thickness of a suitable base course and pavement to prevent the subgrade from being overstressed under a given load. This same principle applies to any layer in the system—the base, subbase, select material, or subgrade.

The evaluation of an expedient, aggregate, or flexible pavement is the reverse of this process. It determines the allowable loading when the in-place thickness, strength, and quality of the materials in the various layers have been established. The thickness of the pavement and soil layers is determined by actual measurement. The strength of the subgrade and overlaying subbase and base courses is determined using CBR tests. Also, the purpose of a pavement evaluation may be much different than that of a design. You should design the airfield for the design aicraft, but to ensure the airfield's suitability to changing conditions, you may evaluate an airfield for use by only one particular aircraft for one or more missions. Since the C-130 and C-17 are the predominant aircraft in the close battle and support areas, evaluation becomes significant only in rear areas, where existing pavements may support missions short of the large cargo aircraft. For this reason, Appendix K includes flexible-pavement curves for most aircraft that normally operate on flexible pavements in the rear area.

The quality of the bituminous pavement structure is the ability of the various layers to support traffic and withstand jet-fuel spillage and blast. The quality of materials in the various layers is determined by visual observation, tests on in-place materials, laboratory tests on samples of the materials, and construction data.

The load-carrying capacity of a flexible pavement is limited by the strength of its weakest component—the bituminous pavement, base, subbase, select, or subgrade. The ability of a given subsurface layer to withstand the loads imposed on it depends on the thickness of material above it and its strength in its weakest condition.

An evaluation must consider possible future increases in moisture content, increases or decreases in density, and the effects of freezing and thawing. The expected use governs the amount of time and effort spent on the evaluation of an existing airfield. If time permits and the required life of the pavement is two years, the evaluation effort should be thorough with appropriate modification for lesser life requirement.

Pavement evaluation may be based on existing design- and construction-control data, data obtained in tests performed especially for evaluation, or a combination of the two. Condition surveys record the existing pavement condition of the facilities being evaluated.

NEW PAVEMENTS

If the airfield to be evaluated was built by US forces, construction-control test data adequate for an evaluation may be secured. Extract data from these records on conditions and materials pertinent to the evaluation. The number of test values needed for an evaluation cannot be prescribed, but obtain enough data to establish a reasonably good statistical probability curve. Where data is insufficient and time permits, perform supplemental tests in accordance with the discussion in the following section:

OLD PAVEMENTS

The following paragraphs describe procedures for evaluating an existing field for which no design or construction-control data is available and for which field and laboratory tests must be made. The condition survey mentioned above is made first. Then, test locations are selected, in-place tests are made, samples for laboratory tests are secured, and test pits are backfilled. Laboratory tests are the final phase in data procurement.

Selection of Test Locations

Selecting the most representative test locations is essential for an accurate evaluation. Also, hold the number of test locations to a minimum to reduce interruptions in normal aircraft operations on the facilities being tested.

The first step in the selection of test locations is to prepare longitudinal profiles of the runways, taxiways, and aprons. This develops a general picture of subgrade, subbase, base, and pavement conditions. From these profiles, select test pit locations where more detailed tests can be performed.

The profiles should show information regarding thickness and types of pavement, base (includes all aggregate layers), and subgrade soil classification. Obtain this data by cutting small holes in the pavement through which thickness measurements can be made. Then, sample the base course, subbase course, and subgrade. Space the small holes about 500 feet apart. A wider spacing may be adequate when uniform conditions exist. Classify the samples in accordance with the USCS (see FM 5-410). Determine the moisture content because variations in moisture content often indicate variations in soil strength.

After profiles have been developed, study them to determine representative conditions. Test pits should be located in typical base and subgrade conditions or where significant strength or traffic intensity exists. Ensure test pits are placed where maximum information can be obtained with minimum testing.

After typical areas of high and low strengths in each material have been determined by observing pavement condition or by studying soil profile, place test pits in areas where traffic intensity is high. This permits determination of the soil strength under traffic conditions.

When no weak areas are found, place test pits where traffic is heavy and loading con ditions are most severe. These cond it ions are usually found in the 1,000-foot sections at runway ends, in the entire lenght of taxi ways, and in taxi lanes on aprons. An air field having a runway, an apron, and connecting taxiways usually requires 12 to 20 test pits for adequate overall evaluation. A minimum of two pits (one at each end) should be required on aprons and on the taxiway system. More pits may be necessary when weak or failed areas are encountered.

Test pits. Test pits (approximately 4 feet wide by 6 feet long) are dug through the pavement to permit the performance of in-place tests and to obtain samples for laboratory tests. Record a description of general conditions in each test pit and visually classify the materials from pit to pit. Measure the pavement thickness to the nearest quarter of an inch. Make several measurements around the sides of the pit to obtain representative values.

Describe each soil course, giving color, in situ conditions, texture, and visual classifications. Perform in-place moisture content, CBR (except when moisture conditions are not satisfactory), and density tests on the base course and subgrade. Use judgment when selecting test locations in the pit. Place the CBR piston or penetrometer so the surface to be penetrated represents an average condition of the surface being tested. The piston should not be set on unusually large pieces of aggregate or other materials.

Space CBR tests in the pit so that areas covered by the surcharge weights of the individual tests do not overlap. Perform these tests on the surface and at each full 6-inch depth in the base and subbase courses, on the surface of the subgrade, and on underlying layers in the subgrade as needed.

Determine the density and moisture content at 1 -foot intervals to a total depth of 4 feet below the surface of the subgrade. Use the results of density and moisture tests at these depths to decide whether additional CBR tests are needed. Locate the tests in the pit so the density determinations are performed between adjacent CBR tests.

Moisture content determination. When coarse material makes up 40 percent or more of the base course, the moisture content of the fine portion may influence the behavior of the base course more, with respect to strength, than the moisture content of the total sample.

The critical portion of material considered is that part passing sieve sizes ranging from Number 200 to Number 4. The Number 40 sieve is the sieve on which separations for the Atterberg liquid and plastic limit determinations are made. The material passing the Number 40 sieve is used to determine the soil's plastic and liquid limits.

CBR tests. Perform three in-place CBR tests (as described in FM 5-5301) or equivalent tests with one of the CBR expedient methods at each elevation tested. However, if the results of these three tests do not show reasonable agreement, make three additional tests. A reasonable agreement among three tests permits a tolerance of 3 where the CBR is less than 10, 5 where it ranges from 10 to 30, and 10 where it ranges from 30 to 60. Where the CBR is above 60, variations in individual readings are not important.

For example, test results of 6, 8, anti 9 are reasonable and can be averaged as 8. Results of 18, 20, and 23 are reasonable and give an average of 20. If the first three tests do not fall within this tolerance, make three additional tests at the same location and use the numerical average of the six tests as the CBR for that location.

Generally, CBR values below 20 are rounded to the nearest point. Values above 20 are rounded to the nearest 5 points. Obtain a moisture-content sample at the point of each penetration.

Density determination. Make three density determinations at each elevation tested if samples of about 0.05 cubic foot volume are taken. If somewhat larger samples are taken, decrease the number of density determinations to two. If a reasonable agreement is not found among the test results, perform two additional tests. A reasonable agreement is considered to provide for a tolerance of about 5 pounds per cubic foot (pcf) wet density. For example, test results of 108, 111, and 113 pcf wet density are in reasonable agreement and can be averaged as 111 pcf.

Sampling. Obtain samples of typical pavement, base-course, and subgrade materials for laboratory tests. Take the base and subgrade samples to ensure representative materials.

Backfilling. Holes cut in flexible pavements can be backfilled satisfactorily if a few precautions are followed. Backfill the subgrade with a material similar to that removed. Place the material in about 3-inch lifts and compact them to the required density with a pneumatic tamper. The backfill for the base course should consist of a material similar to that removed and should be compacted to a high density. The surface of the base course should be primed and the sides of the adjacent pavement swabbed with a liquid asphalt. Use an RC-70 in cold weather and an MC-80 in hot weather.

A hot-mix AC is best for patching pavement, but many successful patches have been made with a cold mix. Avoid a cold mix when it will be subjected to jet blast or fuel spillage. It is not necessary to heat a cold mix in hot weather unless it has hardened. In cold weather, however, the material must be heated until it can be handled satisfactorily.

Compact the patching material thoroughly with a pneumatic tamper. If cold mix is used, swab the surface with liquid asphalt and cover it with small aggregate. Use a smooth-wheeled or pneumatic roller over the surface.

LABORATORY TESTS

Laboratory tests provide data with which to classify materials and determine their strength characteristics. In the laboratory, materials can be reworked or their moisture conditions adjusted to arrive at an estimate of the strength expected under future conditions of increased density or moisture. The following tests apply to both satisfactory and failed areas.

Pavement Tests

Where a pavement consists of more than one course, the cores obtained for testing should be split at the interfaces of the various courses so that each course can be tested separately. Test the cores of each course in the laboratory for Marshall stability; flow; percentage of asphalt; aggregate type, shape, and gradation; specific gravity of bitumen and aggregate; and density. Compute the voids in the total mix and the percentage of voids filled with asphalt from the test results.

Use parts of the chunk samples to determine aggregate gradation; specific gravity of asphalt and aggregate; and penetration, ductility, and softening point of the asphalt. Disintegrate and recompact other chunk samples, and test the recompacted specimens for Marshall stability, flow, and density. Compute their void relationships.

The stability of cores cut from the pavement may be lower than that of the recompacted sample. Part of this difference is due to differences in density because field cores seldom have a density as high as the laboratory-compacted samples. Most variation in stability is attributed to differences in structure of the field and laboratory samples. Another factor is that the asphalt hardens during reheating.

Remove and replace the mix if results are totally unfavorable (for example, if stability is under 500 based on 50 blows or if flow is greater than 20 based on 50 blows). Sometimes, additional compaction increases the stability. (For voids total mix, tolerance is within 1 percent of specifications; for voids filled with asphalt, tolerance is within 5 percent of specifications.)

No standard tests have been developed to determine resistance to spillage. However, a small amount of jet fuel should be spilled on one chunk from each test pit to see if the fuel penetrates the sample quickly or if it puddles on the surface.

Base-Course, Subbase, and Subgrade Tests

Obtain classification data consisting of Atterberg limits, gradation, and specific gravity determinations from design and construction-control tests or tests performed on samples of base-course, subbase, and subgrade materials remolded at three compaction efforts. Develop the moisture density and CBR relationships for the CE 55 compaction test. Where available, include results of tests made on the soaked and unsoaked condition for possible future use.

MAKING THE EVALUATION

Evaluation of expedient pavement requires less effort than evaluation of flexible pavement. Expedient-pavement evaluation procedures are similar to expedient-pavement design procedures covered previously in this chapter.

Evaluation of a flexible pavement consists of two principle determinations—the load-carrying capacity of the entire pavement structure and the quality of the bituminous pavement. The load-carrying capacity is evaluated by applying the proper criteria to the factors of pavement thickness; the CBR of the base course, CBR of subbase, or combined thickness of all courses above the subgrade; and the CBR of the subgrade. The quality of bituminous pavement is judged by its ability to withstand traffic loads, fuel spillage, and jet blast.

Evaluation of rigid pavements requires an understanding of its characteristics, which are beyond the scope of this chapter. The actual procedure, however, is very similar to flexible-pavement evaluation. Essentially, the strength of the subgrade and the condition of the rigid pavement determine whether an existing airfield requires additional overlays to support certain aircraft. (Rigid pavement evaluation is covered in Chapter 3, TM 5-826-3/AFM 88-24.)

EXPEDIENT- AND AGGREGATE-SURFACED AIRFIELDS

The evaluation of unsurfaced, mat-surfaced, and aggregate-surfaced pavements to determine the number of allowable traffic cycles is conducted using the appropriate design aircraft (C-130 or C-17). Since these are the only major aircraft that can operate on small, semiprepared, austere airfields, the curves used in the design process can be used in the evaluation. The procedure is very similar to the actual design procedure.

DESIGN STEPS

1. Determine the airfield location.

2. Determine the aircraft type and weight that will use the pavement.

3. Determine the CBR by using the airfield cone penetrometer or DCP test (found in Appendices I and J, respectively), or estimate the CBR based on soil classification (see FM 5-410).

4. Determine the number of required passes.

5. Knowing the airfield surface type (light-mat, medium-mat, or unsurfaced), use the appropriate curve by entering the left side of Figure 12-6, page 12-11, with the CBR. Follow horizontally to the gross aircraft weight. Then, follow downward to determine the allowable aircraft passes.

Example 11

Given an unsurfaced airfield with a CBR of 9 and soil type ML, determine the number of allowable aircraft passes for a C-130 aircraft with a weight of 130,000 pounds.

Solution 11

The aircraft, weight, and CBR are all given. Using Figure 12-6, page 12-11, enter the left side at CBR = 9 and read right (horizontally) to the C-130 curve. Follow downward and determine that there are 740 allowable aircraft passes.

FLEXIBLE-PAVEMENT AIRFIELDS

The evaluation of flexible pavements should be based on existing conditions. Do not consider the minimum allowable design thickness and maximum allowable design CBR values in Table 12-8, page 12-23, in the evaluation. The evaluation to determine the number of passes allowable is conducted using Figures K-1 through K-36, pages K-1 through K-37, because the evaluation may or may not be based on the C-141 (the design aircraft for flexible pavements). Use the following procedure:

- Determine the aircraft type and weight that will use the pavement. If the aircraft operating weight is unknown, use the weight for the design aircraft (C-141/345 kips).
- Determine the traffic area to evaluate (see Figure 12-5, page 12-7). Do not include overrun areas, Type D traffic areas, blast pads, and other nonload-carrying pavements in the evaluation. However, prepare a statement of their condition (as determined by visual inspection) and record the thickness and quality of the various layers.
- Determine the layer thickness of the select, subbase, base, and AC surface according to the procedure for the DCP or this chapter.
- Determine the CBR of the subgrade, select, subbase, and base. The CBR test can be conducted using test pits described previously in this chapter.

Another method for determining subgrade CBR is to use the DCP (Appendix J). The CBR of the select, subbase, and base also could be established from construction drawings, the AFCESA, or the Corps of Engineers' evaluation reports. The CBR also can be estimated based on soil classification (see FM 5-410). The physical properties on which the evaluation is based are presented in Table 12-18. The evaluation for the runway is based on the pavement thickness in the central 100-foot width for all gear configurations.

- Select the appropriate evaluation curve from Figures K-1 through K-36, pages K-2 through K-37. If there is no curve for the aircraft considered, use the curve for the controlling aircraft (C-141).
- Use the appropriate curve by entering the top with the cover thickness above the subgrade (total thickness of higher CBR material existing above the top of the subgrade). Follow downward to the gross aircraft weight. Then, move horizontally (left or right) to the subgrade CBR. Finally, move downward to determine the number of allowable aircraft passes. Repeat this procedure for each pavement layer (select, subbase, and base) using the cover thickness on top of the layer being considered. Once the number of allowable aircraft passes has been determined for each pavement layer, the most conservative (that is, the lowest) number will control the evaluation.

Table 12-18. Summary of physical property data

Facility Number and Identification	Pavement		Base			Subgrade	
	Thick (in)	Description	Thick (in)	Classification	CBR	Classification	CBR
Primary runway, taxiway, and parking apron	4	Asphaltic concrete	8 15	GW crushed stone GP stabilized gravel	100 50	CL lean clay	15

Example 12

Determine the number of allowable aircraft passes for all F-4 aircraft with a weight of 62,000 pounds. The test pit evaluation of a captured enemy airfield indicates the following conditions:

- Type B traffic area (primary taxiway).
- 4 inches of AC.
- 6 inches of base course, CBR = 80 (GW).
- 4 inches of subbase course, CBR = 40 (GM).

Subgrade, CBR = 10 (CL).

Solution 12

The aircraft type (F-4), weight (62 kips), traffic area (B), layer thicknesses, and CBR values have all been provided. Using Figure K-38, page K-38, enter the top with a cover thickness (above the subgrade) of 14 inches. Read downward to a gross aircraft weight of 62 kips. Then, read right to reach the subgrade CBR value of 10. Finally, read downward to determine a subgrade allowable pass level of 10^4, or 10,000 passes. Repeat these steps for the subbase. Enter the cover thickness = 10 inches, gross aircraft weight = 62 kips, and subbase CBR = 40. The allowable subbase pass level is greater than 100,000. Now, evaluate the base course. Enter the cover thickness = 4 inches, weight = 62 kips, and base CBR = 80. The allowable base pass level is greater than 100,000. The subgrade controls the evaluation with 10,000 passes.

Example 13

Evaluate the airfield described in the previous example for a C-5A weighing 700,000 pounds.

Using the same steps as in the previous example, the allowable passes are as follows:

- Subgrade = 140.
- Subbase = 100,000+.
- Base = 100.000+.

Solution 13

The subgrade controls the evaluation with 140 allowable passes.

Selection of Strength and Thickness values

Carefully select CBR values for use in an evaluation. Thickness values are selected from design or actual measured thickness for the base and subbase layers.

CBR test results from an individual test pit are seldom uniform. Therefore, study the data carefully to determine reasonable values for the evaluation. There are no rules or formulas for the number of values needed. This is a matter of engineering judgment. The following guidelines may assist in determining the number needed. A minimum of five CBR values per facility is required even when the material is known to be uniform, when control tests indicate that placement is uniform, and when available values cover a narrow range. When the uniformity of material and construction are not known, the number of test values should be sufficient to establish a good statistical distribution.

To select values for an evaluation, plot test results on profiles or arrange them in tabular form to show the range of the data. In most cases, the value selected should be a low average, but it should not be the lowest value in a range.

When conditions are uniform, the lower quartile value from a cumulative distribution plot may be used. Where conditions are not uniform, the following example may be helpful.

The subgrade material beneath a facility being evaluated varies so that the facility may be divided into several large areas of differing subgrade material. The in-place CBR values for the entire facility, arranged in ascending order, are as follows: 7, 7, 8, 9, 9, 10, 14, 14, 15, 16, 20, 21, 21, 22, 28, 30, 30, and 31. A study of in-place conditions reveals the degree of saturation of the subgrade is about the same for the entire area covered by the facility, and the degree of saturation is high enough that in-place CBR values can be used for evaluation.

Preliminary analysis of this data shows the statistical distribution for the whole facility is not good, and the values logically fall into four groups. Each group represents one of the areas of different material. The most critical area is that represented by the range of values from 7 to 10 because more of the values fall in that group than in any other. Thus, the evaluation should be based on this area.

Because the range is narrow, a formal statistical analysis is not necessary. A visual inspection of the figures indicates a value of 8 or 9 should be selected.

Regardless of the number of values available and the method used to select the evaluation figure, the number of values and the analytical process used should be described in the evacuation report in sufficient detail to be easily understood later.
Because of certain inherent difficulties in processing samples for laboratory tests and in performing in-place tests on base course materials, it is advisable to assign arbitrary CBR values to certain materials based on their service behavior (see Table 5-3, page 5-12, FM 5-430-00-l/AFPAM 32-8013, Vol 1). Use these CBR values for base-course material when the material meets quality requirements of the specification.

When evaluation tests are made less than three years after construction and indicate plasticity index values greater than 5, consider in-place CBR values but assign no value greater than 50. When tests are made three years or more after construction and indicate plasticity index values greater than 5, use in-place values.

When evaluation tests on subbase materials are made less than three years after construction and tested materials meet the suggested requirements, consider in-place CBR values, but assign no value greater than 50. When tests are made three years or more after construction, use in-place values.

Sometimes, CBR tests tend to underrate certain cohesionless, nonplastic materials that are not confined. If records show adequate performance and service behavior for these materials, use judgment to assign an arbitrary CBR value for evaluation.

Quality Of Bituminous Pavement

The condition of a bituminous pavement, either surface or binder course, is evaluated at the time of sampling by comparing the test data from the core samples with design criteria in TM 5-337. Future behavior of the pavement under additional traffic is predicted by comparing the test data from the recompacted laboratory specimens with the design criteria. The following example shows the prediction of behavior from tests on cores and on recompacted laboratory surface course specimens.

Assume the thickness and aggregate gradation are satisfactory. The current density (cores) is relatively low, the flow is approaching the upper limit, the voids' relationship is outside the acceptable ranges, and the stability is satisfactory.

Data from the recompacted specimens indicate additional compaction from traffic will tend to improve the quality of the pavement. Thus, the pavement probably will adjust itself to heavier loads and tire pressures than it has sustained in the past and will be satisfactory under either high- or low-pressure traffic. At CE 55, the voids' total mix value is below the midpoint of the acceptable range, and the flow is at the upper limit, indicating a mix slightly richer than ideal. However, no danger from flushing (bleeding) is expected.

Ability to withstand fuel spillage. ACs are readily soluble in jet fuels, but tars are not. Maximum distress is caused to AC pavements by fuel frequently dripping on a given area or by the pavement mix being so pervious that it allows considerable fuel penetration. Voids in the total mix control the rate at which penetration occurs. Fuels will penetrate very little into pavements with about 3 percent voids but will rapidly penetrate pavements with high (over 7 percent) voids.

Weathering appears to increase the pavement's resistance to penetration of jet fuels. Pavements about one year old or older usually perform better in this respect than new pavements.

Tar concretes and rubberized-tar concretes are not readily soluble in jet fuel, but saturation with jet fuel is detrimental to the life of such pavements. A low-void, total-mix value in a surface course indicates that it is sufficiently impervious to forestall damage.

Determine the type binder in the surface course, and study the surface course characteristics for resistance to jet fuel. Note poorly bonded thin layers. Use Table 12-19 as a guide for evaluating the types of bituminous pavements from the standpoint of fuel spillage for use in areas throughout the airfield.

Ability to withstand jet blast. Tests have shown that about 300°F is the critical temperature for AC and rubberized-tar concrete. About 250°F is the critical temperature for tar concrete. Field tests simulating pretakeoff checks at the ends of runways indicate the maximum temperatures induced in pavement tests; simulating maintenance checkups were 315°F. Rubberized-tar concretes usually withstand these temperatures. No bituminous pavement resists erosion if afterburners are turned on when the plane is standing still.

Thin surface courses that are not bonded well to the underlying layers may be picked up or flayed by high-velocity blasts even though the binder is not melted. All jet aircraft currently in use produce blasts of sufficient velocity to flay such courses. Surface courses less than 1 inch thick with poor bond to the underlying layers are, therefore, rated as unsatisfactory for all jet aircraft. This rating applies only to parking areas and the ends of runways.

Effects of traffic compaction. When evaluating effects of future traffic on the behavior of the paving mix, compare existing conditions with results of laboratory tests mentioned previously. If the pavement is constructed so voids fall at or about the lower limit of the specified allowable range, planes with high-pressure tires probably will produce sufficient densification to reduce voids in the total mix. When voids fall below the specified minimum, there is no internal air in the asphalt mix for the asphalt to flow into. Such pavement is considered to be in a critical condition. These conditions cannot be translated into numerical evaluations, but they should be discussed and summarized in the evaluation report.

To evaluate the base, subbase, and subgrade from the standpoint of future compaction, compare in-place densities (in percentage of CE 55 maximum density) with design requirements for the various loads and gear configurations the pavement is expected to support. If the in-place density of a layer is appreciably lower than required, remove the surface, base course, and subbase courses and apply proper compaction.

Low-density materials combined with low moisture content permit densification.

Table 12-19. Guidance for evaluating pavement types

Type Pavement	Texture	Uses
Asphalt concrete	NA	Runway and taxiway interiors
Tar and rubberized-tar concrete	Dense	All areas
Tar and rubberized-tar concrete	Open	Runway interiors, runway ends, taxiway interiors, and taxiway ends

Include statements of the possible amount of settlement due to densification in the evaluation of pavements subjected to channelized traffic.

If cohesive materials develop pore pressures, study the possible loss in strength and estimate the lowest probable CBR. Consider this estimated value when selecting the evaluation CBR for that material.

Actual and estimated pavement behavior. Study the traffic history to learn the weights of planes that have been using the field, then compare the behavior of the facilities under actual plane weights with that indicated by the evaluations of the pavement's load-carrying capacities. In making these comparisons, consider the number of coverages produced by each type of plane and the effects of mixed traffic.

No criteria exists for judging the effects of mixed traffic. However, flexible pavements probably can withstand a few applications of loads well in excess of the load they can withstand for full operation. Also, numerous applications of loads below the full operation load (50 percent or less) are not detrimental; in fact, they are probably beneficial.

Exact agreement between behavior of facilities as shown by the evaluation and behavior that occurs under traffic is not expected. This is primarily caused by the difficulties in determining the exact traffic that produced the behavior and because conditions change with time. Study major differences in the evaluation based on the test data and data indicated from behavior under traffic. Discuss the differences in the evaluation report.

As a minimum, the evaluation of an airfield should allow loads and intensity of traffic equal to those previously sustained, provided this traffic does not produce distress. As an operating procedure, frequently inspect the pavements after heavier planes are introduced during the frost-melting period. Limit loads or reduce traffic intensity when high deflections are observed during traffic.

Evaluation for Arid Regions

The danger of saturation beneath flexible pavements is reduced when the annual rainfall is less than 15 inches, the water table (including perched water table) is at least 15 feet below the surface, and the water content of the subgrade does not increase above the optimum determined by the CE 55 compaction test. Under such conditions, reduce the total design thickness of the pavement, base, and subbase courses by 20 percent. Apply this reduction to the select material or to the subbase course having the lowest design CBR value.

Conversely, when evaluating flexible pavements under these conditions, increase the total thickness above the subgrade by 25 percent before entering the evaluation curves. Apply this increase to the select material or the subbase course having the lowest bearing ratio or to the same layer in which the reduction was made in the design analysis.

FLEXIBLE OVERLAY OVER FLEXIBLE PAVEMENTS

An evaluation of a flexible-pavement airfield may determine that the traffic areas do not meet the cover requirements for a particular mission. In this case, it is possible to overlay the existing pavement with additional material to make it satisfactory for use.

An example of the design procedure for applying a flexible overlay to flexible pavement follows.

Example 14

The evaluation of an existing airfield pavement indicates the conditions shown below. Tests on the AC indicate that it is adequate. The directive states the field will be used as a rear area 10,000-foot airfield for 1,000 passes.

4"	AC Pavement
6"	Base Course CBR = 80
6"	Select Material CBR = 20
	Subgrade CBR = 7

Solution 14

The critical aircraft for the rear area 10,000-foot airfield is the C-141, which has a gross weight of 345,000 pounds. The pavement being considered is a Type B traffic area. To design the overlay, check the existing airfield against the thickness design requirements in Figure 12-12, page 12-41. This indicates whether the airfield is satisfactory as is or whether an overlay is needed.

Enter Figure 12-12 with the CBR of each soil layer of the pavements, and read the thickness required above that layer from the curve. The value from the curve is compared with the existing thickness.

If the thickness from the curve is less than the existing thickness, the airfield pavement is satisfactory. If the required thickness is greater than the existing thickness, an overlay is required. The overlay thickness must be equal to the difference between the design thickness and the existing thickness. The results of this example are shown below:

Soil Layer	Existing Thickness Above Soil Layer (in)	Design Thickness (in)	Overlay Thickness Requirement
CBR 7 subgrade	16	24	8
CBR 20 select material	10	11.2	1.2
CBR 80 base	4	3.2	0

Use the largest overlay thickness requirement. An overlay thickness of 8 inches will satisfy the thickness requirement for operating on this pavement for 1,000 passes as a heavy lift, rear-area pavement. It is possible to overlay 8 inches of AC on the existing surface, but this would be prohibitively expensive. A better alternative is to overlay 6 inches (minimum lift thickness) of CBR = 100 base course and 3 inches of AC. The overlay is shown following:

3" AC Pavement

6" Base Course CBR = 100

4" AC Pavement

6" Base Course CBR = 80

6" Select Material CBR = 20

Subgrade CBR = 7

Another method to determine an overlay requirement is to use the evaluation curves, Figures K-1 through K-36, pages K-1 through K-37. Enter these curves at the bottom with the number of aircraft passes and read upward to the layer's CBR value. Then, read horizontally to the aircraft gross weight. Finally, read upward to determine the required thickness above that soil layer. Using the same example as above yields the following information:

Soil Layer	Existing Thickness Above Soil Layer (in)	Design Thickness (in)	Overlay Thickness Requirement
CBR 7 subgrade	16	24	8
CBR 20 select material	10	11.1	1.1
CBR 80 base	4	3.2	0

Thus, this method also would result in an overlay.

NONRIGID OVERLAYS OVER RIGID PAVEMENTS

In the rear areas of the TO, it may be necessary to evaluate existing rigid pavements and to bring them to required strengths by adding nonrigid overlays. Use the following design procedure to determine the nonrigid overlay thickness needed to increase the load-carrying capacity of existing concrete pavements. This design procedure is also used to evaluate existing concrete pavements with nonrigid overlay.

Nonrigid overlays may be AC or flexible. The type of nonrigid overlay used for a given condition depends on the required overlay thickness. In general, the flexible overlay is used when the required overlay is of sufficient thickness to incorporate a minimum 4-inch compacted layer of high-quality, base-course material, plus the required thickness of AC surface course. The AC overlay will be used when less overlay thickness is needed.

The method used assumes the nonrigid overlay on rigid pavement to be a flexible pavement, with the rigid-base pavement assumed to be a high-quality base course with CBR = 100. This is a very conservative assumption. The nonrigid overlay on rigid pavement is designed and evaluated in the same manner as a flexible pavement, the procedure for which was described earlier in this chapter. Thus, when designing and evaluating, it will be necessary to determine the physical constants that are required for flexible pavements.

If an existing flexible overlay has already been placed, the quality of the AC portion of the overlay and the CBR values of the subgrade and base course beneath the rigid base pavement will have to be established. As mentioned above, the rigid-base pavement will be assumed to have CBR = 100.

Example 15

Assume a runway with uniform thickness of nonrigid overlay on rigid pavement throughout its entire width and length must be evaluated. The overlay composed of AC for full depth is 2 inches, the thickness of the rigid base pavement is 6 inches, the base course thickness under rigid pavement is 8 inches, the base course CBR is 40, and the subgrade CBR is 7.

2" AC Pavement

6" Portland Cement Concrete

8" Base Course CBR = 80

Subgrade CBR = 7

This sample airfield is to be used by C-141 aircraft for 5,000 passes. The design load is 345,000 pounds. Tests of the AC indicate that it meets design requirements for stability, density, gradation, voids relations, and other design requirements.

Solution 15

A design curve for traffic area Type B will be required. Enter Figure 12-12, page12-41, with this design load (in kips). It is found that the CBR = 7 subgrade requires 28 inches of cover, CBR = 40 requires 7.3 inches of cover, and CBR = 100 (Portland cement (PC) concrete) requires no cover.

The total cover over the CBR = 7 subgrade is only 16 inches, whereas 28 inches is required. Therefore, the overlay must be 28 - 16 inches, or 12 inches thick.

PAVEMENT AND AIRFIELD CLASSIFICATION NUMBERS

After an airfield pavement has been designed, constructed, or evaluated, aircraft other than the critical aircraft probably will land on the pavement. (These can include foreign national aircraft.) Due to these constraints, it will be extremely difficult to account for all traffic loads in relation to the design life of the airfield. One method to account for this is to set a pavement classification number (PCN) based on the design aircraft, assign an aircraft classification number (ACN) to aircraft based on their load, and then compare the two. The ACN expresses the relative structural effect of an aircraft on different pavement types for specified standard subgrade strengths in terms of a standard single-wheel load. The PCN expresses the relative load-carrying capacity of a pavement in terms of a standard single-wheel load.

The system is structured so that a pavement with a particular PCN value can support, without weight restrictions, an aircraft that has an ACN value equal to or less than the pavement's PCN value. This is possible because ACN and PCN values are computed using the same technical basis.

DETERMINATION OF VALUES

Pavement Classification Numbers

The PCN numerical value for a particular pavement is determined from the allowable load rating, which is usually based on the design aircraft. Once the allowable load rating is established, determining the PCN value js a process of converting that rating to a standard relative value. Curves for converting allowable load ratings to PCN values are presented in Appendix O. The PCN value is usable for reporting the pavement strength only.

Rigid pavement PCN—allowable load curves. For rigid pavements, aircraft landing gear flotation requirements are determined by the Westergaard solution for a loaded elastic plate on a dense liquid foundation (interior load case), assuming a concrete working stress of 399 psi. Four different subgrade strengths are considered: high, 554 pounds per cubic inch (pci); medium, 296 pci: low, 148 pci: and ultralow, 74 pci. Using these parameters, a standard single-wheel load at a tire pressure of 181 psi is computed for each subgrade strength. The standard single-wheel load is expressed in kilograms and divided by 500 to obtain the PCN. Division by 500 is a rounding-off process to make the numbers smaller and more manageable.

Flexible-pavement PCN—allowable load curves. For flexible pavements, aircraft landing gear flotation requirements are determined by the CBR method. As with the rigid pavement, four different subgrade strengths are considered: high, CBR = 15; medium, CBR = 10; low, CBR = 6; and ultralow, CBR = 3. A standard single-wheel load at a tire pressure of 181 psi is computed for each of these subgrade strengths. The standard single-wheel load is expressed in kilograms and divided by 500 to obtain the PCN.

Reporting the PCN. The PCN should be reported in whole numbers, rounding off any fractional parts to the nearest whole number. For pavements of variable strength, the controlling PCN numerical value for the weakest feature of the pavement should be reported as the strength of the pavement. Besides their PCN number, data coded in Table 12-20 must be provided.

ACN values are determined the same way as PCN values because they are relative to the aircraft load and subgrade strength. A set value has not been selected for aircraft since this can vary based on the aircraft load and can be different from takeoff and landing due to full expenditure.

Guidance on Overload Operations

Pavement overload can result from loads that are too large, from a substantially increased application rate, or from both. Loads larger than the defined (design or evaluation) load shorten the design life while smaller loads extend it. Except for massive overloading, pavements in their structural behavior are not subject to a particular limiting load above which they suddenly or catastrophically fail. Their behavior is such that a pavement can sustain a definable load for an expected number of repetitions during its design life. As a result, occasional minor overloading is acceptable, when expedient, with only limited loss in pavement life expectancy and small acceleration of pavement deterioration. For those operations in which the magnitude of overload or the frequency of use does not justify a detailed analysis, the following criteria are suggested:

- For flexible pavements, occasional movements by aircraft with ACN not exceeding 10 percent above the reported PCN should not adversely affect the pavement.

- For rigid or composite pavements where a rigid pavement layer provides a primary element of the structure, occasional movements by aircraft with ACN not exceeding 5 percent above the reported PCN should not adversely affect the pavement.
- If the pavement structure is unknown, the 5-percent limitation should apply.
- The annual number of overload movements should not exceed approximately 5 percent of the total annual aircraft movements.

Such overload movements should not normally be permitted on pavements exhibiting signs of distress or failure. Furthermore, overloading should be avoided during any periods of thaw following frost penetration or when the strength of the pavement or its subgrade could be weakened by water. Excessive repetition of overloads can cause severe shortening of pavement life or require major rehabilitation of pavement. Therefore, where overload operations are conducted, the appropriate authority should review the relevant pavement condition regularly and review the criteria for overload operations periodically.

NOTE: Thickness design for rigid, flexible, and unsurfaced pavement (with or without matting) can be accomplished with computer programs developed by WES. The programs are available from the US Army Transportation Center, ATTN: CEMRD-ED-TT, 12565 West Center Road, Omaha, NE 68144-3869.

Table 12-20. PCN five-part code

PCN	Pavement Type	Subgrade Strength*	Tire Pressure**	Method of PCN Determination
Numerical value	R = rigid	A	W	T = technical evaluation
		B	X	
	F = flexible	C	Y	
		D	Z	U = using aircraft

*Code	Category	Flexible Pavement (CBR)	Rigid Pavement (k) (Pavement Condition Index)
A	High	Over 13	Over 400
B	Medium	8-13	201-400
C	Low	4-8	100-200
D	Ultralow	<4	<100

**Code	Category	Tire Pressure (psi)
W	High	No limit
X	Medium	146-217
Y	Low	74-145
Z	Ultralow	0-73

DESIGN AND CONSTRUCTION OF HELIPORTS AND HELIPADS

CHAPTER 13

This chapter presents information on the design and construction of operational facilities for rotary-wing aircraft. The first step in the design of such facilities is to identify the types and amount of traffic that will use the heliport or helipad. Next, establish requirements for geometric dimensions, surface types, and service facilities. Determine subgrade strength, design load, and design life to determine the proper surface type. The proper surface also depends on expedient matting, expedient membrane, and soil-stabilization requirements. Procedures for marking and lighting heliports and helipads are also discussed.

TYPES OF HELICOPTERS

Army helicopters are classed as observation. utility, cargo, and attack helicopters. Important characteristics of current Army helicopters are shown in Table 13-1, page 13-2. Design criteria given later in this chapter are based on use by the most critical aircraft (greatest pavement load).

- Observation helicopters (OHs) are used for visual, photographic, or electronic observations and the adjustment of fires. OHs are also used for command and control; reconnaissance; surveillance; aerial wire laying; and a limited amount of resupply, evacuation, and aerial fire support.
- Utility helicopters (UHs) are used for missions such as troop and cargo lift, passenger transport, patient movement, command and control, and dissemination of material during psychological operations.
- Cargo helicopters (CHs) are used to support air-movement operations and to transport troops, equipment, and supplies within the battle area. They are also used for refueling tankers and evacuating patients, prisoners, or damaged equipment. Cargo aircraft with vertical takeoff and landing capabilities can transport surface vehicles and other heavy equipment for short distances over natural or manufactured obstacles.
- Attack helicopters (AHs) provide direct aerial fires and escort troop-carrying helicopters and provide a suitable platform for various weapons.

HELIPORT TYPES, DESIGN CRITERIA, AND LAYOUT

The size and configuration of heliports are dictated by the type and number of helicopters accommodated by the facility. The size and configuration change as the tactical

Table 13-1. Characteristics of US Army helicopters

Helicopter	Name	Length (ft)	Width (ft)	Height (ft)	Basic Weight (kips)	Maximum Takeoff Weight (kips)	Gear Type
OH-6A	Cayuse	30.30	26.30	8.25	1.16	2.40	Skid
OH-58A	Kiowa	41.00	35.30	9.50	1.59	3.00	Skid
OH-58C	Kiowa	41.00	35.30	12.00	1.90	3.20	Skid
UH-1C/M	Iroquois	52.83	44.00	12.67	4.83	9.50	Skid
UH-1H/V	Iroquois	57.10	48.00	14.50	5.13	9.50	Skid
UH-60	Blackhawk	64.83	53.67	17.50	11.04	20.25	Single-wheel main gear with trail wheel
CH-47A	Chinook	98.25	59.10	18.50	18.15	33.00	Twin quad
CH-47B	Chinook	99.00	60.00	18.67	19.59	40.00	Twin quad
CH-47C	Chinook	99.00	60.00	18.67	20.48	46.00	Twin quad
CH-47D	Chinook	99.00	60.00	18.67	22.50	50.00	Twin quad
CH-54A	Flying Crane	88.42	72.00	24.42	20.80	42.00	Single tricycle
CH-54B	Flying Crane	88.42	72.00	24.42	21.20	47.00	Single tricycle
AH-1G	Huey Cobra	52.98	44.00	11.70	5.56	9.50	Skid
AH-1S	Huey Cobra	53.08	44.00	13.75	6.60	10.00	Skid
AH-64	Apache	57.67	48.00	15.25	14.66	20.65	Single-wheel main gear with trail wheel

and environmental conditions change. Under some circumstances, several hundred helicopters may be based at a single location. Another set of conditions may require that aircraft density be limited to 25 helicopters. Developed area requirements are for dispersed heliports with densities as low as 25 helicopter per site.

Requirements in the underdeveloped areas of the world are usually satisfied by locating heliports with large aircraft capacities at a fixed-wing airfield. This density is determined by security requirements, responsiveness to supported units, and reduction of airfield construction effort.

TYPES OF HELIPORTS

The four levels of heliport development in the TO are LZs of opportunity, austere forward area fields, substandard but operational support area fields, and deliberate rear area fields.

Landing Zone of Opportunity

This type facility, normally located in the close battle area, represents the minimum cleared area at which a helicopter can land to discharge or pick up passengers or cargo under conditions existing at the time of use. Geometric requirements are kept to the absolute minimum and do not exceed those for a support area helipad or heliport. If the helicopter is to remain in the area, there should be a minimum disturbance of the natural terrain. No construction effort, other than clearing, is expended at LZs of opportunity.

Austere Support Area Field

This construction standard is the minimum acceptable in safety and efficiency for aircraft operations. The heliport is usually limited to a grass or soil surface (preferably grass) with appropriate expedient treatment to permit operations under most weather conditions. The ground should be sufficiently firm, horizontal or nearly so, and clear of any objects likely to be blown about by the rotor.

These heliports are established on a temporary basis for support of a particular operation. The duration of use, determined by the tactical situation, is usually two weeks. Routine organizational maintenance and limited field maintenance are done.

The location of an austere support area airfield is dictated primarily by the tactical situation. It is not necessarily the best location from the standpoint of efficiency of flight operations. Any work required to develop this site is usually done by the unit occupying the site, except for such effort as may be available from an engineer combat battalion. Heliport maintenance is only enough to accomplish the mission.

Support Area Field

This construction standard provides conventional safety and efficiency of operations. Heliport traffic areas are normally surfaced with membrane or landing mat, anti aircraft operate under most weather conditions. Facilities at this site provide for POL resupply and extended maintenance. The field is usually located in the corps area and is constructed by engineer combat or combat heavy battalions.

The magnitude of operations at these fields is far greater than at shaping area fields. The site should be located near flying operations. To economize on the construction effort and to maximize the use of available sites, these heliports may be combined with fixed-wing airfields. Because support area heliports normally operate over a long period of time and may eventually be fitted into the overall theater airfield scheme, maintenance is progressive and vigorous.

Rear Area Field

These heliports are designed and constructed for all-weather operations. A rear area field has a well-graded, thoroughly compacted base and an expedient or conventional surface. The field is usually in the COMMZ and is located at a fixed-wing airfield. Construction is by engineer combat heavy battalions. The location will stress operational efficiency. A high standard of heliport maintenance is provided because of the magnitude of operations and the size of aircraft involved.

Helipads

Helipads are constructed for aircraft that do not require a TGR to become airborne. They are most advantageous where a limited number of helicopters are to be located or at heliports that handle a large volume of traffic where separate landing and takeoff operations are desired. Helipad layouts have been developed for the various helicopters.

FACTORS INFLUENCING DESIGN

The basic TO heliport complex as visualized in development of design criteria for close battle support and rear area heliports, is shown in Figure 10-2, page 10-4. Each heliport shown is included in the complex for a specific purpose. The design of each heliport is based on the requirements for the aircraft listed in Table 13-1. Additionally, geometric requirements and minimum area requirements for each kind of helipad/heliport considered are shown in Tables 13-2, 13-3, and 13-4, pages 13-4 through 13-7.

Factors that influence the development of heliport design criteria are helicopter characteristics, operational considerations, and requirements for expedient airfield surfacing and rustproofing, Location, traffic area, and safety also affect the design of heliports.

Helicopter Characteristics

Helicopter characteristics that influence heliport strength requirements are weight, landing-gear configuration, and tire pressure. Ground run and dimension characteristics affect heliport geometric layouts,

Heliport surfaces are designed to withstand the load applied by the helicopter. This load is distributed to the heliport surface at several points in a pattern determined by the landing gear configuration. The loading for each wheel is determined

Table 13-2. Geometric requirements and minimum areas for heliports/helipads

Item Number	Description	Close Battle Area					Support Area					Rear Area				
		OH-58	UH-60	AH-64	CH-47	CH-54	OH-58	UH-60	AH-64	CH-47	CH-54	OH-58	UH-60	AH-64	CH-47	CH-54
	Landing Pad															
1	Length, feet	12	40	50	50	50	12	40	50	50	50	25	80	80	100	100
2	Width, feet	12	23	25	25	50	12	23	25	25	50	25	46	50	50	100
3	Landing pad grade in direction of approach or departure, percent	3	3	3	3	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
4	Shoulder width, feet	--	--	--	--	--	10	10	10	10	10	25	25	25	25	25
5	Grade of shoulder in direction of approach or departure, percent	--	--	--	--	--	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6	Traverse grade of shoulder, percent															
	Maximum	--	--	--	--	--	3	3	3	3	3	3	3	3	3	3
	Minimum	--	--	--	--	--	2	2	2	2	2	2	2	2	2	2
7	Grade of clear area maximum, percent	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5
	Landing Area															
8	Length, feet	72	120	105	150	150	105	144	120	150	150	105	144	120	150	150
9	Width, feet	72	111	100	125	150	105	144	120	150	150	105	144	120	150	150
	Approach—Departure Zone															
10	Approach departure surface ratio	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1
11	Length, feet	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
12a	Width at end of landing area, feet	72	111	100	125	150	105	144	120	150	150	105	144	120	150	150
12b	Width at outer end, feet	500	555	500	500	500	500	555	500	500	500	500	555	500	500	500
	Takeoff Safety Zone															
13	Length, feet	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
14a	Width at end of landing area, feet	72	111	100	125	150	105	144	120	150	150	105	144	120	150	150
14b	Width at outer end, feet	215	241	233	250	267	237	263	247	267	267	237	263	247	267	267

Table 13-3. Geometric requirements and minimum areas for heliports/helipads

Item Number	Description	Close Battle Area				Support Area				Rear Area			
		OH-58	UH-60	CH-47	CH-54	OH-58	UH-60	CH-47	CH-54	OH-58	UH-60	CH-47	CH-54
	Heliport Runways												
1	Length, ft^1	--	--	--	--	--	--	450	450	--	--	450	450
2	Width, ft	--	--	--	--	--	--	25	50	--	--	40	60
3	Longitudinal grade of runways and shoulders, percent	--	--	--	--	--	--	±2	±2	--	--	±2	±2
4	Transverse grade of runway, percent												
	Maximum	--	--	--	--	--	--	1.5	1.5	--	--	1.5	1.5
	Minimum	--	--	--	--	--	--	0.5	0.5	--	--	0.5	0.5
5	Shoulder width, ft	--	--	--	--	--	--	10	10	--	--	25	25
6	Transverse grade of shoulders, percent												
	Maximum	--	--	--	--	--	--	3	3	--	--	3	3
	Minimum	--	--	--	--	--	--	2	2	--	--	2	2
7	Clearance from runway ℄ to fixed or movable obstacles, ft	--	--	--	--	--	--	125	135	--	--	125	135
8	Cleared areas, slope, percent maximum	--	--	--	--	--	--	5	5	--	--	5	5
	Heliport Taxiways												
9	Width, ft	--	--	--	--	--	--	25	40	--	--	40	60
10	Longitudinal grades of taxiways and shoulders, percent	--	--	--	--	--	--	2	2	--	--	2	2
11	Transverse grade of taxiway, percent												
	Maximum	--	--	--	--	--	--	1.5	1.5	--	--	1.5	1.5
	Minimum	--	--	--	--	--	--	0.5	0.5	--	--	0.5	0.5
12	Shoulder width, ft	--	--	--	--	--	--	10	10	--	--	25	25
13	Transverse grades fo taxiway shoulders, percent												
	Maximum	--	--	--	--	--	--	3	3	--	--	3	3
	Minimum	--	--	--	--	--	--	2	2	--	--	2	2
14	Clearance from taxiway ℄ to fixed or movable obstacles, ft	--	--	--	--	--	--	125	135	--	--	125	135
15	Grade in any direction in taxiway cleared area, percent	--	--	--	--	--	--	5	5	--	--	5	5
	Taxi-Hoverlane												
16	Width, ft^2	75	140	180	200	100	200	240	250	100	200	240	250
17	Longitudinal grade of taxi-hoverlane, percent maximum	10	10	10	10	5	5	5	5	5	5	5	5
18	Transverse grade of taxi-hoverlane, percent												
	Maximum	5	5	5	5	5	5	5	5	5	5	5	5
	Minimum	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Heliport Parking Pad												
19	Length, ft	12	20	50	50	12	20	50	50	25	40	50	100
20	Width, ft	12	20	25	50	12	20	25	50	25	40	100	100

Table 13-3. Geometric requirements and minimum areas for heliports/helipads (continued)

Item Number	Description	Close Battle Area				Support Area				Rear Area			
		OH-58	UH-60	CH-47	CH-54	OH-58	UH-60	CH-47	CH-54	OH-58	UH-60	CH-47	CH-54
21	Parking pad grade in any direction, percent Maximum Minimum	3 0.5	3 0.5	3 0.5	3 0.5	1.5 0.5	1.5 0.5	1.5 0.5	1.5 0.5	1.5 0.5	1.5 0.5	1.5 0.5	1.5 0.5
22	Lateral clearance from rear and sides of parking pad to fixed and/or movable obstacles except other aircraft, ft	25	45	65	55	25	55	75	65	30	65	100	95
23	C-C spacing of parking 40 pads, ft	40	75	150	150	55	80	175	175	55	80	175	175
24	Spacing from edge of taxi-hoverlane to edge of parking pad, ft	10	20	20	20	10	20	20	20	10	20	20	20
	Heliport Overrun												
25	Length, ft	--	--	--	--	--	--	100	100	--	--	100	100
26	Width, ft	Same as runway, plus shoulders											
27	Longitudinal grade, percent	--	--	--	--	--	--	2	2	--	--	2	2
28	Transverse grade, percent Maximum Minimum	-- --	-- --	-- --	-- --	-- --	-- --	3 2	3 2	-- --	-- --	3 2	3 2
	Heliport Clear Zone												
29	Length, ft	--	--	--	--	--	--	100	100	--	--	100	100
30	Width, ft	--	--	--	--	--	--	250	270	--	--	250	270
31	Grades outside of overrun and shoulders, percent	--	--	--	--	--	--	5	5	--	--	5	5
	Heliport Approach-Departure Zone												
32	Approach-departure surface ratio	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1	10:1
33	Length, ft	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
34	Width, ft At end of clear zone or taxi-hoverlane At outer end	75 850	140 850	180 850	200 850	100 850	200 850	250 850	270 850	100 850	200 850	250 850	270 850
	Heliport Takeoff Safety Zone												
35	Length, ft	500	500	500	500	500	500	500	500	500	500	500	500
36	Width, ft	Same as approach departure zone											
	Service Roads												
37	Width, ft[3]	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	23	23	23	23

[1] Where runway length is not shown, takeoff and landing is on taxi-hoverlane.

[2] Taxi-hoverlane is used for takeoff and landing where provided.

[3] Roads should be located so as to require the least engineer effort.

Table 13-4. Minimal area requirements

Helipad or Heliport Type	Landing or Parking Pad (sq ft)	Taxiway (sq ft)	Runway (sq ft)	Overrun (sq ft)	Total traffic area (sq ft[1])	Total clear area (sq ft[2])	Dustproofing and/or Waterproofing Area (sq ft[3])
Close Battle Area Helipad							
OH-58	144	--	--	--	144	5,184	20,100
UH-60	920	--	--	--	400	10,000	39,600
CH-47, AH-64 company	1,250	--	--	--	1,250	18,750	177,000
CH-54	2,500	--	--	--	2,500	22,500	129,000
Close Battle Area Heliport							
UH-60 company	10,000	--	--	--	10,000	313,100	373,300
CH-47 company	20,000	--	--	--	20,000	581,625	922,725
Support Area Helipad							
OH-58	144	--	--	--	144	11,025	20,100
UH-60	920	--	--	--	400	14,400	39,600
CH-47, AH-64 company	1,250	--	--	--	1,250	22,500	177,000
CH-54	2,500	--	--	--	2,500	25,500	129,000
Support Area Heliport							
UH-60 company	10,000	--	--	--	10,000	455,100	494,700
CH-47, AH-64 company	20,000	82,000	11,250	5,000	118,250	969,625	1,394,688
CH-54 company	20,000	91,125	22,500	10,000	133,625	625,375	838,500
Mixed battalion	120,432[4]	92,688	11,250	5,000	229,370	2,022,175	1,994,000
Rear Area Helipad							
OH-58	625	--	--	--	625	11,025	20,100
UH-60	3,680	--	--	--	1,600	14,400	39,600
CH-47, AH-64 company	5,000	--	--	--	5,000	22,500	177,000
CH-54	10,000	--	--	--	10,000	22,500	129,600
Rear Area Heliport							
UH-60 company	40,000	--	--	--	40,000	473,000	516,900
CH-47, AH-64 company	80,000	125,700	18,000	8,000	223,700	1,025,000	1,297,625
CH-54 company	60,000	97,050	27,000	12,000	184,050	618,000	846,025
Mixed battalion	241,875[4]	137,900	18,000	8,000	397,715	2,100,112	2,170,030

[1] Traffic area includes parking or landing pad, taxiway, and runway.

[2] Total clear area is the area inside the lateral clearance line.

[3] This area includes the total clear area and an area around the perimeter, the width of which is determined by rotor downwash as explained in paragraph titled *Area Requirements*, page 13-15.

[4] Includes 80,000 square feet maintenance area.

NOTE: For typical layouts, see Figures 13-2 through 13-5, pages 13-11 through 13-14.

by the total wheel load and the dimensions of the tire area in contact with the heliport surface. The contact area dimensions are influenced by tire pressure. The heliport surface must have sufficient strength to resist repeated applications of maximum unit loads.

Operational Considerations

Sortie rate, tonnage to be handled, estimated heliport life, and the number of helicopters to be accommodated are the operational considerations that influence heliport criteria. Sortie rates determine the number of landings per unit time applied to the heliport surface. Design life indicates the total number of loadings the surface will sustain. The number of helicopters to be accommodated and tonnage to be handled establish taxiway, parking, and other hardstand requirements.

Surfacing and Dustproofing

Heliport traffic areas are brought to design strength by removing and replacing inadequate soils, compacting soil, and applying a bituminous pavement. Landing mats eliminate the need for these operations or reduce the time required to perform them. The mats are placed on low-strength soils to provide support for helicopter operations.

Membranes provide waterproofing and dustproofing on soils that have adequate strength for airfield traffic areas.

See FM 5-410 for soil stabilization methods that add strength to soils with low bearing values.

Dust-control materials are applied to unsurfaced traffic areas to limit the safety hazards and maintenance problems caused by dust. These materials also deny the enemy heliport intelligence gained through observation of traffic-induced dust.

Location Requirements

The level of development to which a heliport is constructed most often depends on its location. As the heliport location approaches the forward edge of the battle area, austerity of construction increases. In close battle and support areas, criteria reflect the requirement for haste in construction, short heliport life, and greater reliance on helicopter performance characteristics. In rear areas, helicopter support facilities are provided, greater numbers of helicopters are accommodated, and heliport dimensions reflect less reliance on helicopter performance characteristics.

Traffic Area Requirements

Locating heliports at logistical airfield complexes assures continued supply of POL and necessary aircraft maintenance parts and material. To avoid saturating or overloading the airfield, limit the total helicopter aircraft to approximately 30 to 100, which is equivalent to one to three companies. Each company or equivalent unit operates from its own area or dispersed hardstands located or satellite in the airfield operational area (Figure 13-1). Traffic areas for helicopters are assumed to carry the same requirements (medium-duty mat, light-duty mat, or membrane) as the parking areas of the basic airfield complex.

Safety Criteria

The tactical situation may necessitate deviations from the safety criteria established in technical manuals. The degree of departure from established criteria are dictated by the degree of risk that the command is willing to accept for that particular situation. If these standards must be compromised, the criteria in this manual are regarded as minimum.

LAYOUT

The geometric design requirements for helicopter landing areas can be simplified into four basic types: helipads, heliports with taxi- hoverlanes, heliports with runways, and mixed battalion heliports.

NOTE: If the tactical situation warrants, helicopter parking dispersion should be increased to the maximum extent possible and protective revetments should be built. The tables and figures in this chapter state the minimum dimensions allowable. Chapter 14 addresses design, construction, and maintenance of fortifica-

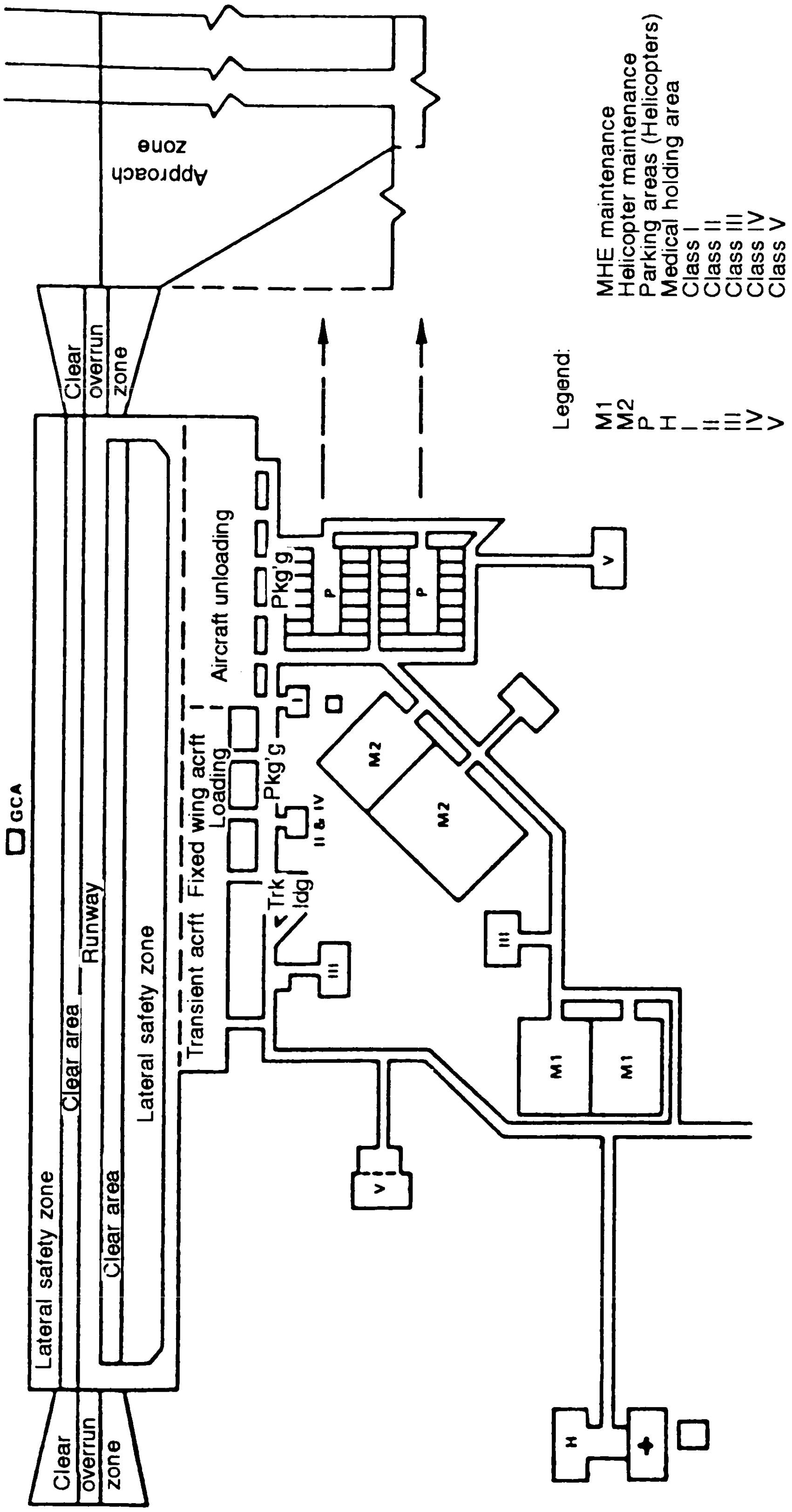


Figure 13-1. Schematic layout of satellite heliport

tions to protect parked Army aircraft from hostile fire and associated damage from exploding fuel and ammunition.

Helipads

The geometric layout and section views of a helipad are shown in Figure 13-2. The minimum dimensional (geometric) requirements are in Table 13-2, page 13-4. The circled numbers in Figure 13-2 identify the item numbers listed in Table 13-2. Use Figure 13-2 with Table 13-2 to determine the geometric requirements for each critical helicopter and each type of landing pad (close battle area, support area, and rear area).

Heliports with Taxi-Hoverlanes

The geometric layout and section views of a heliport with a taxi- hoverlane are shown in Figure 13-3, page 13-12. Parking and landing pads are offset midway across from each other on both sides of a taxi-hoverlane. Helicopters approach and depart this heliport via the hoverlane and approach/departure zone. The circled numbers refer to the item numbers in Tables 13-2 and 13-3, page 13-5, for the various types of heliports.

Heliports with Runways

The geometric layout and section views of a heliport with a runway are shown in Figure 13-4, page 13-13. This heliport, normally located in support or rear areas, is for the heavier wheeled cargo helicopters. The circled numbers in Figure 13-4 identify the item numbers in Table 13-3. Use these numbers to determine the geometric requirements for this type of heliport. Parking pads are offset midway across from each other on both sides of the taxilane. Helicopters normally approach and depart this heliport via the runway.

Mixed Battalion Heliport

The size of the mixed battalion heliport shown in Figure 13-5, page 13-14, is not standard but varies according to the number and types of helicopters that occupy it. This heliport may have a maintenance apron and multiple types of heliports in its layout. Each type heliport must be separately designed to the requirements indicated previously. This facility normally is located only in support or rear areas.

Runway Length

The runway lengths at sea level and 59°F for all helicopters considered are shown in Table 13-3. Runways are not shown in layouts for skid-type helicopters or wheel-mounted helicopters in the close battle area, where the taxi-hoverlane is used for this purpose.

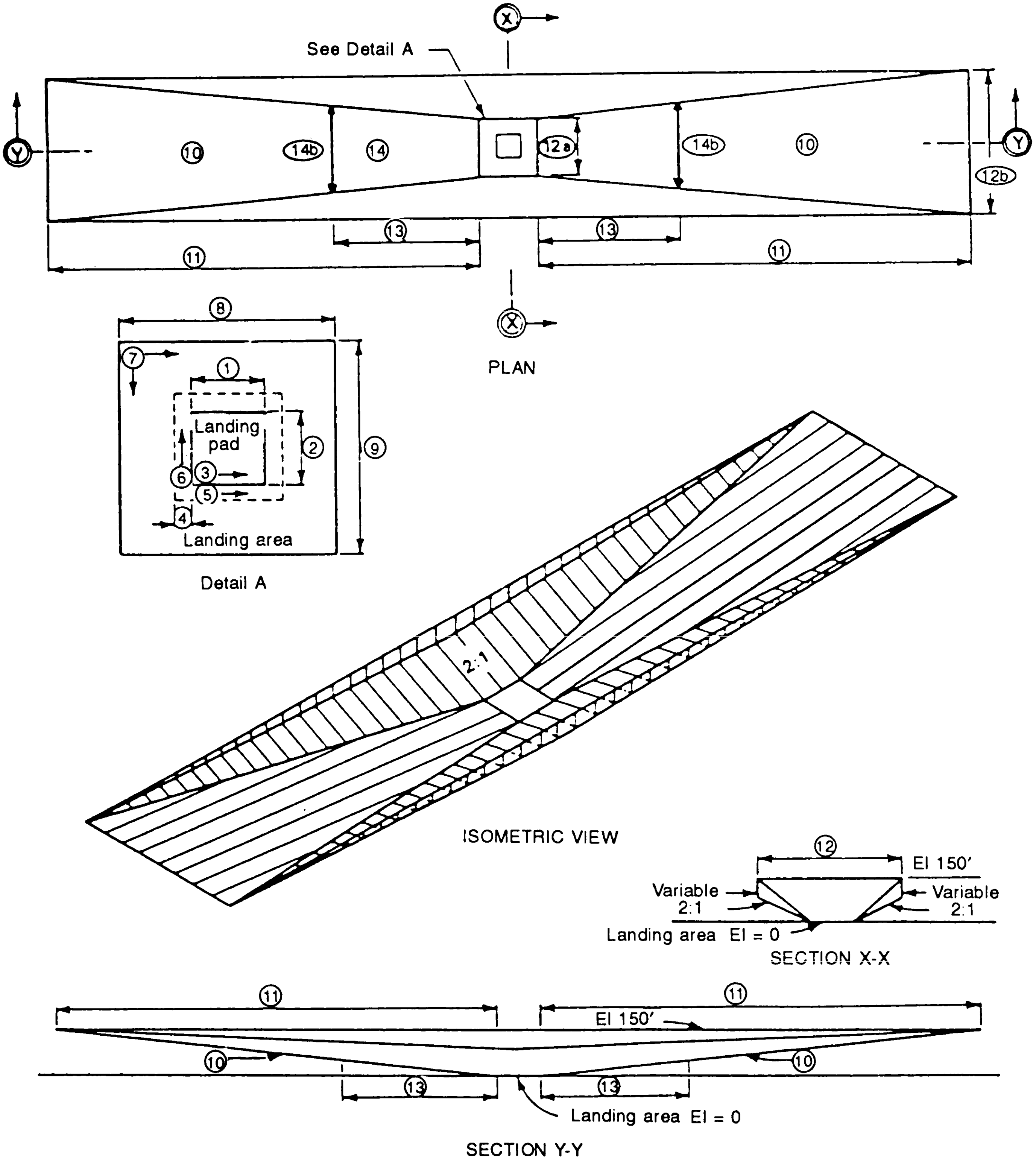
Increase the runway length by 10 percent for each 1,000 feet in altitude above 1,000 feet. Make a temperature correction of 4 percent. for each 10 degrees above 59°F in mean temperatures for the warmest period during which operations will be conducted. In no case is the length of the runway less than the minimum length shown in Table 13-3 for each type heliport.

Runway Orientation

Heliport runways normally are oriented according to the local prevailing winds. This orientation minimizes the detrimental effect. of crosswinds on aircraft operation. Determine this orientation after thoroughly studying wind through graphic analysis, often called a surface-wind rose analysis. (See Chapter 11.) Other factors permitting, align the runway as closely as possible with the prevailing wind.

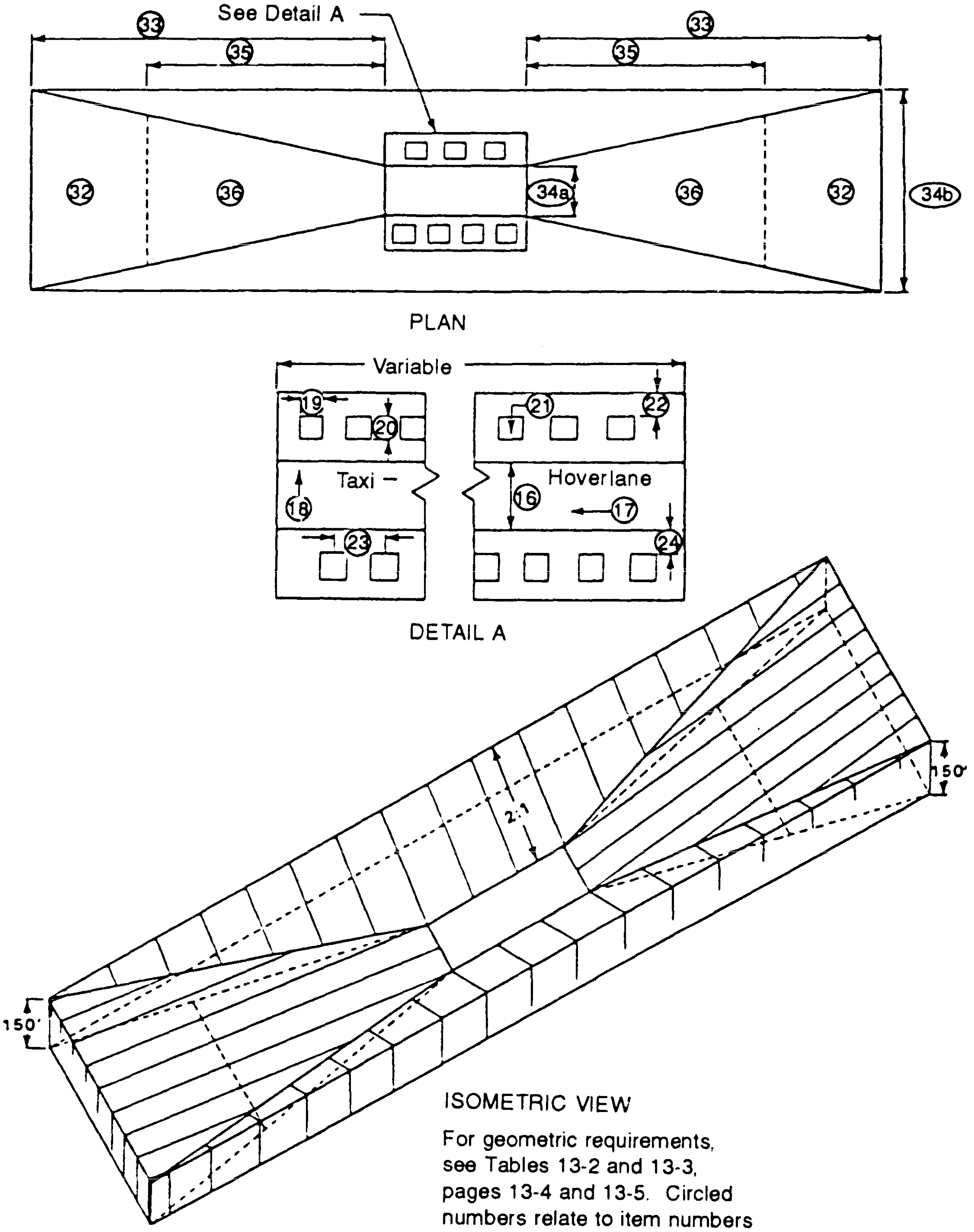
Geometric Requirements

Geometric requirements for close battle, support, and rear area heliports and helipads are shown in Tables 13-2 and 13-3. In general, heliport development consists of arranging a series of individual helipads together at the spacing required to accommodate the type of helicopters expected to operate from the facility. Tables 13-2 and 13-3 show the requirements for parking pads, taxiways, and runways (minimum length, width, and gradient). Related airfield elements such as shoulders, clear areas, overruns, lateral safety zone, clear zone, and approach zone are included in these tables. These requirements are based on the operational characteristics of the aircraft



Note:
For minimum geometric requirements, see Table 13-2, page 13-4. Circled numbers relate to item numbers as listed in Table 13-2.

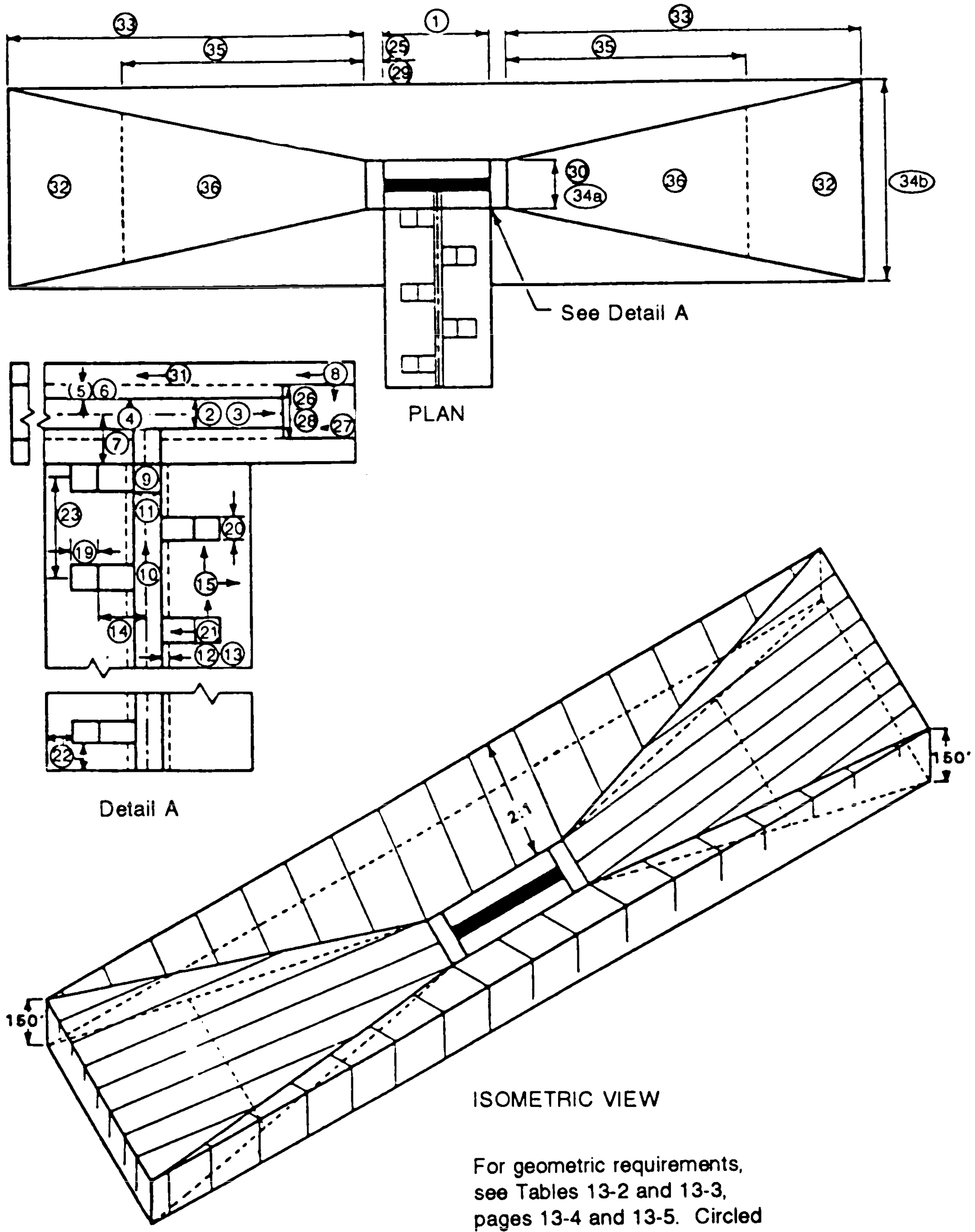
Figure 13-2. Helipad geometry



ISOMETRIC VIEW

For geometric requirements, see Tables 13-2 and 13-3, pages 13-4 and 13-5. Circled numbers relate to item numbers as listed in these tables.

Figure 13-3. Heliport with taxi-hoverlane



For geometric requirements, see Tables 13-2 and 13-3, pages 13-4 and 13-5. Circled numbers relate to item numbers as listed in these tables.

Figure 13-4. Heliport with runway

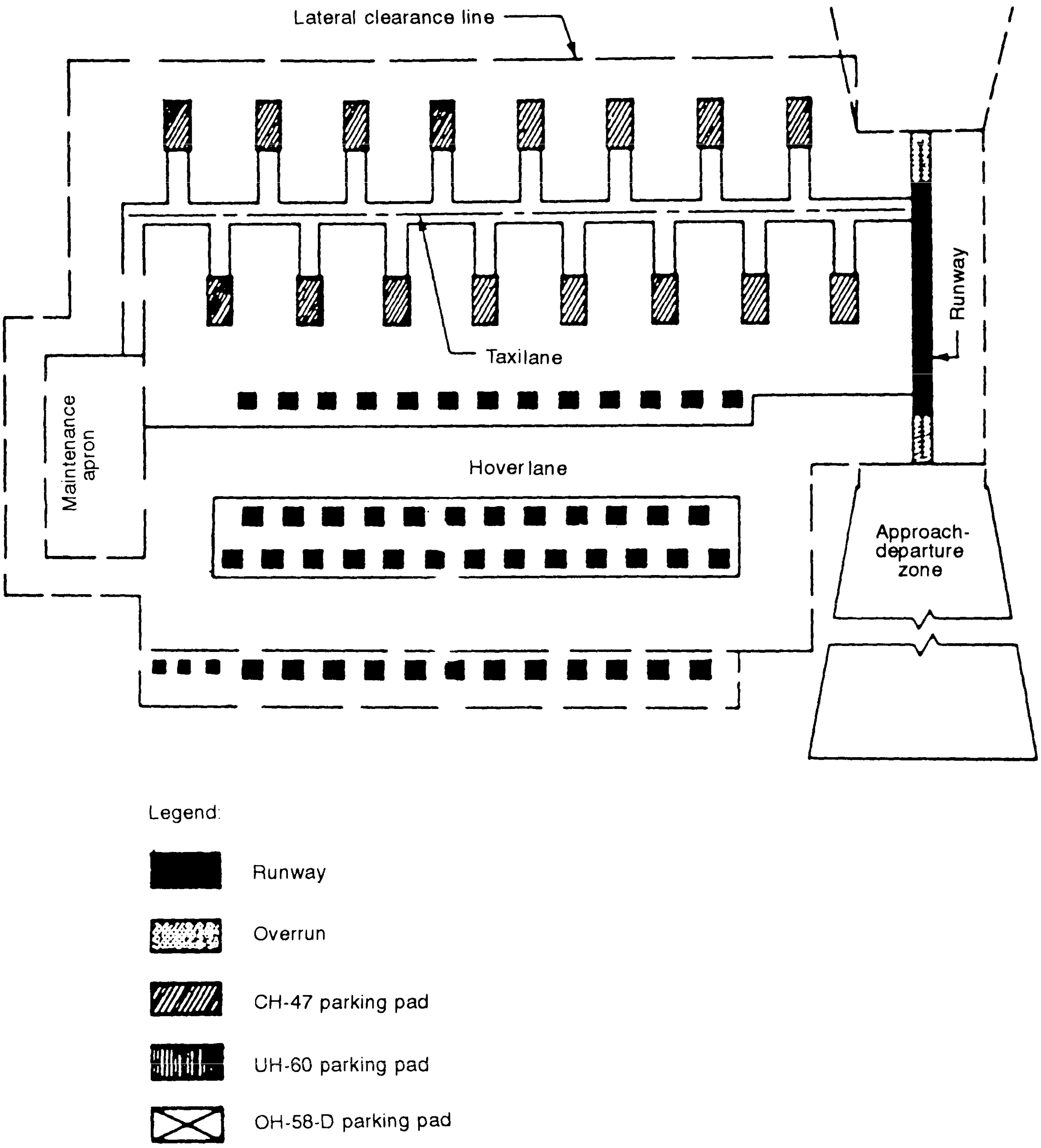


Figure 13-5. Mixed battalion heliport

considered. Therefore, variation in these requirements beyond or outside the limits indicated should not be allowed except where sufficient evidence justifies the change.

Area Requirements

Minimum area requirements for elements of a heliport are shown in Table 13-4, page 13-7. If dimensions must be changed because of existing conditions, the affected areas must be recalculated. The total traffic area is the sum of the parking pad area, taxiway area, and runway area for wheel-mounted helicopters in the support and rear areas. It is equal to only the parking pact areas for skid-mounted and wheel-mounted helicopters in the forward area.

Dustproofing and waterproofing areas for heliports where no landing mat is required are equal to the total area within the lateral clearance line, plus any area around the perimeter of the heliport that is within the area affected by the rotor downwash. The diameter of the area affected by the rotor downwash is shown in Table 13-5. These values are for loose soil. Where other soil conditions exist, the requirements for dustproofing will be smaller.

Table 13-5. Required diameters for dustproofing areas

Helicopter	Diameter of Dustproofing Area When Parked or On a Taxiway (ft)	Diameter of Dustproofing for Landing or Takeoff (ft)
AH-64	150	300
OH-58	150	160
UH-60	150	264
CH-47	300	590
CH-54	300	432

DESIGN OF HELIPORT AND HELIPAD SURFACES

The strength of the subgrade soil must be known to determine the best type of heliport and helipad surface. The type and number of soil tests required depend on the characteristics and location of the materials. Generally, sieve analysis, specific gravity, hydrometer analysis, Atterberg limits, and CBR analysis tests are required. Recommended procedures for treating materials used in the layers of the pavement beneath the surface course are presented in Chapter 5, FM 5-430-00-l/AFPAM 32-8013, Vol 1, and FM 5-410.

DESIGN OF UNSURFACED HELIPORTS

Unsurfaced areas such as deserts, dry lake beds, and flat valley floors serve as possible heliport sites. Special procedures must be exercised to ensure adequate dust control is used. Dust control is described in Chapter 12 and later sections of this chapter. Site reconnaissance and smoothness requirements for heliports are the same as those described in Chapter 12 for airfields.

Surfacing requirements for various subgrade strengths (CBR) for both unsurfaced areas and areas to be surfaced with landing mat are shown in Table 13-6, page 13-16, for traffic areas (runway, taxiway, and apron) and service roads. Overruns are unsurfaced and steps are not usually taken to improve the existing soil strength. The approximate number of traffic passes that a particular helipad or heliport can sustain, if built according to these soil strength requirements, is determined from the subgrade strength curves for specific aircraft.

Predicted traffic volume is a prime factor in determining surface requirements. However, a considerably larger volume of traffic

Table 13-6. *Basic helipad and heliport surfacing requirements*

Helipad or Heliport Type	Anticipated Service Life	Runway, Taxiway, Apron, Helipad, and Road Surfacing Requirements for CBR									
		0-1	1-2	2-3	3-4	4-5	5-7	7-9	9-12	12-17	> 17
Close battle area helipad											
OH-58	1-4 weeks	LM	U	U	U	U	U	U	U	U	U
UH-1H	1-4 weeks	LM	LM	U	U	U	U	U	U	U	U
CH-47	1-4 weeks	MM	MM	MM	LM	LM	LM	LM	U	U	U
CH-54, UH-60, AH-64	1-4 weeks	MM	MM	MM	MM	LM	LM	LM	LM	U	U
Close battle area heliport											
UH-1H company	1-4 weeks	LM	LM	U	U	U	U	U	U	U	U
CH-47 company	1-4 weeks	MM	MM	MM	LM	LM	LM	LM	U	U	U
Support area helipad											
OH-58	1-6 months	LM	U	U	U	U	U	U	U	U	U
UH-1H	1-6 months	LM	LM	U	U	U	U	U	U	U	U
CH-47	1-6 months	HM	MM	MM	LM	LM	LM	LM	U	U	U
CH-54, UH-60, AH-64	1-6 months	HM	HM	MM	MM	LM	LM	LM	LM	LM	U
Support area heliport											
UH-1H company	1-6 months	LM	LM	U	U	U	U	U	U	U	U
CH-47 company	1-6 months	HM	MM	MM	MM	LM	LM	LM	U	U	U
CH-54, UH-60 company	1-6 months	HM	MM	MM	MM	MM	LM	LM	LM	LM	U
Mixed battalion*	1-6 months	HM	MM	MM	LM	LM	LM	LM	U	U	U
Rear area helipad											
OH-58	6-24 months	LM	LM	U	U	U	U	U	U	U	U
UH-1H	6-24 months	LM	LM	LM	U	U	U	U	U	U	U
CH-47	6-24 months	HM	MM	MM	LM	LM	LM	LM	LM	U	U
CH-54, UH-60, AH-64	6-24 months	HM	HM	MM	MM	MM	LM	LM	LM	LM	U
Rear area heliport											
UH-1H company	6-24 months	LM	LM	LM	U	U	U	U	U	U	U
CH-47 company	6-24 months	HM	MM	MM	LM	LM	LM	LM	LM	U	U
CH-54, UH-60 company	6-24 months	HM	MM	MM	MM	MM	LM	LM	LM	LM	U
Mixed battalion*	6-24 months	HM	HM	MM	MM	LM	LM	LM	LM	U	U
Roads											
Close battle	1-4 weeks	LM	LM	LM	LM	U	U	U	U	U	U
Disposal	1-6 months	MM	LM	LM	LM	LM	U	U	U	U	U
Staging and logistics	6-24 months	MM	MM	LM	LM	LM	U	U	U	U	U

*The surfacing requirements shown for the mixed battalion in the support and rear areas are for runways, taxiways, and aprons only. To determine the surfacing requirements for the landing pads, use those values shown for the individual helipads.

U = Unsurfaced soil with or without membrane
LM = light-duty mat
MM = medium-duty mat
HM = heavy-duty mat

may occur at a heliport than was estimated when the subgrade strength requirements were developed. In addition, helicopters may be operated at gross weights different from those in Table 13-6. In such situations, the basic soil strength requirements in Table 13-6 no longer apply. In these cases, the required soil strengths for all reasonable combinations of gross weight and traffic volume are determined through use of the subgrade strength requirements curve in Figure 13-6, page 13-18.

The criteria and procedure used for improving soil strength in order to meet the strength requirements in Table 13-6 are discussed in FM 5-410.

STABILIZATION

When developing TO heliports, use soil-stabilization materials and processes to improve engineering characteristics and performance of existing soils. Soil-stabilization processes and materials described in FM 5-410 can help the engineer select and use appropriate methods of soil stabilization for specific operational and functional needs. The same criteria and principles of stabilization pertinent to the construction of airfields generally apply to heliports. Because differences of design and usage exist, this chapter presents information specifically for heliport development, This information and information in FM 5-410 describe the effective use of soil stabilization n techniques.

For TO heliports, soil stabilization may be used to accomplish one or a combination of three primary functions: strength improvement, dust control, and soil waterproofing.

Strength Improvement

Runways, taxiways, aprons, and parking pads may need stabilization to improve strength. The use of soil-stabilization methods applies primarily to heliports and helipads designed to support operations of the CH-47, CH-54, UH-lH, and AH-64 helicopters. Sometimes it may be desirable and justifiable to construct an improved landing pad for the OH-58 or UH-60 helicopter even though the existing soil may have the required minimum strength to support these aircraft.

Where stabilization for strength improvement is needed, certain basic design requirements must be met, in terms of strength and thickness of a stabilized soil layer on a given subgrade. The minimum strength and thicknesses of the stabilized soil layer shown in Table 13-7, page 13-19, are based on the traffic demands for operations in the areas by the CH-47 and CH-54 helicopters.

No strength or thickness requirements are shown for helipads for the OH-58 or UH-1H helicopters because these skid-equipped machines can operate satisfactorily on unsurfaced soils that have very low strength (Table 13-6). If the existing soil strength is less than the indicated minimum requirements for the OH-58 or UH-1H helicopter, the condition of the soil generally is such that much construction effort is required to achieve an acceptable stabilized facility.

Some soils have sufficient strength to support the OH-58 and UH-1H helicopters but are weak enough to create a nuisance in the form of mud. Where such a condition exists and select borrow material can be obtained conveniently, consider improving the parking pad area by placing a blanket of the select borrow material on the low-strength soil surface. Additionally, drainage must be improved in the local area. A 6- to 8-inch layer of crowned quality soil is usually sufficient to provide a firm parking pad and stable working area.

Proper evaluation of the subgrade is essential. When evaluating the subgrade for stabilization, establish a representative CBR strength profile to a depth that will avoid overstress at any point in the underlying subgrade. The depth of a necessary strength profile depends on the particular heliport and using helicopters, the pattern of the profile, and the manner in which stabilization is achieved.

Use the thickness data in Table 13-7 to establish an adequate strength profile.

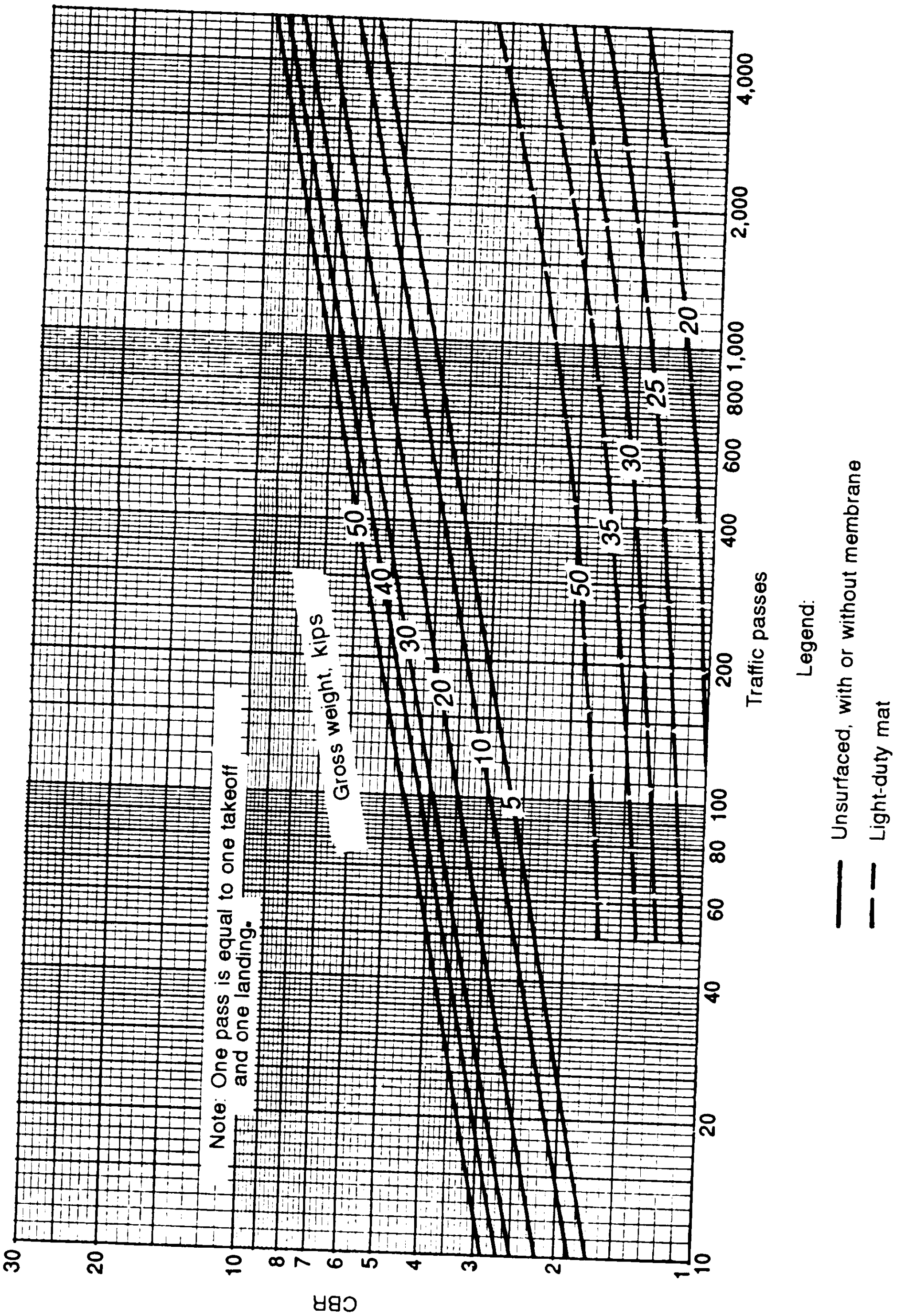


Figure 13-6. Helipad and helipad subgrade strength requirements

Table 13-7. *Strength and thickness requirements*

Helipad or Heliport Type	*Maximum Stabilization Strength Required (in)	Thickness of Stabilized Soil Layer Required (inches) for Runway, Taxiway, Apron, and Helipads for CBR				
		4-5	5-7	7-9	9-12	12-17
Close battle area helipad						
CH-47	10	10	9	7		
CH-54, UH-60, AH-64	13	13	12	9	8	
Close battle area heliport						
CH-47 company	10	10	9	7		
Support area helipad						
CH-47	11	13	11	8		
CH-54, UH-60, AH-64	15	17	15	12	10	8
Support area heliport						
CH-47 company	11	13	12	9		
CH-54 company, UH-60, AH-64	15	16	14	11	9	8
Mixed battalion	11	13	12	9		
Rear area helipad						
CH-47	12	14	12	9	7	
CH-54, UH-60, AH-64	15	18	16	13	11	9
Rear area heliport						
CH-47 company	12	15	13	10	7	
CH-54 company, UH-60, AH-64	15	17	15	12	10	9
Mixed battalion	12	15	13	10	7	

*Chemical stabilization to develop an improved quality layer in excess of 16 inches thick or in areas with an existing strength of less than CBR 4 is not usually practical.

Generally, a profile to a depth of 24 inches is sufficient to indicate the strength profile pattern. The use of Table 13-7, page 13-19, to establish design requirements for soil stabilization is similar to that described in Chapter 12 for airfields.

Stabilization Methods

Stabilization to improve strength of an existing soil can be accomplished by mechanical or chemical methods. Mechanical stabilization methods include compaction of an existing soil or blending of soils to obtain an improved quality soil. The chemical stabilization method involves blending soil with some type of stabilizing material to achieve a more firm and durable soil layer. The stabilizers most commonly used in the construction of heliports are portland cement, lime, and bituminous materials.

Two general methods for applying soil stabilizers are admix application and surface-penetration application. An admix application blends existing soil with another material to achieve a uniform mixture. Admix applications may be mixed in place or off site. The admix application technique is used primarily to incorporate stabilizing materials for strength improvement.

With surface-penetration application, a soil treatment material is placed directly on the ground surface by spraying or other means of distribution. This method is used only for the placement of dust-control agents and soil waterproofers.

Dust Control

Dust is a major problem in helicopter operations during dry weather. Dust can come from almost any unsurfaced area of a heliport complex. Therefore, it is necessary to provide dust control for all areas of a heliport. Membranes and landing mats often are used to cover the primary traffic areas of a heliport such as runways, taxiways, aprons, and parking pads. Where this is the case, dust-control materials are used to control dust on all remaining areas. Without a membrane or landing mat, it may be necessary to use dust-control materials in traffic areas. Materials selected for traffic areas should provide dust control and waterproof the soil surface to prevent loss of strength during wet weather operations.

Dust-control and soil waterproofing materials are described in Table 12-7, page 12-23, and FM 5-410. Recommendations for their use and guidance in selecting appropriate materials for traffic and nontraffic areas of a heliport are discussed in FM 5-410. When estimating material requirements, use Table 13-4, page 13-7, to determine the areas for each heliport element.

Areas that may require dust control include runways, overruns, taxiways, aprons, taxi-hoverlanes, parking pads, roadways, and all peripheral areas that are subjected to the downwash from helicopter rotors. (See Table 13-5, page 13-15.) All exposed ground within the entire heliport complex should be dust-free, and any area not protected by membrane or landing mat requires dust-control treatment.

Soil Waterproofing

Areas that may require waterproofing to maintain soil strength include runways, overruns, taxiways, aprons, parking pads, and roadways for support vehicles.

Expedient Surface Design

Design Steps. The design steps for an expedient surface heliport or helipad are as follows:

1. Determine the heliport location. Normally this is given in the mission statement as close battle area, support area, or rear area.

2. Determine the geometric requirements for heliport or helipad from Tables 13-2 and 13-3, pages 13-4 and 13-5.

3. Determine the using aircraft and associated gross weight. Again, this information will be presented in the mission statement. Gross weights for aircraft are shown in Table 13-1, page 13-2.

NOTE: Use 15 kips as the minimum weight for aircraft gross weight.

4. Determine the strength of the subgrade in terms of critical CBR. This information is normally extracted from the battalion soils analyst or Air Force CCTs or given as part of the mission statement. Determination of the critical CBR is described in detail in Chapter 12. Ensure the subgrade thickness requirements from Table 13-7, page 13-19, are met.

5. Determine surface requirements from Table 13-6, page 13-16, based on critical CBR.

6. Determine the required strength from Figure 13-6, page 13-18, in terms of CBR based on the anticipated traffic passes for design aircraft (from mission order) and surface requirements from step 5. Compare the required CBR to the critical CBR in step 4. If the required CBR is less than the critical CBR requirements, the site is suitable. If it exceeds the critical CBR, existing soil CBR must be increased or a new site selected.

Example

Determine if a site is suitable for 200 passes for a UH-60 Blackhawk heliport in the support area. Also determine if soil strength is uniform with depth, yielding an average CBR of 7 in the top 12 inches.

Steps:

1. Heliport location: Support area.

2. Helipad geometric requirements: Given in support area UH-60 (Table 13-2, page 13-4).

3. Using aircraft: UH-60 Blackhawk
   Gross weight: From Table 13-1, page 13-2, 20,250 pounds (20.25 kips)

4. Critical CBR = 7 for uniform strength profile (given).

5. From Table 13-6, a light mat must be used unless the existing soil can be improved to a CBR greater than 17.

6. Required CBR based on 200 anticipated traffic passes: From Figure 13-6, the required CBR is 4, less than the critical CBR: therefore, this site is suitable for the mission.

MAT- AND MEMBRANE-SURFACED HELIPORTS AND HELIPADS

Many aircraft require the use of mats or membranes to operate successfully in areas of low subgrade strengths as previously discussed. Membrane is used for rustproofing and waterproofing. Table 13-6 details basic surfacing requirements for the critical aircraft in the three heliport locations. Table 13-4, page 13-7, details the total area required for heliport construction based on criteria in Tables 13-2 and 13-3, pages 13-4 and 5. Table 13-8, page 13-22, shows the material requirements of heavy-duty, membrane-surfaced heliports and helipads. A thorough discussion on mat and membrane placement is contained in Appendices L, M, and N.

MAT REQUIREMENTS

It is possible to calculate and tabulate expedient matting requirements for specific facilities because heliport and helipad designs are standardized. Use the guide on page 13-23 to locate information required for this process.

Table 13-8. Material requirements for heavy-duty, membrane-surfaced heliport and helipads

Airfield Type	Anticipated Service Life	Pads Required # Size (ft)	Pads # Size (ft)	Runway # Size (ft)	Connecting Taxiway # Size (ft[5])	Taxiway # Size (ft)	Maintenance Pad # Size (ft)	# Parts Required for Construction Part I[2]	# Parts Required for Construction Part V[3]	# Parts Required for Replacement and Maintenance Part VC	# Parts Required for Replacement and Maintenance Part VI[4]	Required Trimming of Membrane Sections
Close Battle Area Heliport												
CH-47 company	2 weeks	16 50 X 25	16 53 X 33	None	None	None	None		8			Trim 8 @ 53 X 66 into 16 pads @ 53 X 33.
UH-60 company		25 20 X 20	24 26 X 33	None	None	None	None		7			Trim 6 @ 53 X 66 into 24 pads @ 26 X 33.
			1 53 X 66									Do not trim; 1 @ 53 X 66
Close Battle Area Helipad												
CH-54	2 weeks	1 50 X 50	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
CH-47, AH-64		1 50 X 25	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
UH-60		1 20 X 20	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
UH-58		1 12 X 12	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
Support Area Heliport												
CH-54 company	1-2 mo	8 50 X 50	[1]	9 53 X 66	32 53 X 66	16 53 X 66	None	6		6	6	Do not trim; use surfacing as received.
CH-47, AH-64 company		16 50 X 25	[1]	9 53 X 66	48 53 X 66	29 53 X 66	None	9		9	9	Do not trim; use surfacing as received.
UH-60 company		25 20 X 20	24 26 X 33	None	None	None	None		7			Trim 6 @ 53 X 66 into 24 pads @ 26 X 33.
			1 53 X 66									Do not trim; 1 @ 53 by 66
Mixed battalion		16 50 X 25	[1]	9 53 X 66	64 53 X 66	38 53 X 66	28 53 X 66	16		16	16	Trim 6 @ 53 X 66 into 24 pads @ 26 X 33.
		50 20 X 20	24 26 X 33									Trim 13 @ 53 X 66 into 26 @ 53 X 33.
			26 53 X 33									Trim 1 @ 53 X 66 into 3 pads @ 22 by 53.
		3 12 X 12	3 22 X 53									Do not trim; 139 @ 53 X 66
Support Area Heliport												
CH-54	1-2 mo	1 50 X 50	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
CH-47, AH-64		1 50 X 25	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
UH-60		1 20 X 20	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
OH-58		1 12 X 12	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
Rear Area Heliport												
CH-54 company	6-12 mo	8 100 X 100	32 53 X 66	9 53 X 66	16 53 X 66	15 53 X 66	None	8		8	8	Do not trim; use surfacing as received.
CH-47, AH-64 company		16 50 X 100	32 53 X 66	9 53 X 66	32 53 X 66	29 53 X 66	None	11		11	11	Do not trim; use surfacing as received.
UH-60 company		25 40 X 40	25 53 X 66	None	None	None	None		25			Do not trim; use surfacing as received.
Mixed battalion		16 50 X 100	[1]	9 53 X 66	64 53 X 66	38 53 X 66		19		19	19	Trim 1 @ 53 X 66 into 3 pads @ 53 X 22.
		50 40 X 40	50 53 X 66									Do not trim; 189 @ 53 X 66
		3 25 X 25	3 53 X 22									
CH-54	6-12 mo	1 100 X 100	4 53 X 66	None	None	None	None		4			Do not trim; use surfacing as received.
CH-47, AH-64		1 50 X 100	2 53 X 66	None	None	None	None		2			Do not trim; use surfacing as received.
UH-60		1 40 X 40	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.
OH-58		1 25 X 25	1 53 X 66	None	None	None	None		1			Do not trim; use surfacing as received.

[1] Pad requirements in close battle, support, and rear areas are limited in number and size; therefore, prefabricated membrane surfacings 53 ft long and 66 ft wide are furnished without trimming required. Requirements for heliports in all areas are of such number and sizes that it is more cost effective to trim sections to approximate sizes.

[2] Part I membrane outfit, heavy duty, runway/heliport surfacing consists of components required to surface a runway or heliport section 500 ft long by 60 ft wide.

[3] Part V membrane outfit, heavy duty, helipad/replacement surfacing consists of components required to surface a helipad section 50 ft long by 60 ft wide and/or replace a runway/heliport section.

[4] Part VI membrane outfit, heavy duty, maintenance surfacing consists of components required to maintain surfacing 500 ft long by 60 ft wide.

[5] Size of surfacing shown for connecting taxiway includes area used as pad.

Table	Page	Title	Function
12-2	12-5	Mat Characteristics	Lists characteristics of specific mat types.
13-4	13-7	Typical Minimum Area Requirements	Specifies total area based on the geometric requirements established in Tables 13-2 and 13-3, pages 13-4 through 13-6.
13-6	13-16	Basic Helipad and Heliport Surfacing Requirements	Surfacing material type required to support a function of the CBR, area of operation and facility mission.
M-1 through M-22	M-2 through M-23	Mat Requirement Tables for Helipads and Heliports	Quantity of mat required, in bundles, weight, and volume, for a specific facility (mission and location).

MEMBRANE REQUIREMENTS

Membrane requirements for specific heliports and helipads can also be calculated. The following tabulation shows what tables are used in this process:

Table	Page	Title	Function
13-2 and 13-3	13-4 through 13-6	Minimum Geometric Requirements for Helipads and Heliports	Specifies area requirements for specific area and mission facilities. Information is given in component pieces, such as landing pad and taxi-hoverlanes.
13-6	13-16	Basic Helipad and Heliport Surfacing Requirements	Surfacing material type required as a function of the CBR, area of operation, and facility mission.

THICKNESS DESIGN PROCEDURE

The design procedure for flexible-pavement surfaces for heliports and helipads is almost identical to that of airfields as discussed in Chapter 12.

DESIGN STEPS

1. Determine the heliport/helipad location.
2. Determine the design aircraft and gross weight.
3. Check soils and construction aggregates.
4. Determine the number of passes required.
5. Determine the total surface thickness and cover requirements.
6. Complete the temperate thickness design.
7. Adjust thickness design for frost susceptibility.
8. Determine compaction requirements and subgrade depth.
9. Draw the final design profile.

STEP 1. DETERMINE THE HELIPORT/HELIPAD LOCATION

Flexible pavements are only constructed for heliports/helipads in the rear area.

STEP 2. DETERMINE THE DESIGN AIRCRAFT AND GROSS WEIGHT

Flexible-pavement structures have the capability to support large cargo helicopters with tremendous gross weights as well as small helicopters with large tire pressures. As with fixed-wing aircraft, it is logical to design the heliport/helipad for only the most constraining aircraft, the CH-47D Chinook. If the designer knows, however, that the heliport/helipad will be used only by a specific aircraft, its load can be used for the design. The CH-47D has a design gross weight of 50 kips.

STEP 3. CHECK SOILS AND CONSTRUCTION AGGREGATES

The procedure for evaluating materials for flexible-pavement structures is the same as for fixed-wing airfield structures. First, locate borrow sites and evaluate them for suitability as select and subbase courses. Use Table 12-9, page 12-24, to check soil characteristics and strength against the specifications for each layer. Second, check the strength and gradation of the base course. The strength of a known material is determined from Table 12-10, page 12-24, while the gradation of a soil must meet the specifications in Table 12-11, page 12-26, based on the MSA. Third, check the materials above the compacted subgrade for frost susceptibility. Frost-susceptible borrow materials cannot be used in the design. If the subgrade is frost susceptible, determine the frost group and soil support index from Tables 12-12 and 12-13, pages 12-26 and 12-30.

STEP 4. DETERMINE THE NUMBER OF PASSES REQUIRED

Since the rear area is considered temporary construction (6-24 months), design flexible-pavement heliports/helipads to sustain an appropriate number of passes. Remember, one pass refers to one takeoff and one landing.

STEP 5. DETERMINE THE TOTAL SURFACE THICKNESS AND COVER REQUIREMENTS

Enter the curve, Figure 13-7, for the the soil CBR and number of required passes. The resulting thickness is the cover required above that particular soil layer to protect it from shear failure. Second, the apshalt thickness (inches) is a function of the strength of the base course as follows:

	Pavement	Base
100 CBR Base	3	6
80 CBR Base	4	6

STEP 6. COMPLETE THE TEMPERATE THICKNESS DESIGN

Same as for fixed-wing aircraft.

STEP 7. ADJUST THICKNESS DESIGN FOR FROST SUSCEPTIBILITY

These design steps are the same as previously discussed for fixed-wing airfields. See pages 12-31 and 12-32 for a review.

STEP 8. DETERMINE THE COMPACTION REQUIREMENTS AND SUBGRADE DEPTH

Depth (inches) of required subgrade compaction below the surface of all areas of a heliport/helipad is 24 inches for cohesive soils and 30 inches for cohesionless soils. At a minimum, subgrade will be compacted to 6 inches.

STEP 9. DRAW THE FINAL DESIGN PROFILE

Draw the final design profile as previously shown for fixed-wing airfields.

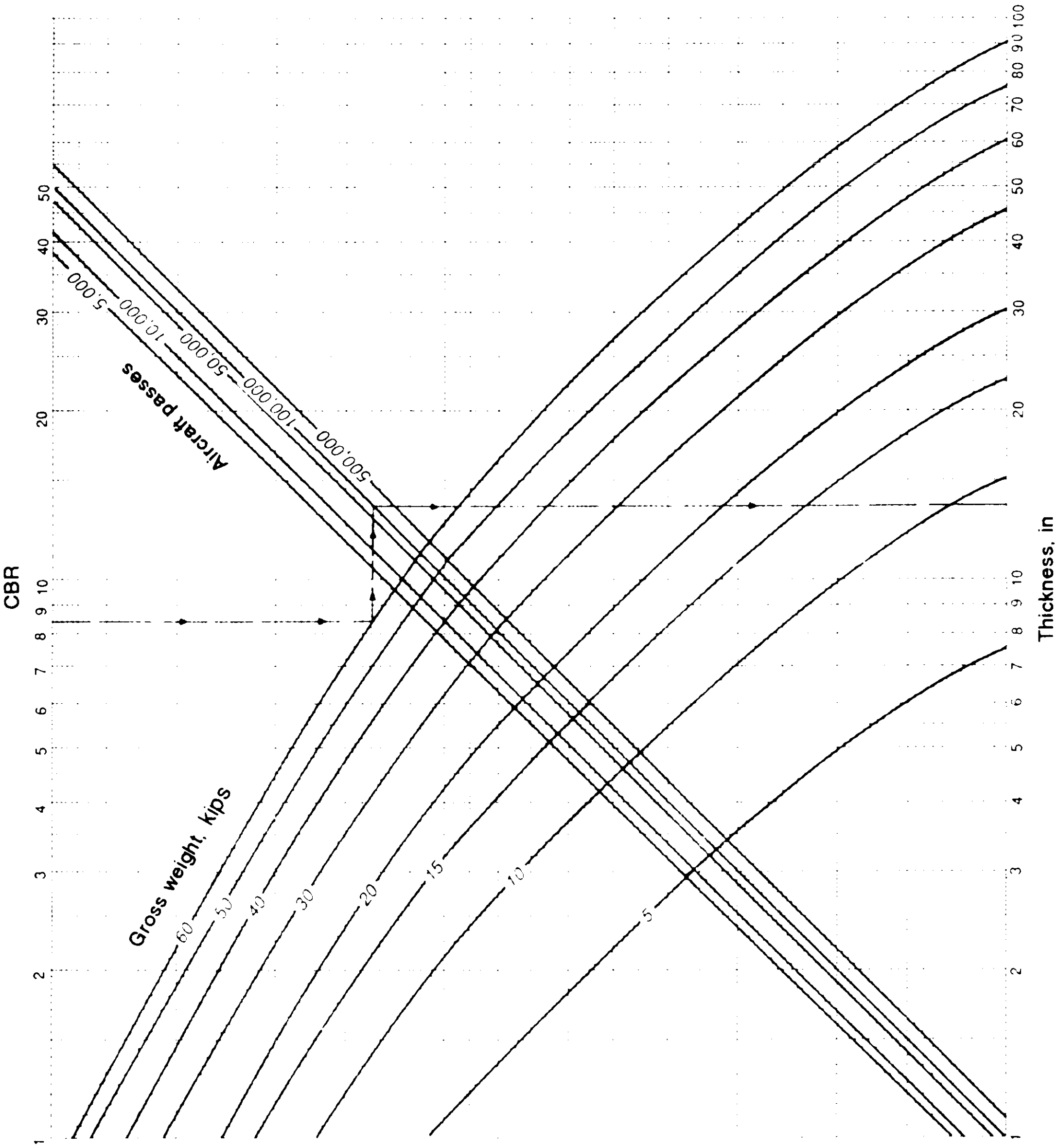


Figure 13-7. Flexible pavement design curve for heliports and helipads

Example

Design pavement for the parking/loading area of a rear area heliport in Central America, capable of handling 5,000 passes of a CH-47D aircraft. The soil layers have already been determined by the soils analyst.

Subgrade: Clay, PI = 12, LL = 20; natural CBR = 4; compacted CBR = 5.

Borrow A: Select material CBR = 15, PI = 7.

Borrow B: Subbase material CBR = 40, PI = 4.

Base course (limestone): CBR = 80, PI = 4. Meets gradation specifications for MSA (2-inch) (Table 12-12, page 12-26).

Solution

Step 1. Airfield location (given) = rear area/Type C traffic area.

Step 2. Design aircraft = CH-47/50 kips.

Step 3. Check soils and construction aggregates:

a. Select and subbase (given).

Borrow A: Select material CBR = 15.

Borrow B: Subbase CBR = 40.

b. Base course: Limestone, CBR = 80; meets gradation.

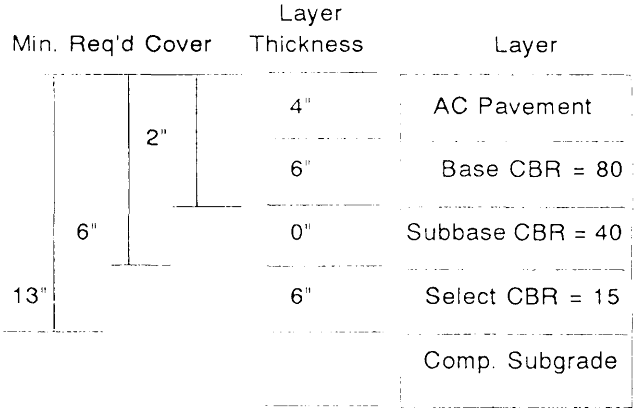
c. Frost is not a concern in Central America.

Step 4. Number of passes (given) = 5,000.

Step 5. Determine the thickness requirements from Figure 13-7, page 13-25.

Material	Minimum Required Cover
Compacted subgrade CBR = 5	13"
Select material CBR = 15	5.7" or 6"
Subbase CBR = 40	2"

Step 6. Complete the temperate thickness design.



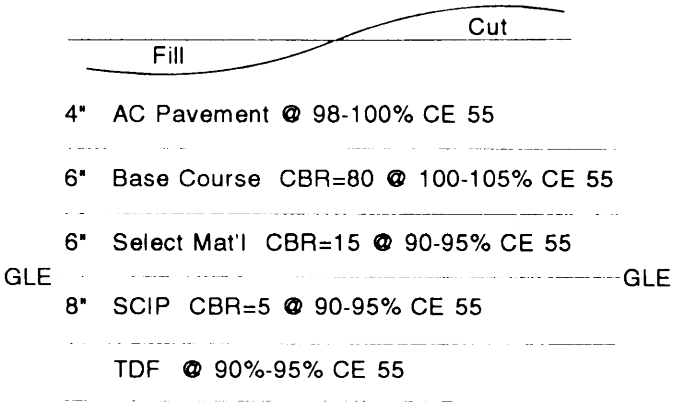
See Table 12-15, page 12-37, with the traffic area (C) and the base course CBR (80) to find that the thickness of the AC pavement = 4 inches. See Table 12-16, page 12-40, for a further breakdown of the specific course in the pavement design. Next, from Step 4, calculate the layer thicknesses. For instance, the cover required over the select material is 6 inches. With the base course and the AC pavement combined, the thickness is already 10 inches; therefore, a subbase is not required. To meet the cover requirement over the select material, the thickness of the subbase must be at least 3 inches; 6 inches is used because it is the minimum size layer thickness.

Step 7. Frost adjustment not applicable.

Step 8. Determine subgrade depth and compaction requirements. From Table 12-17, page 12-42, determine the required depth of subgrade compaction. Since the subgrade is cohesive (PI = 5), the depth required is 24 inches. The total design thickness is 16 inches; therefore, the depth of subgrade compaction is 8 inches. Next, determine the compaction requirements for each layer from Table 12-18, page 12-55.

Layer	Compaction Requirement
Compacted subgrade	90-95% CE 55
Select material	90-95% CE 55
Base course	100-105% CE 55
AC pavement	98-100% CE 55

Step 9. Draw the final design profile.



SPECIAL DESIGN CONSIDERATIONS

Special airfield flexible-pavement design considerations, such as designing for frost areas, designing for arid areas, and using stabilized soil layers discussed in Chapter 12, apply to flexible-pavement heliports and helipads as well, As such, no further discussion will be made on these areas.

Evaluation of flexible pavements of heliports and helipads follow the exact same procedure as detailed in Chapter 12, page 12-52, Evaluation or Airfield Pavements. As such, no further discussion will be made on this subject.

MARKING AND LIGHTING OF HELIPORTS AND HELIPADS

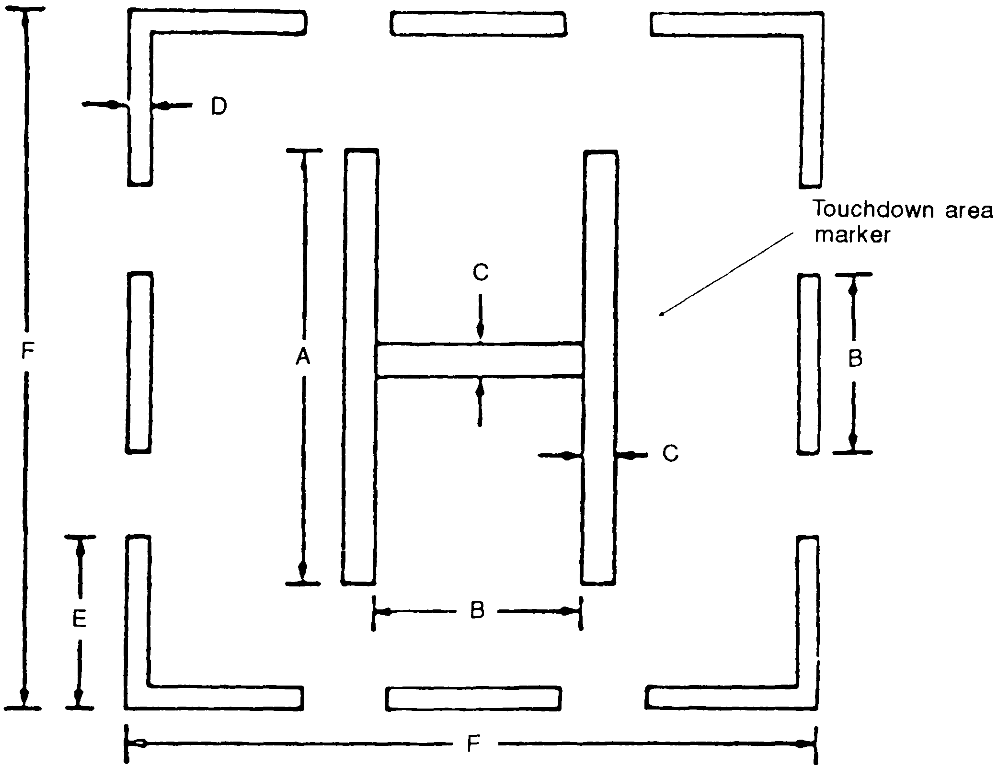
This section implements STANAG 3619, Helipad Marking (Edition 2, Amendment 2) and STANAG 3652, Helipad Lighting (VMC)(Amendment 3).

Depending on the tactical situation. the marking pattern defined here is placed on all surfaced helipads or helicopter runways, whether the surfacing material is concrete, asphalt, mat, or membrane. The lighting specified is provided by generator-powered lighting units if the traffic areas are surfaced; battery-powered lighting units are acceptable otherwise.

MARKING PATTERN

The touchdown area marker for helipads is shown in Figure 13-8, page 13-28. The dimensions of the pattern compared with the pad size are also shown. On all helipads, the center of the marking pattern is placed at the center of the pad. The vertical bars of the letter *H* should be parallel to two opposite sides of the helipad. The marking pattern is also placed on both ends of all runways and taxi-hoverlanes used for landings. This pattern indicates a safe touchdown point. It is not placed at parking areas or where helicopters do not normally land or takeoff.

The marking pattern should be either white paint or tape, and it should be edged in black when placed on a light-colored



DIMENSIONS

A: 0.6F (maximum of 66 feet)
B: 0.5A

Helipad Size (F) (ft)	Pattern Line Width (C) (ft)	Border Edge Width (D) (ft)	Corner Edge Length (E) (ft)
12-19	1.0	0.5	4.6
20-40	2.0	1.0	4.6
41-59	3.3	1.3	4.6
60-79	4.3	2.0	7.2
80-99	4.6	2.0	9.8
100-148	6.6	2.5	11.5

Figure 13-8. Touchdown area marking

surface. The broken-line border around the perimeter of the pad is included on all helipads.

MARKING OF TEMPORARY HELICOPTER LANDING FIELDS

Temporary airfields are not usually marked. When they are marked, use the following procedures:

Corner Marking

Mark the four corners with regulation panels—0.50 by 0.65 meter (20 by 26 inches) or 1.80 by 0.66 meters (71 by 26 inches)—or by improvised panels of comparable size that are a different color than the ground.

Obstacle Marking

As far as possible, mark telephone wires, electric wires, and similar objects near the area. The direction of the sun's rays in relation to the direction of landing or takeoff may make them difficult for the pilot to see.

Indication of Wind Direction

This indication is of primary importance. The following methods can be used:

- Place a wind sock outside the area.
- Place smoke machines or fires emitting clearly visible smoke outside the area. Arrange them to avoid all risk of fire.
- Use a staff experienced in helicopter landings to stand with their backs to the wind, arms raised in a V-shape close to the spot where the helicopter is to touch down.

Identification of the Unit

The unit's identity signals must be arranged outside the area near the four corners of the field. If possible, the signals should be legible from the landing direction and be on the right of the landing area.

LIGHTING FOR HELIPADS

The following discussion concerns helipad lighting for visual meteorological conditions (VMC). Helipad lighting for instrument meteorological conditions (IMC) is beyond the scope of TO construction. IMC helipad lighting is discussed in STANAG 3684.

Each helipad must be surrounded by a perimeter of aviation yellow, omnidirectional lights, preferably not more than 13 inches in height. The lights will be placed in accordance with the following requirements:

- Lights will not be less than 1 foot nor more than 3 feet from the border of the landing pad and will be an equal distance apart on parallel sides.
- The separation between lights on a side will not be less than 15 feet nor more than 25 feet. This separation will be equal on a given side and will not differ by more than 5 feet between adjacent sides. Lights on parallel sides will be placed opposite each other.

Table 13-9 gives the number of lights required as a function of the length of the line of lights on a side, using the shortest distance permitted by these requirements. If the dimensions of the landing pad differ

Table 13-9. Lighting requirements for helipads

Length of side (ft)	12-19	20-50	51-100
Light placement	4 corners	4 corners plus 1 intermediate light per side	4 corners plus 3 intermediate lights per side

by more than 10 feet between adjacent sides, the long side will contain at least one more light than the short side. Table 13-10 shows the application of these requirements to the helipads developed for the control helicopters used in this manual.

LIGHTING FOR HELICOPTER RUNWAYS

Lines of aviation yellow, bidirectional lights will be located on each side of the runway at a distance of not less than 3 feet and nor more than 5 feet from the surfaced edge of the runway. The spacing within the line of lights will be approximately 40 feet apart but not less than 35 feet nor more than 45 feet.

These lines of lights will be extended past the ends of the runway to intersect lines of aviation yellow, bidirectional lights placed not less than 20 feet and not more than 25 feet from the surfaced end of the runway. The spacing within these lines will be approximately 10 feet, but not less than 5 feet nor more than 15 feet. Lines of green, threshold lights will be placed not less than 5 feet nor more than 10 feet from the surfaced end of the runway. The spacing within these lines will be approximately 10 feet but not less than 5 feet nor more than 15 feet. There will be no fewer than six threshold lights in each line.

LIGHTING FOR TAXI-HOVERLANES

Heliports for company-size or larger units will normally be designed to permit mass landings on the taxi-hoverlane between the parking pads (Figure 13-3, page 13-12). The lighting will be as follows:

Table 13-10. Application of requirements given in Table 13-9, page 13-29

		Landing Pad (ft)	Clear Zone (ft)	Light Perimeter (ft)	# Lights Per Side	Distance Between Lights (ft)	# Lights Per Pad
OH-58							
Close battle	Width	12	72	16	2	16	4
	Length	12	72	16	2	16	
Support	Width	12	105	16	2	16	4
	Length	12	105	16	2	16	
Rear	Width	25	105	29	3	15	8
	Length	25	105	29	3	15	
UH-60							
Close battle	Width	20	100	24	3	12	8
	Length	20	100	24	3	12	
Support	Width	20	120	24	3	12	8
	Length	20	120	24	3	12	
Rear	Width	40	120	44	3	22	8
	Length	40	120	44	3	22	
CH-47, AH-64							
Close battle	Width	25	125	29	3	15	8
	Length	50	150	54	3	27	
Support	Width	25	150	29	3	15	8
	Length	50	150	54	3	27	
Rear	Width	50	150	54	3	27	12
	Length	100	150	104	5	26	
CH-54							
Close battle	Width	50	150	54	3	27	8
	Length	50	150	54	3	27	
Support	Width	50	150	54	3	27	8
	Length	50	150	54	3	27	
Rear	Width	100	150	104	5	26	16
	Length	100	150	104	5	26	

- Place a landing pad at each side of the taxi-hoverlane that has a common centerline with the taxi-hoverlane. The size of the helipad will be determined by the largest control aircraft using the facility. Mark and light the landing pad in accordance with the requirements given previously in this chapter.
- Place aviation yellow lights that are not more than 13 inches in height and not less than 1 foot or more than 3 feet from the edge of the taxi-hoverlane and midway between parking pads. These lights will not exceed one-half the intensity used on the landing pad perimeter lights.
- Place two aviation red lights at the two corners of each parking pad farthest from the taxi-hoverlane. These lights will not exceed 13 inches in height and will have approximately 10 percent of the intensity used for the landing pad perimeter lights.

TAXIWAY LIGHTS

The following taxiway lighting system is required to designate paths followed by the helicopter in going between landing/take-off, service, and parking areas. This lighting system will not be used on taxi-hoverlanes used for mass landings.

Lateral Limits

The basic taxiway lighting system will consist of a line of elevated or semiflush, blue guidance lights on each side of the taxiway, defining the lateral limits and direction of the taxiway. Taxiway lights will not be installed in those sections where surfaced aprons adjoin the taxiways. The lines of taxiway lights normally will be between 1 and 3 feet from the paved edge of the taxiway.

Straight Sections of Taxiways

On straight sections of taxiways, the pairs of lights will be uniformly spaced on centers approximating 40 feet but not less than 35 feet nor more than 45 feet apart. The longitudinal spacing of the pairs of lights will be calculated from the nearest point of tangency (PT) of the fillet, curve, or corner at one end of the section to the nearest PT of the fillet, curve, or corner at the other end of the section. Companion lights on opposite sides of a taxiway will be located on lines perpendicular to the centerline of the taxiway. Where it is practicable to light only a single straight edge of taxiway section, the lights will be uniformly spaced between the PTs or corners or between points opposite the PTs or corners, as applicable.

Curved Sections of Taxiways

On curved sections of taxiways, taxiway lights will be uniformly spaced on radial lines from the center of the curve. The spacing will be determined by the radius of the applicable curved edge of the taxiway. The taxiway lights will be spaced approximately 13 feet apart on the periphery of the curve, but not less than 10 feet nor more than 16 feet apart, except that no curve will have fewer than three light locations, including those at the PTs.

RECOMMENDED EQUIPMENT

Available equipment recommended to meet the lighting requirements in this manual is listed under Federal Aviation Authority (FAA) numbers. The recommended equipment is to be used in series circuits controlled by constant current regulators having five-step brightness controls. The intensity of different elements (such as pad perimeter, runway, and taxiway) of a lighting system should be controlled separately.

The lights in each element of a system are to be coupled to the series circuit through direct-burial, insulating transformers (L-834 or L-844, depending on the regulator). A transformer and an L-823 connector kit will be required for each light fixture. The cable to be used can be Number 8, stranded, 5 kilovolts (kv), cross-linked polyethylene. The light fixtures recommended for each element in the lighting system are as follows:

- Helipad. The fixture recommended for the helipad perimeter light is the stake-mounted, L-810 base with yellow L-810 lens in place of red. In the L-810 base, a medium prefocus socket is used for 6.6 ampere series circuit, 10 and 20 lumen lamps.

- Taxi-Hoverlane. The fixture recommended for the taxi-hoverlane taxiway and landing lighting is the stake-mounted L-822 with standard blue L-822 lens.

- Obstruction. The fixture recommended for obstruction lighting is the L-810 base with standard red L-810 lens.

- Runway. Until bidirectional lights with an appropriate beam spread for helicopters become available, the same fixtures may be used on runways that are used for heliports. The threshold lights should have green lenses in place of red.

HELIPADS IN HEAVILY FORESTED AREAS

Occasionally, situations develop that require clearing a helipad in a wooded area too dense to permit air landing of a clearing crew. In these conditions, personnel, equipment, and technique of operation employed by an engineer squad rappelling from a hovering helicopter to clear an expedient helipad are described in the following paragraphs. The procedure requires two helicopters to transport the clearing squad and to carry engineer equipment in underslung boxes.

PERSONNEL

The squad consists of a noncommissioned officer in charge (NCOIC) and two teams (A and B). Each team is composed of a noncommissioned officer and five other soldiers (two chain-saw operators, two ax operators, and one brush-hook operator). The weight of each individual is assumed to be 200 pounds.

EQUIPMENT

The weight of the box, loaded with equipment, is approximately 333 pounds. The following equipment is containes in the box:

- 2 chain saws.
- 1 brush hook.
- 3 axes.
- 1 block-and-tackle set (1 single block and 1 double block).
- 1 set of climbers with safety straps.
- 1 can of gas.
- Sixteen 2-1/2-pound blocks of C-4.
- 2 oil cans.
- 250 feet of demolition cord.
- 1 galvanometer.
- One 10-cap blasting machine.
- 20 electric caps (should be carried by personnel and will be stored separate from explosives and fuel).
- 1 brace and bit.
- 1 sledgehammer.
- 2 wedges.
- 2 screwdrivers.
- 2 pliers.

PROCEDURE

The procedure is divided into two phases—delivery of equipment and personnel and preparation of the helipad.

Delivery of Equipment and Personnel

Equipment is delivered to the proposed helipad area by lowering it in a box designed to protect and offer ready access to the contents. The equipment requirements may be changed to suit the expected area of use.

The box is slung beneath the helicopter by the aircraft cargo hook. Rappelling ropes are attached to the box and secured to the floor D-rings within the helicopter to prevent oscillation. In the event of in-flight emergency because the pilot cannot jettison the external load, engineers within the cargo compartment are responsible for cutting or releasing ropes upon direction by the pilot or copilot. To lower the box to the ground, the cargo hook is released and the box is lowered by hand using the attached rappelling ropes.

Rappelling of personnel from the helicopter is performed as taught by Army service schools using the Swiss seat with snap links. For a complete discussion of rappelling, see FM 90-4.

Preparation of the Helipad

Personnel in the team are equipped with field equipment, machetes, weapons, and other items that can be easily carried on the person but would not interfere with rappelling activities. Other field gear, if needed, is enclosed in the equipment box lowered from the helicopter.

The first person on the ground removes the rappelling rope from the equipment box. The NCOIC, who is either the first or second person on the ground, will start laying out precut strips of engineer tape to mark the perimeter of the proposed helipad. The amount of tape laid out to define the area depends greatly on the terrain and vegetation encountered. Figure 13-9, page 13-34, shows the tape layout and the configuration of the helipad.

Personnel are organized as described previously. Two teams, one per helicopter, with an NCOIC are the desired composition for the accomplishment of the mission within the time allotted. One team is fully capable of preparing a helipad, but clearing time makes this undesirable.

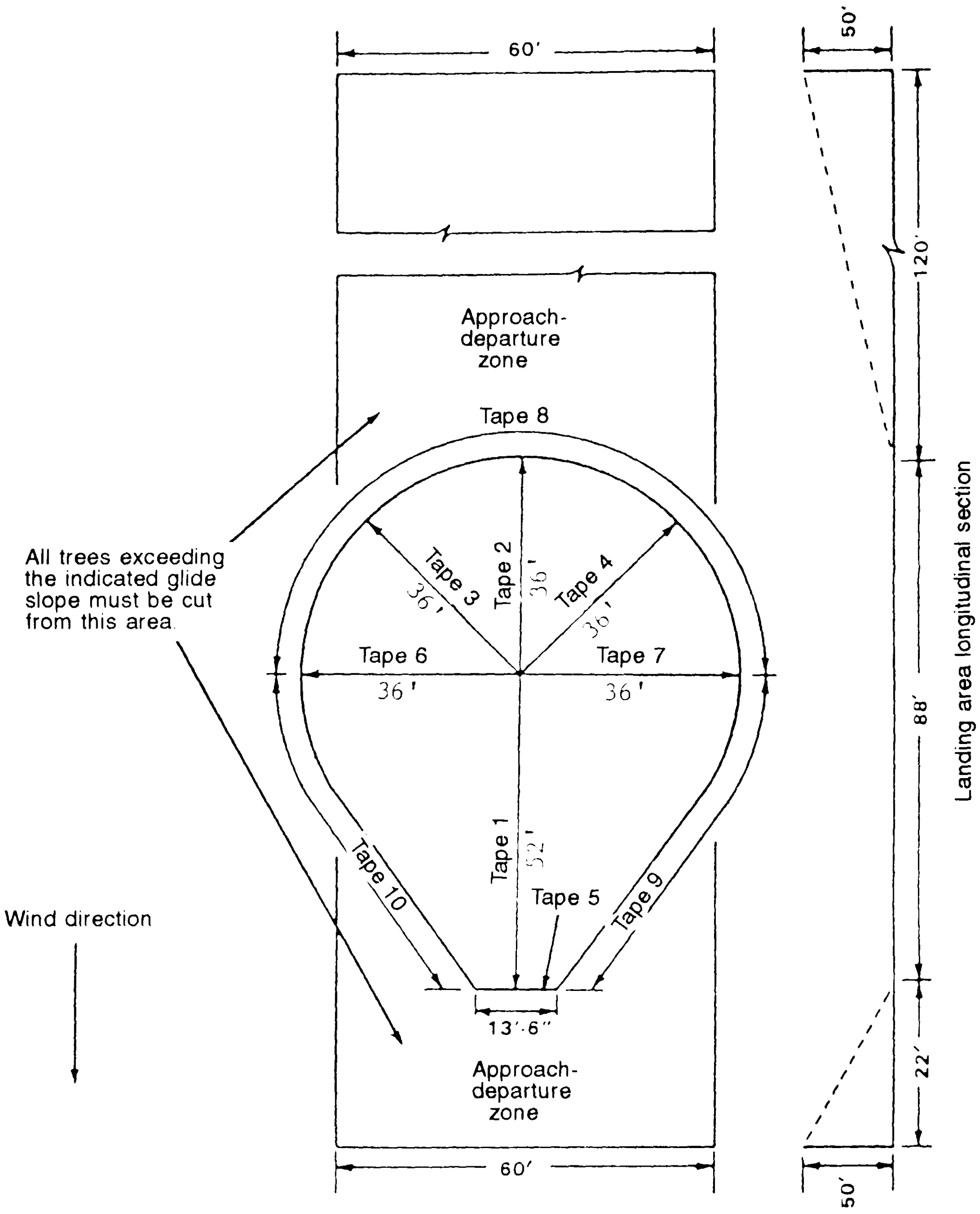
The chain-saw, ax, and brush-hook crews move into the proposed helipad area and begin clearing the undergrowth. The next step is felling and clearing trees and other vegetation within the periphery of the tape-marked helipad.

Trees are felled as close as possible to the ground level, with the necessary limbing and bucking performed for easy removal. When felling and cutting, any vegetation that may be sucked up into the helicopter blades must be removed from the helipad proper. Vegetation should not be burned. When time permits or in marshy areas, the felled timbers may be used to prepare a hardened landing pad.

Landing pad logs are leveled to ensure a satisfactory surface upon which the helicopter skids can rest without danger of bending. The perimeter of the helipad must be checked to ensure vertical clearance.

In densely wooded areas and jungle forests, it is necessary to fell additional trees to provide an approach and departure zone. These zones are necessary to provide adequate clearance of obstacles 50 feet in height. (The normal time for clearing such a helipad in tropical zone forests by well-trained soldiers should not exceed three hours if trees do not exceed 12 inches in diameter.)

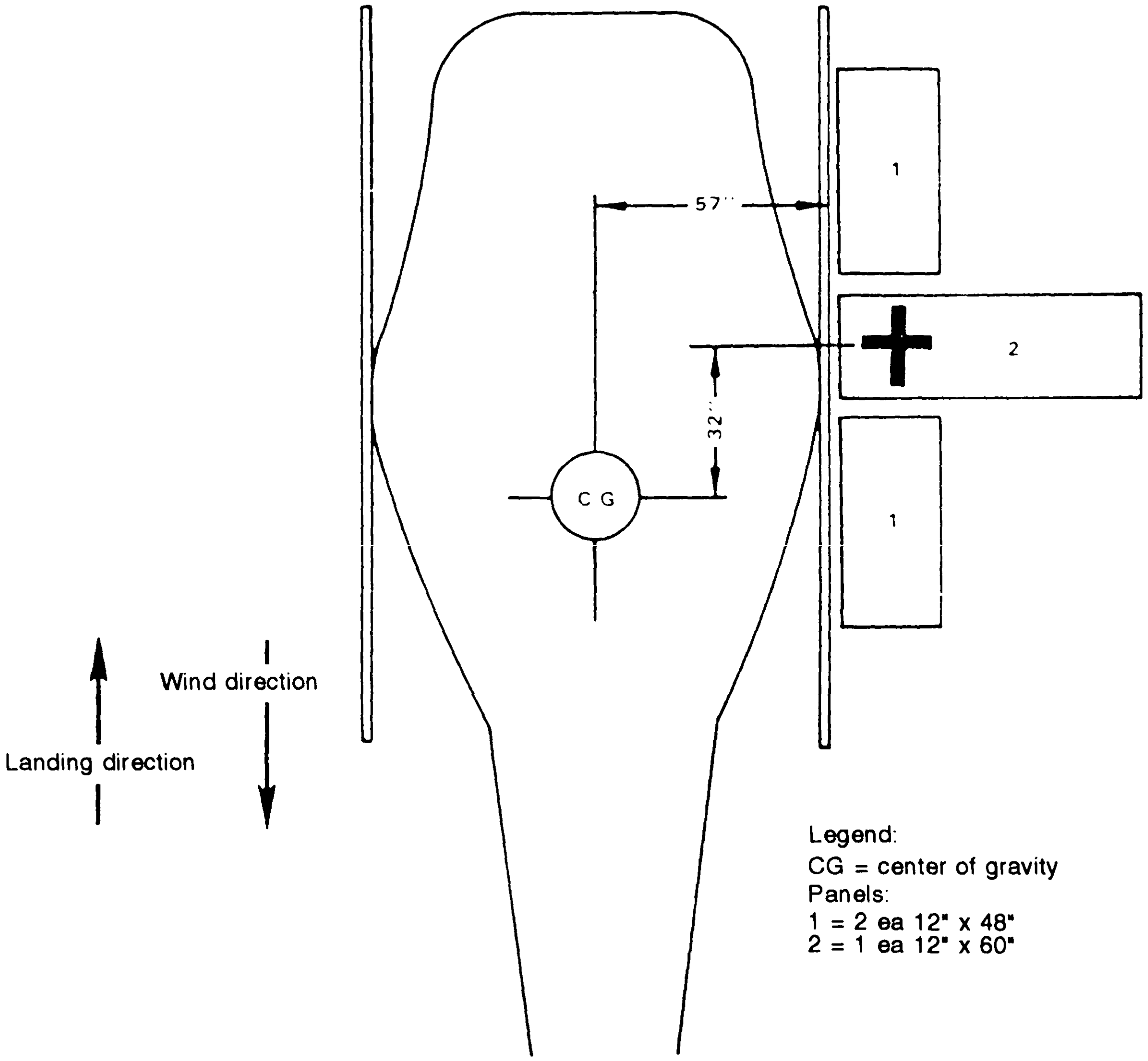
Before a helicopter lands in a forested helipad, landing reference panels are placed adjacent to the desired helicopter touchdown point. The landing reference panels serve as a visual guidance system during approaches and must be carefully positioned and firmly secured before a helicopter lands. Figure 13-10, page 13-35, shows the correct placement of landing reference panels on the ground.



Typical layout of landing area and clearances

Tapes may be added or deleted, as required, depending on terrain and vegetation.

Figure 13-9. Helipad tape layout and configuration



Legend:
CG = center of gravity
Panels:
1 = 2 ea 12" x 48"
2 = 1 ea 12" x 60"

Center of gravity location should be 38' from the leading edge of the forward obstructions and 36' from obstructions on the left and right. Panels, if possible, should be placed so that skid of helicopter comes to rest adjacent to panels.

Figure 13-10. Panel placement

FORTIFICATIONS FOR PARKED ARMY AIRCRAFT

CHAPTER 14

This chapter provides information to assist in the selection design construction, and maintenance of fortifications to protect parked aircraft from hostile ground fire and the associated damage effects of exploding fuel and ammunition on or near the aircraft. Details of other types of fortifications are in FM 5-103 and TM 5-302-1. This chapter applies to nonnuclear warfare only.

AIRCRAFT FORTIFICATIONS

Aircraft fortifications generally mask the lower parts of the aircraft and provide limited protection to the upper parts. For planning purposes, the protection of aircraft provided by fortifications does not consider overhead protection or structures built to the height required to mask the upper portions of rotary-wing aircraft. However, the fortification plans in this chapter can be adapted to different situations provided large protective structures can be constructed.

Several basic types of fortifications are discussed that satisfy various weather, topographical, and military considerations, including those that can be constructed with hand-tools organic to tactical units. Note that substantial quantities of earth or other protective materials are required to achieve minimum protection against all types of ammunition, including small arms.

FORTIFICATION PLANNING

When planning the construction of aircraft fortifications, engineers must consider the following items:

- Thickness and ballistic data.
- Weather and topography.
- Military considerations.
- Protective materials.

THICKNESS AND BALLISTIC DATA

Tables 14-1 and 14-2, pages 14-2 and 14-3 show tabulated thickness data summarized from the ballistic data in the graphs from Appendix P. Table 14-1 shows the thickness of material to defeat the fragmentation from the weapons shown, and Table 14-2 shows the thickness of protective materials required to resist penetration by various types of ammunition. The ballistic data and list of materials are incomplete. However, facilities may be designed to withstand the effects of other ammunition by using this chapter as a guide.

The graphs represented in Figures P-1 through P-11, pages P-2 through P-12, provide detailed ballistic data for different types of ammunition under Condition I, when no standoff is used. Each graph pertains to 1 of the 11 types of protective material discussed. Figures P-12 through P-22, pages P-13 through P-23, provide penetration data under Condition II when a shell standoff is used. Figures P-23 through P-33, pages P-24 through P-34, provide penetration data under Condition III, when a wooden standoff is used. Figure 14-1 shows the three standoff conditions.

WEATHER AND TOPOGRAPHY

The susceptibility of earthwork to the influence of heavy rains or other extreme

Table 14-1. *Material thickness requirement for fragment protection*

Material	High-Explosive Shell and Rockets			General Purpose Bombs			
	75 mm (in)	105 mm (in)	155 mm (in)	45 kg (100 lb) (in)	120 kg (250 lb) (in)	225 kg (500 lb) (in)	450 kg (1000 lb) (in)
Walls:							
Brick masonry	4	6	8	8	10	13	17
Concrete, plain	4	5	6	8	10	15	18
Concrete, reinforced	3	4	5	7	9	12	15
Lumber	8	10	14	15	18	24	30
Piles of loose material between boards:							
Brick rubble	9	10	12	18	24	28	30
Gravel, small stones	9	10	12	18	24	28	30
Earth	15	18	24	24	30	--	--
Sandbags filled with:							
Brick rubble	10	10	20	20	20	30	40
Gravel, small stones	10	10	20	20	20	30	40
Sand	10	10	20	30	30	40	40
Earth	20	20	30	30	40	40	50
Parapets of:							
Sand	12	18	24	24	36	36	48
Earth	24	36	48	36	48	60	--

NOTE: Figures are based on dry material. If wet material is used, double figures.

Table 14-2. Thickness requirements to resist penetration

Types of Ammunition	Soil Wet	Soil Dry	Sand Wet	Sand Dry	Clay Wet	Clay Dry	Soil Cement Bituminous Concrete	Concrete	Timber	Aluminum	Steel
					Condition I - No Standoff						
.30-cal ball (AP)	36	24	36	24	44	30	18	9	60	2.6	1.3
.50-cal ball (AP)	54	36	45	30	80	54	18	9	120	4.4	2.2
57-mm recoilless rifle	18	12	18	12	36	24	20	10	20	9.0	5.0
82-mm recoilless rifle	40	27	41	27	80	54	42	22	48	21.0	12.5
90-mm recoilless rifle	60	40	63	42	120	80	66	33	76	32.0	19.5
107-mm recoilless rifle	72	48	70	48	144	96	84	42	88	40.0	22.5
60-mm mortar	72	48	45	30	100	64	20	10	20	2.8	1.0
81-mm mortar	90	60	63	42	136	90	26	18	27	3.7	1.3
120-mm mortar	103	70	70	48	180	120	32	16	36	4.7	1.7
					Conditions II and III - ¼-Inch Timber Standoff						
.30-cal ball (AP)	18	12	18	12	22	15	9	6	30	1.3	0.6
.50-cal ball (AP)	27	18	26	15	40	27	9	6	60	2.2	1.1
57-mm recoilless rifle	9	6	9	6	18	12	10	6	10	4.5	2.5
82-mm recoilless rifle	20	13	21	13	40	27	21	11	24	10.5	6.3
90-mm recoilless rifle	30	20	30	21	59	40	33	17	38	16.0	9.3
107-mm recoilless rifle	36	24	35	24	71	48	42	21	44	20.0	11.3
60-mm mortar	36	24	22	15	50	32	10	5	10	1.4	0.5
81-mm mortar	45	30	31	21	66	45	13	7	14	1.9	0.6
120-mm mortar	52	35	35	24	90	60	16	8	18	2.4	0.8

NOTES:

1. Figures refer to the depth (in inches) a delay-fuzed round will penetrate into different materials. *The amount of material required to defeat fragments from the fragmentation ammunition given is considerably less than shown.*

2. Conditions I, II, and III are shown in Appendix P.

3. Timber standoffs are *ineffective against* .30- and .50-cal ball (AP) ammunition. If a timber standoff is used, design the structure as a Condition II structure. Then determine if the structure will resist penetration by .30- and .50-cal ball (AP) ammunition as a Condition I structure. If not, increase the thickness of the standoff to the values found in the table for Condition I opposite .30- and .50-cal ball (AP) ammunition.

weather conditions affects the construction of earth revetments. Erosion over an extended period reduces the resistance of penetration. Periods of wet weather produce soil moisture that is generally high and changes the strength of materials. Soils with a high moisture content have very little strength or resistance to penetration. Dampness adversely affects most protective materials, including wood and steel. These materials require treatment or protection against deterioration for prolonged use.

Consider the topography of the area near an airfield when determining the protective requirements for parked aircraft. For example, high ground within 3,500 meters that offers good observation for effective mortar or direct fire may negate the success of fortifications unless an active perimeter defense with effective counterfire is provided. Similarly, wooded areas, villages, or other sites that permit concealment close to parked aircraft enable guerrillas and saboteurs to assemble. In such cases, both active and passive defense fortification measures are required.

MILITARY CONSIDERATIONS

The effectiveness of fortifications and other passive defense measures is substantially increased by an active perimeter defense against infiltration, sabotage, or similar tactics. Therefore, it is best to confine protective construction to an area that can be adequately defended.

Dispersion and Camouflage

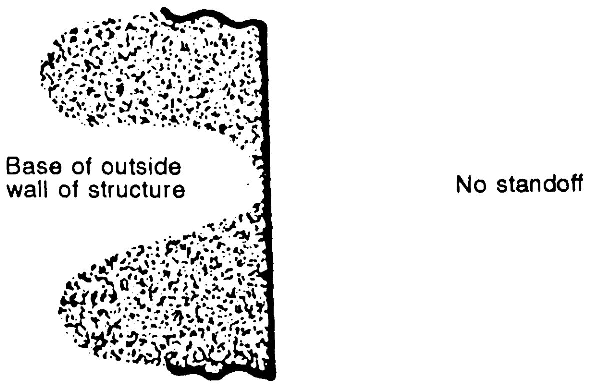
If dispersal of aircraft is possible and consistent with active defense measures, varied parking patterns provide fewer lucrative targets for indirect-fire weapons. Prefabricated, hard parking surfaces such as landing mats increase lethal areas of bursting rounds due to induced fragmentation. Effects of other hardened surfaces, such as bituminous materials and concrete, are unknown but probably increase fragment success as well. Reduced damage from indirect-fire attacks should result when parking areas can be adequately maintained on sod or on a surface that does not cause fragment ricochet. Conceptual layouts of airfields that provide random dispersal of parking areas are shown in Figures 14-2 through 14-4, pages 14-5 through 14-8.

Fortifications should be considered in their relationship to, and as a means of augmenting, other forms of protection, including dispersion, camouflage, and active defense measures. The use of protective structures for parked aircraft should increase the combat effectiveness of the unit as do similar measures that protect personnel and weapons. The type of fortifications constructed is governed by the tactical situation: enemy capabilities; the availability of materials, construction equipment, and personnel to accomplish the required work; and an available area for construction.

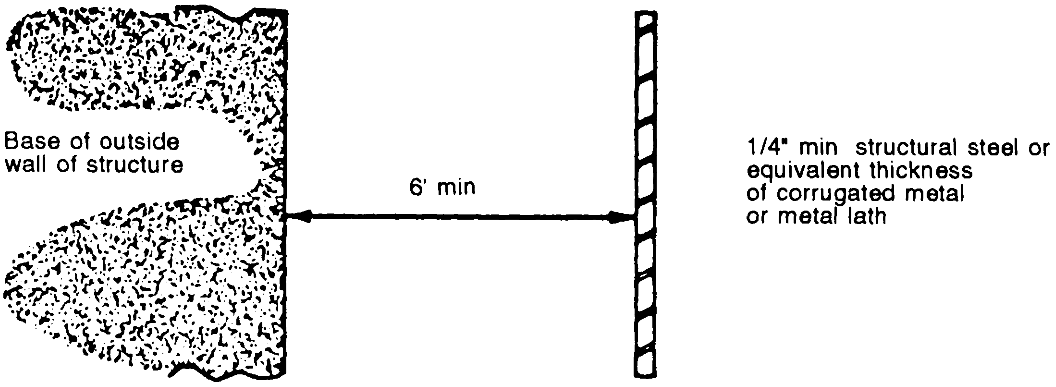
Weapons Capabilities

Fortifications should be capable of resisting penetration by the most effective type of ammunition to which the structure is likely to be exposed. Table 14-2, page 14-3, shows that 120-millimeter mortar and 107-millimeter rifle ammunition generally are most effective against the materials considered. A steel standoff shown in Figure 14-1 reduces the effectiveness of most ammunition by detonating it before it strikes the fortification. Consequently, a lesser thickness of protective material can be used with a standoff than without one. The data in Table 14-1, page 14-2, is based on a penetration resistance factor (PRF) of 1.00. This figure is used for comparative purposes because it provides the minimum thickness of material required to resist penetration by a given type of ammunition at optimum range. The graphs in Appendix P are plotted to show the thickness of material required for PRFs that are smaller or larger than 1.00. The graphs provide a means of estimating the amount of protection afforded when material thicknesses differ to meet local specifications for protection.

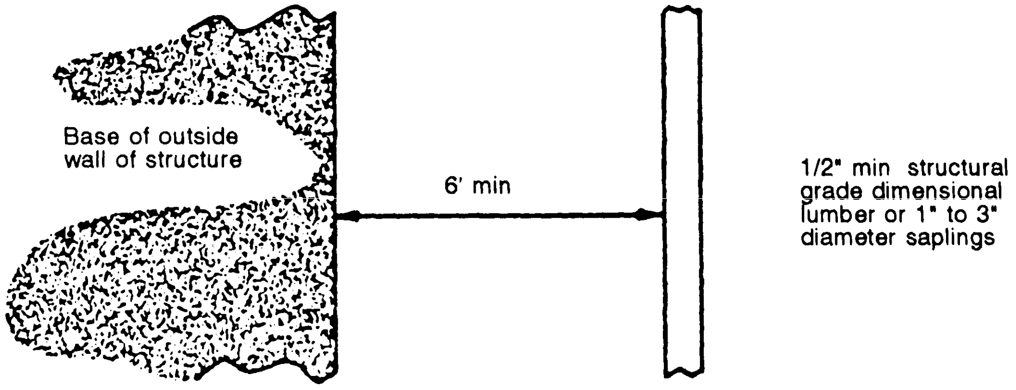
NOTE: PRFs of 1.00 or more are effective. PRFs of less than 1.00 are ineffective. For economy of materials, design structures with a PRF slightly larger than 1.00.



① NO STANDOFF - CONDITION I



② STEEL STANDOFF - CONDITION II



③ WOOD STANDOFF - CONDITION III

Figure 14-1. Examples of standoffs for Conditions I, II, and III

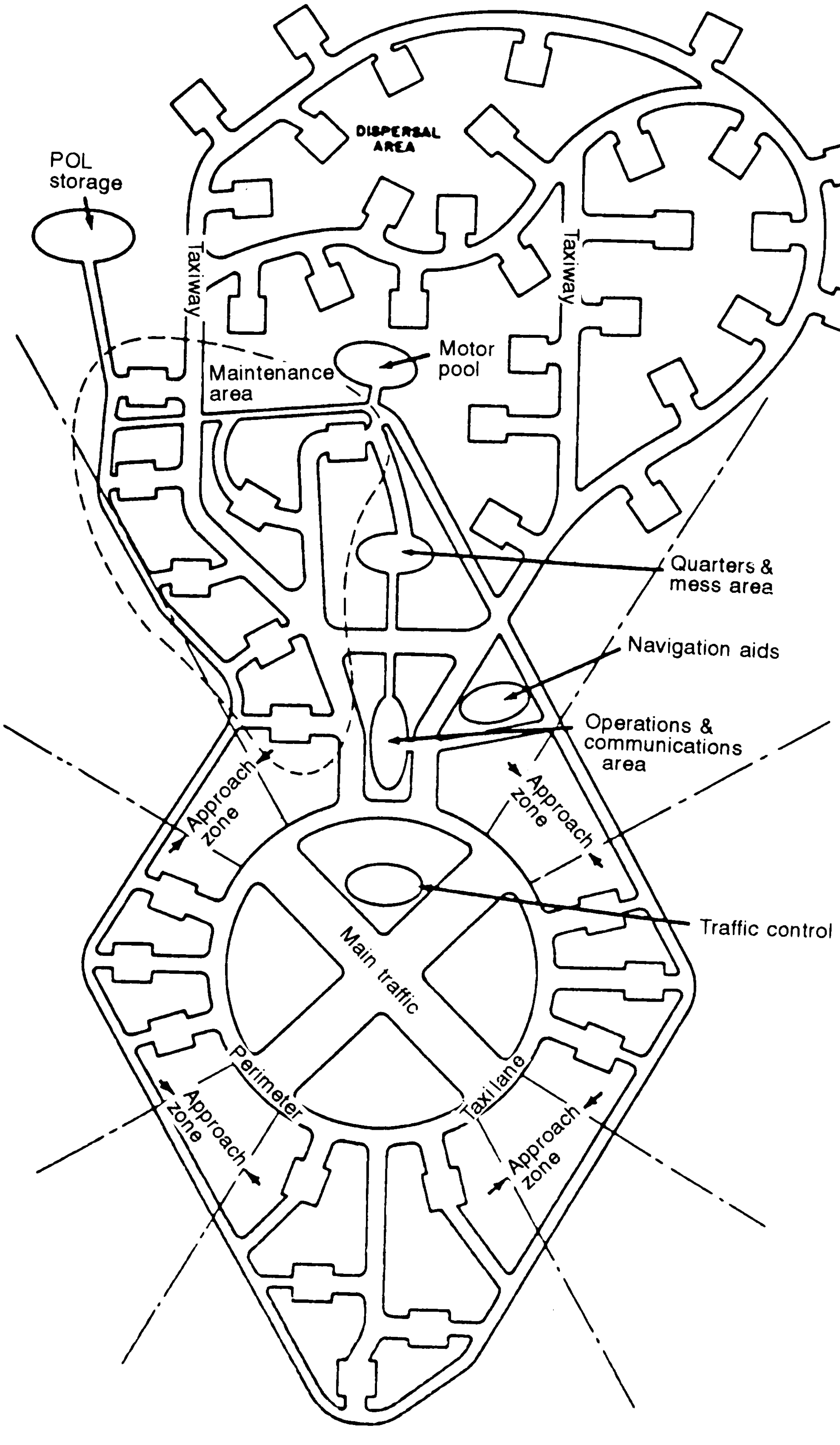


Figure 14-2. Heliport layout

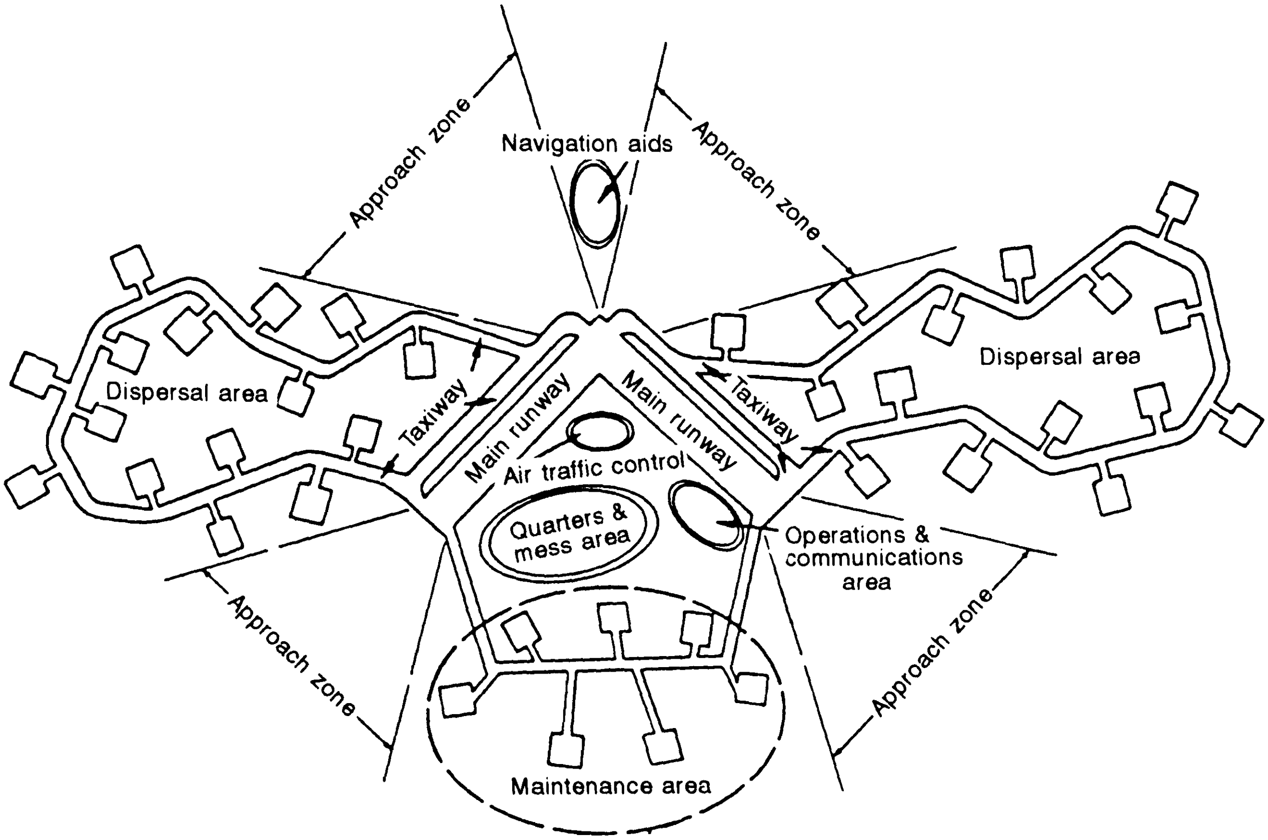


Figure 14-3. Layout for all types of aircraft

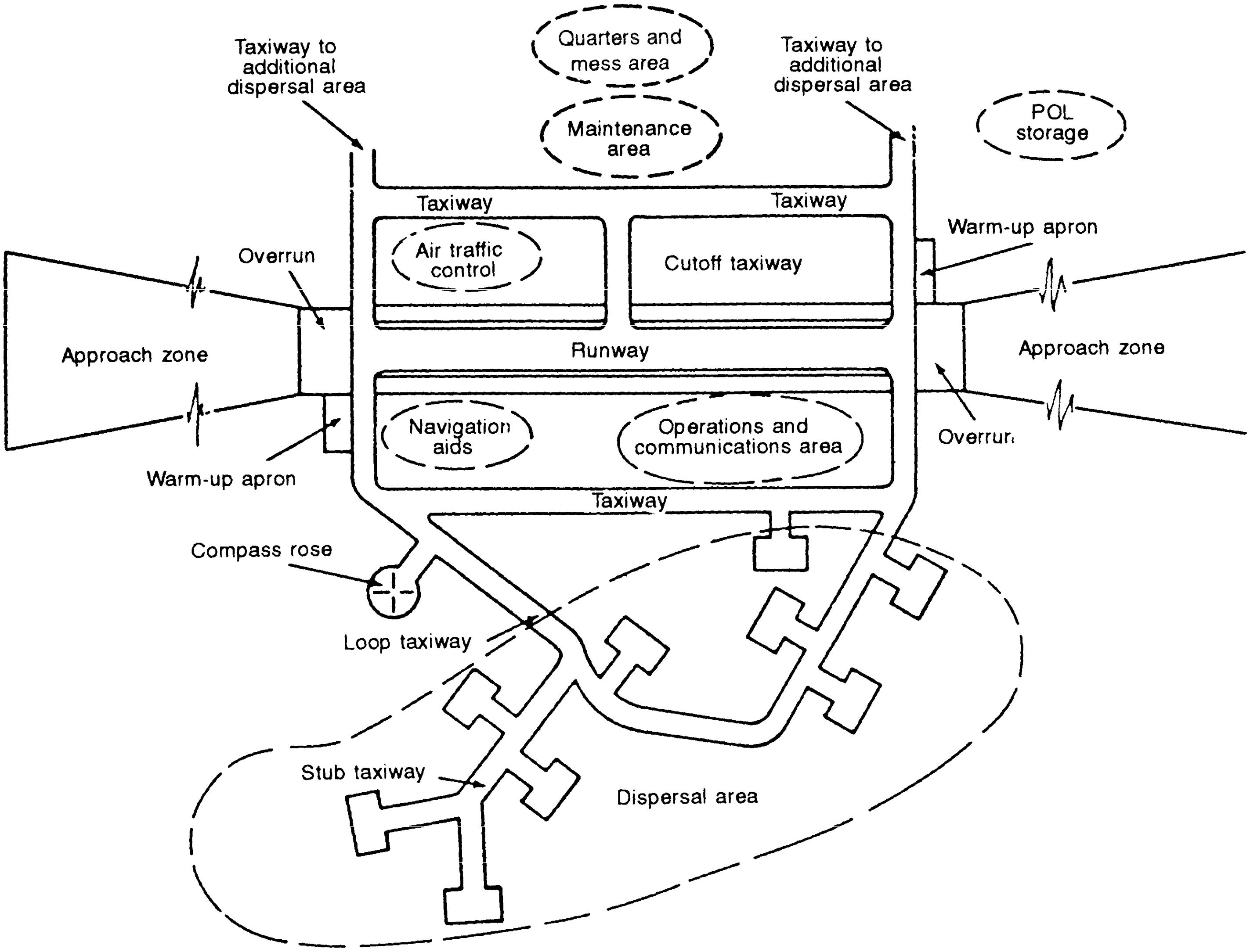


Figure 14-4. Layout for fixed-wing aircraft

PROTECTIVE MATERIALS

The selection of construction materials for fortifications is influenced by availability. The protective qualities of the following materials are described below:

- Soils.
- Soil cement.
- Concrete.
- Timber.
- Steel.
- Asphalt sandwich.
- Plywood.
- Ice, snow, and ice concrete.
- Expedient fortification materials.

The techniques of construction, preservation, and repair or rehabilitation are described later in this chapter.

Soils

Dry soil resists penetration better than wet soil. Table 14-2, page 14-3, indicates that the thickness of wet soil must be approximately double that of dry-soil requirements to resist penetration by a given type of ammunition. It is best to select dry soil for earth revetments and to provide a waterproof cover for the completed earth structures to conserve manpower and materials. An expedient test to determine moisture content in soils is to observe the reaction of a handful of soil when squeezed into a ball. If it retains the shape of a ball, consider it a wet soil. If it fails to adhere, consider it a dry soil. Wet clay is the most susceptible to ballistic penetration and is the least effective fortification material. Dry sand has the most resistance to penetration and is the most desirable soil for fortification.

Soil Cement

Table 14-2 indicates that soil cement is highly resistant to mortar and ball ammunition but considerably less resistant to recoilless rifle ammunition. Prepare soil cement by mixing 1 part by weight of portland cement with 10 parts by weight of dry earth or 6 parts by weight of sand-gravel. When placed in sandbags, the cement sets as the bags take on moisture. This procedure prolongs the useful life of sandbags, which normally deteriorate quite rapidly, particularly in damp climates. Filled sandbags also may be dipped in a thin mixture of cement and water. To produce cement in large quantities, follow the procedures described in FM 5-742.

Concrete

The characteristics, mixture, placement, reinforcement, and curing of concrete and the construction of forms are explained in FM 5-742. Concrete construction should not be undertaken except under qualified supervision to avoid uneconomical use of critical materials.

Timber

Timber can be used as a retaining wall for earth revetments. In addition to support, it contributes to the effective resistance of the fortification. Timber used for this purpose may be either hard or soft but should be free of knots and other imperfections that affect its rigidity or resistance to penetration. When used against earth, treat timber with a preservative such as tar or creosote to prolong its usefulness. Wood such as bamboo may be used for retaining walls if woven into mats and adequately supported, but it has no effective resistance to penetration.

Steel

Steel may be available in forms such as corrugated metal, sheet piling, or pierced landing mat. Consider the thickness of these materials used to retain earth revetments when determining its resistance to penetration. If the material has holes larger than 1/2 inch, disregard its resistance to penetration.

Asphalt Sandwich

This asphalt mix is made into a sandwich between sheets or plates by pouring it into forms. A 2-inch thickness of asphalt mix gives considerable protection from small-arms and conventional-weapons fire. Field-expedient asphalt mixes can be used but are not as effective as hot plant mixes. The fragment-defeating capability is directly related to the aggregate size used in the asphalt mix. The most effective size is coarse aggregate 1/4 inch or larger. To increase the PRF, use layers of asphalt sandwich instead of a greater thickness of asphalt. The asphalt can be left in the forms and installed as protection if the asphalt alone is not sufficient. Asphalt sandwich plates are most effective when at least one plate is left attached to the form on the friendly side. A 2-inch asphalt sandwich of 60 percent aggregate, 30 percent mineral filler, and 10 percent asphalt binder (by weight) with attached 26-gauge steel sheets is 100 percent effective at 30 feet from the detonating point to the wall. These protective walls must be braced and anchored to resist blast effects.

Plywood

One or more layers of plywood make an effective field-expedient protective wall. As more layers of plywood are added, the amount of protection increases. Table 14-3 shows the effectiveness of up to three layers of 3/4-inch fir plywood. Although three layers of plywood stopped a high percentage of fragments from all munitions shown, there is still a large number of lethal fragments perpetrating the plywood. Brace and anchor the plywood to provide stability against blast and aircraft movement. If time allows, form the plywood into a box-type structure and fill it with soil. This will increase protection considerably above that furnished by the plywood layers.

Ice, Snow, and Ice Concrete

Ice concrete is a dense, frozen mixture of sand and water or sand with gravel, crushed rock, and water. At least 10 percent of the mixture should be sand. Add only enough water to make the mixture slightly liquid. A sheet of ice concrete that is 4 inches thick will freeze solid in four to six hours at -13°F. It may be used for overhead cover, parapets, breastworks, or as a sandbag filler. Minimum thicknesses of snow and ice for protection against small arms are as follows:

New snow	13 feet
Tamped snow	8-10 feet
Frozen snow	6.5 feet
Ice	3.25 feet
Ice concrete	1-2 feet

Expedient Fortification Materials

A suitable retaining wall for sandbag or earth revetments is constructed using landing mat supported by wire rope and pickets. Bulkhead-type fortifications are also constructed with these materials.

Corrugated metal, if available in sufficient quantity, is a satisfactory substitute for revetment retaining walls and bulkhead-type fortifications. Additional quantities of wales and vertical supports to withstand the pressure of the earth fill are required to correct its lack of rigidity.

Table 14-3. Plywood protective walls

	1.91 cm (¾ in) Thick 1 Layer	**3.8 cm (1½ in) Thick 2 Layers**	**5.72 cm (2¼ in) Thick 3 Layers**
Threat		% Effective*	
81 mm	60	82	91
82 mm	64	86	97
4.2 in	24	55	71
107 mm	47	71	86
120 mm	60	84	91

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

$$\% \text{ effectiveness} = \left(\frac{\text{number of penetrating fragments}}{\text{total no. of impacting fragments}}\right) \times 100$$

Ammunition boxes filled with earth provide limited protection. They can be used as a retaining wall or bulkhead if they are adequately supported with wales and vertical supports.

A substantial bulkhead fortification is provided by using Conex-type containers filled with moderately dry sand, gravel, or soil. An example of this expedient is shown in Figure 14-5, page 14-12.

Unserviceable 55-gallon drums can be stacked in different configurations and then filled with sand to provide limited protection. Drums can be stacked for extra height but they must be welded together. Run a steel angle or pipe the length of the wall and weld it to each drum for added stability. Weld each level to the level below it.

Sand grid can be used in layers to construct fortifications. Backfill material should be dry and cohesionless. A bituminous coating can be sprayed over the structure to limit water penetration.

Combining Materials

A more effective and substantial fortification usually results if availability and construction skills permit the combined use of two or more materials. For example, the use of timber and soil (dry soil) without standoff may be considered by referring to Table 14-2, page 14-3, or the graphs in Figures P-2 and P-9, pages P-3 and P-10, for the different materials shown. The 8-inch timbers provide a PRF of 0.3 (8-inch actual thickness divided by the 27 inches of timber given in Table 14-2 as adequate to resist penetration) against 81-millimeter mortar ammunition. The total PRF must equal 1.00, so a sufficient thickness of dry soil must be added for an additional PRF of 0.7 (1.0 - 0.3 = 0.7). Because a single thickness of 60 inches of dry soil will resist penetration by 81-millimeter mortar ammunition, 42 inches (0.7 x 60 = 42) of dry soil must be combined with 8-inch timbers for a PRF of 1.00. This design, featuring a combination of materials, represents a savings in materials and manpower and reduces the areas required for the structure.

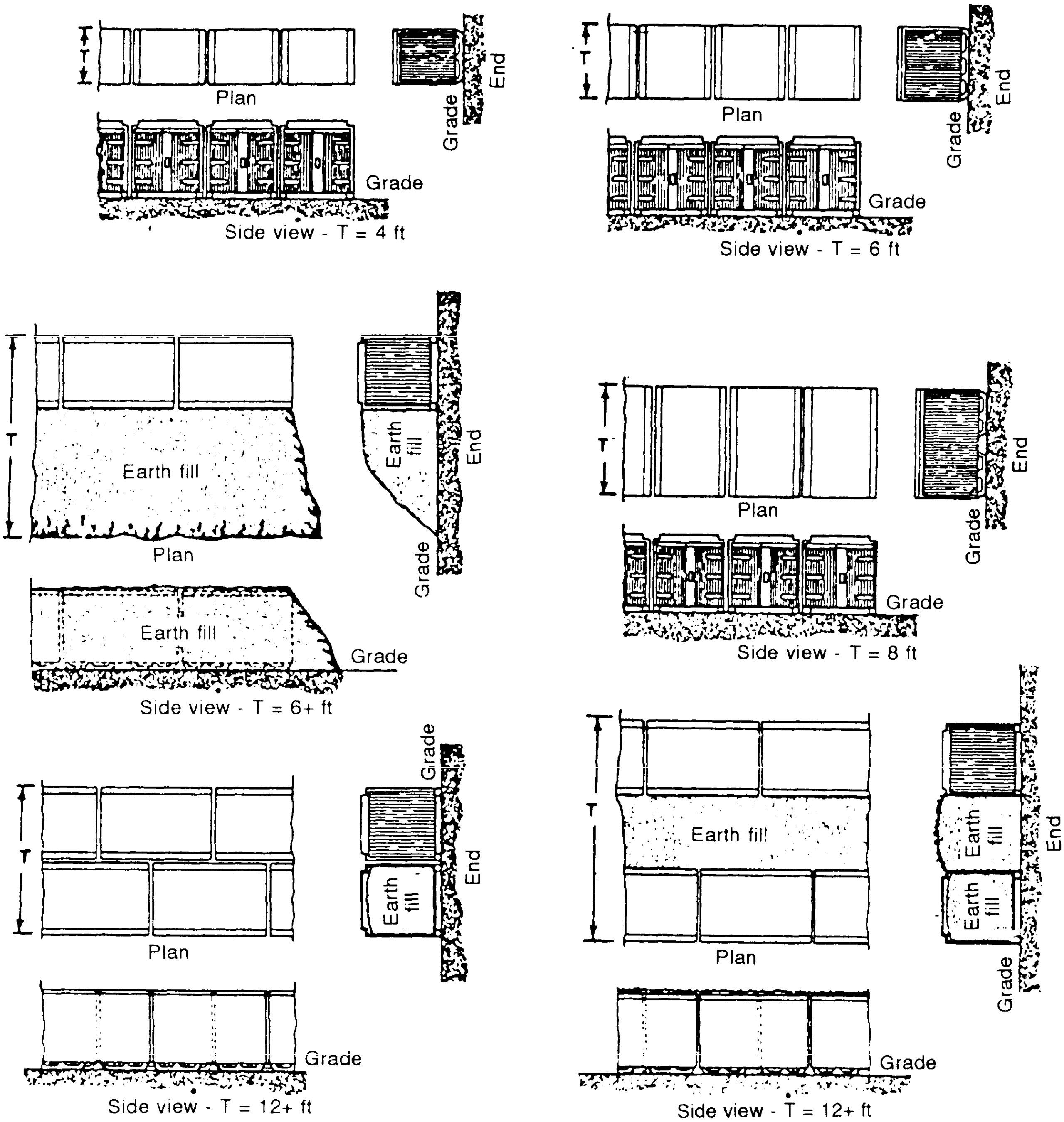
FORTIFICATION DESIGN AND CONSTRUCTION

Space is a limiting factor that affects airfield size, type, configuration, and the layout of fortification. Therefore, it is necessary to ensure the airfield area, the anticipated aircraft population, the duration of occupancy, and the area adjacent to the airfield available for dispersal of aircraft are consistent with the tactical situation. Each airfield presents problems in one or more of the above areas for which general guidelines apply. The type of fortification may require modification if there is insufficient space for aircraft dispersal. For example, some areas of the airfield may permit construction of one type of fortification, while other areas may only permit construction of less protective fortification.

Topography such as a deep stream immediately adjacent to the field may minimize the protection required. Maximum protection consistent with mission requirements and available resources should be the guiding consideration in aircraft fortifications.

DESIGN CRITERIA

The size and shape of a revetment are important in determining the total effectiveness of a revetment system. The height of a revetment system is critical. For example, if a *fly-in/fly-out* capability is necessary for a utility helicopter revetment, the height and effectiveness of the revetment system is limited. Inside dimensions of fortifications necessary to accommodate different types of Army aircraft are listed in Table 14-4, page 14-13. The dimensions given provide limited clearances for aircraft movement and servicing. The area inside the fortification should be the minimum required to tow the aircraft into the fortification and to avoid restricted movement and servicing. The inside area of the fortification also should provide for the largest aircraft in use. Coordinate the inside dimensions of fortifications for Air Force aircraft with the Air Force to satisfy their need.



Legend:

T = thickness of revetment

Figure 14-5. Bulkhead revetment using containers

Table 14-4. Fortification dimensions

Type of Aircraft (Capacity)	Partial Protection[1]			Improved Protection[2]			Full Protection[3]		
	Width W	Height H	Length L	Width W	Height H	Length L	Width W	Height H	Length L
Observation helicopter (pilot and observer)	20	4	40	20	7	40	46	13	45
Util/attack helicopter (2 man crew; up to 2,855 lb payload)	25	5.5	50	25	9	52	58	16	68
Cargo helicopter (4 man crew, up to 10 tons payload)	35	11	80	35	17	90	82	19	90
Fixed-wing observer, utility, surveil, trainer	66	12	50	--	--	--	68	15	52
VTOL/STOL	30	11	60	--	--	--	--	--	--

[1] Partial protection. These dimensions allow "fly in/out" capability for helicopters. However, the engine compartments are exposed. The dimensions represent minimum sizes for fixed-wing aircraft.

[2] Improved protection. These dimensions are recommended for maximum labor and material economy and maximum protection. Rotor blades and helicopters project over the walls.

[3] Full protection. These dimensions enclose the entire aircraft. Although helicopter rotor blades are contained within the revetment, the widths given for improved protection are more desirable.

NOTE: Obtain specific dimensions for aircraft from the using unit. All dimensions are in feet.

Designing for Effects of Ammunition

Besides providing protection from hostile ground fire, fortifications should be arranged and spaced to minimize the explosive effects of bulk ammunition stored within the fortifications or on the aircraft. A shell, grenade, or other charge exploded near bulk quantities of ammunition normally sets off a chain reaction that damages or destroys several aircraft. Fortifications can reduce these interacting explosive effects. To determine ammunition effects, estimate the equivalent explosive weight of the ammunition on and near aircraft within a proposed aircraft fortification area. Equivalent explosive weights are found in Table 14-5, page 14-14. Include the explosive weight of the hostile round in the total explosive weight if it is a significant percentage of the total. Apply the computed weight to the graph (Figure 14-6, page 14-15) to determine theoretically safe distances with or without a protective barrier or wall between aircraft, Figure 14-7, page 14-16, shows how to orient fortifications to provide safe distances. TWO intervening walls are required between the protected aircraft and the explosive before any reduction in safe distance is obtained.

Designing For Effects of Fuel

The destructive force of exploding fuel is considerably less than the force resulting from exploding ammunition. Protective measures against ammunition with an explosive weight of 100 pounds or more compensate for fuel explosions in the same area. If ammunition or fuel is present, the distance between aircraft should not be less than 85 feet when there are two intervening walls or not less than 150 feet when there are less than two walls. Slope the floor of the fortifications to control the direction of flow of spilled burning fuel. If burning fuel flows under other aircraft, the heat could result in additional explosions.

Estimation Of Weapons' Effects

Intelligence estimates should disclose the types of ammunition against which protection is required. Reconcile the effects of ammunition with soil conditions or moisture content because high-velocity ammunition has more penetration effect against wet or damp soil than it has against dry material. Other factors being equal, provide protection against the type of ammunition having the greatest penetration potential, (See Tables 14-1, 14-2, pages 14-2 and 14-3, and Appendix P.)

Table 14-5. Equivalent explosive weights

Military Munitions	**Equivalent Explosive Weight Factors**
Shells (all types)	0.70
Rockets	0.70
Grenades	0.70
Small arms (ball and AP ammo)	0.40
Military Explosives	
TNT	1.00
Composition C-4	1.30
Sheet explosive	1.30
Tetrytol	1.20
Ammonium nitrate	0.50
Military dynamite	1.00

NOTE: Multiply the above factors by the estimated weight of the ammunition to derive equivalent explosive weight.

The essential factors in fortification design are the most effective type of ammunition in common use and the resistance of the protective material available for fortification purposes. The relationship between these two factors has been reduced to the PRF previously defined. A factor of 1.00 provides the theoretical minimum thickness of a given material to resist penetration by the types of ammunition shown in the graphs (Appendix P) under the three construction conditions.

Selection of Materials

If a choice of materials is available, base the selection on the protective characteristics of the different materials or a combination of the materials that will resist penetration by the most effective type of ammunition expected. Other considerations include handling methods, appropriate equipment, labor skills, and the type of fortification being constructed. Use Table 14-6, page 14-17, to estimate the quantities of material required for different types of fortifications. Table 14-6 also states waste factors.

Spacing and Configuration of Fortifications

Fortification spacing should provide an arrangement of individual aircraft protective structures that ensures access to the aircraft for efficient servicing, maintenance, and tactical operations. Anticipated active defense measures for the area are an important consideration in this regard.

Dispersal of aircraft is contingent primarily on the available area. Dispersal should cause the aircraft to be separated sufficiently to minimize the danger of interacting ammunition and fuel explosions. Avoid any consistent pattern that facilitates adjustment of high-angle fire on the aircraft. Conceptual layouts of aircraft dispersal are shown in Figures 14-2 through 14-4, pages 14-6 through 14-8.

Fortification Design Example

Fortification for 10 aircraft, type UH-1H, is required to provide maximum protection with available materials. Given–

- Known weapons in use:
  - .50-caliber machine guns
  - 90-millimeter recoilless rifles
  - 60-millimeter mortars
- Available materials:
  - 2-inch sheathing–12,000 square feet (retaining wall)
  - 2-inch x 4-inch lumber–14,000 linear feet (vertical supports)

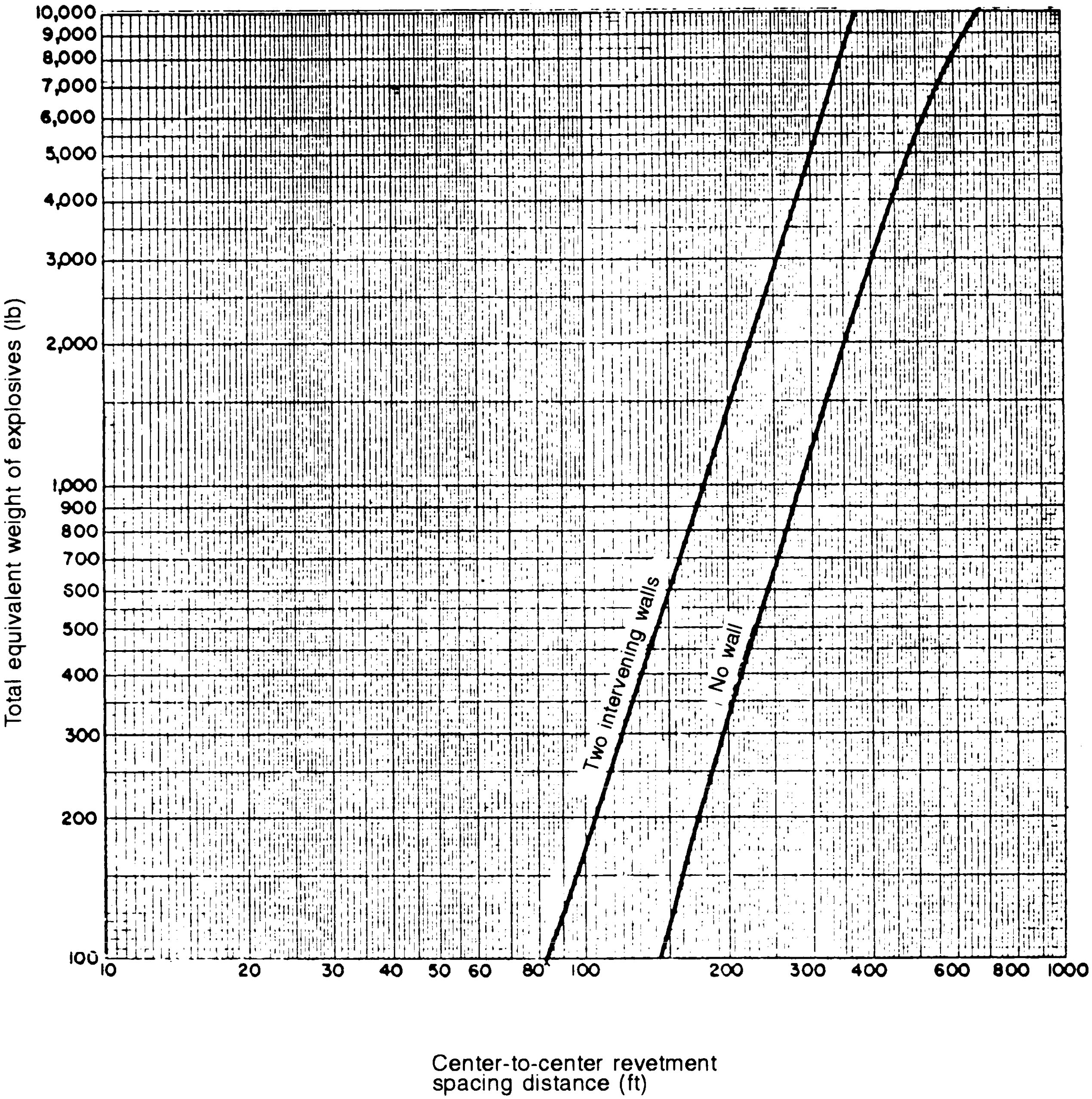
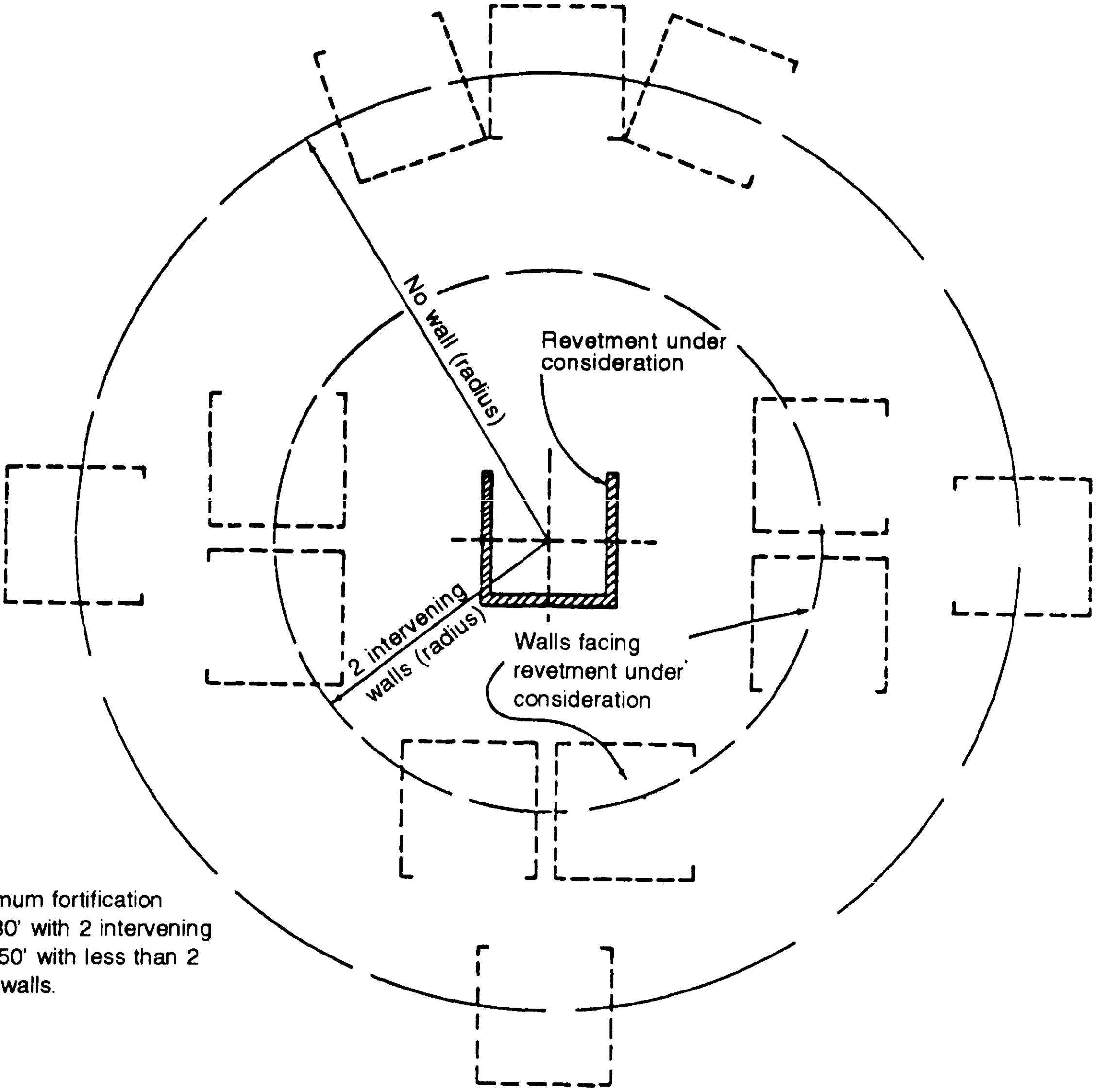


Figure 14-6. Safe distances for explosives with or without a protective barrier



Note: Minimum fortification spacing is 80' with 2 intervening walls and 150' with less than 2 intervening walls.

Figure 14-7. Orientation of fortifications to provide safe distances

Table 14-6. Material requirements for various fortifications

		Gravity Revetments			Bulkhead Revetments				
			Dimensioned	Steel		Dimensioned Timber		Steel	Earth
Material[1]	Unit	Logs	Timber	Sheet Pile	Logs	Field Erect	Prefab	Sheet Pile	Revetments
Filler (earth)	cu yd	$0.4(TH+H^2/2)$	$0.4(TH+H^2/2)$	$0.4(TH+H^2/2)$	0.4TH	0.4TH	0.4TH	0.4TH	$0.4(TH+H^2)$
Sheathing	sq ft	10(H+1)	10H	10(H+2)	20H	20H	2H(T+10)	20(H+2)	--
Waterproofing material[2]	sq yd	--	1.1H	--	--	2.2H	2.2H(T+10)	--	--
Cover material	sq yd	1.1T+1.7H	1.1T+1.7H	1.1T+1.7H	1.1(T+2)	1.1(T+2)	1.1(T+2)	1.1(T+2)	--
Scabbing[3]	lin ft	100	100	100	150	2TH+100	--	100	--
Wire rope cable	lin ft	6H+9T+27	12H+18T+54	8H+12T-24	24T+96	18T+72	--	15T+60	--
Cable clamps	each	60	110	75	150	110	--	80	--
Nails and spikes	lb	100	100	20	150	150	150	20	--
Vertical supports	lin ft	14(H+3)	11(H+2)	--	12(H+2)	22(H+2)	4H	--	--
		(two sizes)	--	--	--	--	H(T+10)	3.3H	--
Wales	lin ft	--	--	3.3H	--	--	--	--	--
Braces	lin ft	--	--	--	2.2(H+1)	--	--	--	--
Soil retainer	sq yd	1.1(H+1)	--	--	--	--	--	--	--
Concrete	cu yd	--	--	--	--	--	--	--	--
Cement	cu ft (sack)	--	--	--	--	--	--	--	--
Reinforcing bars	lin ft	--	--	--	--	--	--	--	--
Soil	cu yd	--	--	--	--	--	--	--	--

[1] Add 20 percent waste factor for sheathing and 10 percent waste factor for all other materials.

[2] For one layer only. Multiply by the number of layers if laminated.

[3] Scabbing is reusable.

NOTE: H is height, in feet; T is thickness, in feet.

- Accessory materials, including wire cable, clamps, nails, and bolts
- Dry sand for filler

Ž Aircraft armament:

- 7.62-millimeter ammunition-100 pounds
- Rockets-200 pounds

1. Determine a preliminary fortification design for a gravity revetment (condition I–no standoff) to provide full lateral protection. See Figures 14-8 through 14-10, pages 14-18 through 14-20 for sketches of revetments.

2. Determine the dimensions of a full protective structure for UH-1H aircraft. from Table 14-4, page 14-13.

Width = 58 feet
Height = 16 feet
Length = 68 feet

3. Estimate required materials using Table 14-6. Material available after computation of waste factor.

Sheathing–20 percent waste factor = 80-percent usable material = 0.80 x 12,000 square feet = 9,600 square feet.

Vertical supports–10 percent waste factor = 90 percent usable material = 0.90 x 14,000 linear feet = 12,600 linear feet.

Linear feet of sheathing required for retaining wall:

(Width (W) + 2L) x number of aircraft = {58 + (2 x 68)) x 10 = 1,940 linear feet or 194 10-foot sections.

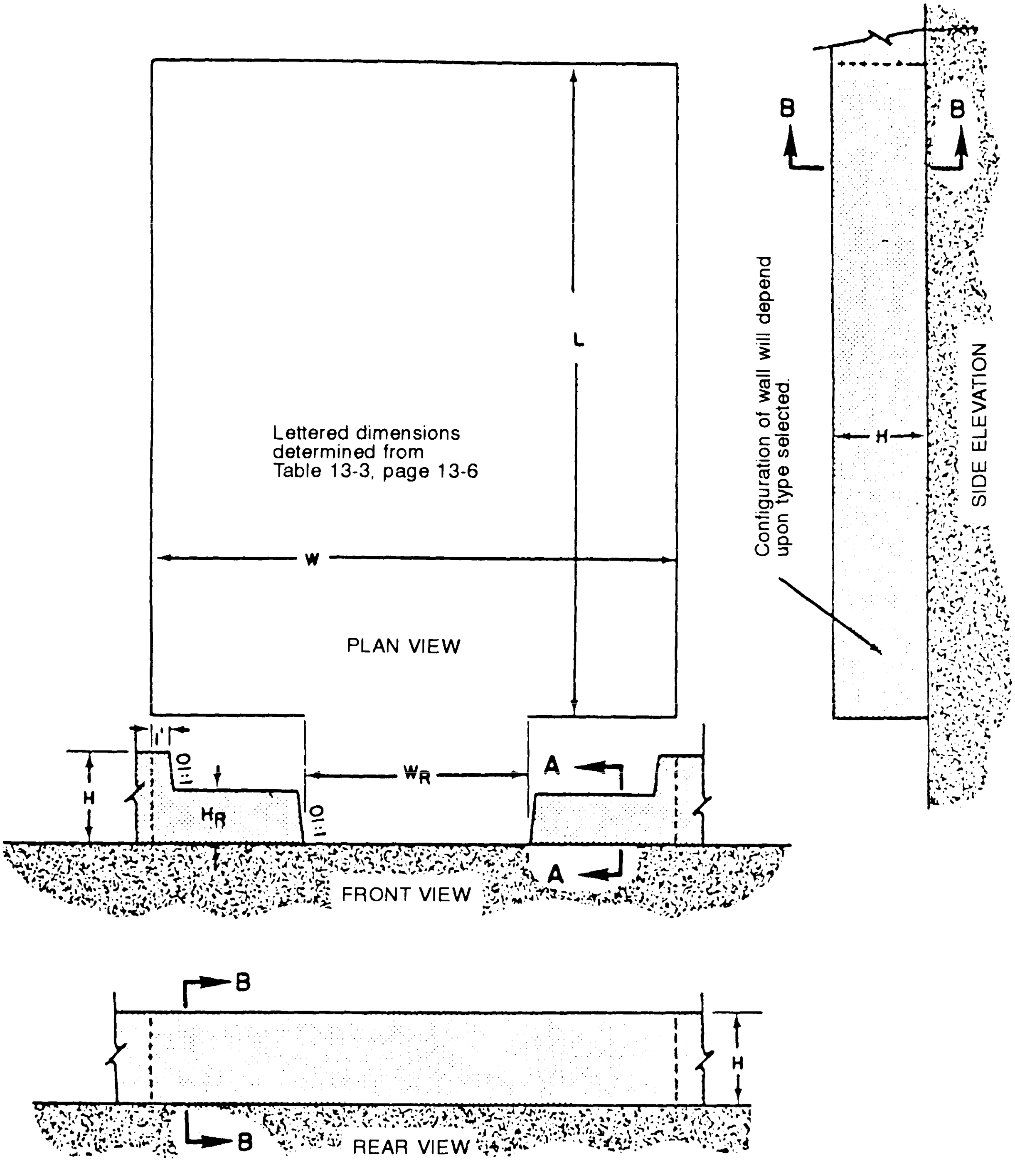
Sheathing area for gravity revetments:

10 height (H) per 10-foot section = (10 x 16) x 194 = 31,040 square feet.

NOTE: The amount of sheathing required for this type of protection exceeds the amount available (12, 000 square feet). Therefore, the design must be adjusted accordingly. Partial lateral protection (Figure 14-9) is one possibility. This will protect each side of the aircraft and leave the ends of the fortification open.

4. Revise the fortification design using the improved protection dimensions in Table 14-4.

Width = Not applicable (NA)
Length = 52 feet
Height = 9 feet

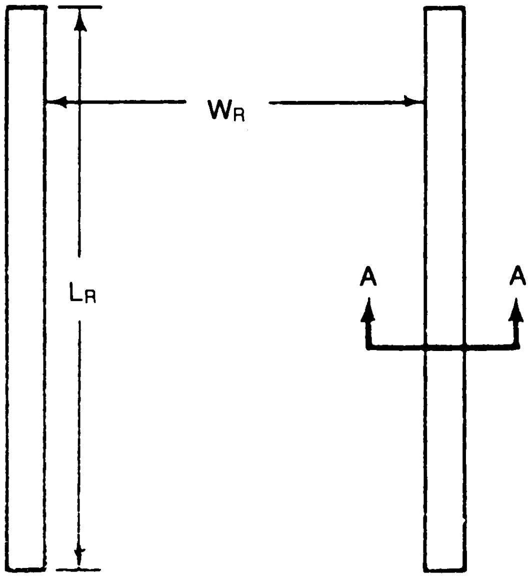


Lettered dimensions determined from Table 13-3, page 13-6

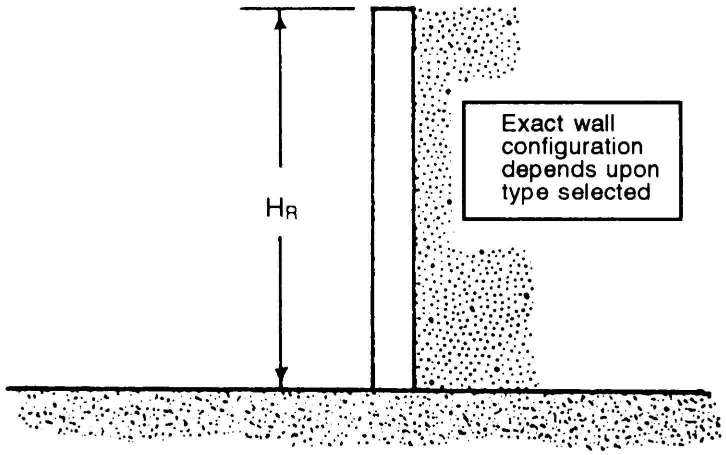
Configuration of wall will depend upon type selected.

Exact wall configuration is dependent upon type selected. Section AA shall be proportional to section BB.

Figure 14-8. Plan view of a revetment for rotary-wing aircraft for full lateral protection



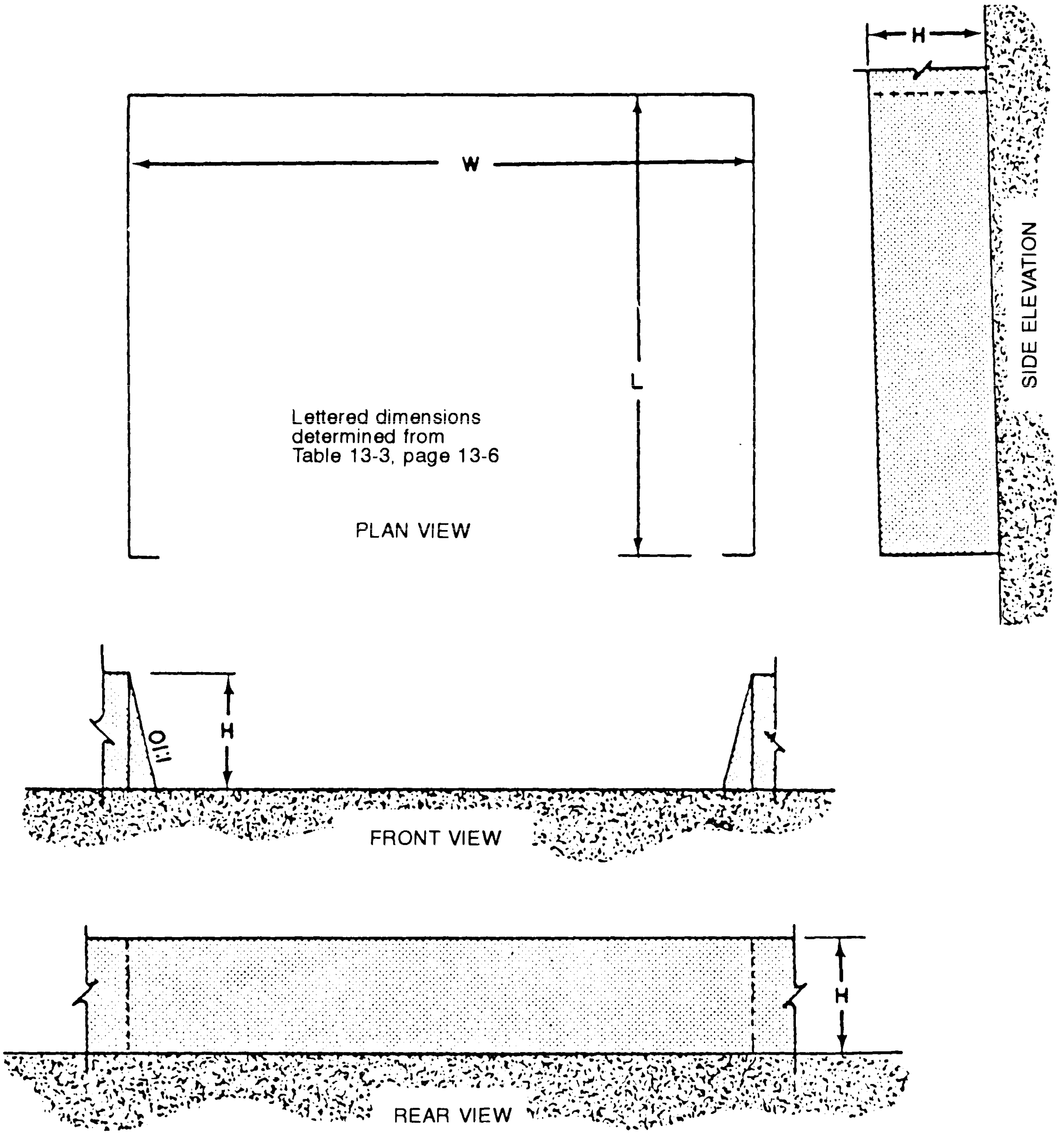
PLAN VIEW



Exact wall configuration depends upon type selected

SECTION A-A

Figure 14-9. Plan view of a revetment for rotary-wing aircraft for partial lateral protection



Lettered dimensions determined from Table 13-3, page 13-6

Exact wall configuration depends upon type selected

Figure 14-10. Plan view of a revetment for fixed-wing aircraft

5. Repeat the material computations shown for preliminary design-gravity revetment, Condition I.

Linear feet of sheathing required: (Number of aircraft x 2 x L) = 10 x 2 x 52= 1,040 linear feet or 104 10-foot sections.

Sheathing area:

10H per 10-foot section = (10 x 9) x 104 = 9,360 square feet < 12,000 square feet.

Vertical supports (dimensional lumber, using the formula in Table 14-6, page 14-17):

11(H + 2) per 10-foot section = 11(9 + 2) x 104 = 12,584 linear feet < 14,000 feet.

6. Determine the thickness of protective material. Use a PRF of 1.00 (Tables 14-1 and 14-2, pages 14-2 and 14-3, or Figure P-4, page P-5) for 90-millimeter ammunition, which requires 42 inches of dry sand for penetration resistance. Round up to the nearest foot to yield 48 inches (4 feet).

7. Determine the volume of filler material.

= 0.4 (thickness x height (TH) + ($H^2/2$) per 10-foot section.
= 0.4 {4 X 9 + ($9^2/2$)} X 104 = 3,182 cubic yards.

8. Determine spacing of revetments.

Calculate the total equivalent weight of explosives from Table 14-5, page 14-14.

7.62 mm—100 x 0.04 = 40 pounds
Rockets—200 x 0.70 = 140 pounds
Total = 180 pounds

Enter the vertical scale of the graph in Figure 14-6 opposite 180 pounds, then proceed horizontally to the intersection of the curves and read on the horizontal scale.

108 feet—intervening walls
170 feet—no walls between aircraft

9. The final design type and dimensions follow:

Gravity revetment, dimensioned timber:

Sheathing—Height-9 feet
Length-52 feet

Protective material:

Thickness—48 inches (top); 11-foot base, assuming a 45-degree angle of repose for sand

Fortification spacing:

108 feet—intervening walls
170 feet—no walls between aircraft

DESIGN OF THIN-WALLED REVETMENTS

Thin-walled revetments have been developed for protection of attack, utility, and cargo-type helicopters. These revetments have plywood or corrugated metal walls and contain 12 inches of soil fill. Thin-walled revetments may be post-supported or freestanding. Post-supported revetments use either timber or pipe posts and are designed primarily for protection of cargo-type helicopters. Freestanding revetments are designed for protection of utility and attack helicopters. They provide protection from fragmentation of near misses (10 meters) from mortars and artillery rounds up to 155 millimeters. Thin-walled revetments (12 inches thick) require less fill material, space, equipment, and construction time than thick-walled revetments (4 feet or more). See Table 14-4, page 14-13, for approximate dimensions in accordance with the degree of protection desired. Detailed construction drawings can be found in FM 5-103 and TM 5-302-1.

Post-Supported Revetments

The following points should be kept in mind when constructing post-supported revetments:

Postholes. Holes for both timber and pipe posts should be as large as practical. Alignment will be easier if a truck-mounted hole borer with a 22-inch-diameter bit is used.

Depth of posts. Table 14-7, page 14-22, shows the depths that posts should be sunk in soil and concrete for revetments of various heights.

Use the maximum depths in Table 14-7 for posts in soil or concrete if soil properties are unknown. For tall revetments (9 to 16 feet high), the horizontal bearing area should be increased by attaching 2- x 12-inch lumber (or larger) to both 6-inch dimensions of the 6- x 12-inch timber posts. These attachments should extend from the ground surface to the bottom of the posts. Ideally, the stabilization of the posts will be improved by 25 percent if the horizontal bearing area is increased.

Installation of Walls

Drill holes in the plywood, corrugated-metal wall revetment materials, and horizontal braces on the ground before attaching them to the posts.

Fill Materials

A scoop loader is ideally suited for placing fill material. Tamp periodically while placing the fill material to eliminate air pockets and improve the soil's resistance to fragment penetration.

Waterproofing

To minimize the moisture content, cap each completed revetment with membrane, asphalt, concrete, roofing paper, sandbags filled with a soil-cement mixture, or other waterproofing material.

Freestanding Revetment

Freestanding, plywood revetments and freestanding, corrugated-steel revetments may be anchored with arrowhead anchors, screw-type anchors, steel pickets, or wooden or steel stakes. On concrete surfaces, brace the revetments or secure the footings with weights. Safety precautions limit the height of freestanding revetments to a maximum of 6 feet. Specific designs of plywood and corrugated-steel, freestanding revetments are in QSTAG 306. M8A1 landing mat A-shaped and sand-grid revetment designs are in TM 5-302-1. Other designs are presented later in this chapter.

Table 14-7. Post depths

Revetment Height (ft)	Required Depth of Post (ft)	
	Soil	Concrete
5.5	3-4	2
9-11	4-5	3-4
12-16	6	5

Prefabricated, Movable Revetments

An example of a prefabricated, movable revetment is the precast concrete unit. Precast concrete units are high in permanency, low in troop cost, easy to repair, and relocatable. Their physical characteristics vary. The height ranges from 4 to 12 feet. The width varies with the height of the unit, but the maximum width at the base of the concrete unit is 5.5 feet. The length of the precast unit is 8 feet for heights up to and including 9 feet. Note that rotor strike may occur on the utility-type helicopter if this type revetment is more than 5.5 feet. Figures 14-11 and 14-12 show two types of relocatable, precast, concrete revetments.

CONSTRUCTION PROCEDURES FOR REVETMENTS

Construction procedures in this section are for the following fortifications:

- Standoff.
- Sandbag revetments.
- Sand-grid revetments.
- Main structure, gravity revetments.
- Main structure, earth revetments.
- Main structure, bulkhead revetments.
- Main structure, freestanding wall.

Construction drawings for these revetments are found in TM 5-302-1. A quality-control checklist for revetment construction is also included.

Make the layout of a fortification with a transit, if available. Otherwise, lay out the fortification using a compass and tape.

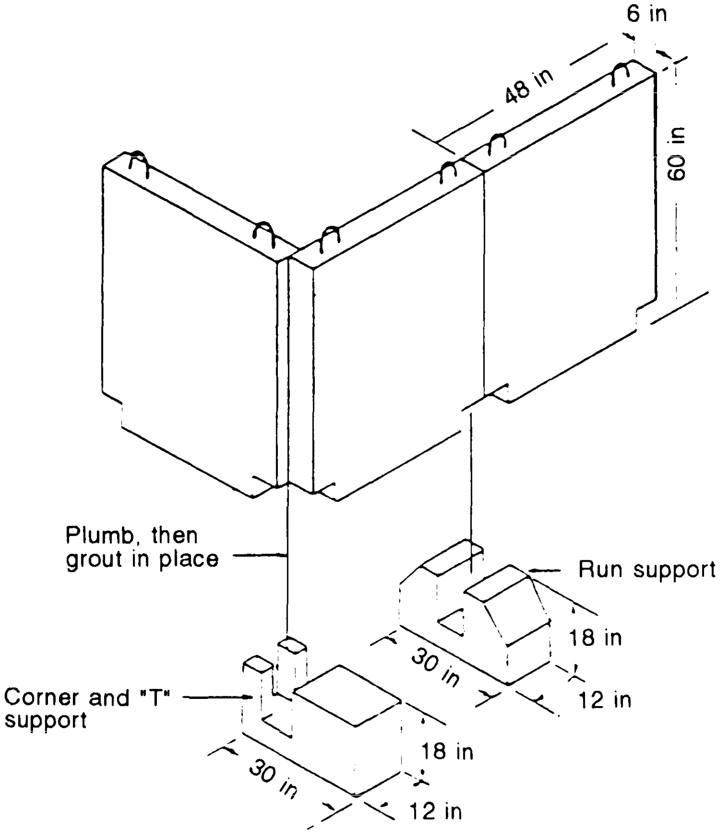


Figure 14-11. Movable, precast, concrete revetment with movable 4- to 9.5-foot sections

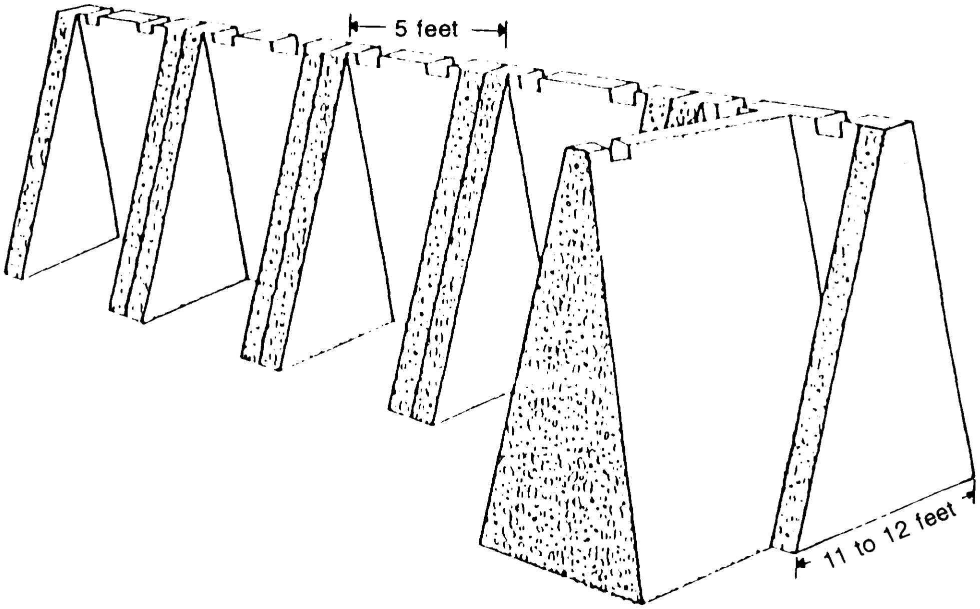


Figure 14-12. Movable, precast, concrete revetment with movable 11- to 12-foot sections

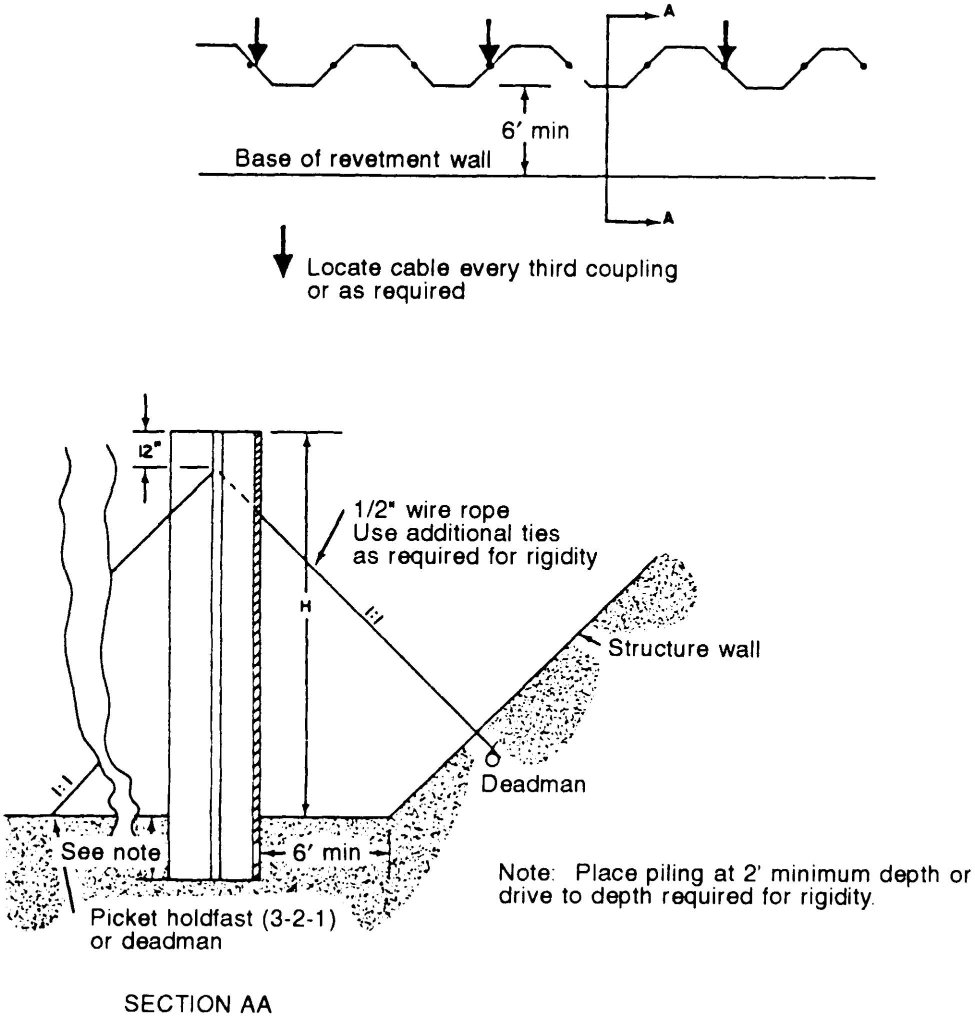
Standoffs

The use of a standoff is optional but desirable. See Figures 14-13 through 14-16, pages 14-24 through 14-27, for details.

Drainage. Install a temporary drainage system for the area during construction. Incorporate this system into the final drainage plan. See Chapter 6, FM 5-430-00-1/AFPAM 32-8013, Vol 1, for drainage details.

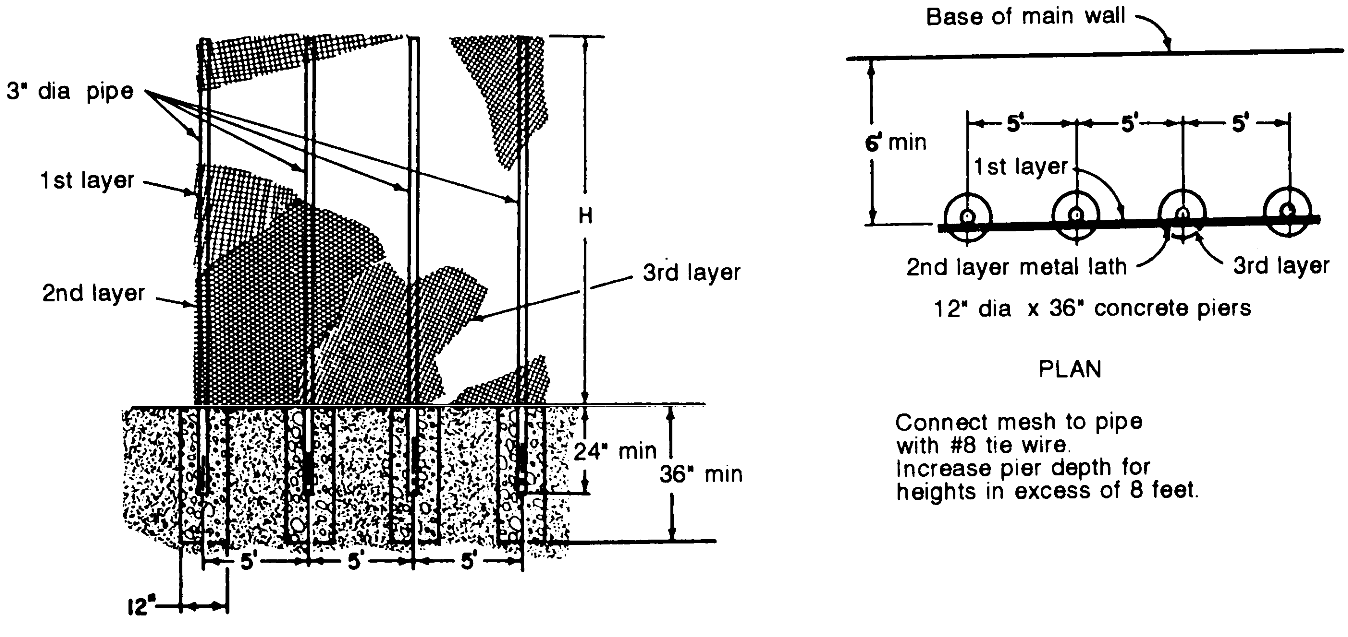
Assembly details. Standoff walls may be constructed using mass production procedures. For dimensional timber, assemble the walls on the ground before erecting them. The framing consists of vertical and horizontal structural members and/or temporary scabbing. Framing is assembled as the first step in retaining-wall construction. The sheathing is attached after the frame is constructed. If logs are used instead of dimensional timber in framing the wall or standoff, the exterior or exposed horizontal members are laid out first. The two rows of vertical logs are attached next. Finally, the interior horizontal members and sheathing are attached, which completes the assembly of the rigid wall for erection.

After the sheathing is attached to the frame, apply the waterproofing agent, mark anchor points on the walls, and adjust the anchorages.



Note: Place piling at 2' minimum depth or drive to depth required for rigidity.

Figure 14-13. Standoff construction using steel sheet pile - Condition II



SIDE VIEW

PLAN

Connect mesh to pipe with #8 tie wire. Increase pier depth for heights in excess of 8 feet.

Figure 14-14. Standoff construction using expanded metal lath - Condition II

Postholes. Dig postholes and construct anchor points concurrently. Temporary anchorages may be required until construction of the main wall is completed.

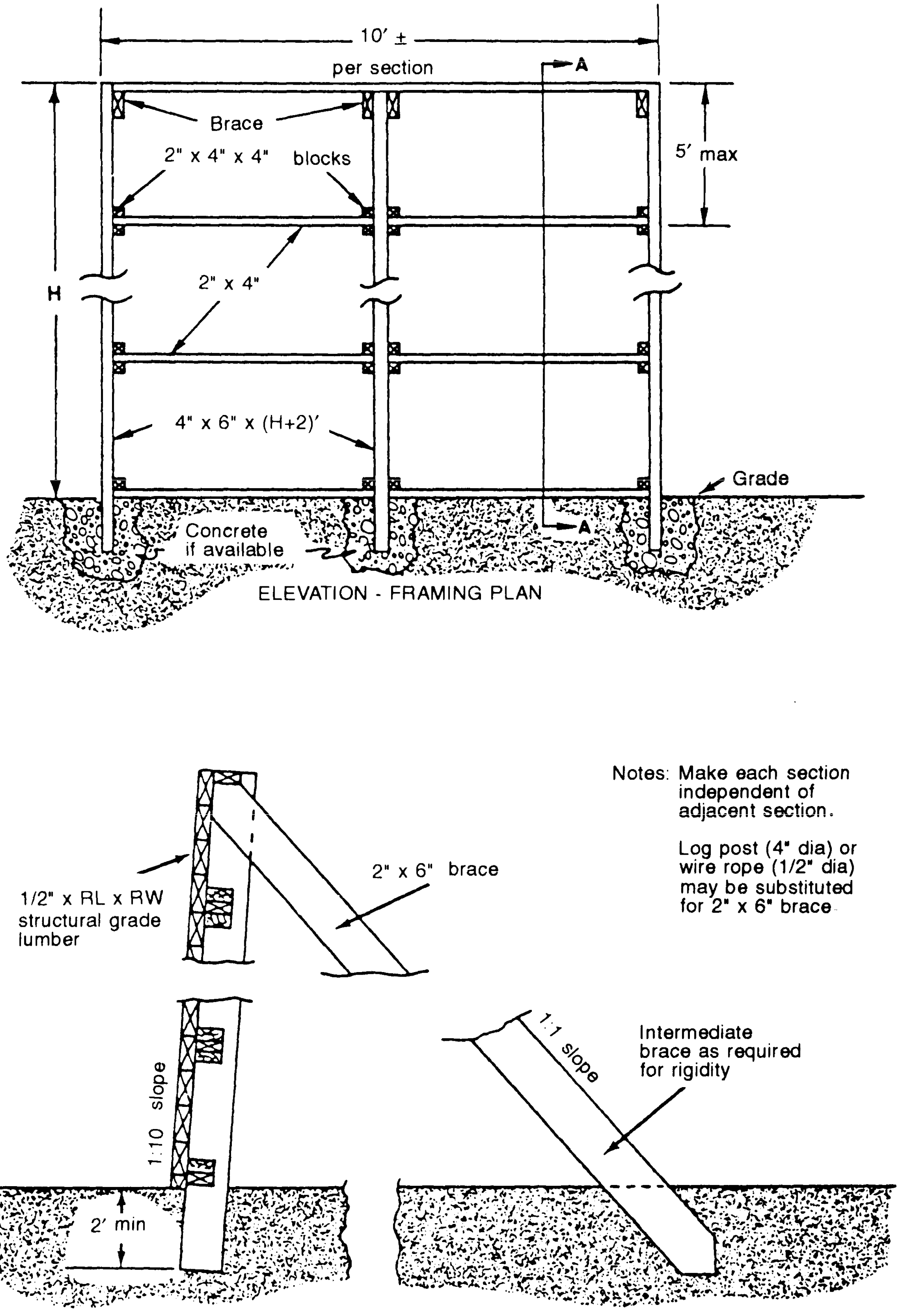
Erection. After each section is completed, transport it to the erection site and tilt it into position. Place each section so that a gap of about 1/2 inch is left between it and the adjoining section to facilitate repairs and reduce combat damage.

Anchorages. Loosely attach anchor cables and supports and align the wall. Once aligned, tighten the cables and supports and backfill the postholes, preferably with concrete. Figures 14-17 and 14-18, pages 14-28 and 14-29, show anchorage details.

Final drainage. Inspect, repair, or improve the temporary drainage structures and incorporate them into the permanent system.

Sandbag Revetments

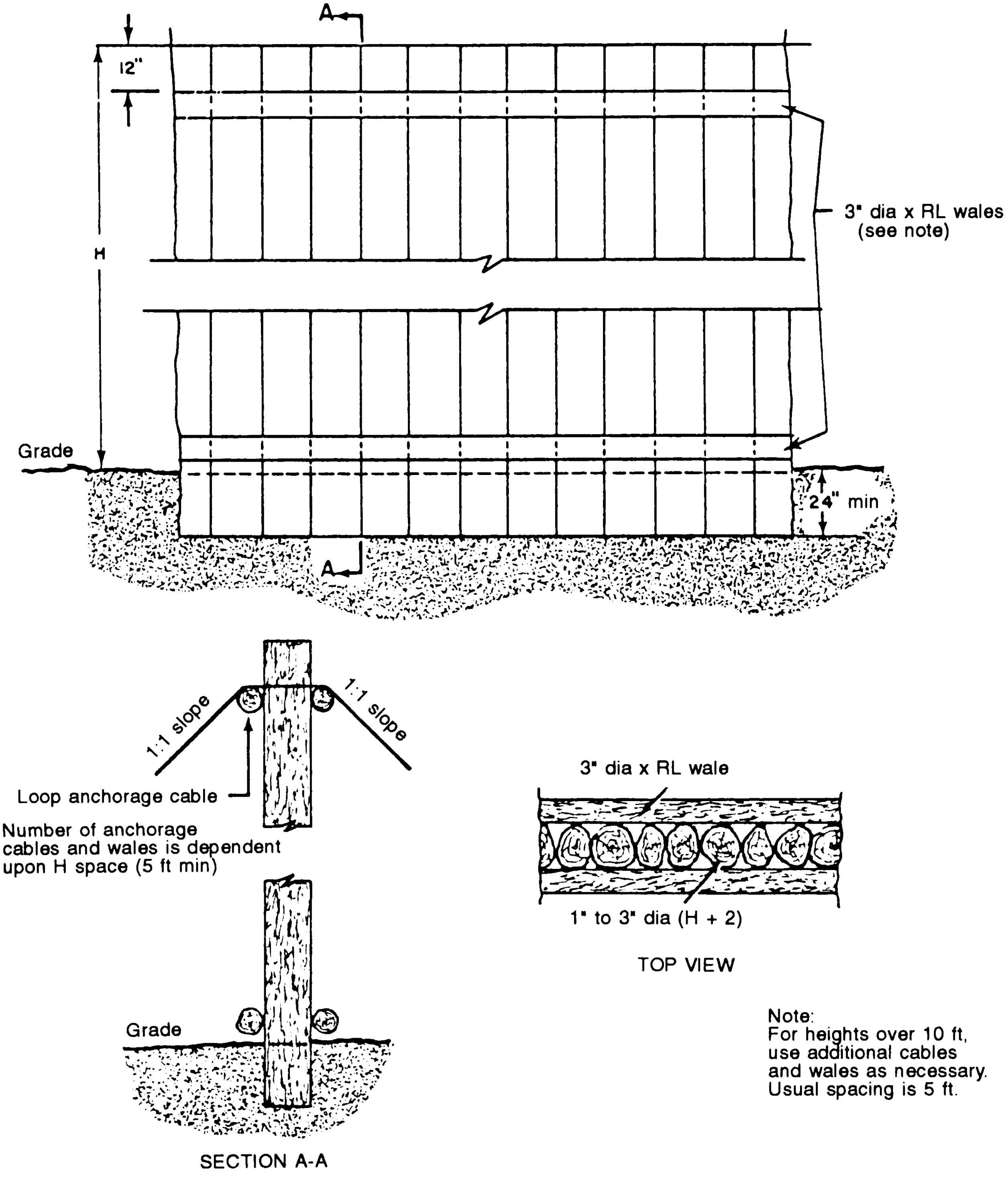
Revetments constructed with filled sandbags are a practical expedient for fortifications, particularly when equipment is limited to hand tools or when skilled personnel are not available to supervise the construction of other types of protective structures. Fill the bags at the construction site with sand hauled to the location. The bags also can be filled where the sand is available and hauled to the site; however, this procedure is less preferable because the bags may be damaged during handling.



Notes: Make each section independent of adjacent section.

Log post (4" dia) or wire rope (1/2" dia) may be substituted for 2" x 6" brace.

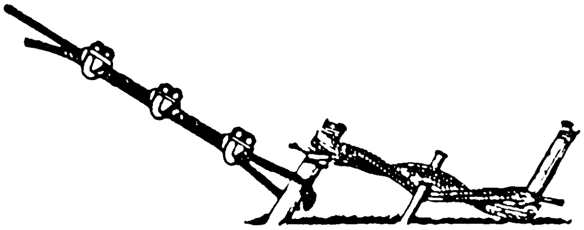
Figure 14-15. Standoff construction using dimensioned lumber - Condition III



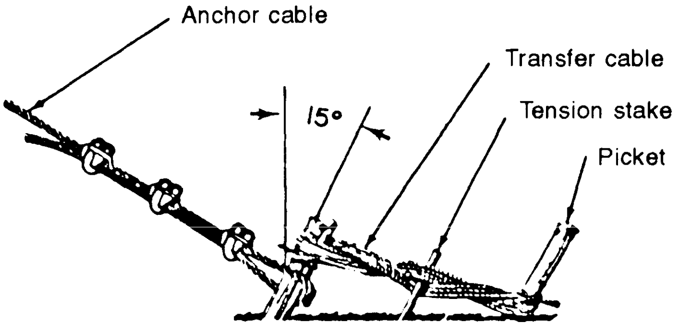
Note:
For heights over 10 ft, use additional cables and wales as necessary. Usual spacing is 5 ft.

Figure 14-16. Standoff construction using logs - Condition III

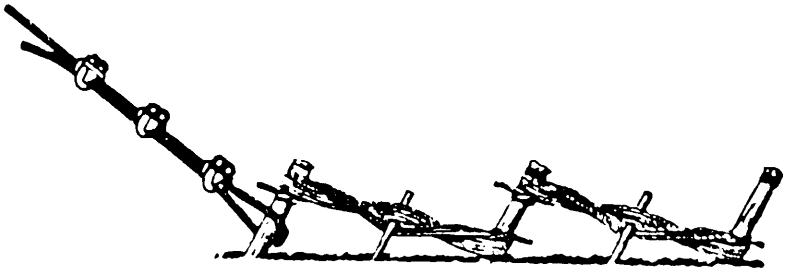
Wall Height (H)	Combination	Anchor or Tie Cable (Wire Rope) Size
10"	1-1	1/4"
12"	1-1	1/4"
14"	2-1 or 1-1-1	1/4"
16"	2-1 or 1-1-1	5/16"
18"	3-2-1	5/16"
20"	3-2-1	5/16"
22"	3-2-1	3/8"
24"	3-2-1	3/8"
26"	3-2-1	3/8"
28"	3-2-1	7/16"
30"	3-2-1	7/16"



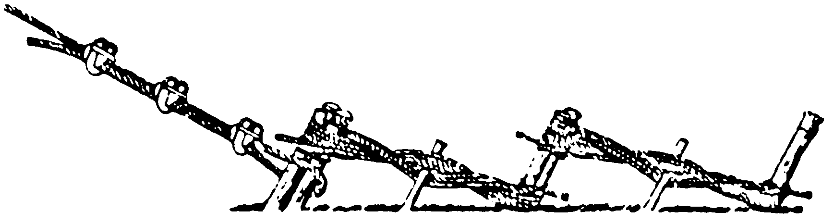
1-1 COMBINATION



2-1 COMBINATION

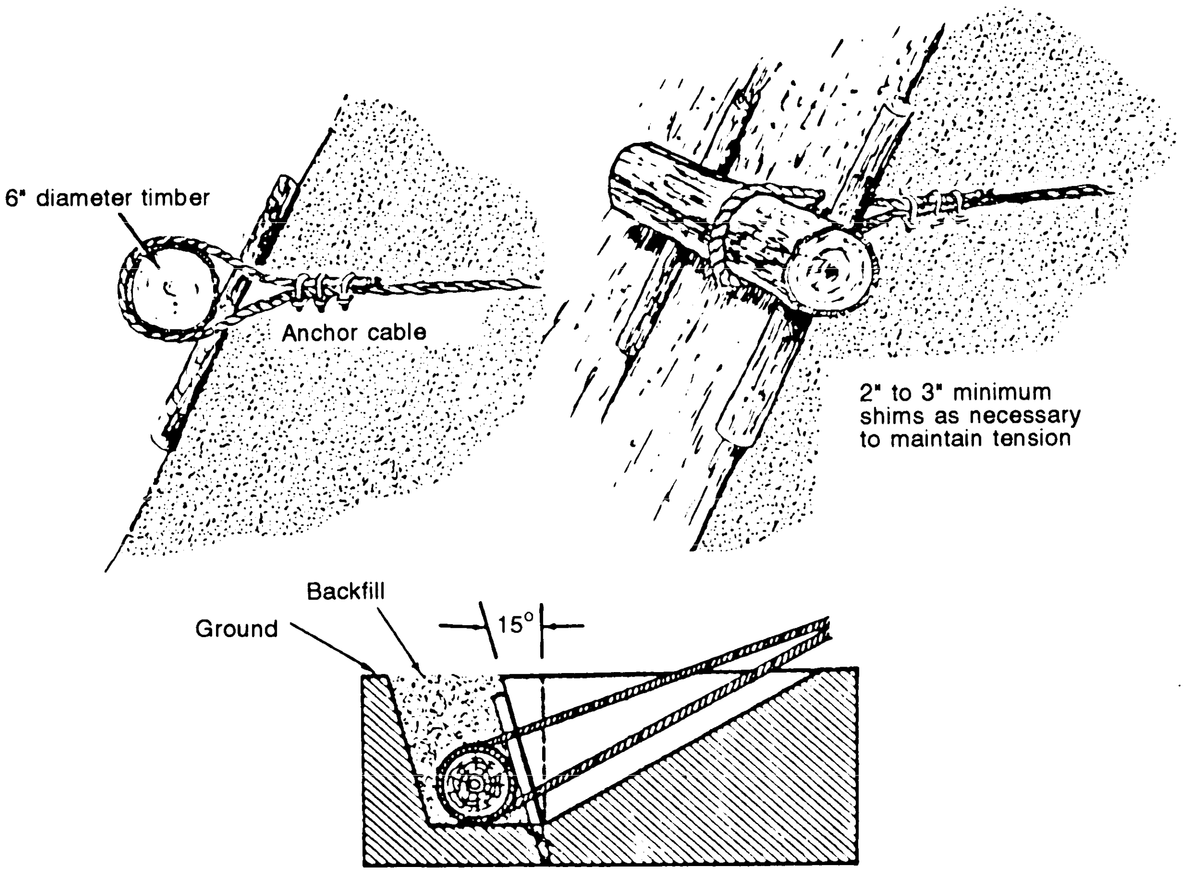


1-1-1 COMBINATION



3-2-1 COMBINATION

Figure 14-17. Anchorage detail of picket holdfasts and wire rope sizes



LOG DEADMAN

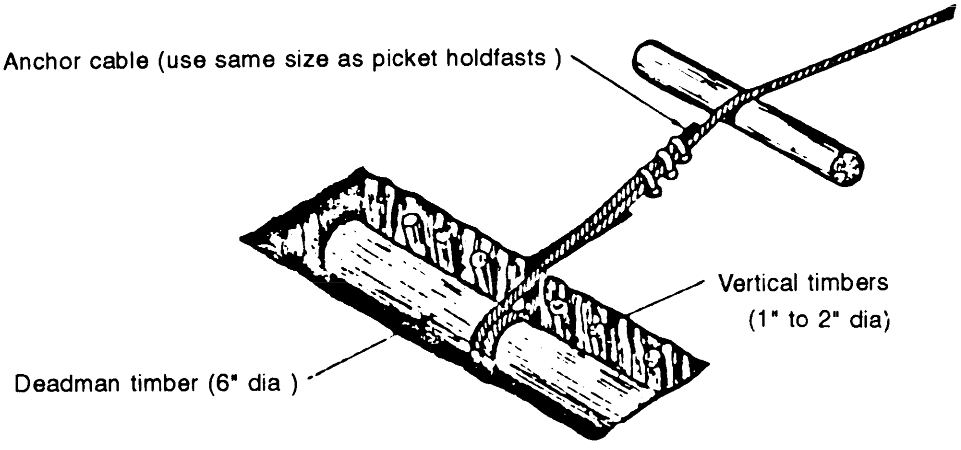


Figure 14-18. Anchorage detail of a log deadman

A disadvantage of sandbag revetments is that the bags deteriorate rapidly, particularly in damp climates. Thus, the filler material may run out, reducing the protective characteristics and endangering the stability of the revetment. Shell hits may require replacement of bags. Figure 14-19 shows the proper construction for a sandbag revetment.

Material. Loose soil is required for effective sandbag revetments. A procedure for stacking bags is shown in Figure 14-19. Stack sandbags without a retaining wall if the sides of the stacks are sloped approximately 1:5. The substitution of a soil-cement mixture described previously partially overcomes the disadvantage of burlap bag deterioration.

Stadoffs. A standoff provides substantially more protection when used to augment sandbag revetments. Previously discussed construction details are shown in Figures 14-13 through 14-16, pages 14-24 through 14-27.

Drainage. Provide drainage to route water away from the fortification area to reduce settlement and consequent weakening of the revetment.

Sand grid. Sand-grid material can be used to provide an expedient method of constructing field fortifications and revetments. It provides protection up to .50 caliber small-arms fire and blast and fragmentation protection from artillery or mortar rounds and light antitank weapons.

The sand grid should be placed on a firm, level foundation to increase the stability of the fortification constructed. U-pickets are used in each of the four corners of the grid to secure it after the grid has been stretched to the proper length, If the revetment being constructed is longer than one section of grid material, another section of

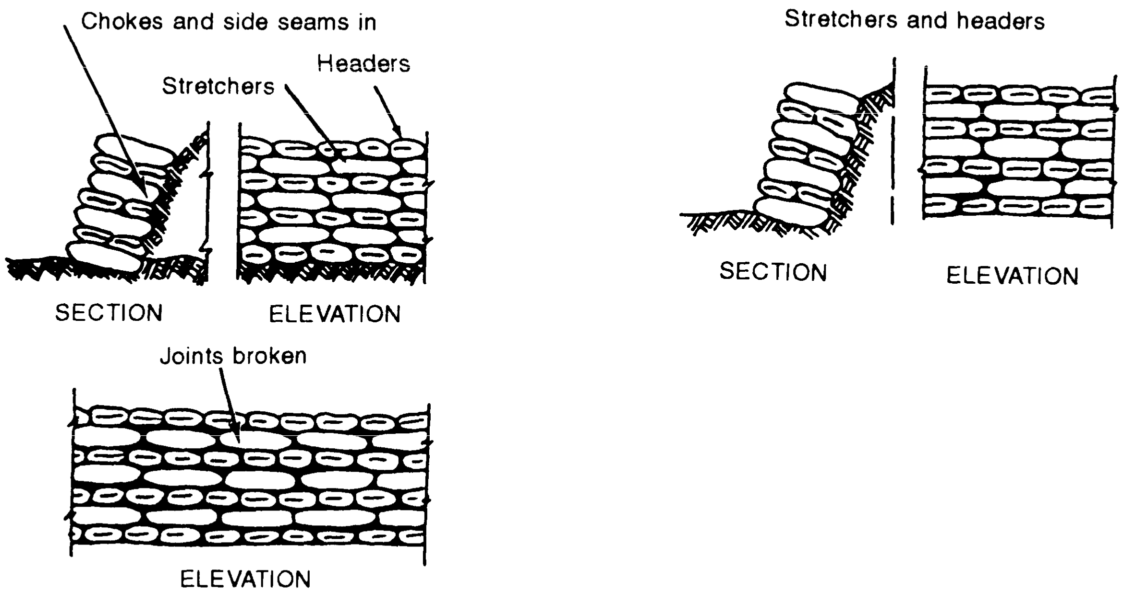


Figure 14-19. Sandbag retaining- wall revetment

grid can be attached to the first. Small holes should be punched in the top and bottom of the plastic and then secured with wire or rope. Soil, sand, or gravel can be used as fill material. Some compaction of the material is advised, especially if the revetment will be over 6 feet tall. After one layer of grid has been filled, it should be leveled in preparation for the next layer. A sheet of filter material, fabric, or plastic should be placed between each layer of grid to provide support for the next grid section and to help prevent excessive fill leakage. The joints of each successive layer should be staggered to provide additional stability, and total height should not exceed nine layers of grid. Figure 14-20, page 14-32, illustrates the steps of sand-grid construction.

Main Structure, Gravity Revetments

Figures 14-8 through 14-10, pages 14-18 through 14-20: Figures 14-13 through 14-18, pages 14-24 through 14-29; and Figures 14-21 through 14-26, pages 14-33 through 14-38, show construction details for these revetments. The construction procedures are the same as for standoffs except for the following special considerations:

- Complete and waterproof the wall sections. Place them upright, align them, and secure them with temporary anchorages, Then, backfill postholes, preferably with concrete.
- Place backfill against the wall in such a manner as to avoid disturbing the alignment. At the specified heights, construct anchorages and place cable and deadmen in the earth fill. Tighten the anchorage cable just enough to preclude movement after work is complete. Remove any temporary anchorage.
- Install the protective waterproof cover or sod after the fill is placed to the specified height and thickness,.

Main Structure, Earth Revetments

See Figure 14-27, page 14-39, for construction details. Apply waterproofing or sod for a protective cover.

Main Structure, Bulkhead Revetments

Refer to Figures 14-8 through 14-10, pages 14-18 through 14-20, and Figures 14-28 through 14-32, pages 14-40 through 14-44, for construction details. The construction procedure is the same as for standoffs, except for the following specific requirements:

- Place the opposing sections upright after both inner and outer wall sections are completed and waterproofing is applied. Use sturdy spacer blocks to hold the walls apart at the specified distances while the tie cables are tightened. Backfill the postholes, preferably with concrete.
- Carefully deposit the filler material to avoid displacing the spacer blocks or damaging the tie cables.
- Apply a waterproof cover and remove any temporary anchor cables.

Main Structure, Freestanding Walls

See Figures 14-33 and 14-34, pages 14-45 and 14-46, for construction details. Install a temporary drainage system for the area during construction. Incorporate this system into the final drainage plan. See Chapter 6 for drainage details and FM 5-742 for the construction method for forms, concrete placement, and form removal.

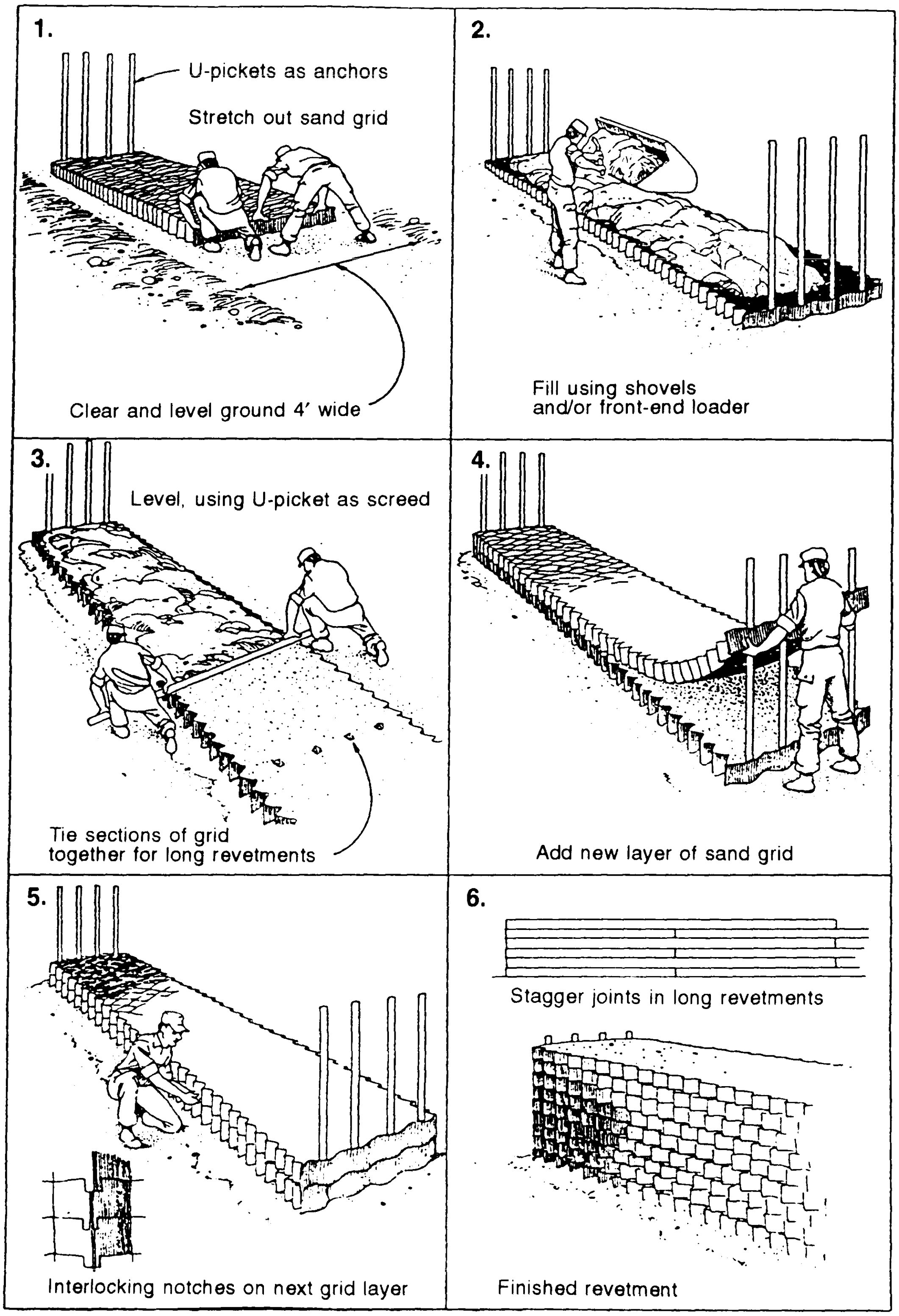


Figure 14-20. Sand-grid construction steps

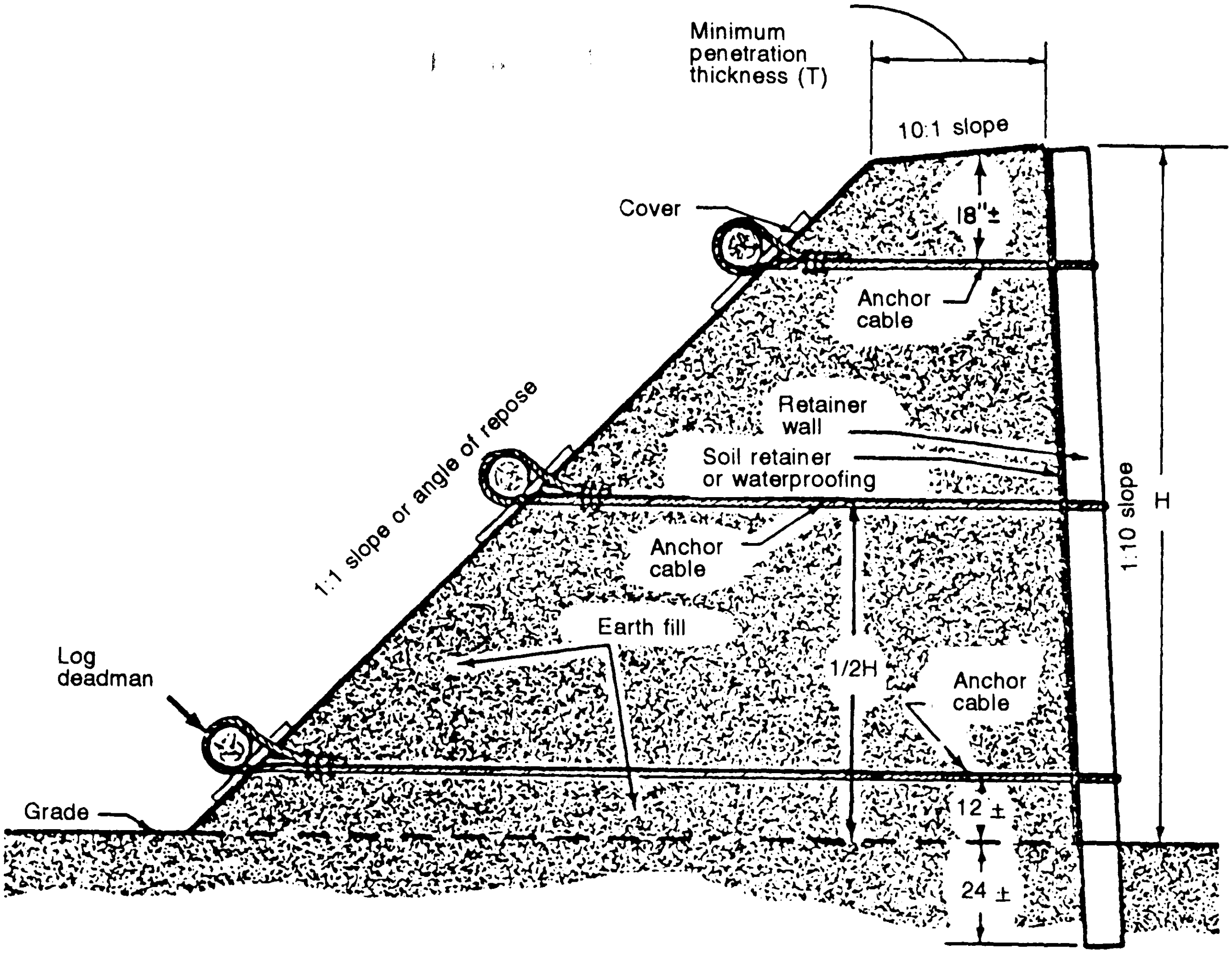


Figure 14-21. Detail of gravity revetment

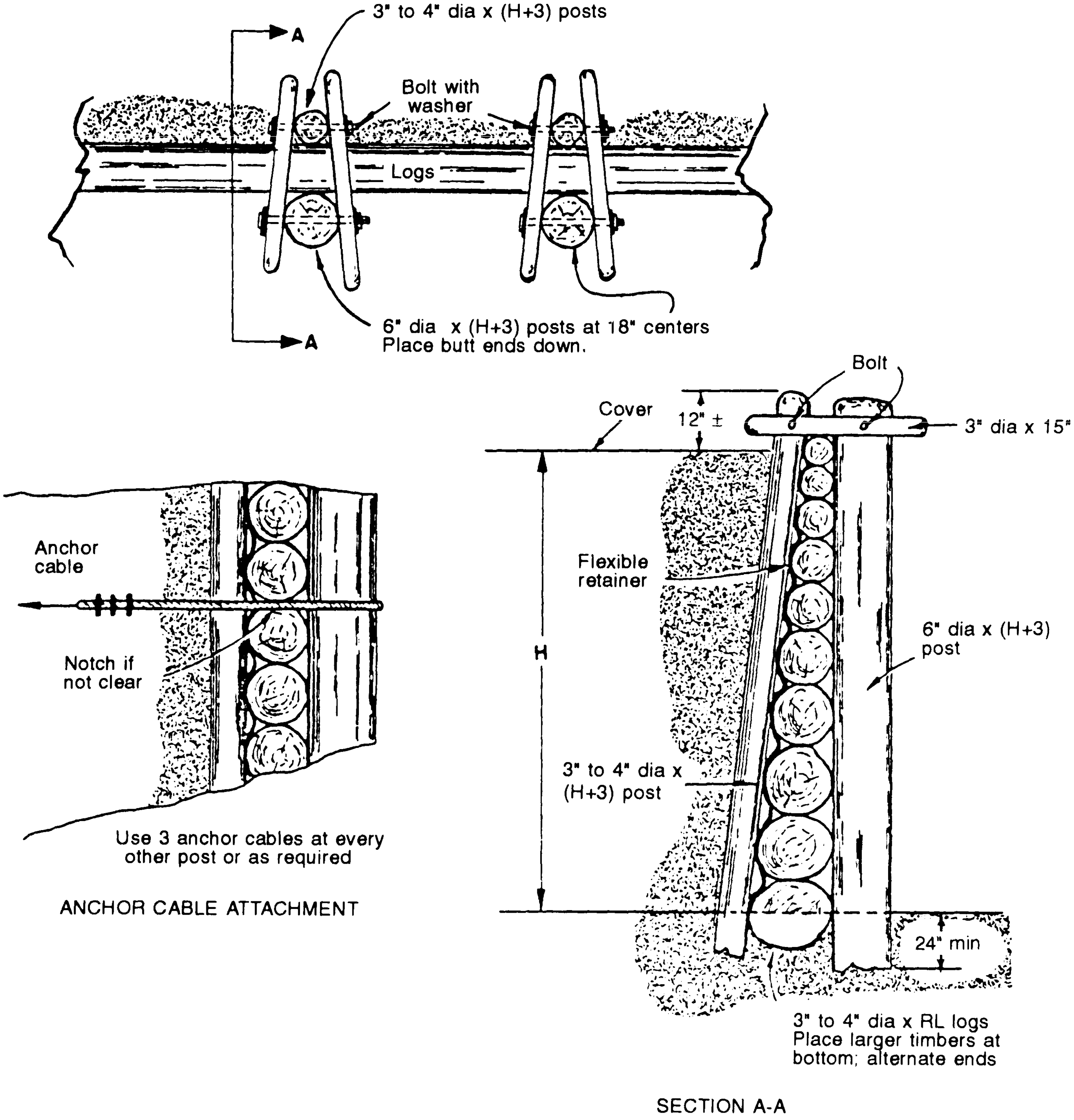
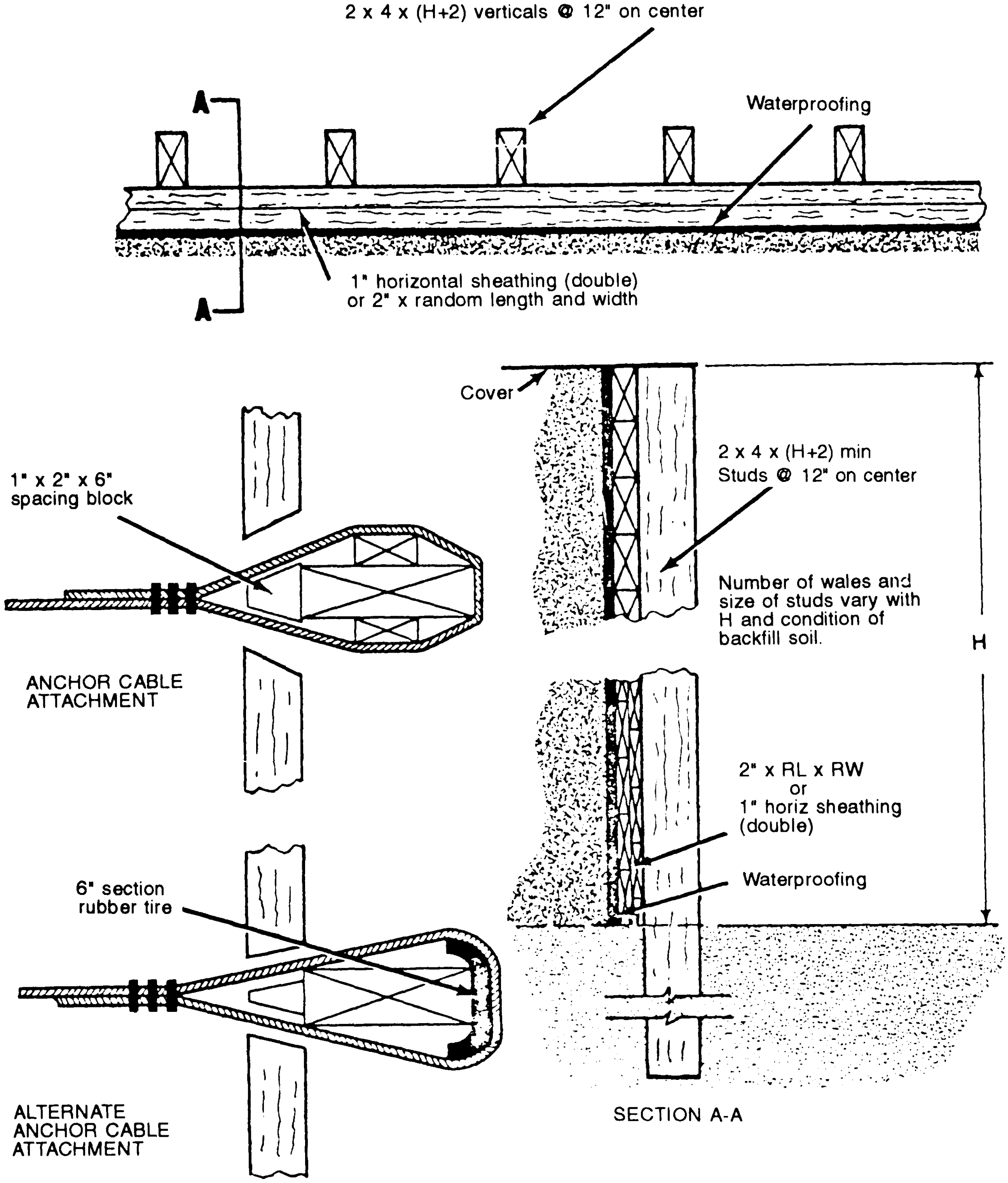
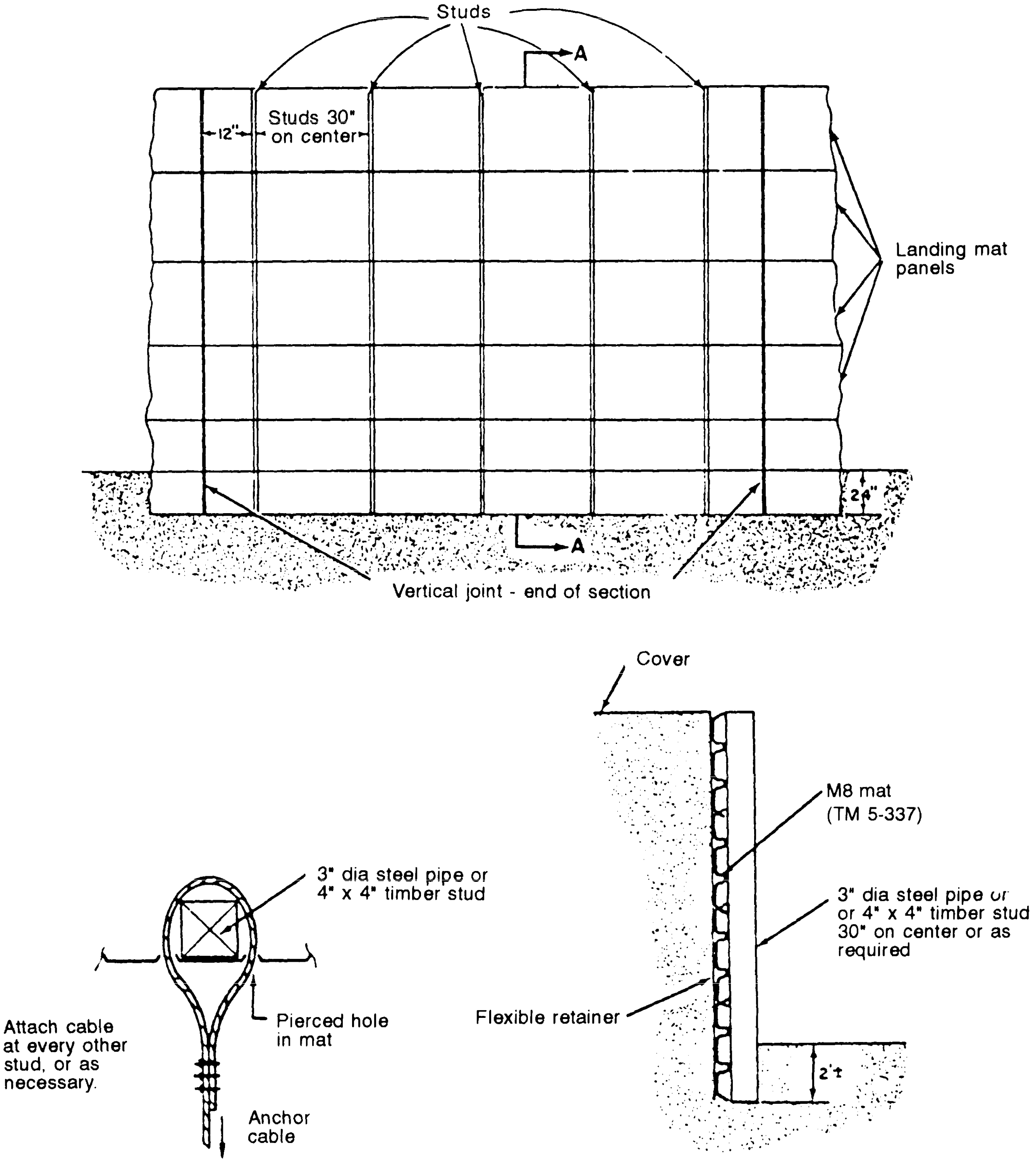


Figure 14-22. Log gravity revetment



Note: Use 1 group of 3 anchor cables on alternate studs.

Figure 14-23. Dimensioned-timber gravity revetment



ANCHOR CABLE ATTACHMENT

SECTION A-A

Figure 14-24. Landing-mat gravity revetment

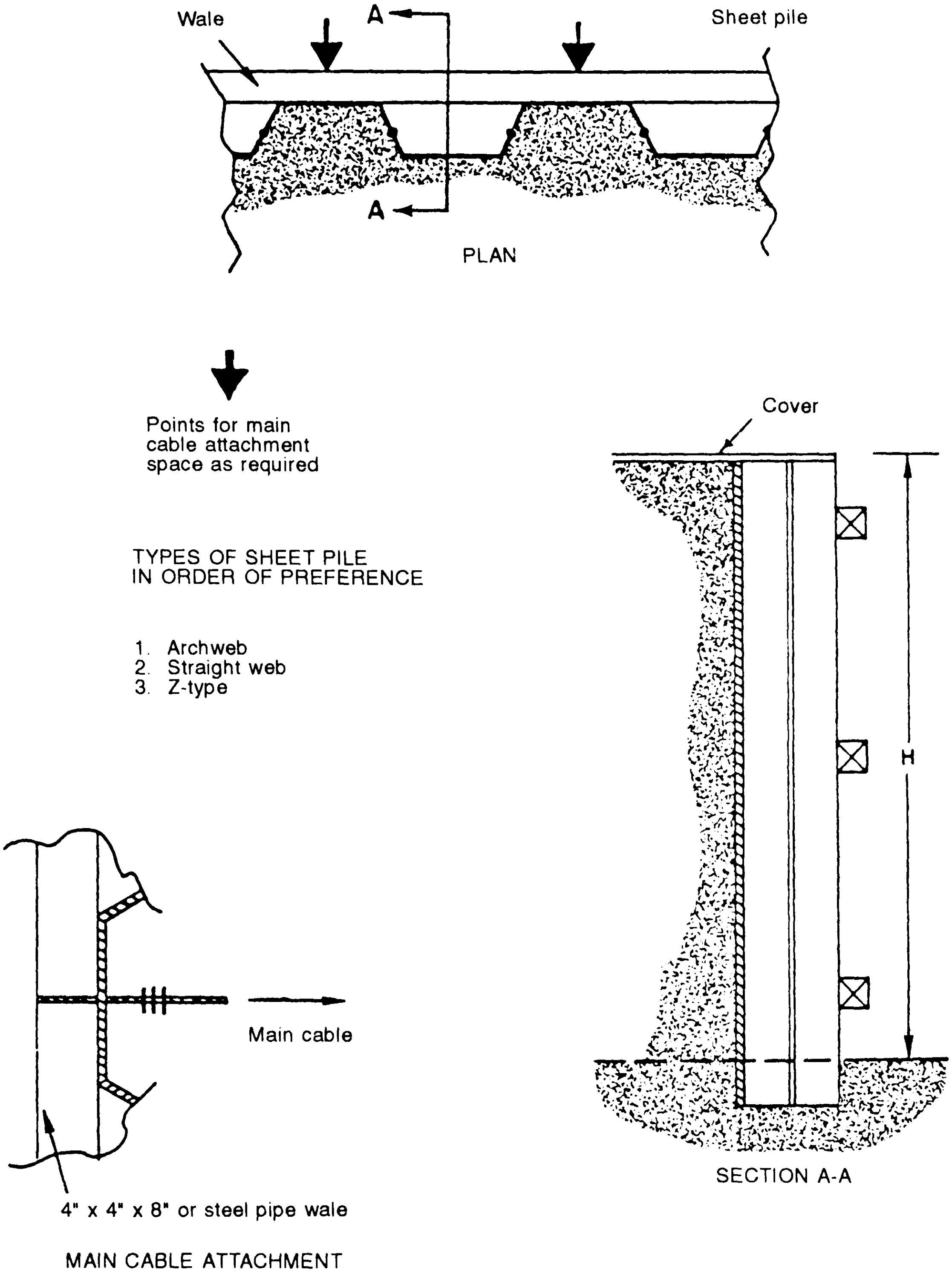
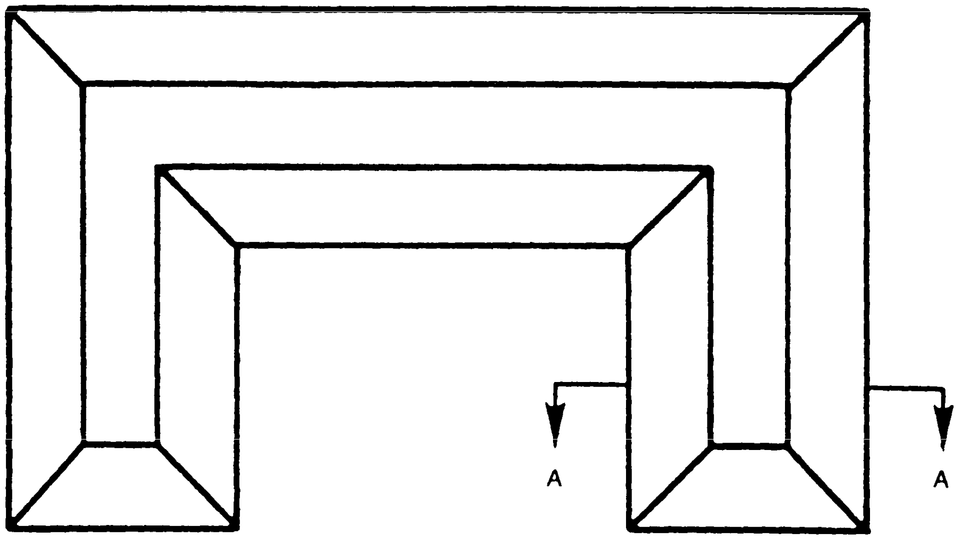
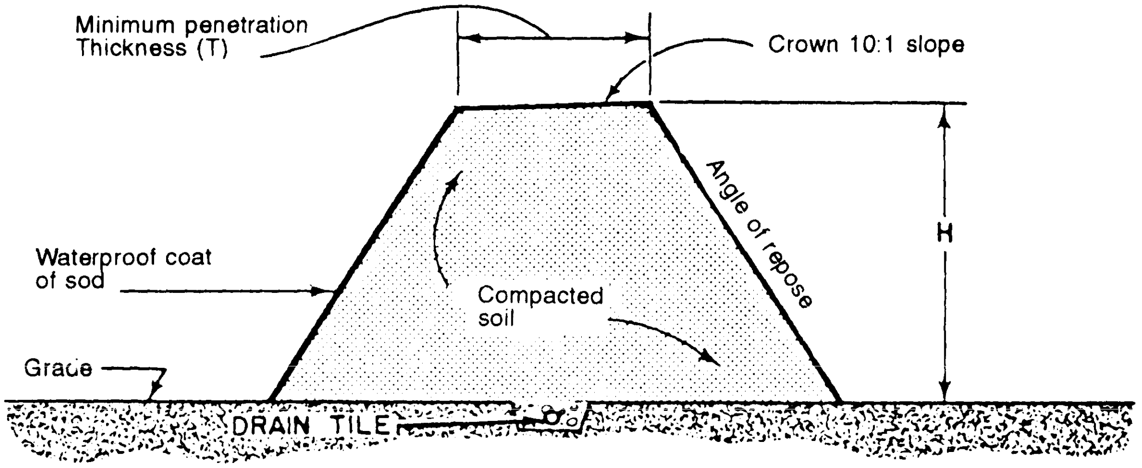


Figure 14-25. Steel sheet-pile gravity revetment



PLAN



SECTION A-A

Note:
Waterproofing may be asphalt cutback or cement slurry. Traffic on the revetment must be prohibited in order to preserve the coating.

Figure 14-26. Earth gravity revetment

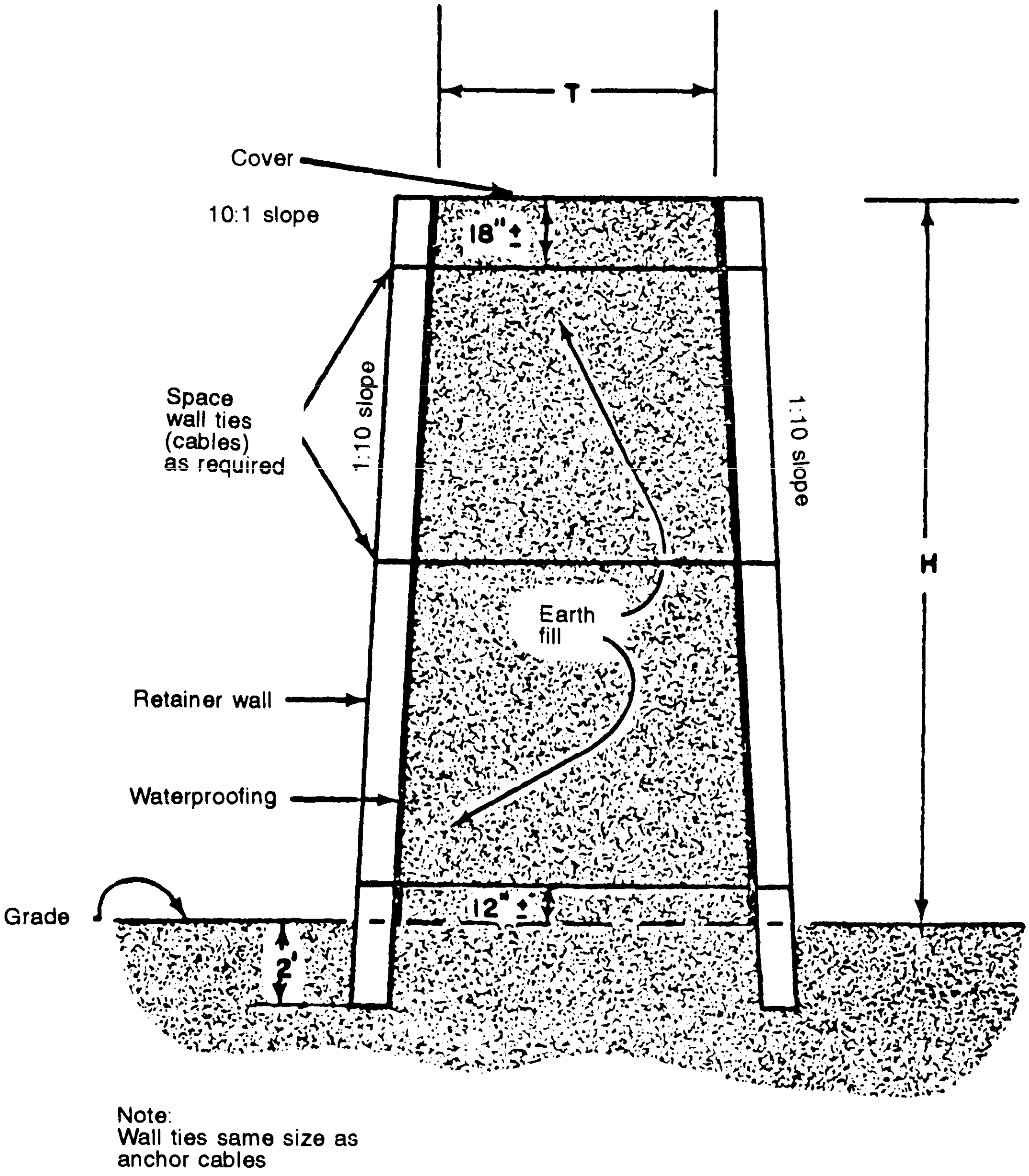


Figure 14-27. Earth gravity revetment

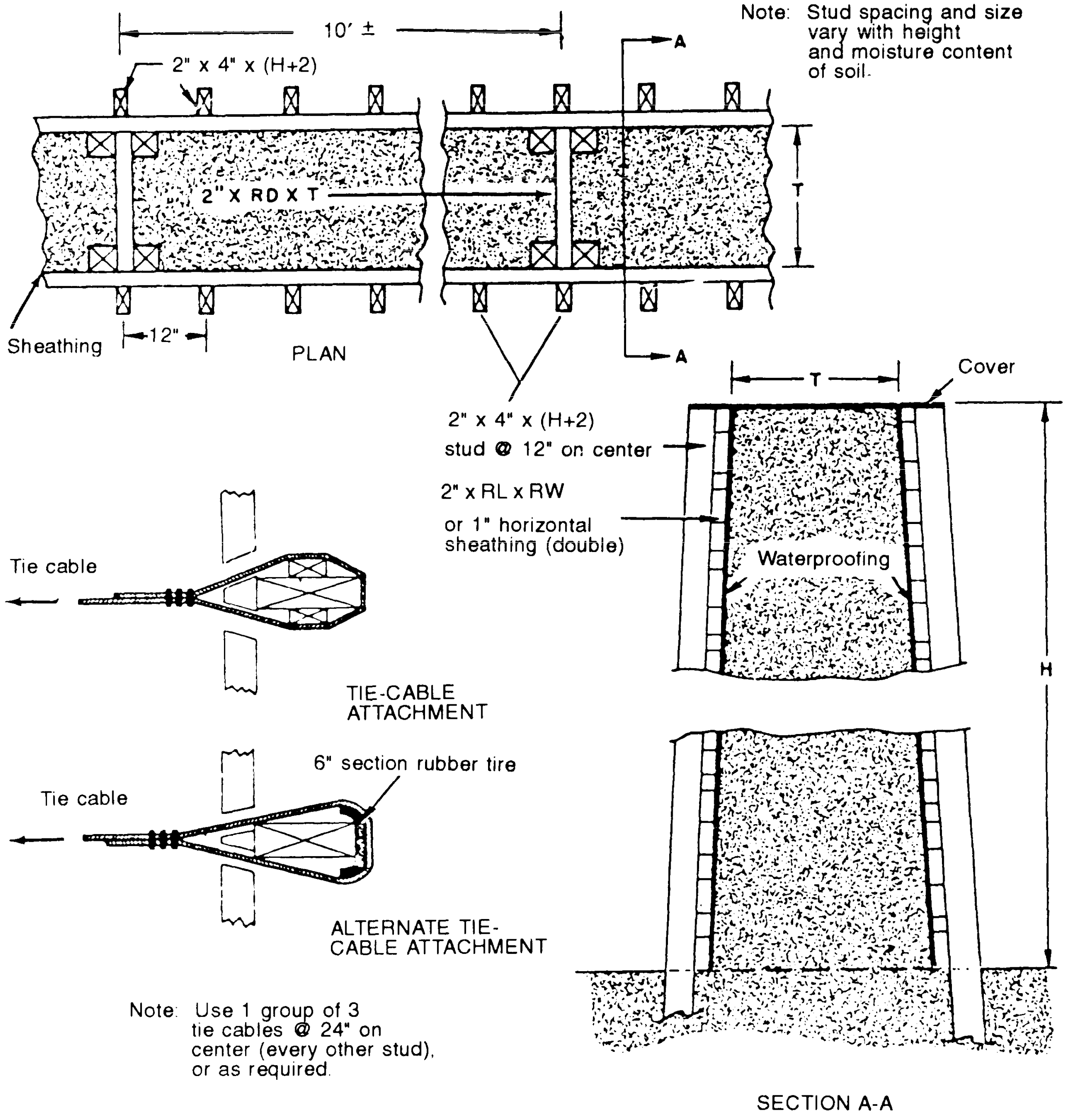
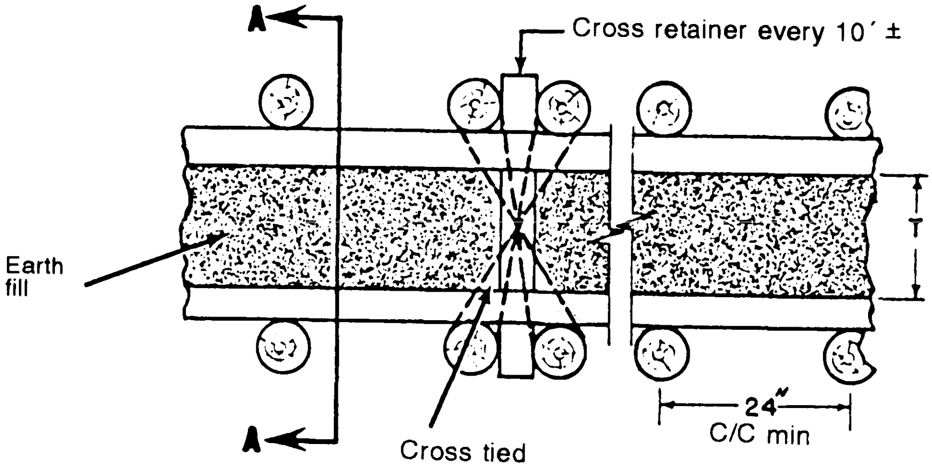
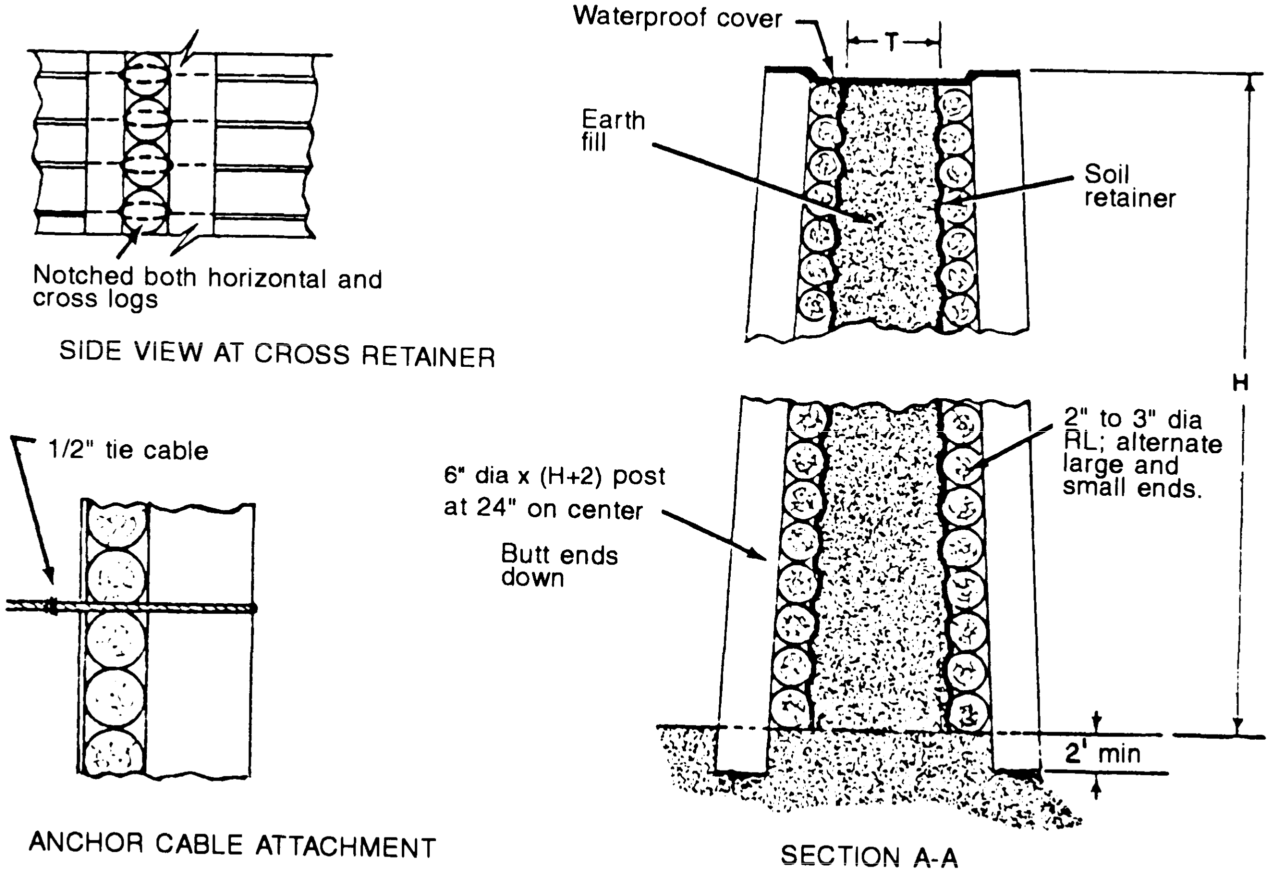


Figure 14-28. Dimensioned-timber bulkhead revetment



PLAN VIEW

Size and spacing of posts vary with height

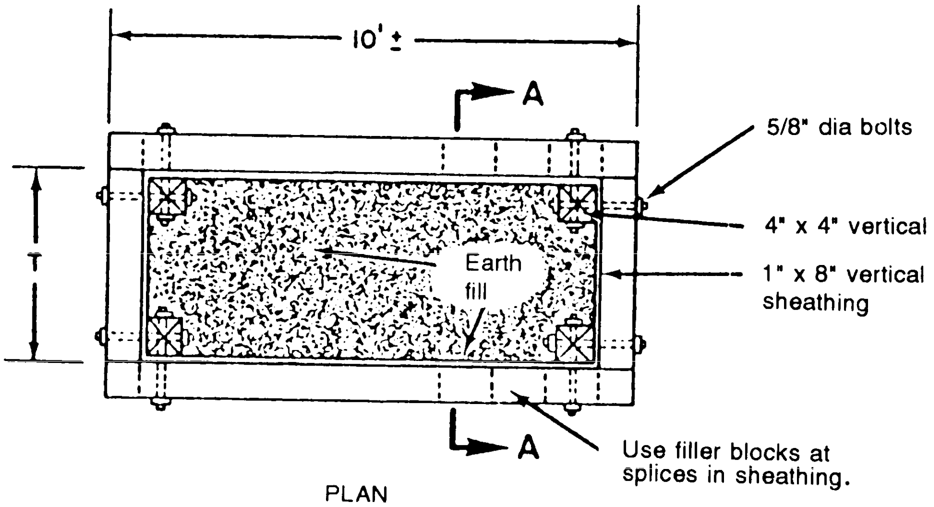


SIDE VIEW AT CROSS RETAINER

ANCHOR CABLE ATTACHMENT

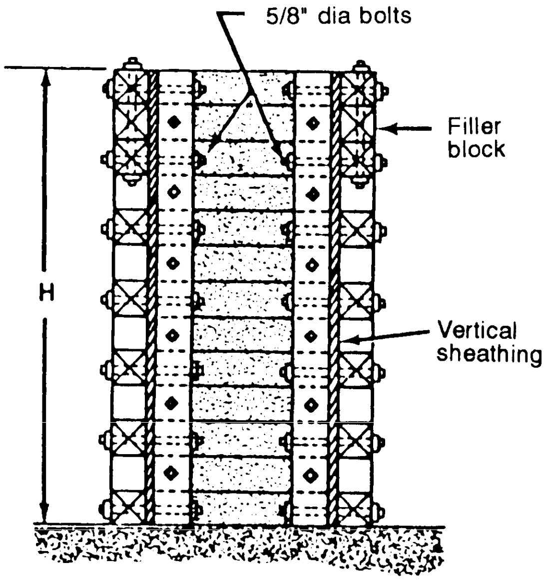
SECTION A-A

Figure 14-29. Log bulkhead revetment



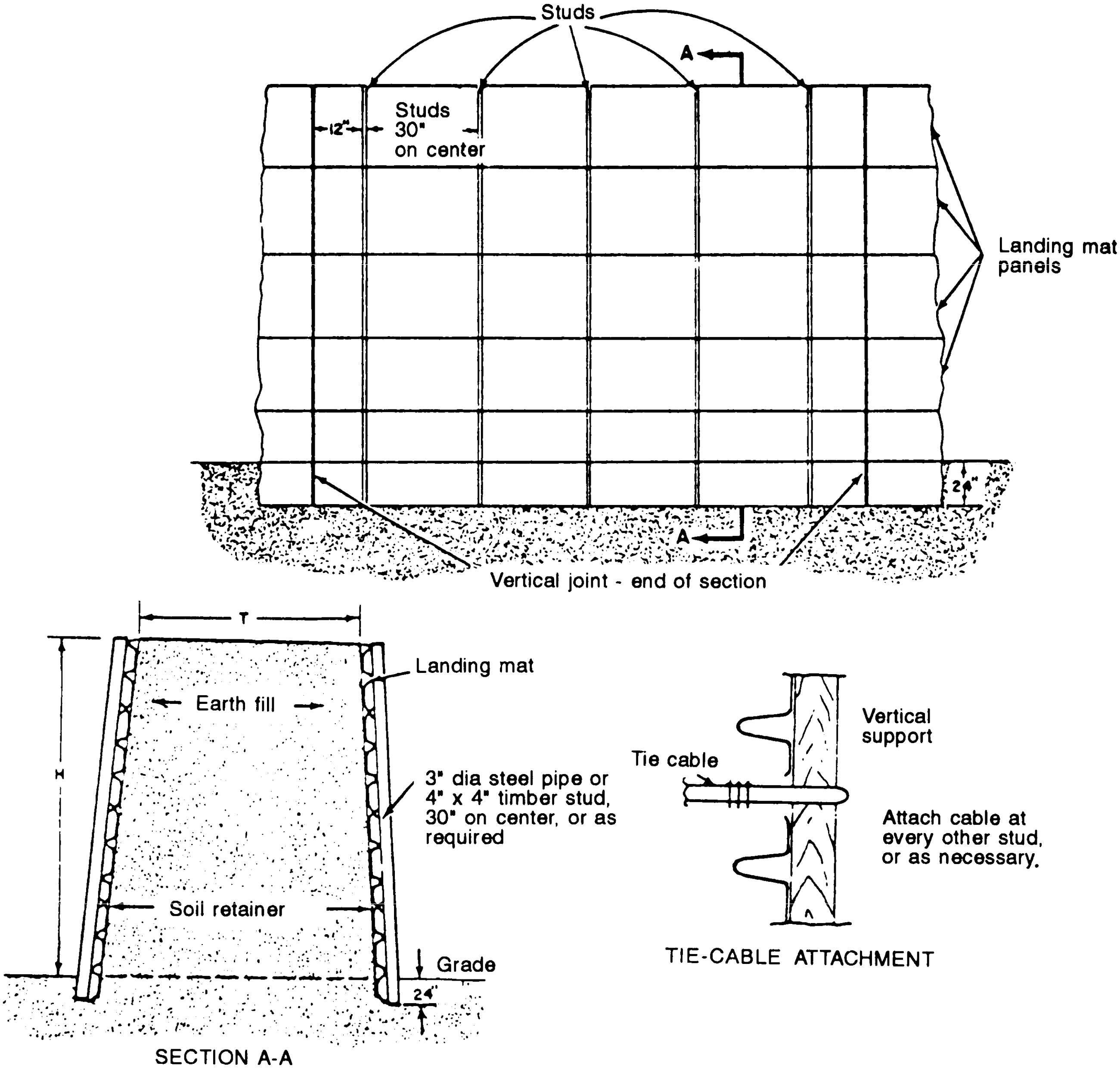
PLAN

Note: Use waterproofing on interior.



SECTION A-A

Figure 14-30. Prefabricated, dimensioned-timber crib used as a bulkhead revetment



SECTION A-A

TIE-CABLE ATTACHMENT

Figure 14-31. Landing-mat bulkhead revetment

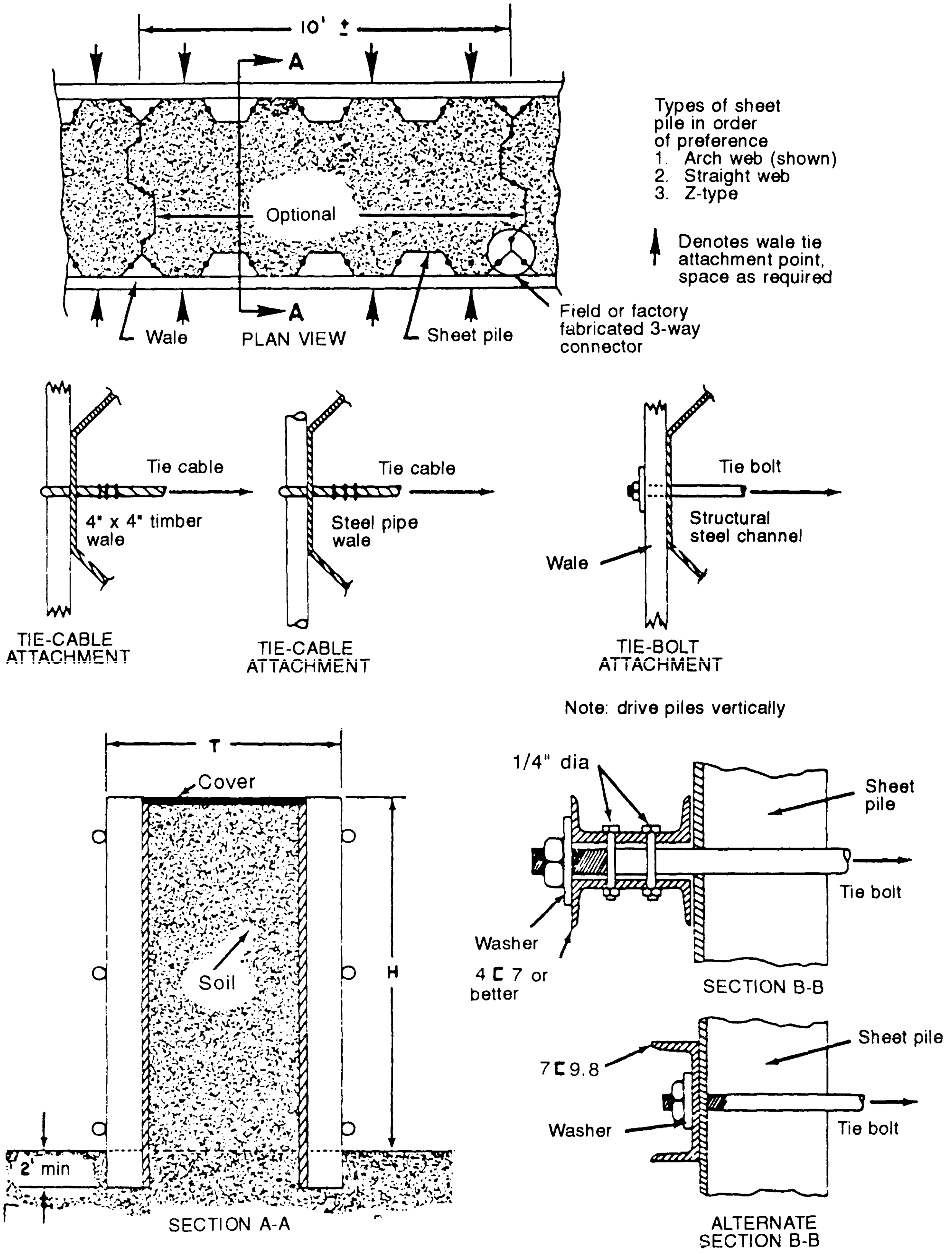
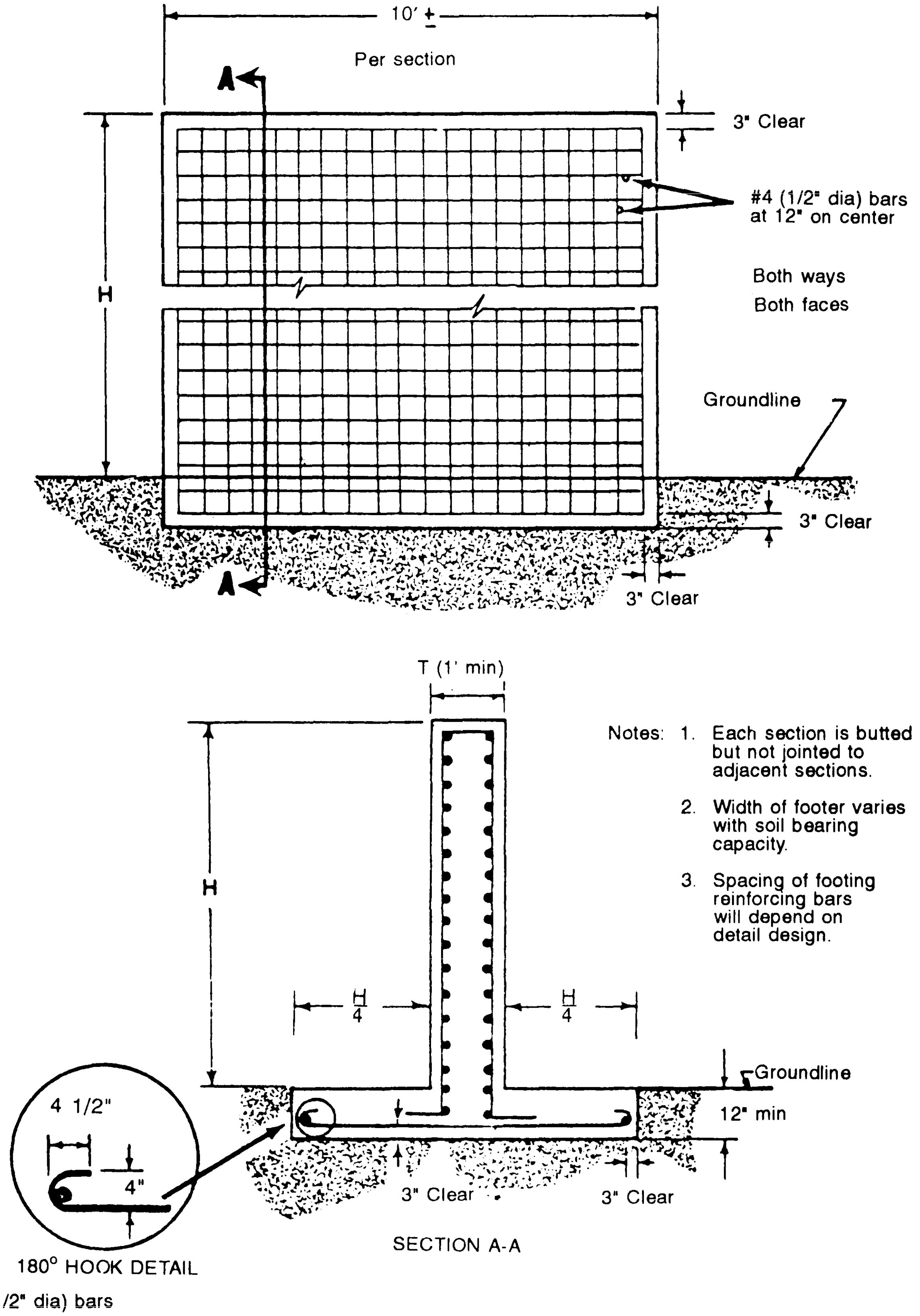


Figure 14-32. Steel sheet-pile bulkhead revetment



Notes:
1. Each section is butted but not jointed to adjacent sections.
2. Width of footer varies with soil bearing capacity.
3. Spacing of footing reinforcing bars will depend on detail design.

Figure 14-33. Reinforced-concrete, free-standing wall

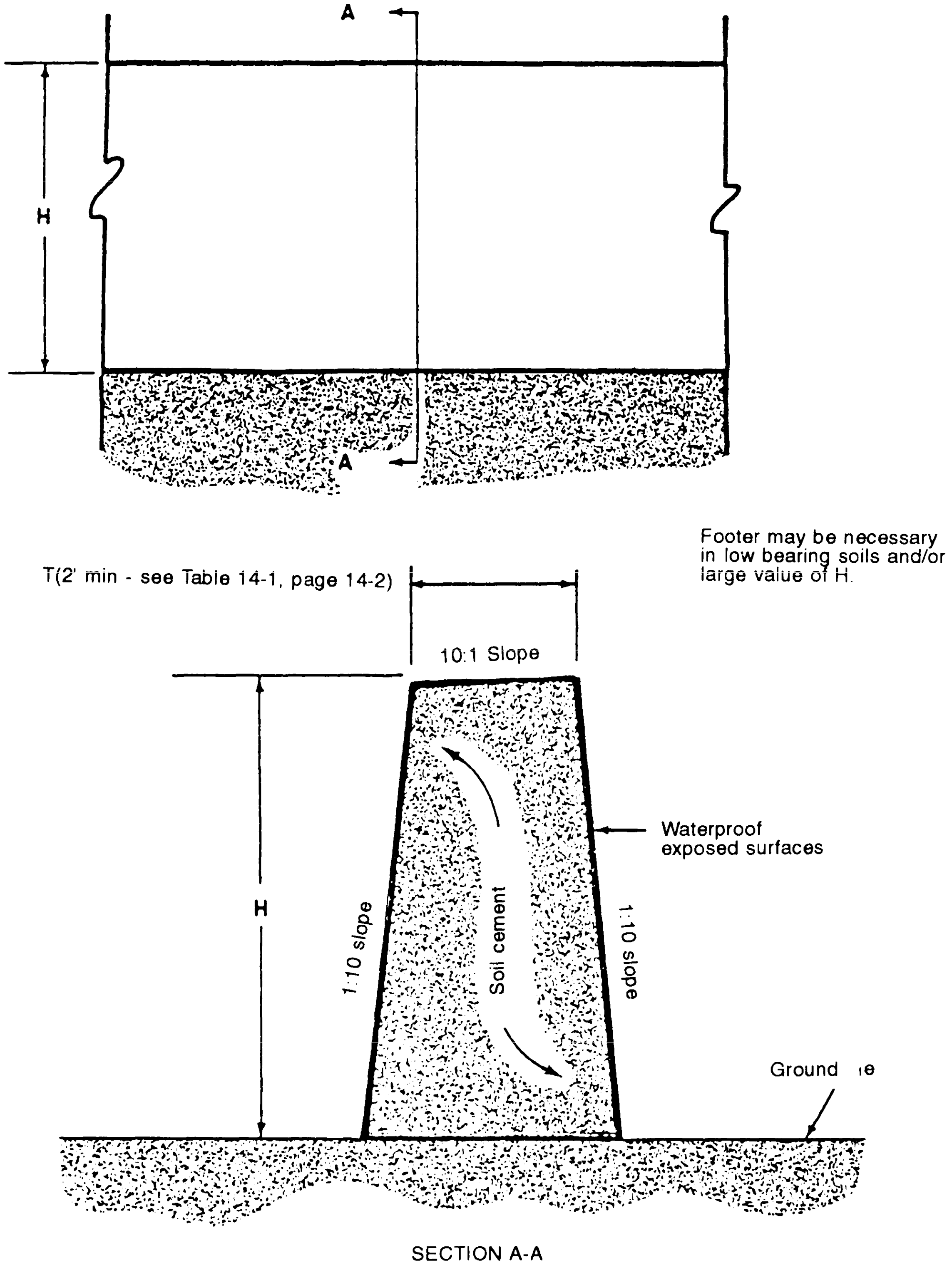


Figure 14-34. Soil-cement, free-standing wall

CONSTRUCTION- CONTROL CHECKLIST

A checklist for the different construction operations follows. Frequent reference to it will assure the supervisor that no important items are overlooked. This list applies to a typical fortification project. Some details may differ from the specific project, but it is a helpful guide when modified for current projects.

1. Preconstruction planning:

☐ Manpower and equipment scheduled for maximum utilization.
☐ Materials (both at the site and distributed).
☐ Structure dimensions determined for interior width, interior height, width of top of wall, width of base of wall, and location and size of openings.

2. Layout criteria (Figures 14-8 through 14-10, pages 14-18 through 14-20):

☐ Centerline established.
☐ Corners located.
☐ Reference points (construction references) established.
☐ Inside wall base established.
☐ Outside wall base established.
☐ Standoff established.
☐ Openings located.

3. Standoff criteria (Figures 14-13 through 14-18, pages 14-24 through 14-29):

☐ Temporary drainage installed.
☐ Assembly line established; construct wall on ground.
☐ Postholes dug.
☐ Anchor points installed: temporary points may be necessary.
☐ Wall tilted into position.
☐ Anchorages and supports attached.
☐ Wall aligned.
☐ Anchorages and supports tightened.
☐ Postholes backfilled.
☐ Temporary drainage structures repaired.

4. Main-structure, gravity-revetment criteria (Figures 14-17 through 14-26, pages 14-28 through 14-38):

☐ Temporary drainage installed.
☐ Assembly line established; construct on the ground.
☐ Postholes dug.
☐ Waterproofing applied.
☐ Wall tilted into position.
☐ Temporary anchorage attached.
☐ Wall aligned.
☐ Temporary anchorage installed.
☐ Postholes backfilled.
☐ Backfilled and permanent anchorages installed concurrently.
☐ Wall alignment checked.
☐ Temporary anchorage removed.
☐ Cover placed.
☐ Drainage structure checked and repaired.
☐ Standoff permanent anchorages installed.

5. Main-structure, earth-revetment criteria (Figure 14-27, page 14-39):

☐ Temporary drainage installed.
☐ Soil placed, compacted, and shaped.
☐ Waterproofing or sod applied to revetment.
☐ Drainage structures checked and repaired.

6. Main-structure, bulkhead criteria (Figures 14-28 through 14-32, pages 14-40 through 14-44):

☐ Temporary drainage installed.
☐ Assembly line for both inner and outer walls established; construct both on the ground.
☐ Postholes dug.
☐ Waterproofing applied.
☐ Walls tilted into position.

Walls aligned.

☐ Spacer blocks correct length.

☐ Spacer blocks installed.

☐ Tie cable tightened.

☐ Postholes backfilled.

☐ Cover placed.

☐ Drainage structures checked and repaired.

☐ Standoff permanent anchorages installed.

7. Main-structure, freestanding-wall criteria (Figures 14-33 and 14-34, pages 14-45 and 14-46):

☐ Temporary drainage installed.

☐ Assembly line for forming established.

☐ Materials at mixer.

☐ Forms stripped when set up.

☐ Curing material applied.

☐ Footing backfilled.

☐ Drainage structures checked and repaired.

☐ Preservative applied after curing.

MAINTENANCE, REPAIRS, AND IMPROVEMENTS

Normal deterioration of construction materials exposed to weather necessitates periodic inspections. Erosion, rot, rust, and poor drainage reduce the protection which fortifications are designed to provide. Timely inspection and repair prevent the need for complete replacement of fortification sections. The following inspections are the minimum required:

- Earth cover, particularly before and during rainy seasons or under other adverse weather conditions.
- Wood members, including walls and horizontal and vertical members, for deterioration.
- Loose vertical supports in the ground, particularly following heavy rains.
- Ditches and pipes, to ensure they are clean and free of debris.
- Headwalls, for settlement or shell damage.

Standoff Repairs

The purpose of a standoff is to detonate shells directed at the fortifications. Therefore, frequent maintenance or replacement of damaged sections is required. Replace damaged sections with prefabricated sections following the construction procedures outlined previously.

Gravity Revetment Repairs

Anchorages shown in construction details provide for deadmen outside the revetment. Complete the following steps to replace a wall section:

1. Remove the damaged retaining-wall section, and disconnect the anchor cable.

2. Remove all soil that has slumped into the interior of the fortification.

3. Construct the replacement-wall sections according to the original specifications.

4. Apply waterproofing material to the wall.

5, Raise the new wall section into place and attach the anchor cable.

6. Backfill new postholes and refill old holes.

7. Fill voids in backfill with suitable soil and apply cover.

8. Repair any damage to the drainage system.

Earth Revetment Repairs

Complete the following steps to repair this type of revetment:

1. Remove earth from the parking area.

2. Replace earth displaced from the revetment.

3. Reshape damaged slopes.

4, Repair waterproof cover or replace sod.

5. Repair any damage to the drainage system.

Bulkhead Revetment Repairs

Complete the following steps to repair this type of revetment:

1. Remove damaged wall sections, disconnect the tie cables, and redig the postholes in the damaged area.
2. Remove all soil that has slumped beyond the wall lines.
3. Construct replacement wall sections as in the original construction.
4. Apply waterproofing.
5. Raise wall sections into place and attach tie cables and spacer blocks.
6. Fill postholes.
7. Fill voids in backfill with suitable soil and apply cover.
8. Repair any damage to the drainage system.

Freestanding, Movable Revetment Repairs

Because these revetments are made of precast concrete, repairs to these structures are described in FM 5-742.

Improvements

Increase the protection provided by aircraft fortifications by adding earth fill and a protective cover to the gravity revetment.

The addition of a steel or wooden standoff to the original construction increases the penetration resistance significantly without disturbing or altering the original construction.

If wet soil is used initially for gravity revetments, the addition of dry soil increases the protective characteristics of the fortification.

Modify bulkhead-type revetments by using the bulkhead as a retaining wall for an earth revetment. This expedient increases the resistance to penetration and increases fortification protection when circumstances preclude the use of a standoff.

Sometimes the serviceability of fortifications must be prolonged. When rapid deterioration of earth-type revetments is apparent, consider constructing permanent-type structures with reinforced concrete or soil-cement walls if the necessary materials, skills, and equipment are available.

APPENDIX I

AIRFIELD CONE PENETROMETER

The airfield cone penetrometer is a probe-type instrument that gives an index of soil strength. It uses a 30-degree, right circular cone with ***a*** *base diameter of 1/2 inch and an indicator that gives a reading directly in terms of an AI.*

The AI then can be used to estimate a CBR value, as shown in FIgure I-1, page 1-2. This correlation has been established to yield values of CBR that generally are conservative. The tendency towards conservatism is necessary because there is no unique relationship between these measurements and a wide range of soil types. The curve should not be used to estimate AI values from the CBR determination because these generally would not be conservative.

BASIC SET

The airfield cone penetrometer must not be confused with the trafficability penetrometer, which is a standard military item included in the soil test set. If the trafficability penetrometer is used to measure the AI, the reading obtained with the 0.2-square-inch cone must be divided by 20, and the readings obtained with the 0.5-square-inch cone must be divided by 50.

The airfield cone penetrometer comes with a carrying case that is 14 3/4 inches long and houses the cone unit and a handle that screws off the base. Two 12 5/8-inch extensions are graduated every 2 inches. and two 11/32-inch wrenches are used to tighten the set in assembly. An extra cone and an extra pin for the handle are also included.

The airfield cone penetrometer is constructed of durable metals and needs little care other than cleaning and oiling. The calibration should be checked occasionally. The load indicator should read *O* when the instrument is suspended by the handle and 15 when a 150-pound load is placed on the handle. If an error of more than 5 percent is noted, the penetrometer should be recalibrated.

The airfield cone penetrometer does well when used in silt or clay. In gravel the readings are meaningless, and the AI is determined for the soil beneath the gravel layer.

Sands require special treatment. Many sands occur in a loose state. When very dry, sands show increasing AIs with depth, but the 2-inch depth index is often low— about AI 3 or 4. Sands can usually support aircraft with requirements much higher than AI 3 or 4 because the strength of the sand increases under the confining action of the aircraft tires. Generally, dry sand or gravel is adequate for aircraft in the C- 130 class, regardless of the penetrometer readings. Avoid sands and gravel in a *quick* condition (water percolating through them). Evaluation of moist sands should be determined by the same method as used for a fine soil.

Because soil conditions are immediately and significantly affected by weather, an evaluation is valid only for the period immediately after measurements are made. However, the evaluation will remain constant as long as the soil moisture content does not change.

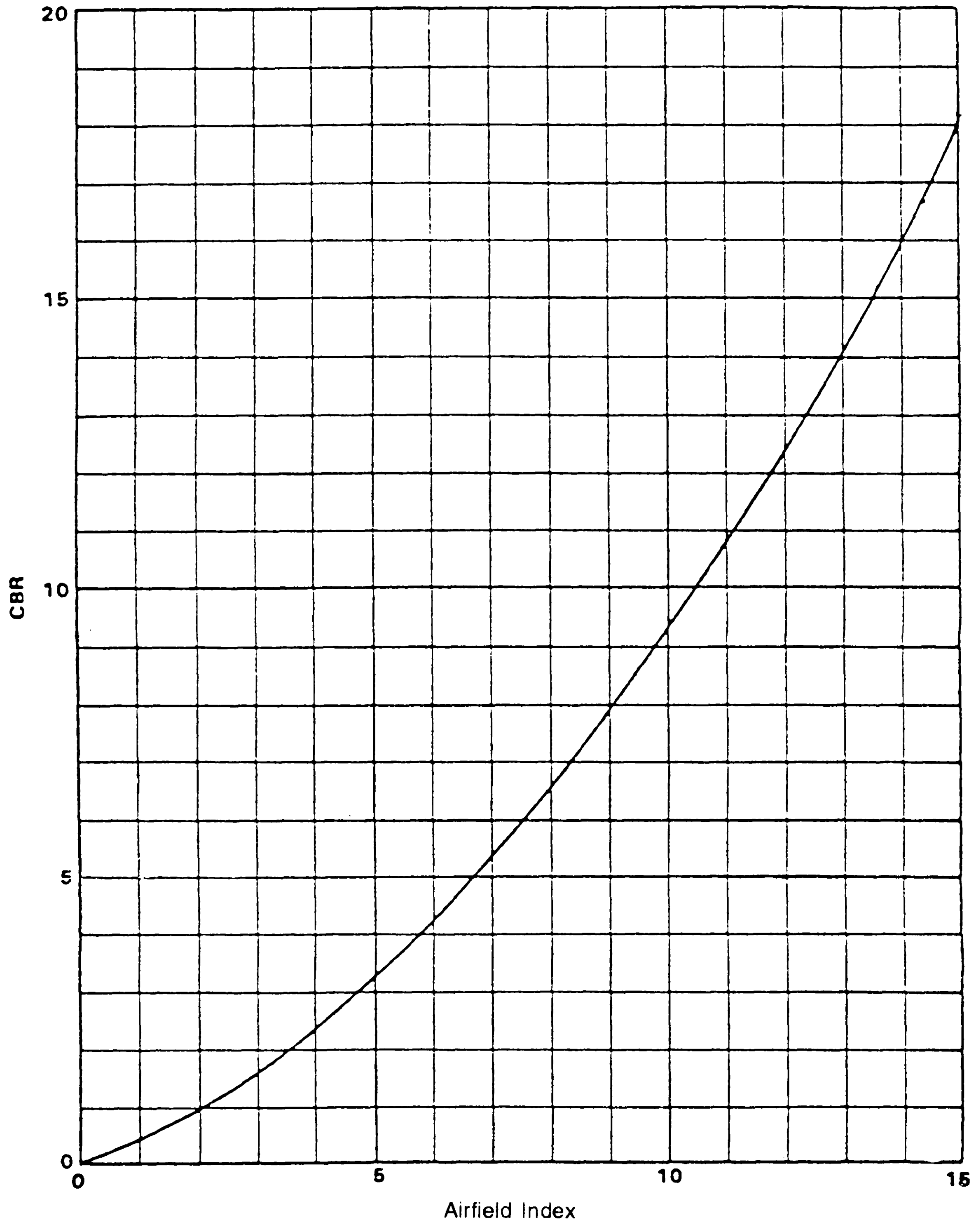


Figure I-1. Correlation of CBR and AI

ASSEMBLY AND OPERATION OF AN AIRFIELD PENETROMETER

To assemble an airfield penetrometer, detach the handle and cone from the housing, attach the staff extension to the housing, and attach the cone to the staff extension. Insert the handle to the top of the housing and tighten the extension using an 11/32-inch wrench. Be careful not to overtighten because excessive force can bend or break the shafts.

Use the following procedures to operate an airfield penetrometer:

1. Inspect for tightness and ensure the handle, cone, and extension are properly attached.

2. Place the penetrometer in a vertical posi tion on the soil, and place hands in a vertical position on the handle.

3. Slowly apply force at a rate of 1/2 inch to 1 inch per second, and penetrate the soil. Take readings at 2-inch increments, up to 24 inches or until a maximum AI (15) is obtained. Discard the 0-inch reading. Record readings in tabular fashion for the engineer's use similar to the sample format shown in Figure I-2, page I-4.

If you suspect the cone is encountering stone or other foreign body at the depth where a reading is desired, make another penetration nearby.

Take five penetrations at each location, using an X configuration in a 12-inch radius circle. Note the readings at each 2-inch increment. Once an AI (15) has been reached, the follow-on depths can be assigned an AI (15) after the following criteria have been satisfied:

A minimum of three sites must be tested to ensure the lower depth has an AI 15 or higher. These tests should be taken at least every 6 inches down to the 24-inch depth or lower for the heaviest C-130 landing and highest pass levels if very low (4) AI values are suggested to exist below the 24-inch depths. An auger may be used to penetrate to the desired depth. At a minimum, one reading must be taken on the turnarounds, the parking apron, and off center on the runway.

If a suspected abnormal layer is present, take enough readings to the 24-inch layer to verify the extent of the area. Since this is the most critical area, the entire atrfield must be evaluated based on the abnormal layer.

4. After the readings at a site have been taken, the readings for each depth at the site are averaged. The critical depth is then determined, and the critical AI is determined by averaging the average readings in the critical depth. After all critical AIs are determined for all sites, the lowest critical AI is assigned for the entire airfield.

5. Determine the surface thickness requirements as described in Chapter 12.

DETERMINATION OF CRITICAL AI RUNWAYS AND TAXI WAYS

1. The first reading will be taken 50 feet from one end of the runway/taxiway on the centerline.

2. Follow-on readings will be read every 200 feet and will be staggered 20 feet off the centerline. This means that if the second reading is 20 feet right of the centerline, the third reading will be 20 feet left of the centerline, and so on.

3. This pattern will be repeated until the midpoint is reached. After the midpoint, the survey team will go to the other end of the runway/taxiway, start the readings 50 feet on center from that end, and repeat the survey pattern back to the midpoint (Figure I-3, page I-5).

PARKING APRONS

1. Locate the center of the area and take the first set of readings.

2. Take the rest of the readings every 200 feet in both directions until the extent of the area has been covered (Figure I-3).

SOIL STRENGTH EVALUATION
AIRFIELD INDEX (AI)

AIRFIELD:
LOCATION:

DATE:

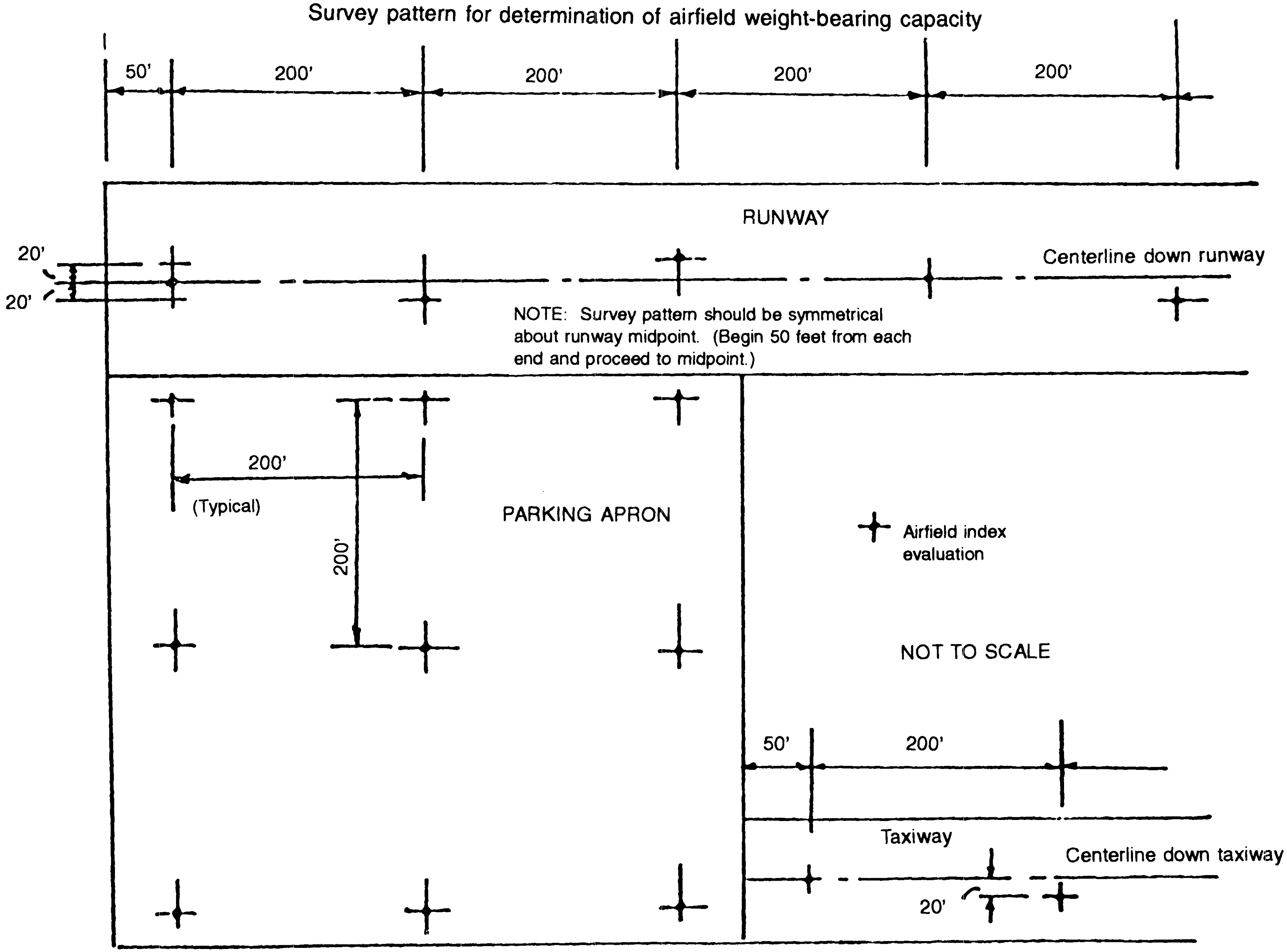
DEPTH	AIRFIELD INDEX	SUM	AVG

CRITICAL DEPTH:

CRITICAL AI:

COMMENTS:

Figure I-2. Sample format for AI data sheet



NOTE: Survey pattern should be symmetrical about runway midpoint. (Begin 50 feet from each end and proceed to midpoint.)

Figure I-3. Survey pattern for taxiways and parking apron

HAMMERHEAD TURNAROUNDS

1. Locate the enter area and take the set of readings.

2. Take the rest of the readings 40 feet in both directions until the extent of the area has been covered (Figure 1-4). A minimum of one reading at the parking apron, runway, and hammerhead must be taken to the 24-inch depth to ensure the soil profile is accurate. If a soft layer is suspected or located beneath a hard, upper layer, take enough readings down to the 24-inch depth to ensure complete and accurate coverage of the area.

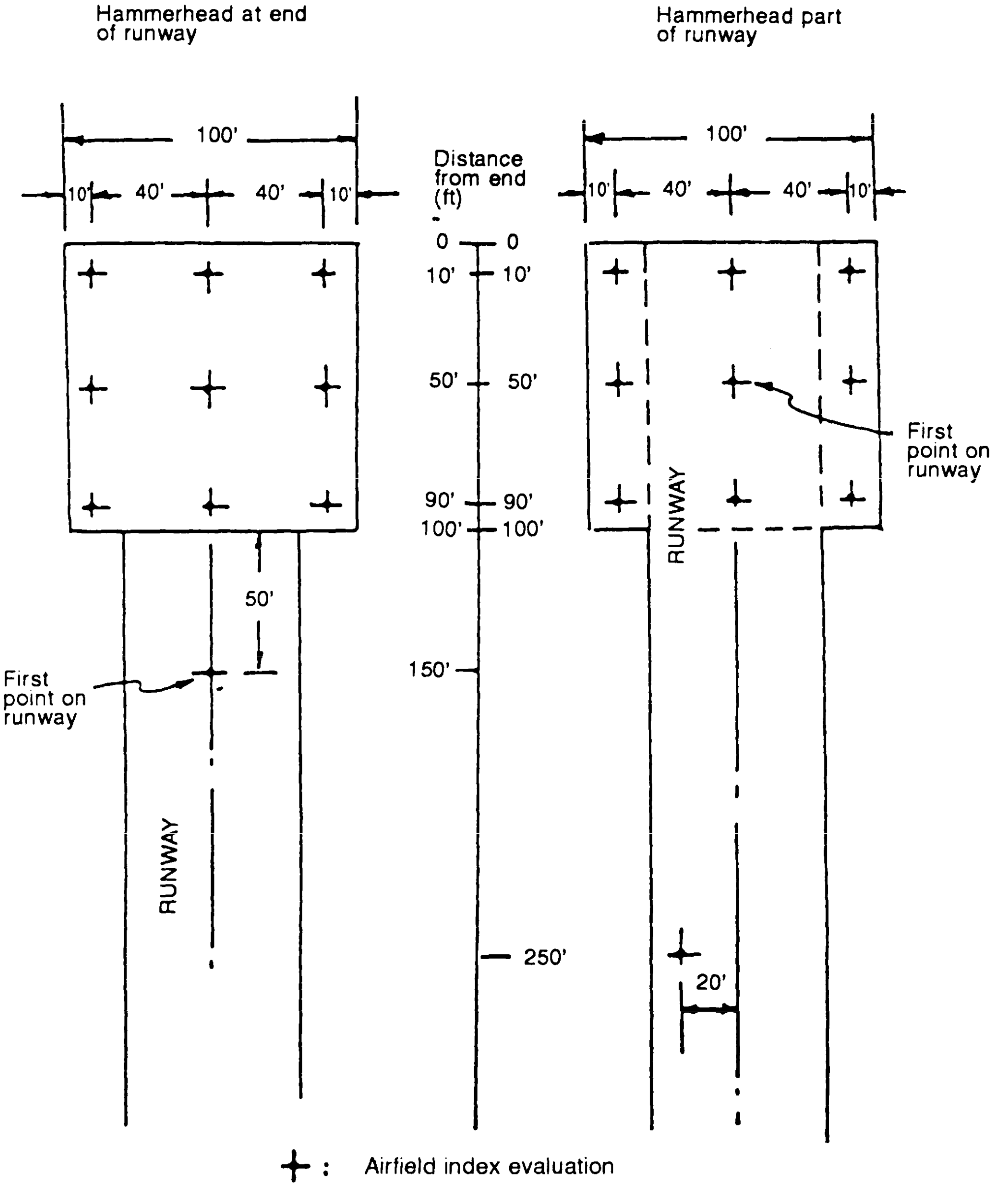


Figure I-4. Survey pattern for hammerhead turnarounds

APPENDIX J

DESCRIPTION AND APPLICATION OF DUAL-MASS DYNAMIC CONE PENETROMETER

The purpose of this appendix is to describe the DCP, its use, and the application of data obtained by its use. Procedures are presented for using the DCP to measure soil strength and correlating DCP index with CBR strength values required for operation of aircraft and military vehicles on unsurfaced soils. Procedures are also presented for using the DCP to evaluate aggregate surfaced roads and airfields for military operations based on the existing soil strength conditions.

DESCRIPTION, USE, AND MAINTENANCE OF DCP

DESCRIPTION OF DUAL MASS DCP

Dual-Mass DCP Device

The dual-mass DCP consists of a 5/8-inch-diameter steel rod with a steel cone attached to one end which is driven into the pavement or subgrade by means of a sliding dual-mass hammer (Figure J-1, page J-2). The angle of the cone is 60 degrees, and the diameter of the base of the cone is 0.79 inches. The cone is hardened to increase service life. The diameter of the cone is 0.16 inch larger than that of the rod to ensure that the resistance to penetration is exerted on the cone. Figure J-2, page J-3, shows an assembled DCP with vertical scale for measuring the cone penetration depth. The DCP is driven into the soil by dropping either a 17.6-pound or 10.1-pound sliding hammer from a height of 22.6 inches. The 17.6-pound hammer is converted to 10.1 pounds by removing the hexagonal set screw and removing the outer steel sleeve, as shown in Figure J-3, page J-4. This procedure can be accomplished during a test since the outer steel sleeve is designed to slide over the DCP handle. The cone penetration caused by one blow of the 17.6-pound hammer is essentially twice that caused by one blow of the 10.l-pound hammer. The 10.1-pound hammer is more suitable for use and yields better test results in weaker soils having a CBR value of 10 or less. The 17.6-pound hammer penetrates high-strength soils quicker and may be preferred when these type soils are encountered. However, the 10.1 -pound hammer can be used on soils up to CBR 80. The depth of cone penetration is measured at selected penetration or hammer-drop intervals, and the soil shear strength is reported in terms of DCP index. The DCP index is based on the average penetration depth resulting from one blow of the 17.6-pound hammer. The average penetration per hammer blow of the 10. l-pound hammer must be multiplied by two in order to obtain the DCP index value. The DCP is designed to penetrate soils to depths of 36 inches. Individual DCP index values are reported for each test depth resulting in a soil-strength-with-depth profile for each test location.

Dual-Mass DCP Kit

Figure J-4, page J-5, shows a dual-mass DCP kit designed for Army engineer use. The kit includes the following items:

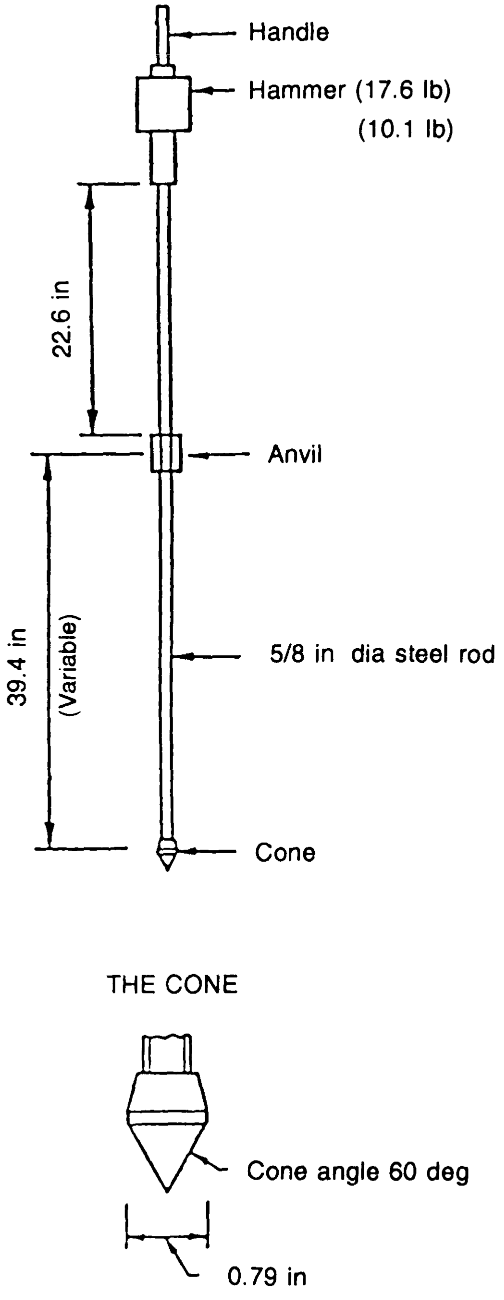


Figure J-1. Dual-mass DCP

Figure J-2. Assembled DCP with vertical scale

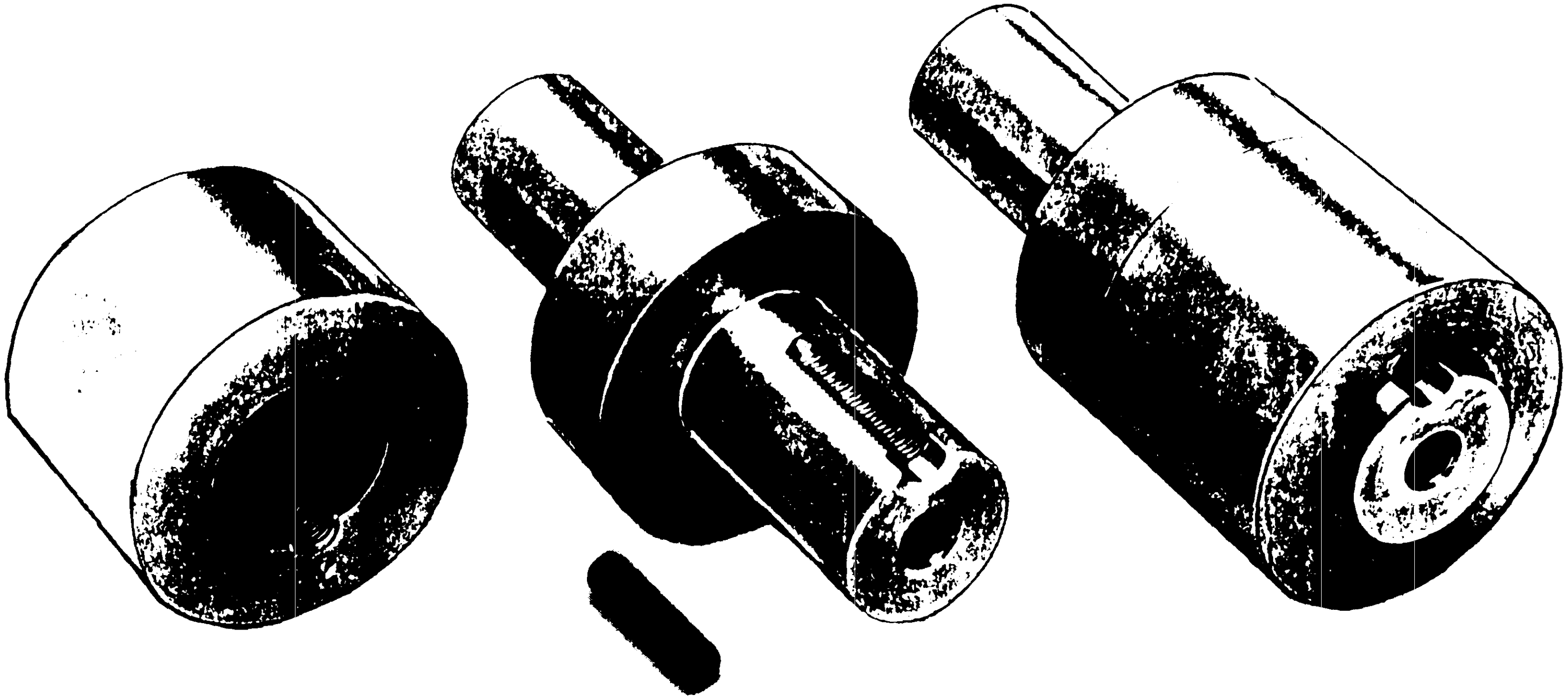


Figure J-3. Dual-mass hammer showing the removable steel sleeve, set screw, 10.1-pound hammer and 17.6-pound hammer configuration

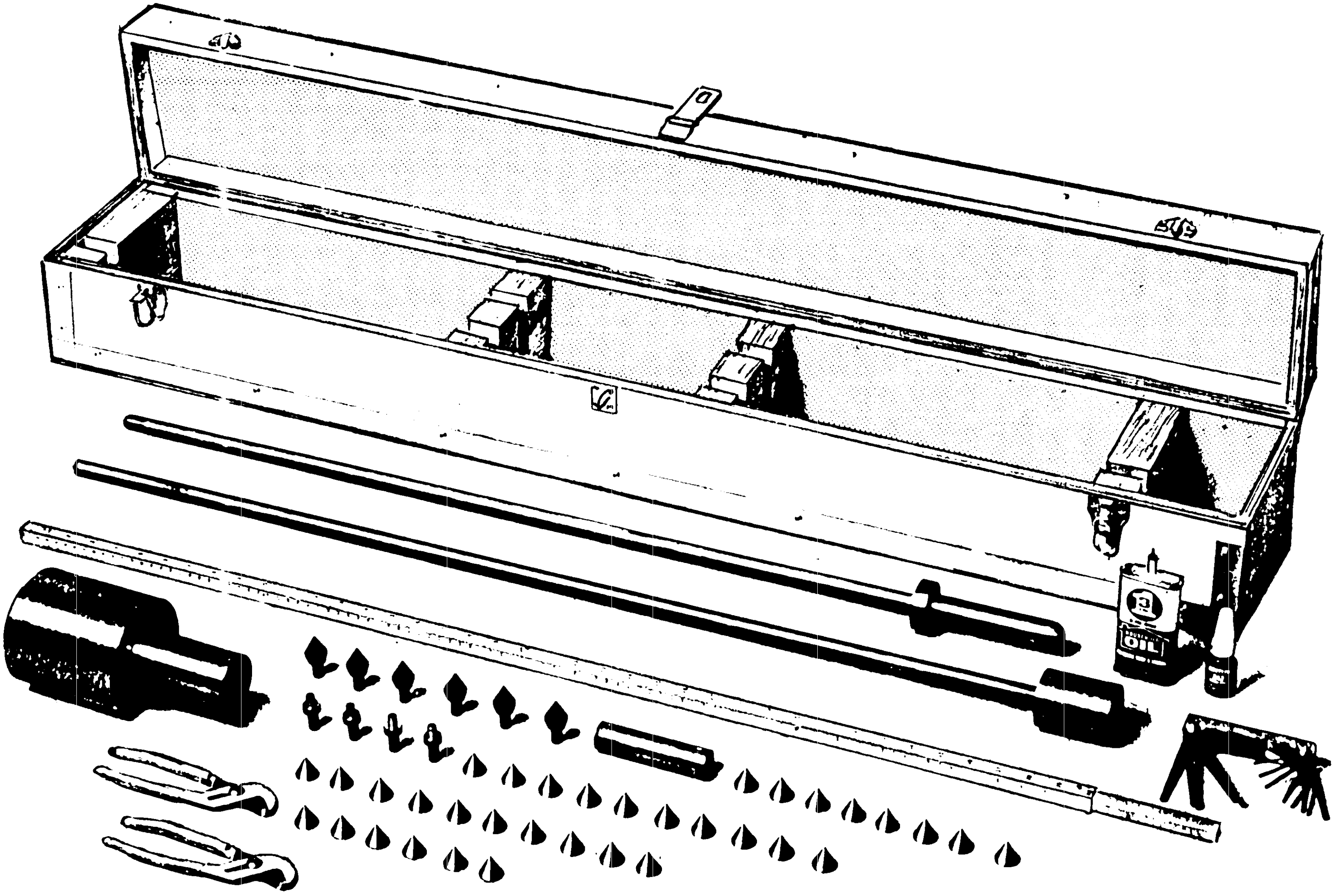


Figure J-4. Dual-mass DCP test kit

- Case assembly.
- Top rod threaded and welded to the handle.
- Bottom rod threaded and welded to the anvil.
- Dual-mass hammer.
- Vertical scale in centimeters and inches.
- Go/no go gauge.
- Six hardened, 60-degree, fixed cones.
- Three hardened cone adapters and 200 disposable cones.
- Two channel lock pliers,
- One can of light, lubricating oil.
- Thread-locking compound.
- Hexagonal wrench set (5/64 to 1/4 inch).

Acquisition

The DCP test kit shown in Figure J-4, page J-5, is not a current government stock item, and it is not available on the commercial market. Test kits and component parts are currently manufactured at WES and are available to other government agencies for cost reimbursement. A US patent on the DCP test kit is pending. Until a patent license with a commercial manufacturer can be obtained, the test kit can be made by the user or a contractor. A complete set of plans can be obtained by contacting WES at (601) 634-2282.

Disposable Cone

The disposable cone is for use in soils where a standard cone is difficult to remove. The disposable cone mounts on an adapter and is shown in Figure J-5. At the conclusion of the test, the disposable cone easily slides off the cone adapter, allowing the operator to easily remove the DCP device from the soil. The disposable cone remains in the soil. Use of the disposable cone approximately doubles the number of tests per day that can be run by two operators.

Go/No Go Gauge

The go/no go gauge is used to ensure the cone's base diameter is within proper tolerance. Each new cone should be checked before use and at selected usage intervals to ensure the cone's base diameter is within a proper tolerance of between 0.78 and 0.8 inch. The cone must be replaced if its base diameter fits into both ends or neither end of the go/no go gauge. The cone is within proper tolerance when it fits into only one end of the gauge.

Use

The DCP test causes wear to the metal parts of the DCP device. Parts of the DCP device will eventually suffer fatigue failure and will have to be repaired or replaced, In order to ensure maximum service life, the DCP should be inspected before it is used to ensure all joints are tight. Thread-locking compound should be used on loose joints. Also, the cone's base diameter should be checked to ensure it is within tolerance. If the cone point becomes bent or too blunt to penetrate around aggregate, it must be replaced.

Two people are required to operate the DCP, One person holds the device by its handle in a vertical position and taps the device using the hammer until the base of the cone is flush with the surface of the soil. The second person then checks the device for a zero reading by holding the vertical scale between the soil surface and bottom of the hammer. The bottom of the 4-inch-diameter portion of the hammer should read *0 millimeters* on the vertical scale. In weak soils, the weight of the DCP device will sink the cone past its zero reading. In this case, a zero-blow penetration reading is recorded, in millimeters, at the actual measured pretest depth. The hammer is then raised to the bottom of the handle and dropped. Care should be exercised when raising the hammer to ensure the hammer is touching the bottom of the handle but not lifting the cone before it is allowed to drop. The hammer must be allowed to fall freely with its downward movement not influenced by any hand movement. The operator should also be careful not to exert any downward force on the handle after dropping the hammer. Both the operator and the recorder should keep

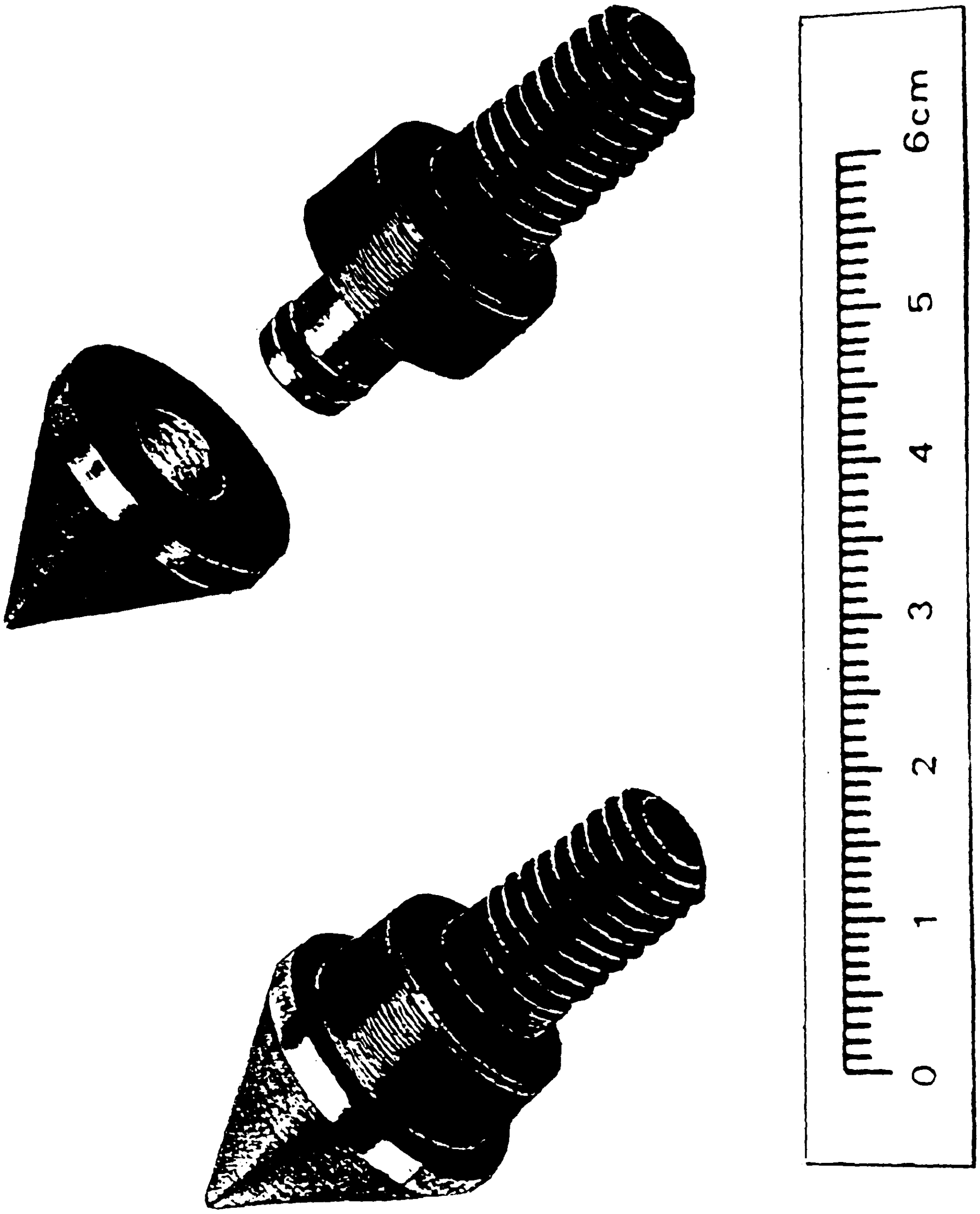


Figure J-5. Disposable cone and adapter

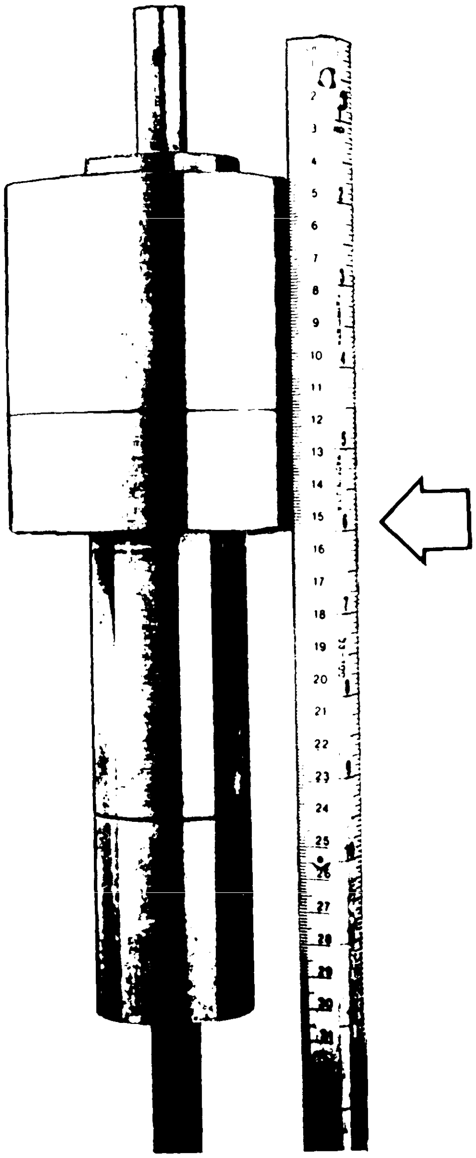


Figure J-6. Example of penetration measurement showing a penetration of 150 mm

track of the number of hammer drops (blows) between measurements. The recorder is responsible for recording the number of hammer blows between measurements. He is also responsible for measuring and recording the penetration after each set of hammer blows. Penetration measurements are recorded to the nearest 5 millimeters. As an example of how to read the penetration depth, Figure J-6 shows a penetration depth of 150 millimeters.

The cone must penetrate a minimum of 25 millimeters between recorded measurements. Data taken at less than 25-millimeter penetration increments are unnecessary and sometimes result in inaccurate strength determinations. The number of hammer blows between measurement recordings will generally be 20, 10, 5, 3, 2, or 1, depending on the soil strength and thus cone penetration rate. Both the operator and recorder should be alert to sudden increases in the cone-penetration rates during the test. Any noticeable increase in the penetration rate indicates a weaker soil layer. The operator should stop and allow the recorder to record the blow count and penetration depth whenever a weaker soil layer is encountered.

After the cone has been driven to the desired test depth (maximum 39 inches), it is extracted from the soil by driving the hammer against the top handle. Caution must be exercised during this operation to prevent damage to the DCP device. The hammer must be raised in a vertical direction (rather than in an arcing motion), or the rod may be bent or broken where it con-connects to the anvil. In soils where great difficulty is encountered in extracting the DCP device, disposable cones should be used. Using disposable cones will save wear and tear on both the device and the operator. In soils with large aggregate, the DCP may try to penetrate the soil at a slant rather than from a vertical direction. The operator should not apply force to the handle of the DCP in an attempt to force it to penetrate the soil vertically. Lateral force on the handle in an attempt to make the DCP penetrate the soil vertically will cause the upper handle rod to fatigue and break at the point where it screws into the anvil. instead, the test should be stopped when the handle deviates laterally 6 inches or more from the vertical position, and a new test should be attempted at another location.

DCP Maintenance

The DCP should be kept clean, and all soil should be removed from the penetration rod and cone before each test. A light application of spray lubricant or oil should be applied to the hammer slide rod before each day's use. All joints should be constantly monitored and kept tight. Loose joints will lead to equipment failure Any problem joints should be treated with a joint-locking compound. The lower penetration rod should be kept clean and lubricated with oil when clay soils are tested

SOIL STRENGTH EVALUATIONS WITH DCP

Number of Measurements

The number of measurements to be made, location of the measurements, depth of measurements required, and frequency of recording data with depth vary with type of road or airfield pavement operation and with time available for conducting the tests. For this reason, hard-and-fast rules for the number of tests required in evaluating roads and airfields are impracticable. Soil conditions are extremely variable. The strength range and uniformity of the soils or existing pavement materials will generally control the number of measurements necessary. In all cases, it is advisable to first test those spots that appear to be weakest. since the weakest condition controls the pavement evaluation, Penetrations in areas that appear to be firm and uniform may be few and widely spaced. In areas of doubtful strength, penetration tests should be more closely spaced. No less than three penetration tests should be made in each area having similar type soil conditions.

Reading Depths in Soil

Soil strength usually increases with depth, but in some cases a thin, hard crust will overlay a soft layer, or the soil will contain thin layers of hard and soft material. For this reason and the fact that many aircraft and some military vehicles will effect the soil to depths of 36 inches or mom, it is recommended that each penetration be made 10 a depth of 36 inches unless prevented by a very hard condition at a lesser depth. Soil test depths may be reduced when required traffic operations are known and the thickness requirements indicate that a reduced thickness above the subgrade controls the evaluation.

Correlation of DCP Index with CBR

Correlation of DCP index with CBR is necessary since the CBR is the soil strength value used for designing and evaluating unsurfaced. aggregate-surfaced, and flexible pavements for military roads and airfields. A data base of field CBR versus DCP index values was collected by WES technicians from many sites and different soil types (Table J-1, page J-11). In addition, correlation test results by Harison (1987), Kleyn (1975), Livneh and Ishai (1987), and Van Vuuren (1969) were compared with the data-base test values (Figure J-7, page J-12). General agreement was found between the various sources of information. The equation log CBR = 2.46 - 1.12 (log DCP) was selected as the best correlation. In this equation, DCP is the penetration ratio in millimeters per blow for the 17.6-pound hammer. Figure J-8, page J-13, shows a plot of the correlation of CBR versus DCP index. Table J-2, page J-14, shows a tabulated correlation of DCP index with CBR.

Data Tabulation

The data can be tabulated in spread-sheet format with the only data input values required being that of the number of hammer blows, hammer weight, and cone penetration recorded to the nearest 5 millimeters after each set of hammer blows. Figure J-9, page J-15, shows a sample format for a DCP data sheet.

Data Analysis

The user should group test data for locations having similar type soil conditions. For each location group, an individual should make a combined data plot showing CBR, interpreted from Figure J-8 versus depth in inches as shown in Figure J-10, page J-16. From this data, an average data plot of CBR versus depth in inches should be developed. Average data plots for each location having similar type soil conditions are used in the following pavement evaluations.

APPLICATION OF DCP DATA

EVALUATION

TM 5-822-12 can be used for evaluating the potential of military operations on unsurfaced soils and aggregate-surfaced roads and airfields based on existing soil conditions. The evaluation procedure is the reverse of the design procedure. CBR and thickness evaluation data from the DCP tests are used to enter the appropriate set of design curves in this manual or in FM 5-430-00-1/AFPAM 32-8013, Vol 1, to determine the allowable design index for roads or allowable gross weight and aircraft pass configuration for airfields. The design index for roads is then used to determine the allowable road class and number of vehicle passes per day for various traffic categories.

For unsurfaced soils in which the soil strength increases with depth, the average strength of the top layer is first used in order to make sure that compaction to a higher strength or the addition of a surfacing aggregate layer is not required. If the top layer of soil is adequate to support the desired design index or aircraft passes, then the strength of weaker soil layers beneath the top layer is used in order to check for adequate thickness requirements of the surfacing layers of soil.

For aggregate-surfaced roads and airfields, both the subgrade soil strength and aggregate layer strength should be used to ensure that the aggregate thickness and strength requirements are adequate for a given design index or aircraft pass level.

SPECIAL CONSIDERATIONS

Weather

Because soil conditions are immediately and significantly affected by weather, an evaluation is valid only for the period immediately after measurements are made for unsurfaced pavements. However, it can usually be assumed that the evaluation will remain constant as long as no rain occurs. Gravel-surfaced pavements will be affected to a much lesser extent by rain.

Clay Soils

DCP tests in highly plastic clays are generally accurate for depths to approximately

Table J-1. Data base of field CBR versus DCP index values

CBR (%)	DCP Index (mm/blow)	Soil Type	CBR (%)	DCP Index (mm/blow)	Soil Type	CBR (%)	DCP Index (mm/blow)	Soil Type	CBR (%)	DCP Index (mm/blow)	Soil Type
62	3	SW	15	10	CL	16	16	CL	7	24	CL
88	3	SM-SC	10	11	CL	18	16	CL	10	24	CL
100	3	SM-SC	20	11	CL	22	16	SW	8	24	CL
38	3		32	11	SW	16	16	CL	3	26	CL
40	4	SC	19	11		18	16	CL	8	26	CL
46	5	SW	46	11	SC	14	16	CL	6	29	CL
38	5	SW	19	12	CL	23	17	SW	7	30	CL
52	5	SW	24	12	SW	11	17	SP-SM	8	30	CL
34	6	SW	16	12	CL	14	17	CL	7	30	CL
29	6	SP-SM	12	12	CL	18	17	CL	14	32	CL
27	6		16	12	GC	16	17	SW	3	35	CL
33	7	SW	25	12	CL	22	17	CL	11	40	CH
53	7	SP-SM	32	13	SW	15	17	CL	7	40	CH
27	7	CL	19	13	CL	7	17	CL	7	41	CH
16	7	SP-SM	25	13	CL	22	18	SW	9	42	CH
30	7		17	13	SW	13	18	CL	9	44	CH
44	7	SW	16	13	CL	18	18	CL	9	45	CH
38	7		31	13	CL	12	18	CL	9	48	CH
18	8	CL	16	14	CL	7	18	CL	4	48	CH
22	8	CL	17	14	CL	10	18	CL	9	49	CH
39	8	SW	12	14	CL	4	19		4	51	CH
25	8	SC	25	14	SW	12	19		3	53	CH
22	9	CL	15	15	CL	4	19	CL	5	62	CH
20	9	SW	12	15		6	20		3.8	65	CH
21	10	SW	10	15	CL	9	20	SP-SM	5	65	CH
32	10	SW	10	15	CL	6	22	CL	4.9	67	CH
21	10	SW	17	15	CL	11	22	CL	4	69	CH
47	10	SW	15	15	CL	13	23	CL	4.8	83	CH
8	10	CL	21	15	CL	6	23	CL	3	111	CH

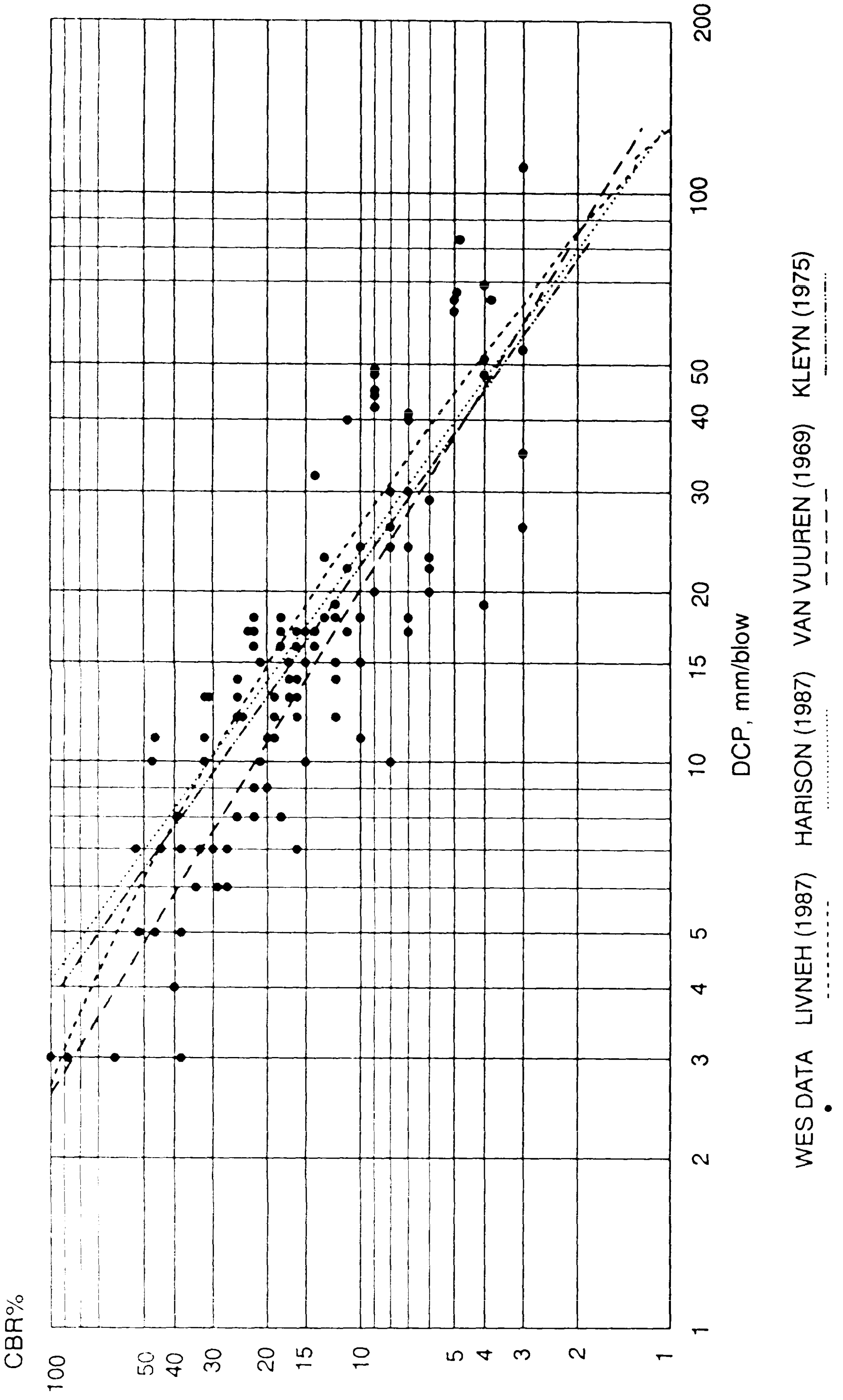


Figure J-7. DCP versus CBR

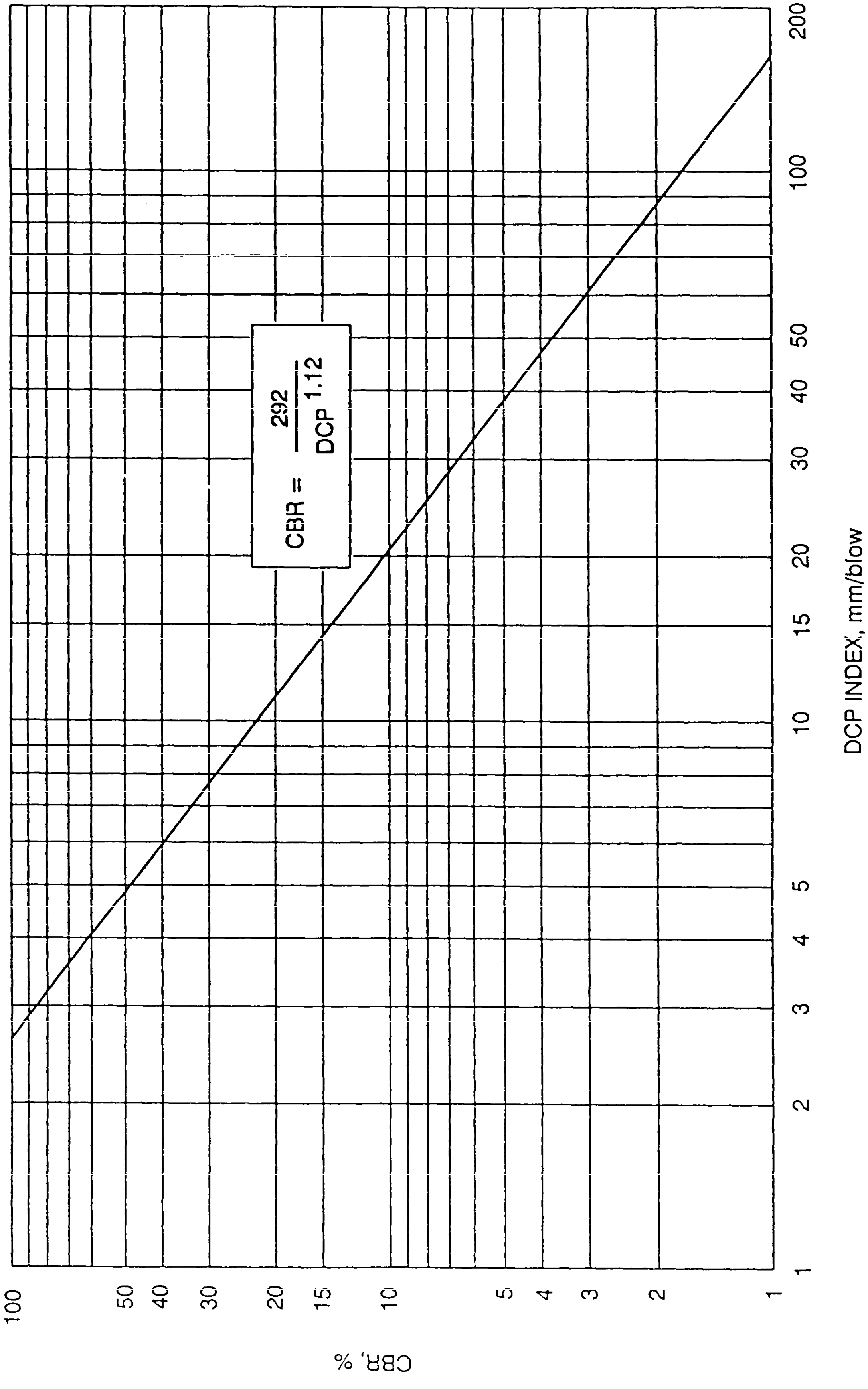


Figure J-8. Correlation plot of CBR versus DCP index

Table J-2. Tabulated correlation of CBR versus DCP index

DCP Index (mm/blow)	CBR (%)	DCP Index (mm/blow)	CBR (%)
<3	100	51	3.6
3	80	52	3.5
4	60	53-54	3.4
5	50	55	3.3
6	40	56-57	3.2
7	35	58	3.1
8	30	59-60	3.0
9	25	61-62	2.9
10-11	20	63-64	2.8
12	18	65-66	2.7
13	16	67-68	2.6
14	15	69-71	2.5
15	14	72-74	2.4
16	13	75-77	2.3
17	12	78-80	2.2
18-19	11	81-83	2.1
20-21	10	84-87	2.0
22-23	9	88-91	1.9
24-26	8	92-96	1.8
27-29	7	97-101	1.7
30-34	6	102-107	1.6
35-38	5	108-114	1.5
39	4.8	115-121	1.4
40	4.7	122-130	1.3
41	4.6	131-140	1.2
42	4.4	141-152	1.1
43	4.3	153-166	1.0
44	4.2	166-183	0.9
45	4.1	184-205	0.8
46	4.0	206-233	0.7
47	3.9	234-271	0.6
48	3.8	272-324	0.5
49-50	3.7	>324	<0.5

DCP DATA SHEET

Project: **Date:**

Location: **Soil Type(s)**

#of Blows (1)	Cumulative Penetration (mm) (2)	Penetration per Blow Set (mm) (4)	Penetration per Blow (mm) (5)	DCP Index (6)	CBR % (7)	Depth in. (8)

(1) Number of hammer blows between test readings.
(2) Cumulative cone penetration after each set of hammer blows.
(Minimum penetration between test readings should be 25 mm.)
(3) Difference in cumulative penetration (2) at start and end of hammer blow set.
(4) (3) divided by (1).
(5) Enter 1 for 17.6 lb hammer, 2 for 10.1lb hammer.
(6) (4) X (5).
(7) From CBR versus DCP correlation.
(8) Previous entry in (2) divided by 25.4, rounded off to 0.1 in.

Figure J-9. Sample format for DCP data sheet

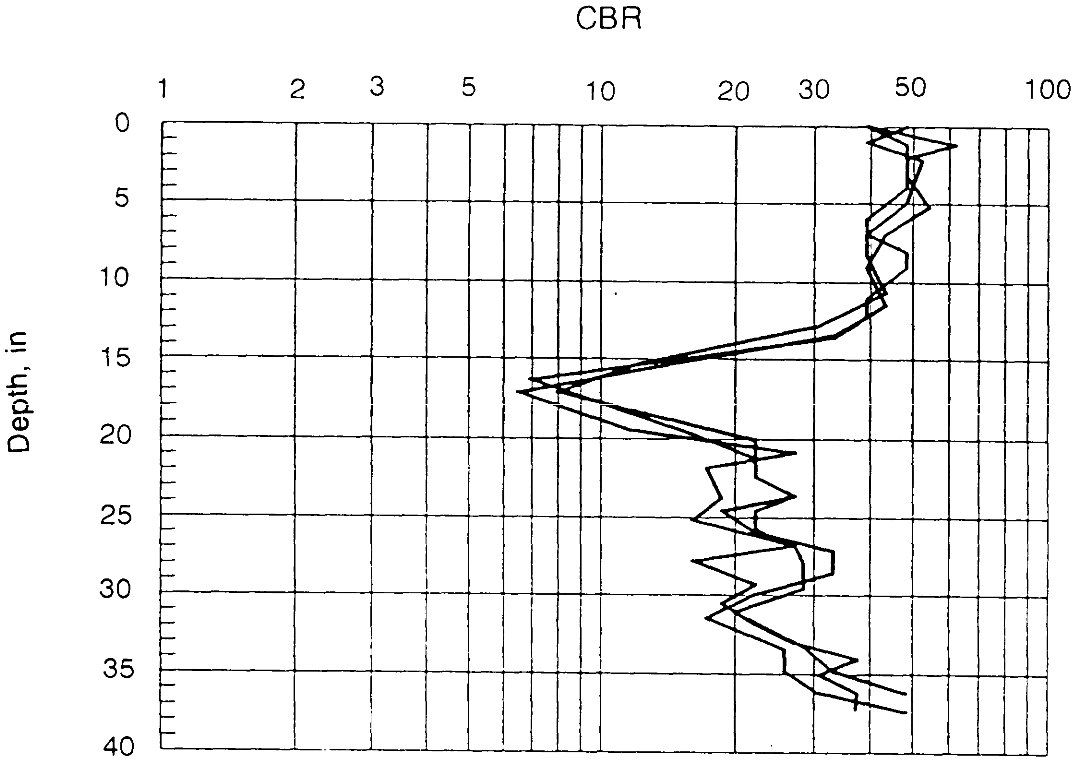


Figure J-10. Example of DCP data plot for three tests in similar type soils

12 inches. At deeper depths, clay sticking to the lower rod may indicate higher CBR values than the actual values. Oiling the penetration rod will help prevent the clay from sticking to the penetration rod; however, it will not significantly improve the test results. A 2-inch-diameter (or larger) auger can be used to open the test hole up after each 12-inch DCP test penetration. This will eliminate clay lower-rod friction problems and allow the test to accurately measure the clay soil strength for an additional 12 inches.

Sands

Many sands occur in a loose state. When relatively dry, such sands show no DCP index values for the top few inches and may show increasing DCP index values with depth. The confining action of aircraft tires will increase the strength of the sand. Generally, any dry sand or gravel will be adequate for aircraft in the C-130 class, regardless of the DCP index values. All sands and gravels in a quick condition (water percolating through them) must be avoided. Evaluation of moist sands should be based on the DCP tests as described earlier.

Soil Remolding

Soil remolding is the changing or working of a soil by traffic. The effects of traffic remolding may have a beneficial, neutral, or detrimental effect and result in a change of soil strength. Additional DCP tests should be run after some traffic has been applied to determine any changes that may have occurred in soil strengths.

Cone-Penetration Refusal

If the cone does not penetrate 25 millimeters after 10 blows with the 17.6-pound hammer (20 blows with the 10.1-pound hammer), the test should be stopped. If this firm material is a stabilized soil or high-strength aggregate base layer, it should be cored or drilled with an auger to allow access of the DCP cone to underlying layers. The DCP test can then proceed through the access hole after the depth of the material layer has been recorded. The material layer is assigned a CBR value of 100+. However, if a core or auger drill is not available, the 17.6-pound DCP hammer can normally be used to drive the lower rod and cone through the firm material. If the cone penetration was stopped by a large rock or other object, the DCP should be extracted and another attempt made within a few feet of the initial test. The DCP is generally not suitable for soils having significant amounts of aggregate greater than a 2-inch-sieve size.

APPENDIX K

FLEXIBLE-PAVEMENT EVALUATION CURVES

The evaluation of a flexible-pavement structure for airfields, helipads, or heliports can be accomplished by applying the design values assigned to the various layers to the curves given in Figures K-1 through K-36, pages K-2 through K-37, and by applying the criteria presented in Chapter 12 to determine the flexible-pavement structure.

Table K-1 shows the different aircraft in each of the Group Indexes and also lists the page numbers.

Table K-1. Air Force aircraft Group Index

Group Index and Page Number												
I K-2	II K-4	III K-6	IV K-8	V K-10	VI K-12	VII K-14	VIII K-16	IX K-18	X K-20	XI K-22	XII K-24	XIII K-26
C-23* C-12 C-21 A-37	F-15* A-7 A-10 C-20 F-4 F-5 F-14 F-16 F-100 F-101 F-102 F-105 F-106 T-33 T-38 T-39	F-111*	C-130*	C-9* C-7 DC-9 C-140	T-43* 737	B-727* C-22	E-3* 707 C-135 KC-135 VC-137 DC-8 EC-18 A-300 B-767	C-141* B-1 B-757	C-5*	KC-10* DC-10 L-1011 C-17	E-4* 747 VC-25	B-52*

*Controlling aircraft

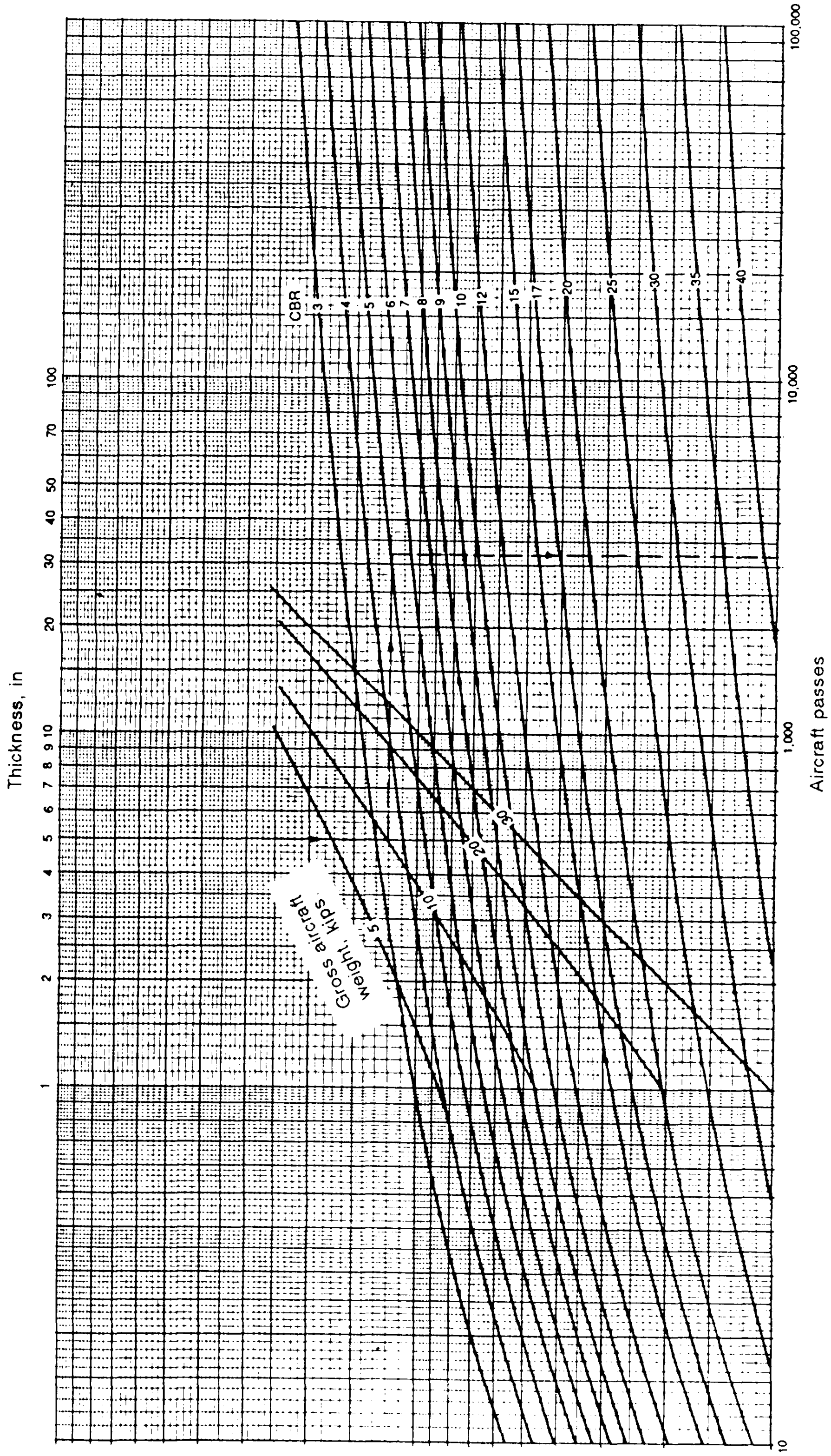
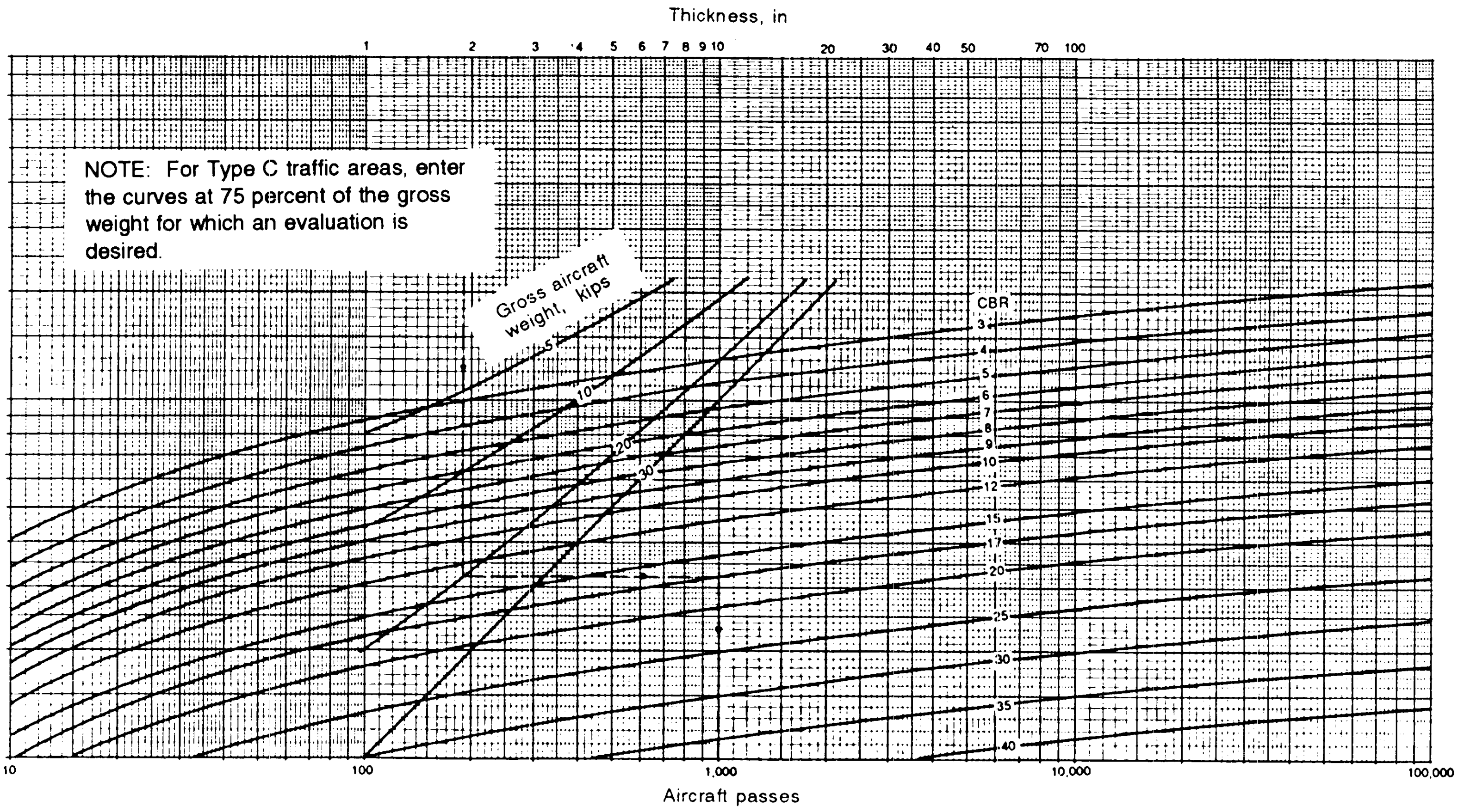


Figure K-1. Flexible-pavement evaluation curves, Group Index I, Type A traffic areas



NOTE: For Type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-2. Flexible-pavement evaluation curves, Group Index I, Type B and C traffic areas

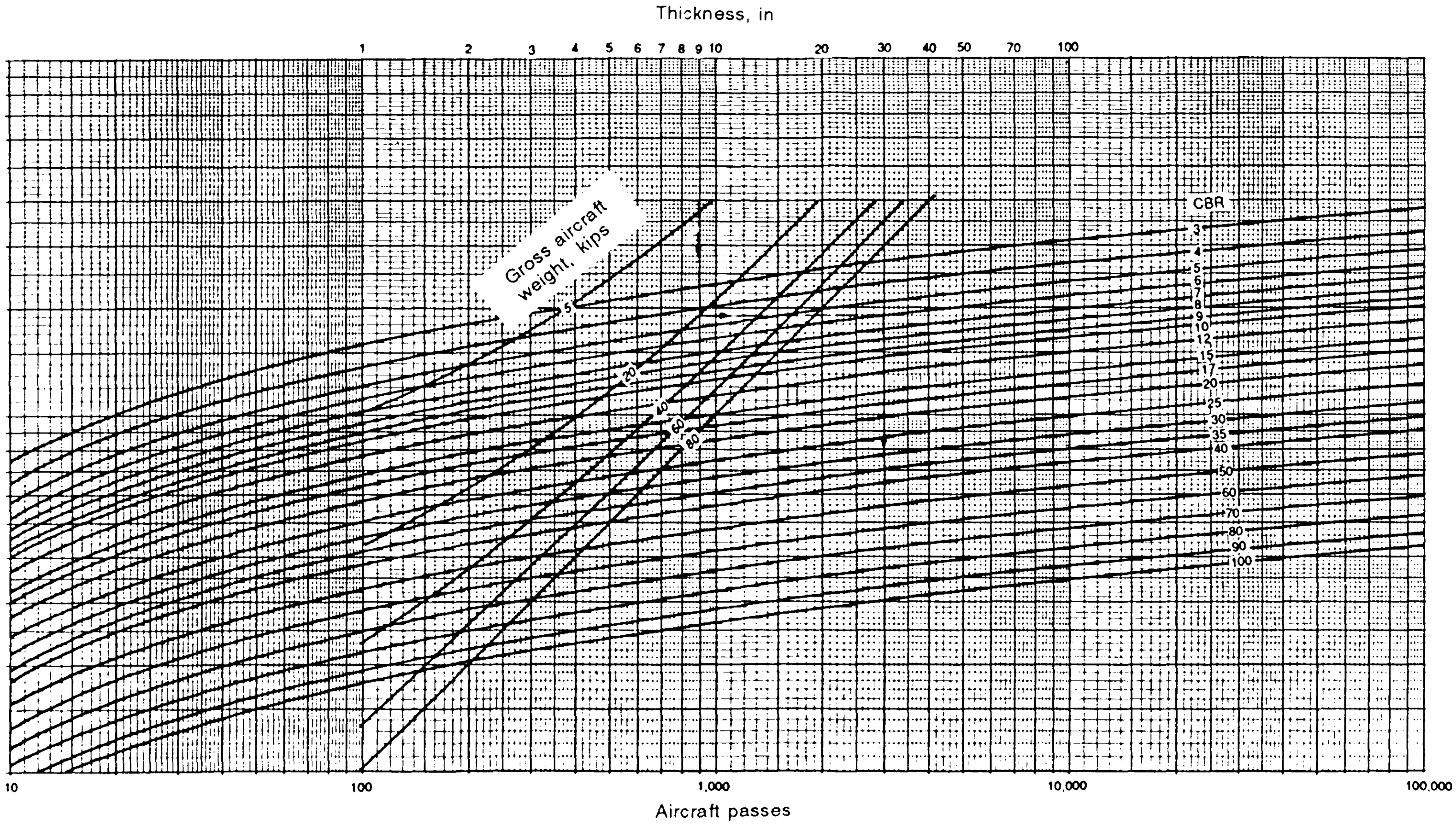
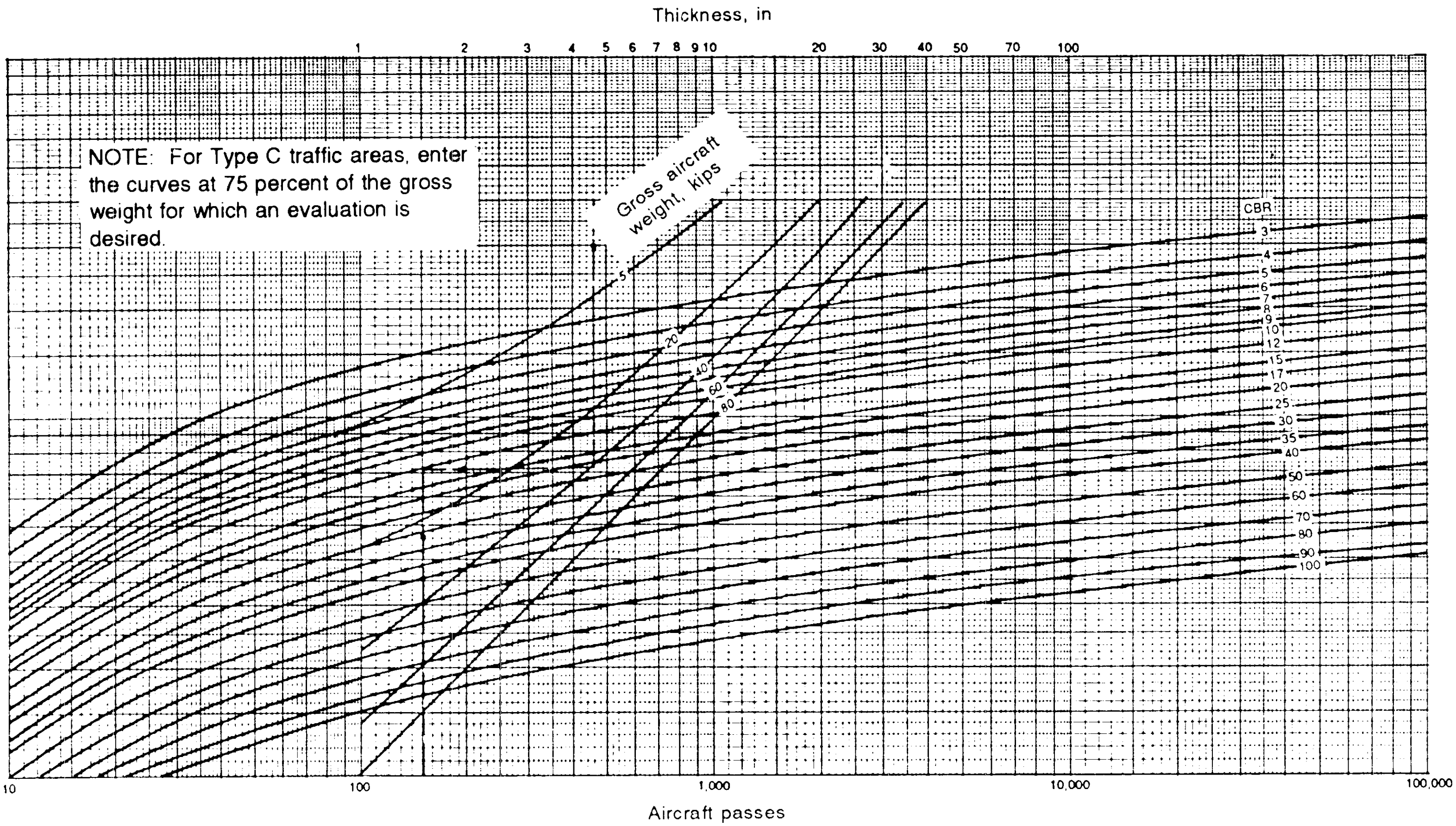


Figure K-3. Flexible-pavement evaluation curves, Group Index II, Type A traffic areas



NOTE: For Type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-4. Flexible-pavement evaluation curves, Group Index II, Type B and C traffic areas

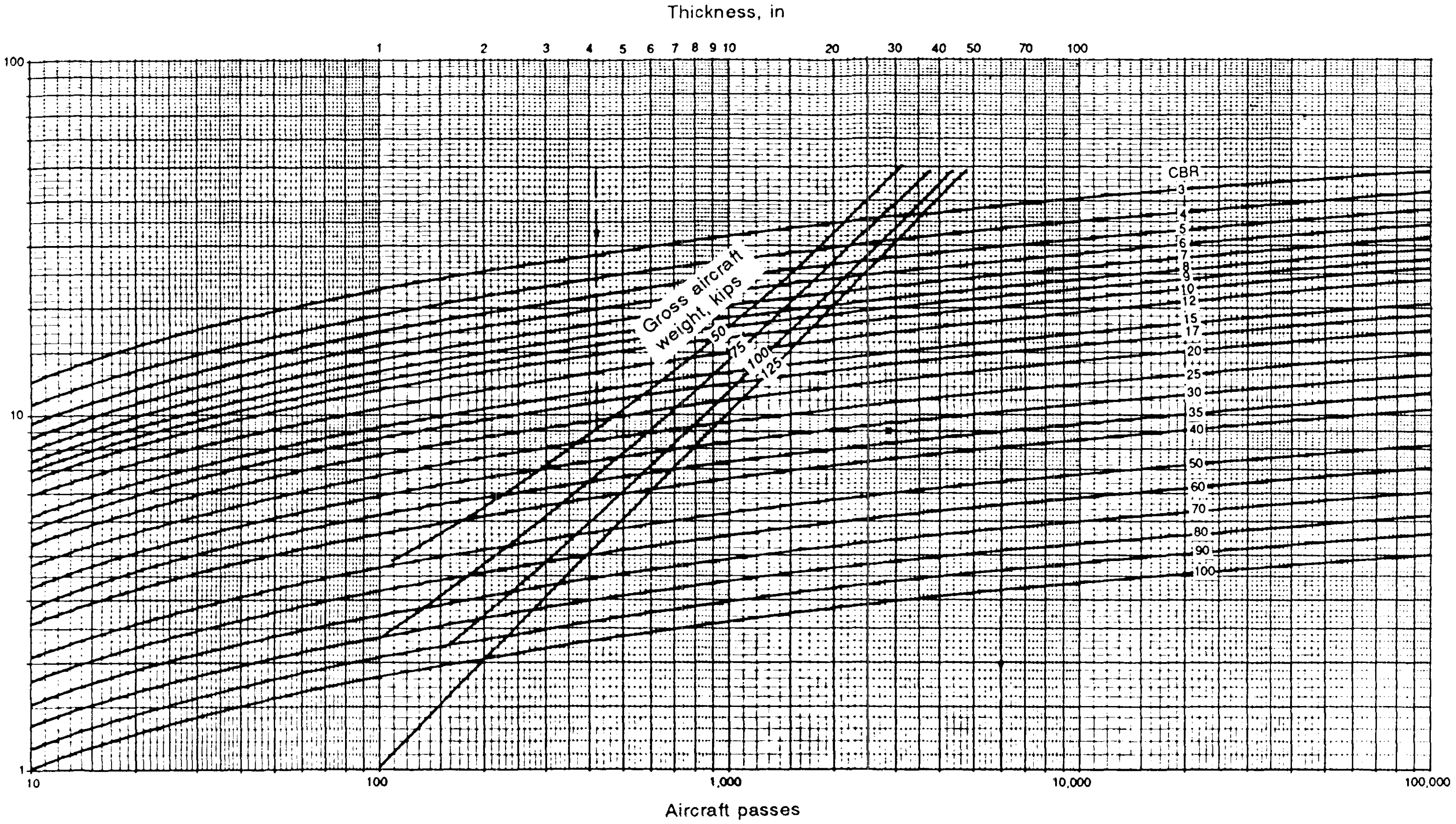
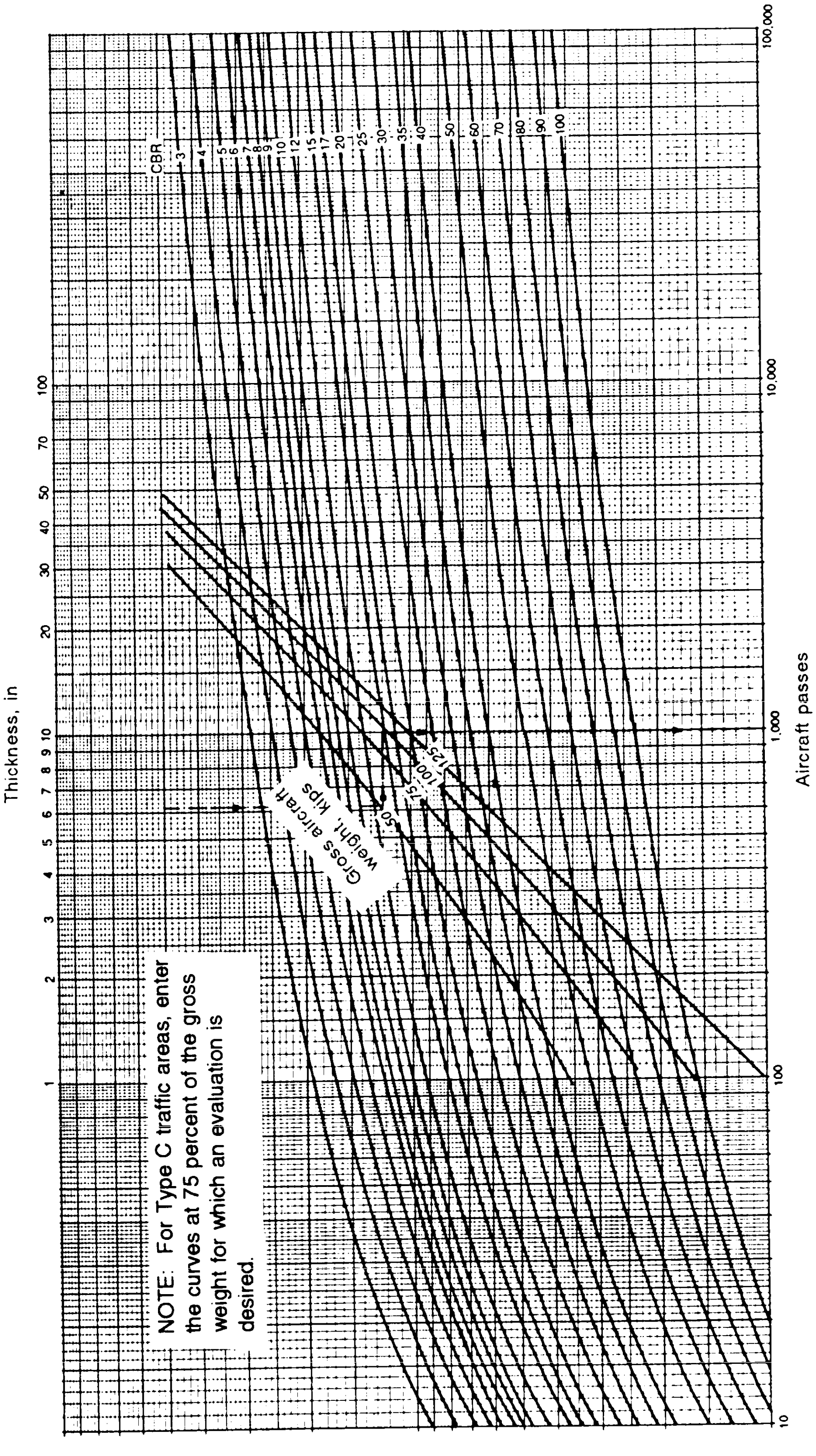


Figure K-5. Flexible-pavement evaluation curves, Group Index III, Type A traffic areas



NOTE: For Type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-6. Flexible-pavement evaluation curves, Group Index III, Type B and C traffic areas

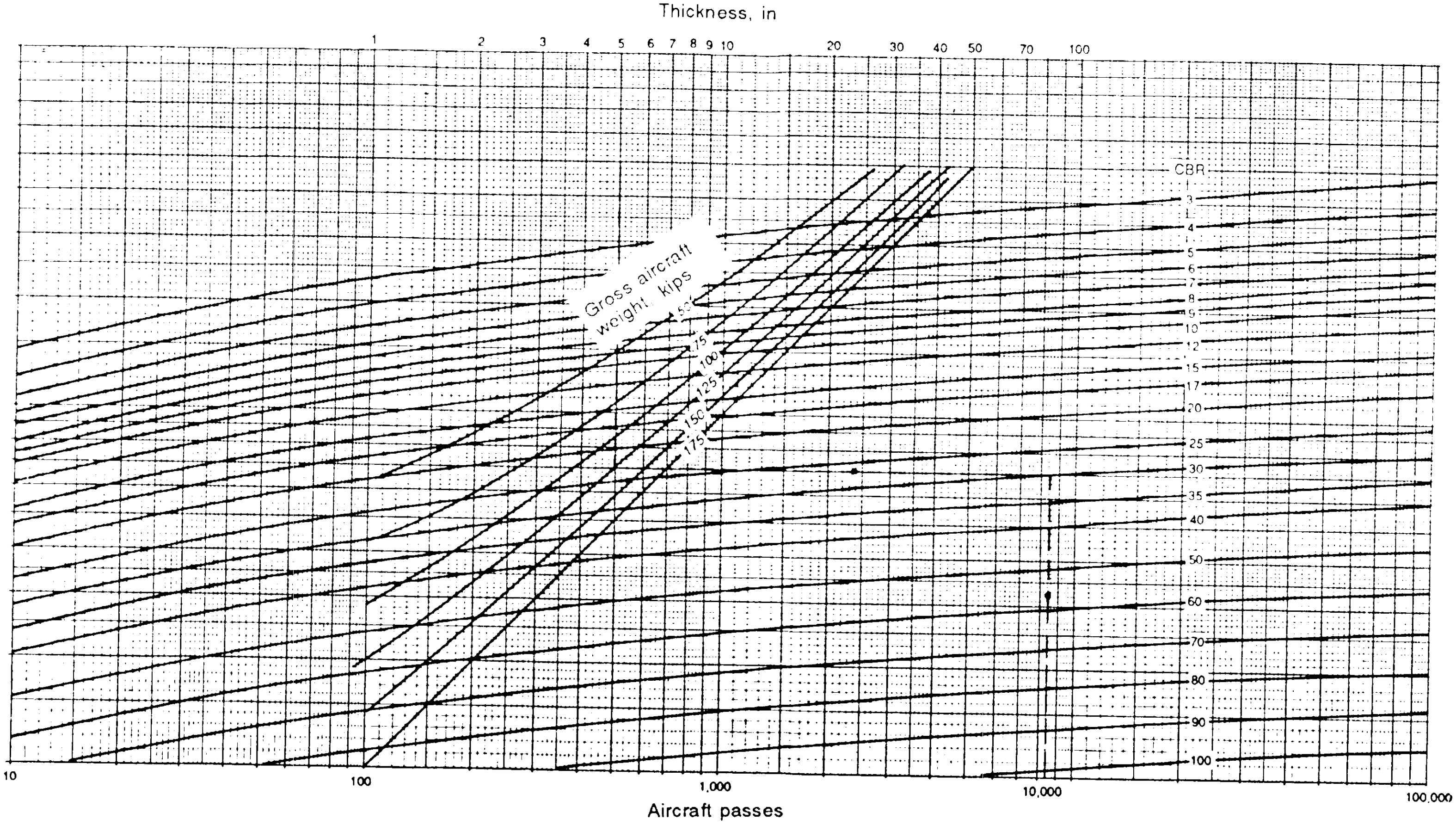
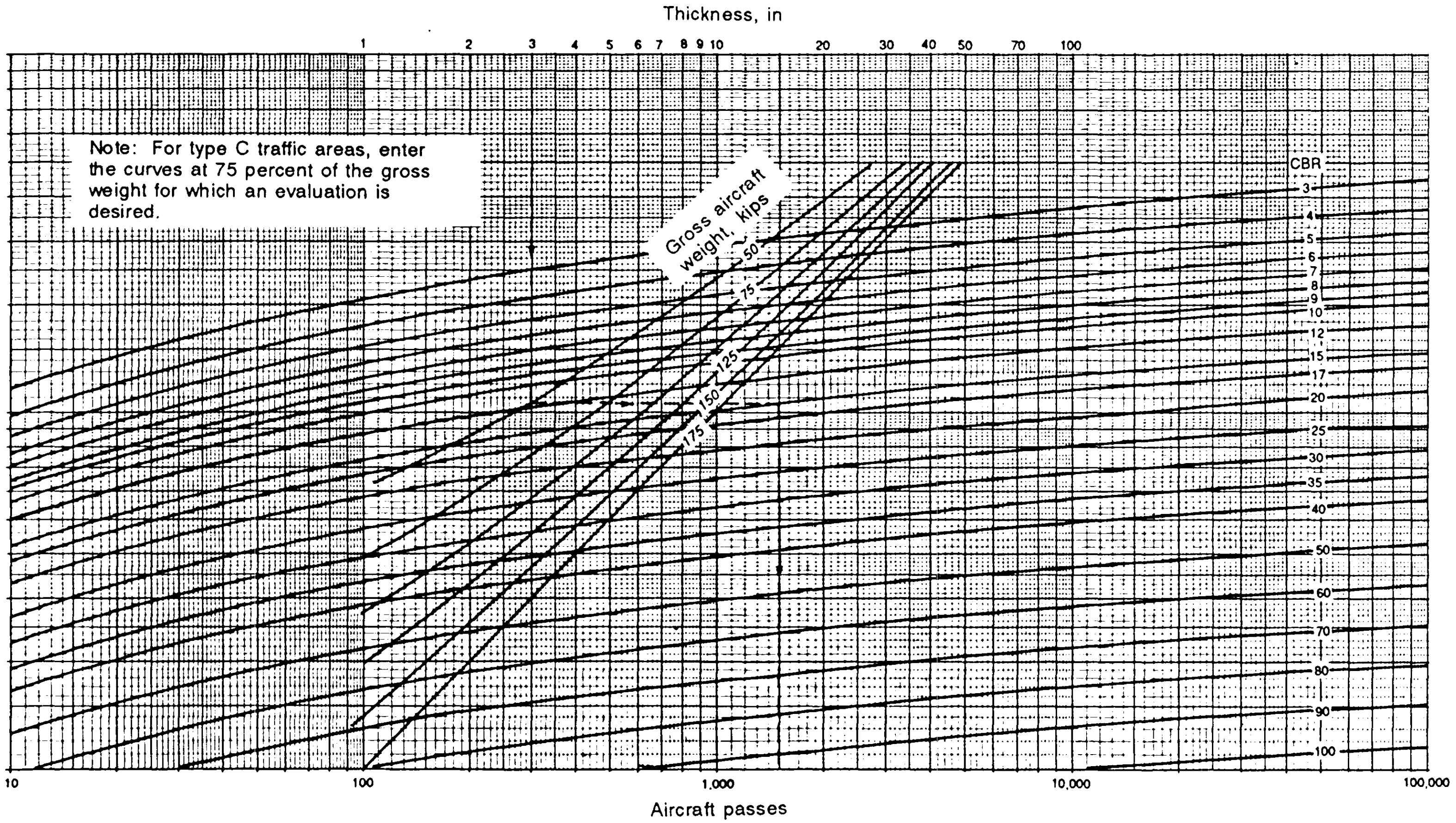


Figure K-7. Flexible-pavement evaluation curves, Group Index IV, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-8. Flexible-pavement evaluation curves, Group Index IV, Type B and C traffic areas

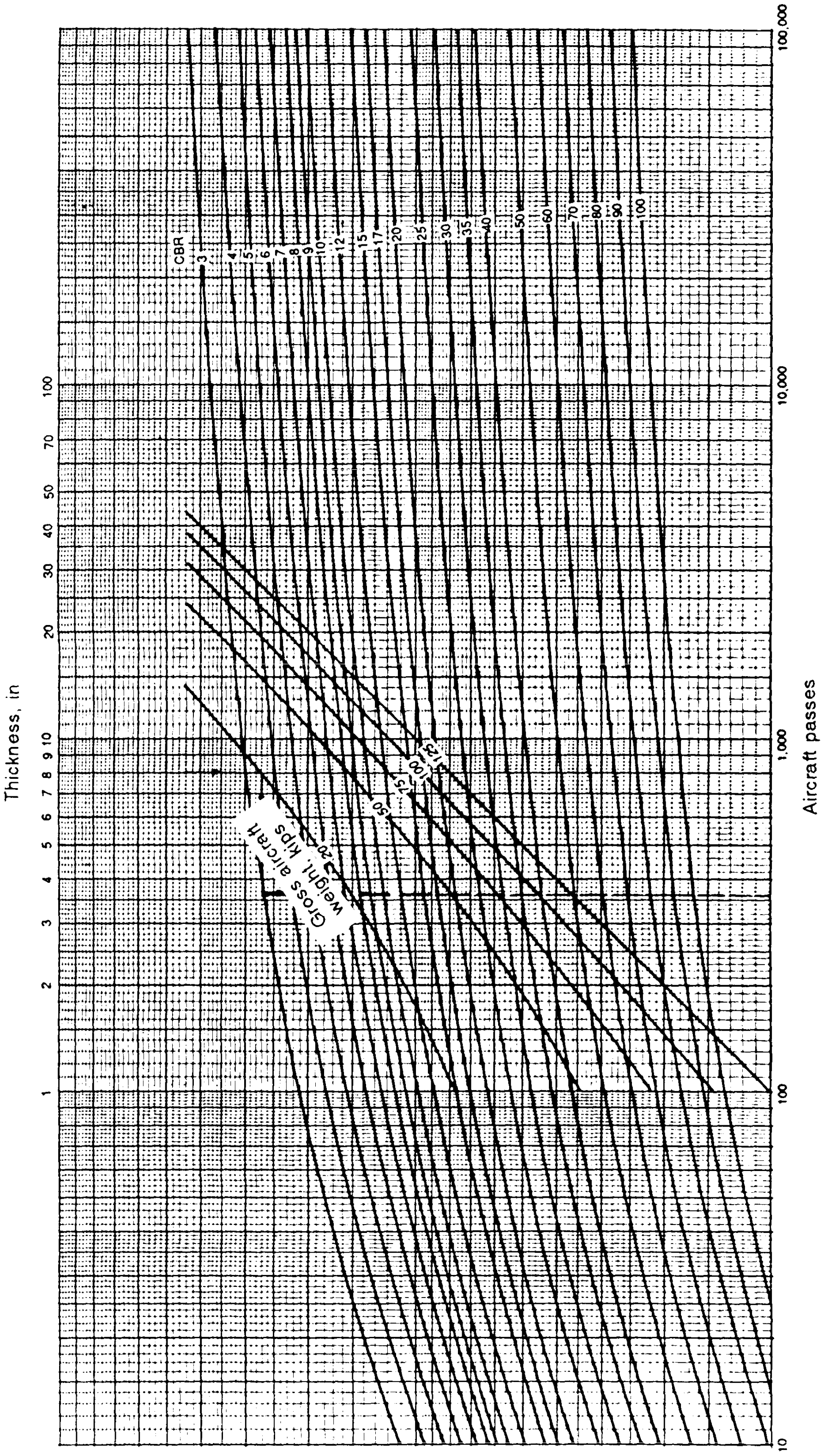
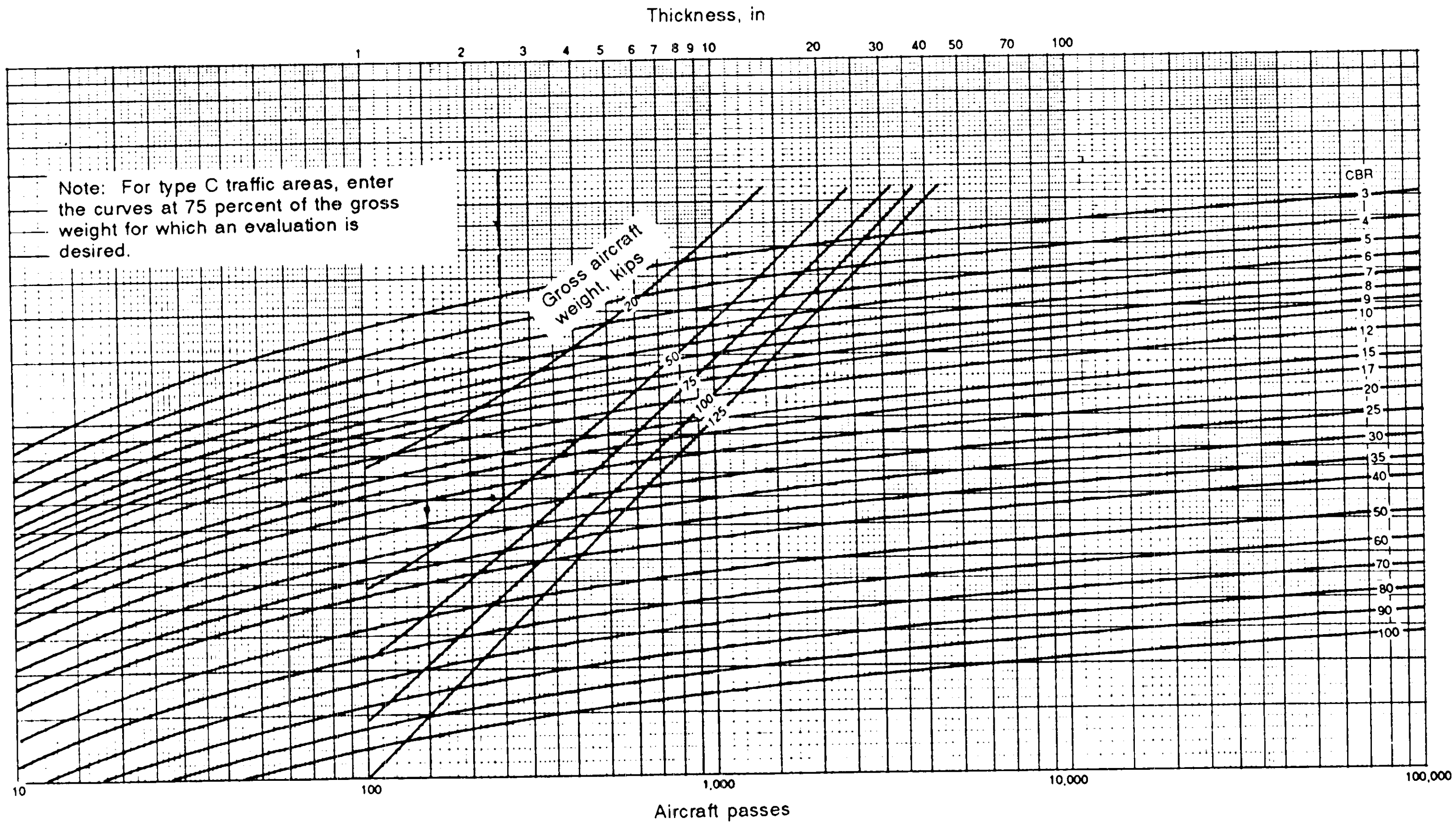


Figure K-9. Flexible-pavement evaluation curves, Group Index V, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-10. Flexible-pavement evaluation curves, Group Index V, Type B and C traffic areas

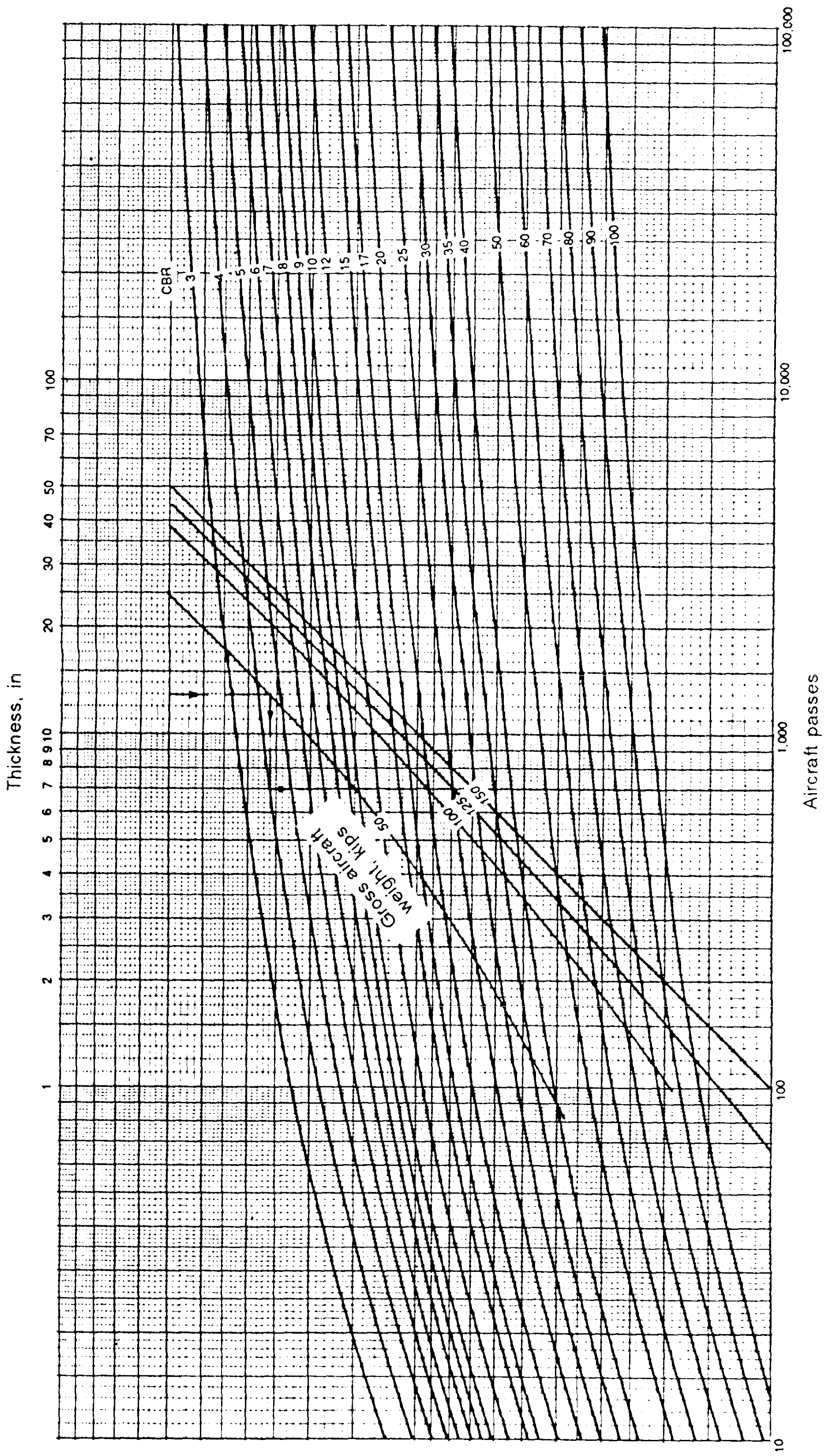
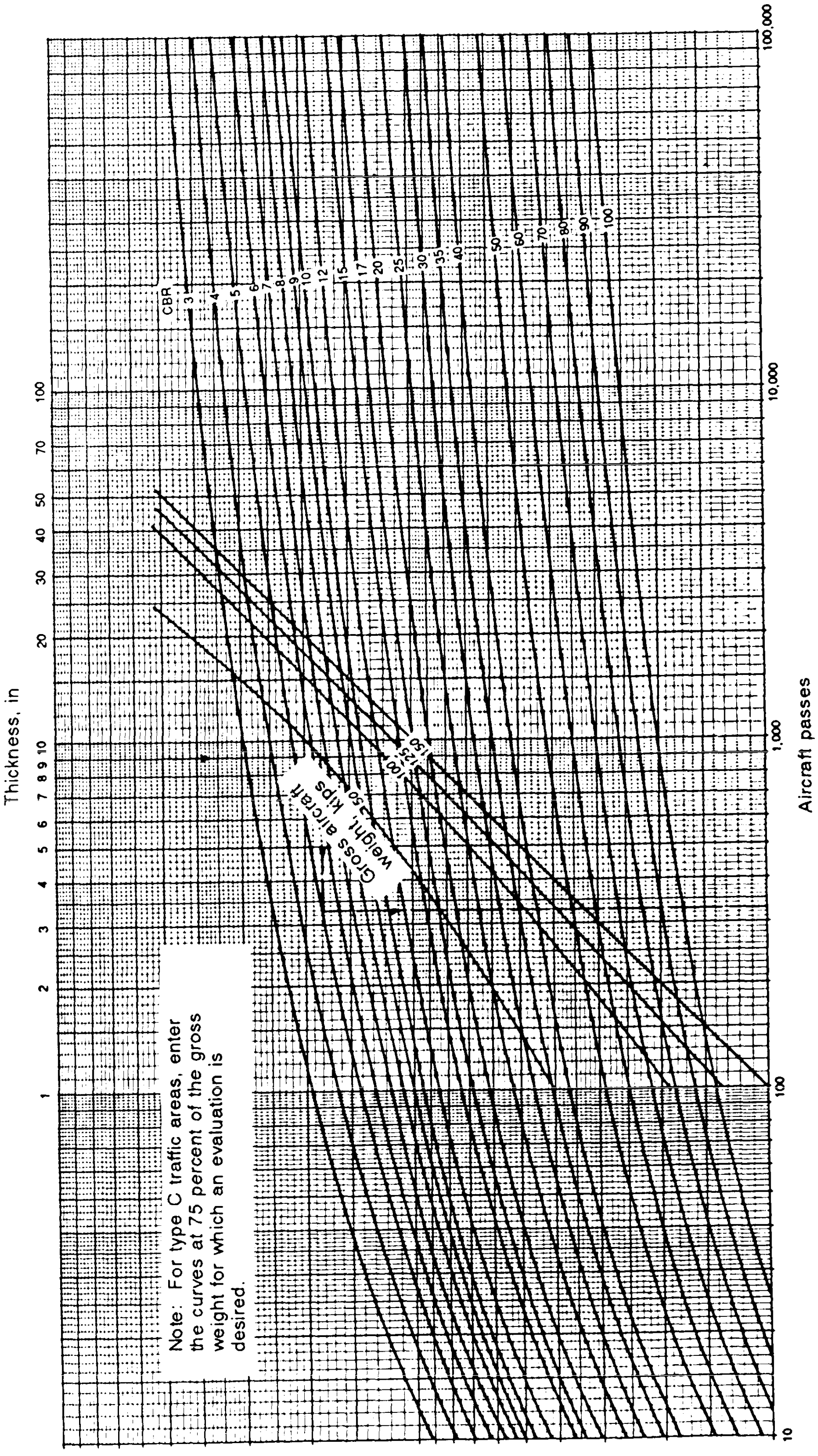


Figure K-11. Flexible-pavement evaluation curves, Group Index VI, Type B and C traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-12. *Flexible-pavement evaluation curves, Group Index VI, Type B and C traffic areas*

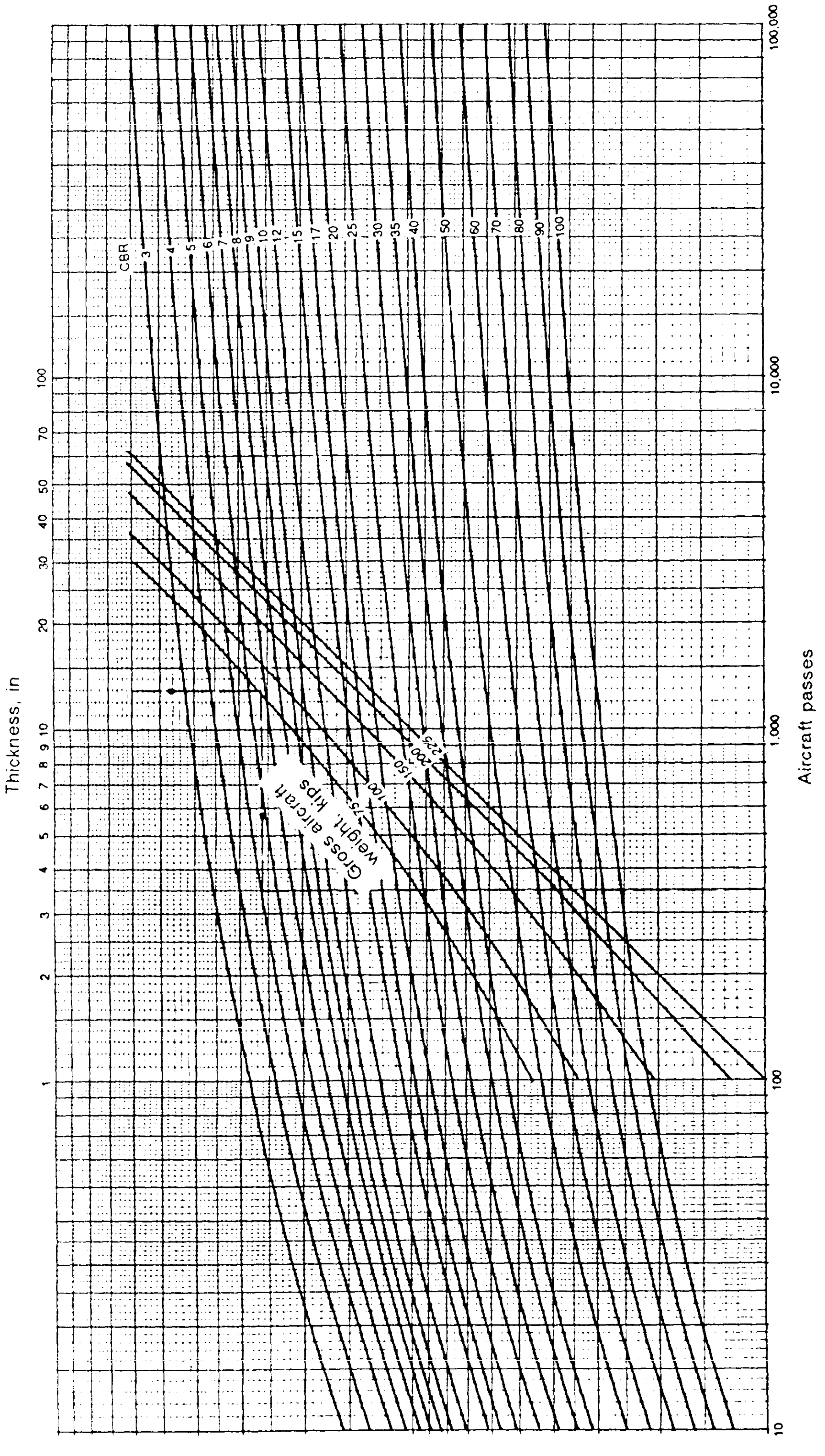
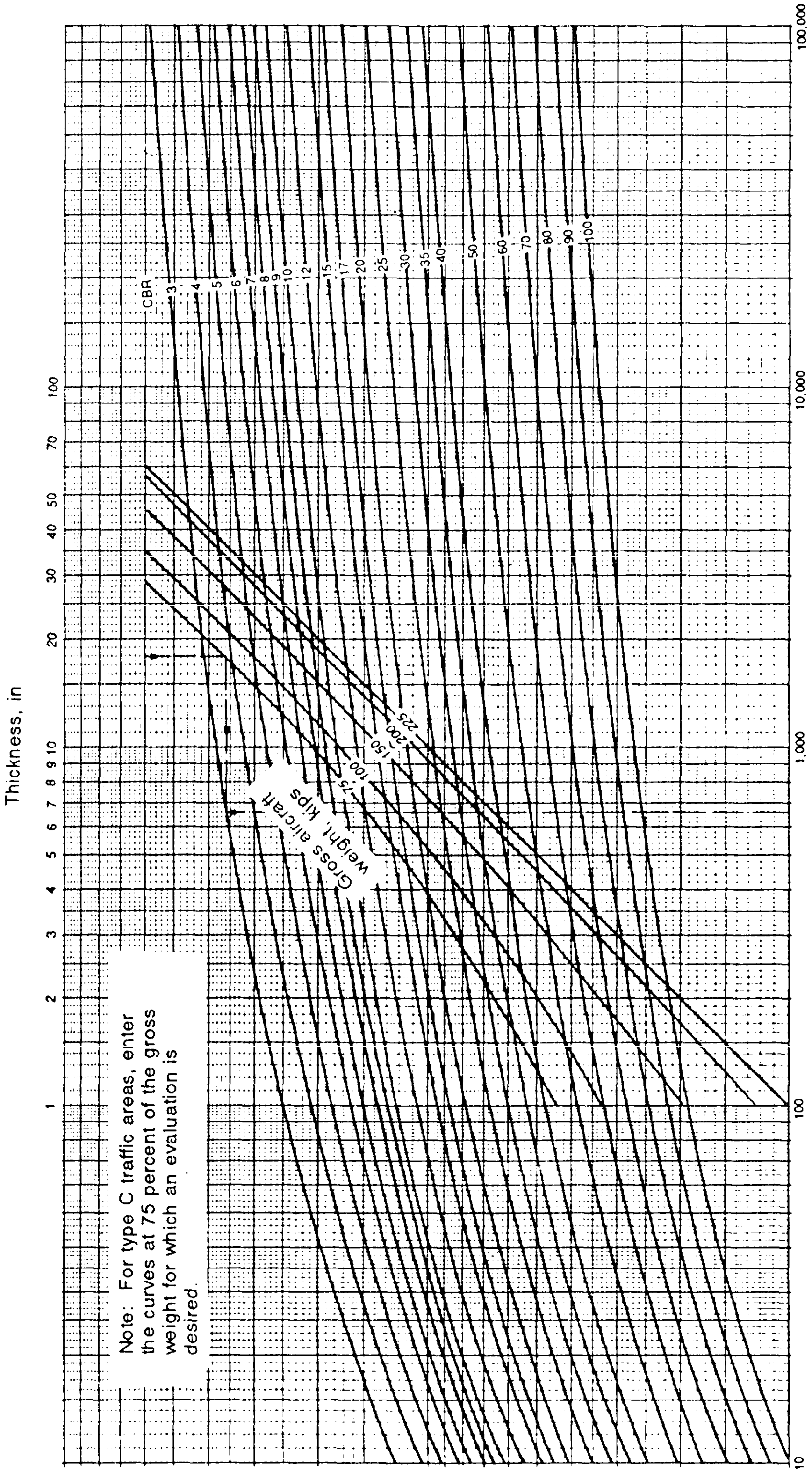


Figure K-13. Flexible-pavement evaluation curves, Group Index VII, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-14. Flexible-pavement evaluation curves, Group Index VII, Type B and C traffic areas

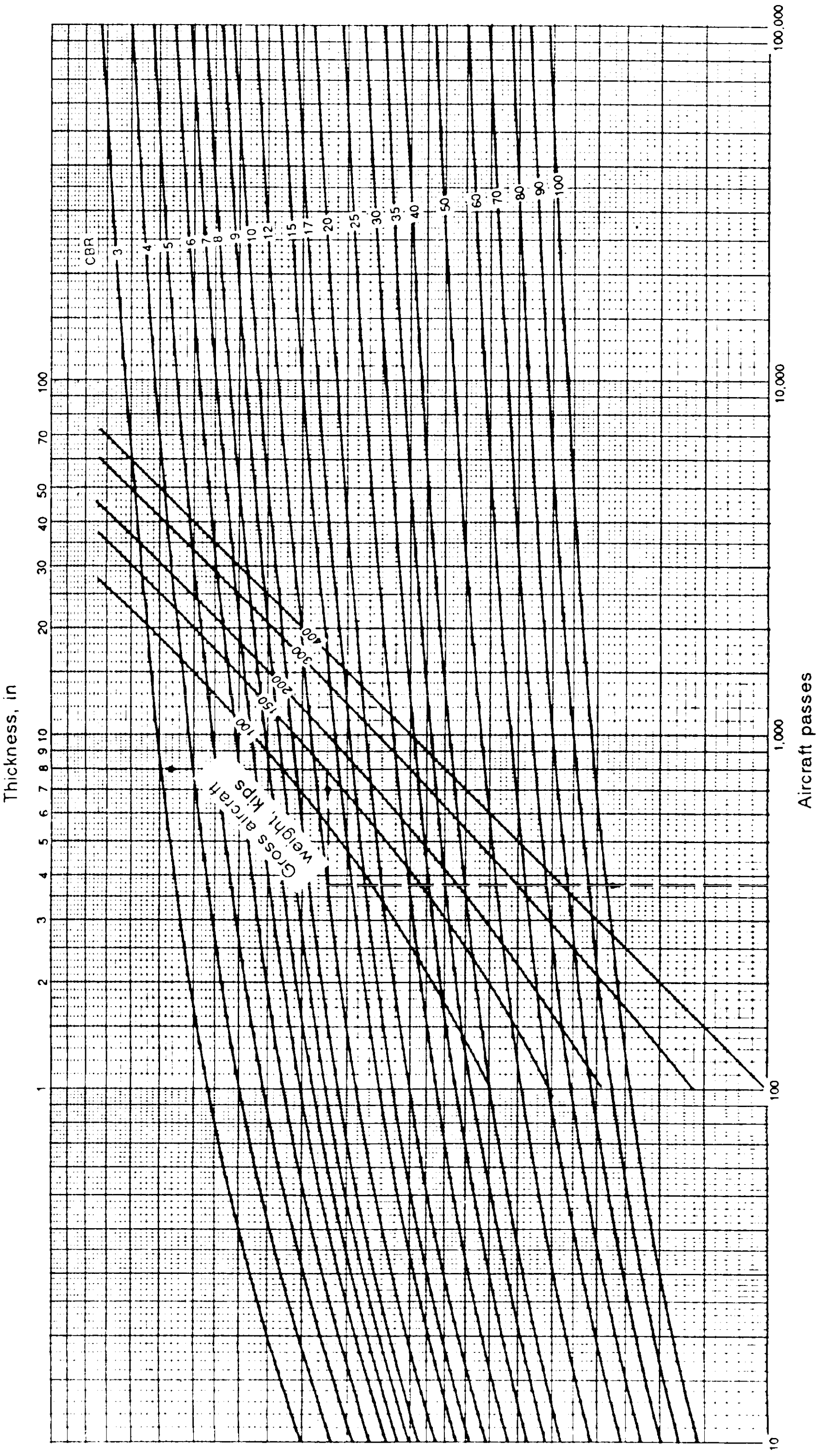
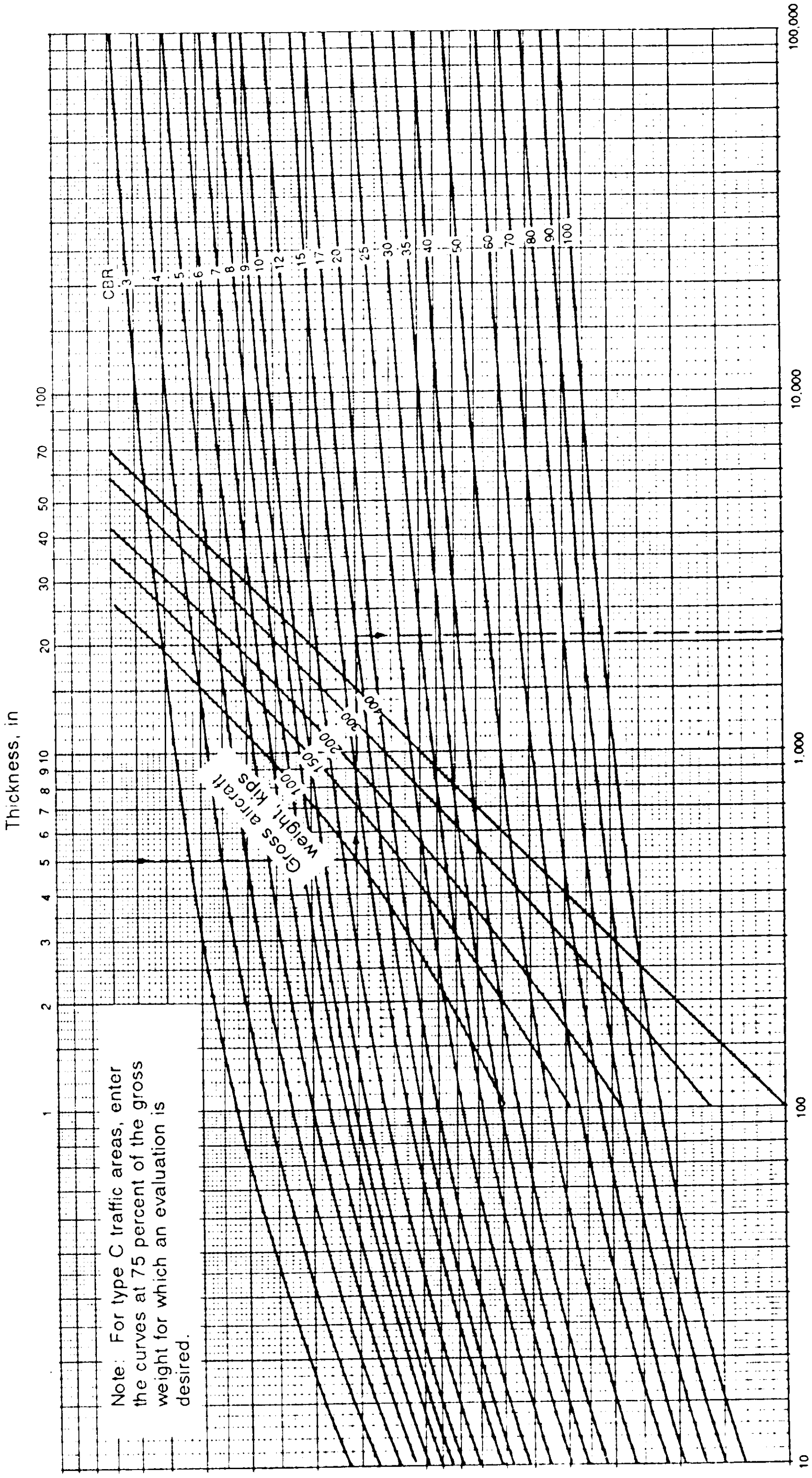


Figure K-15. Flexible-pavement evaluation curves, Group Index VIII, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-16. Flexible-pavement evaluation curves, Group Index VIII, Type B and C traffic areas

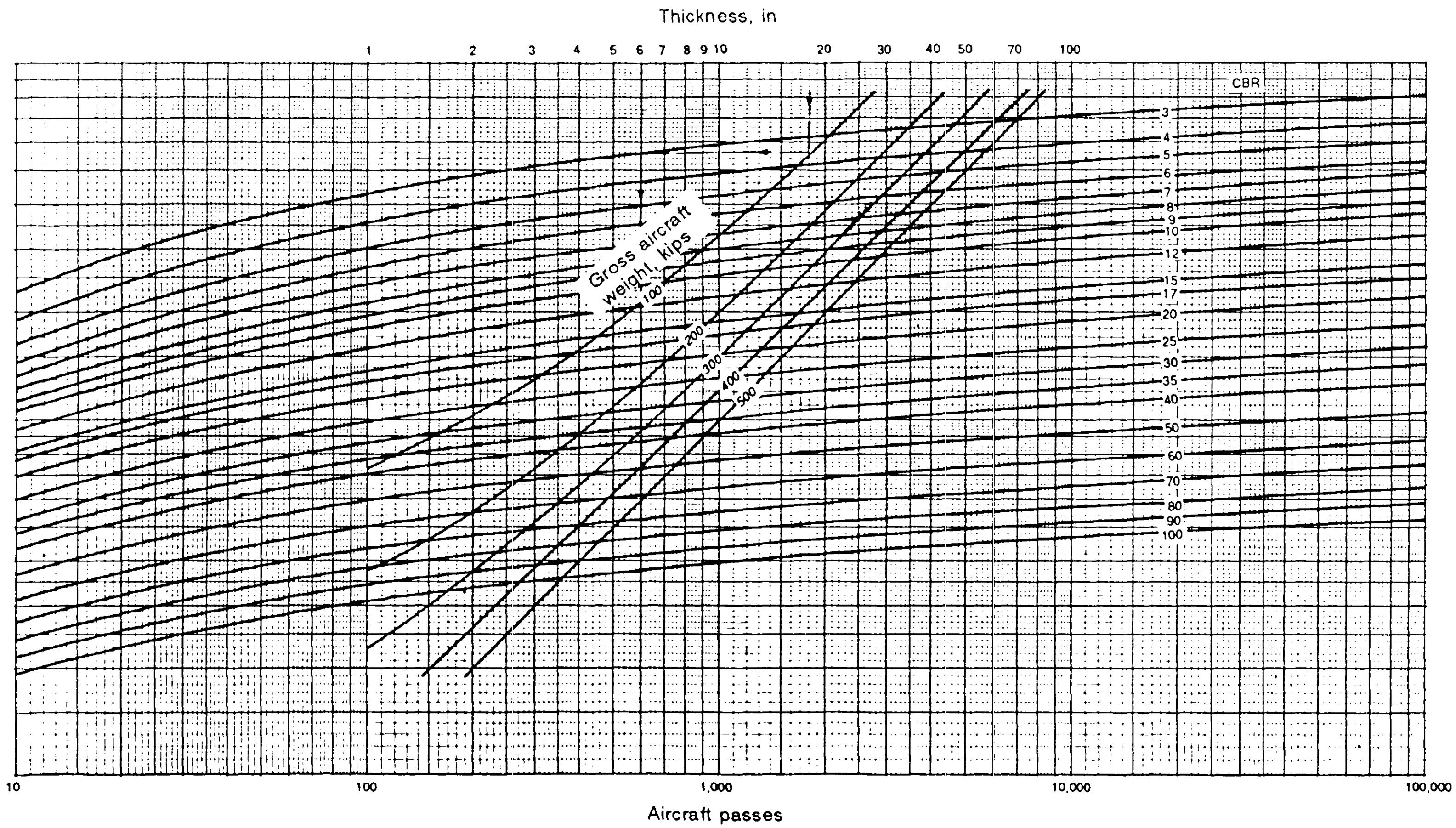
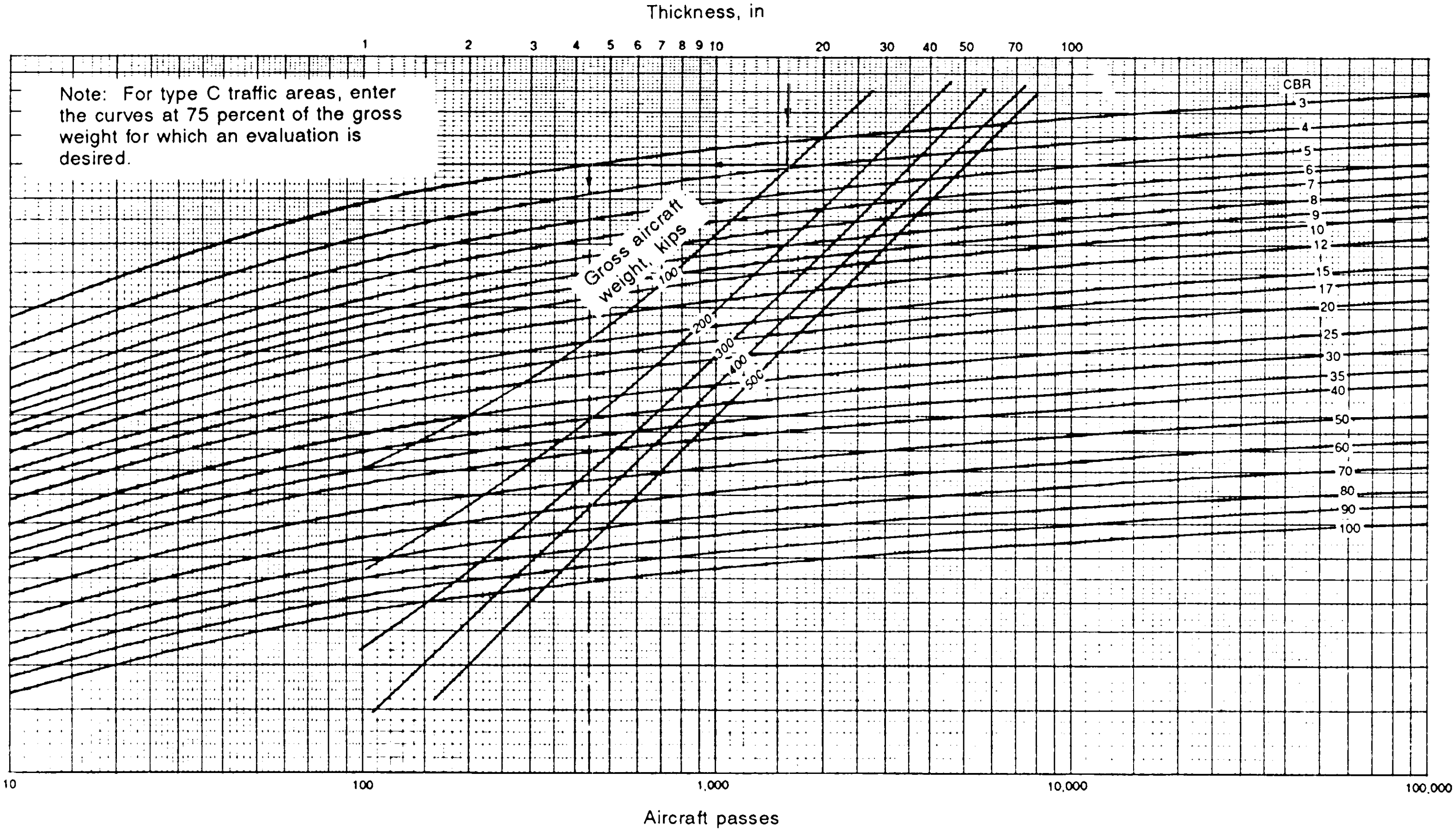


Figure K-17. Flexible-pavement evaluation curves, Group Index IX, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-18. Flexible-pavement evaluation curves, Group Index IX, Type B and C traffic areas

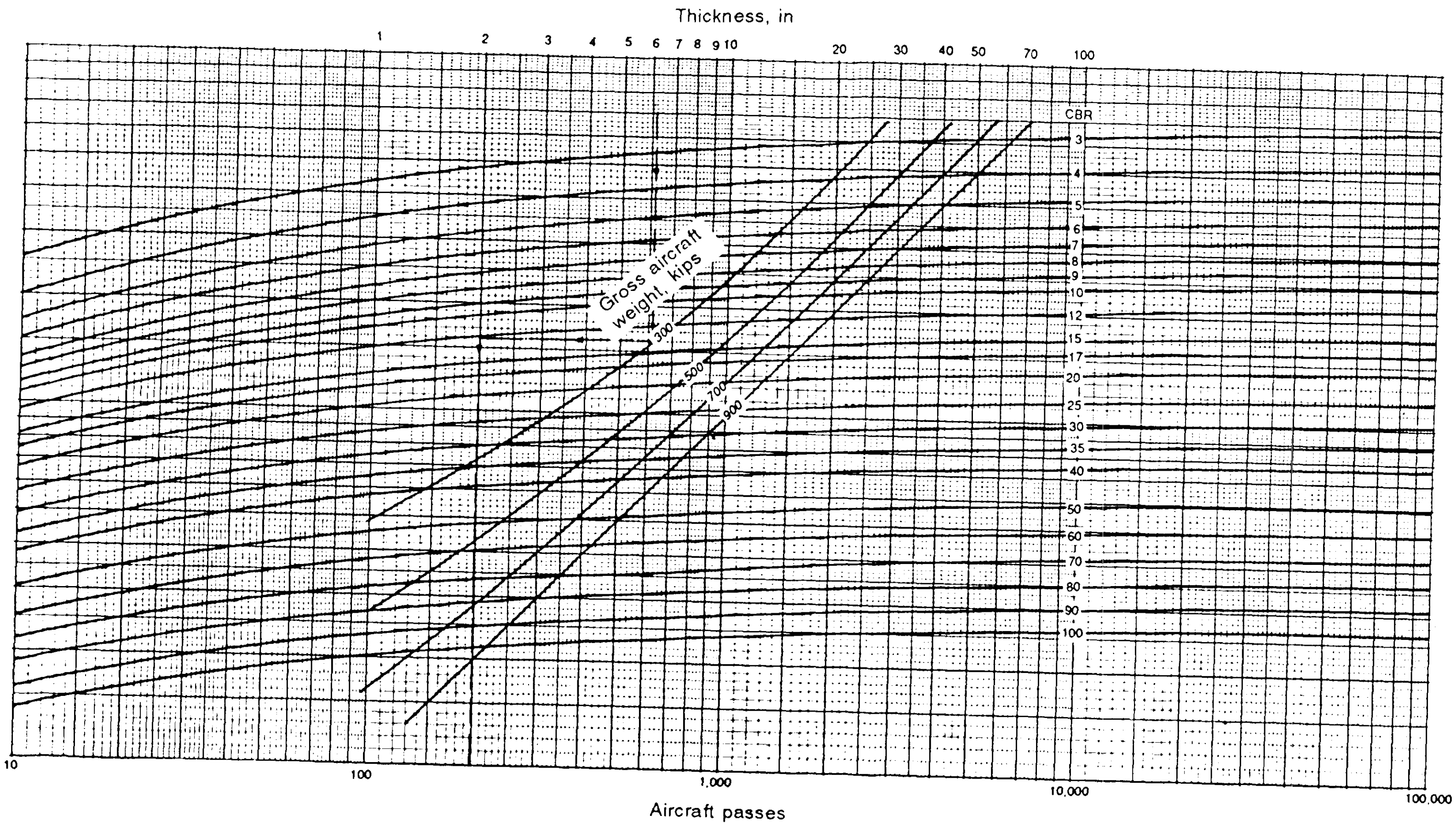
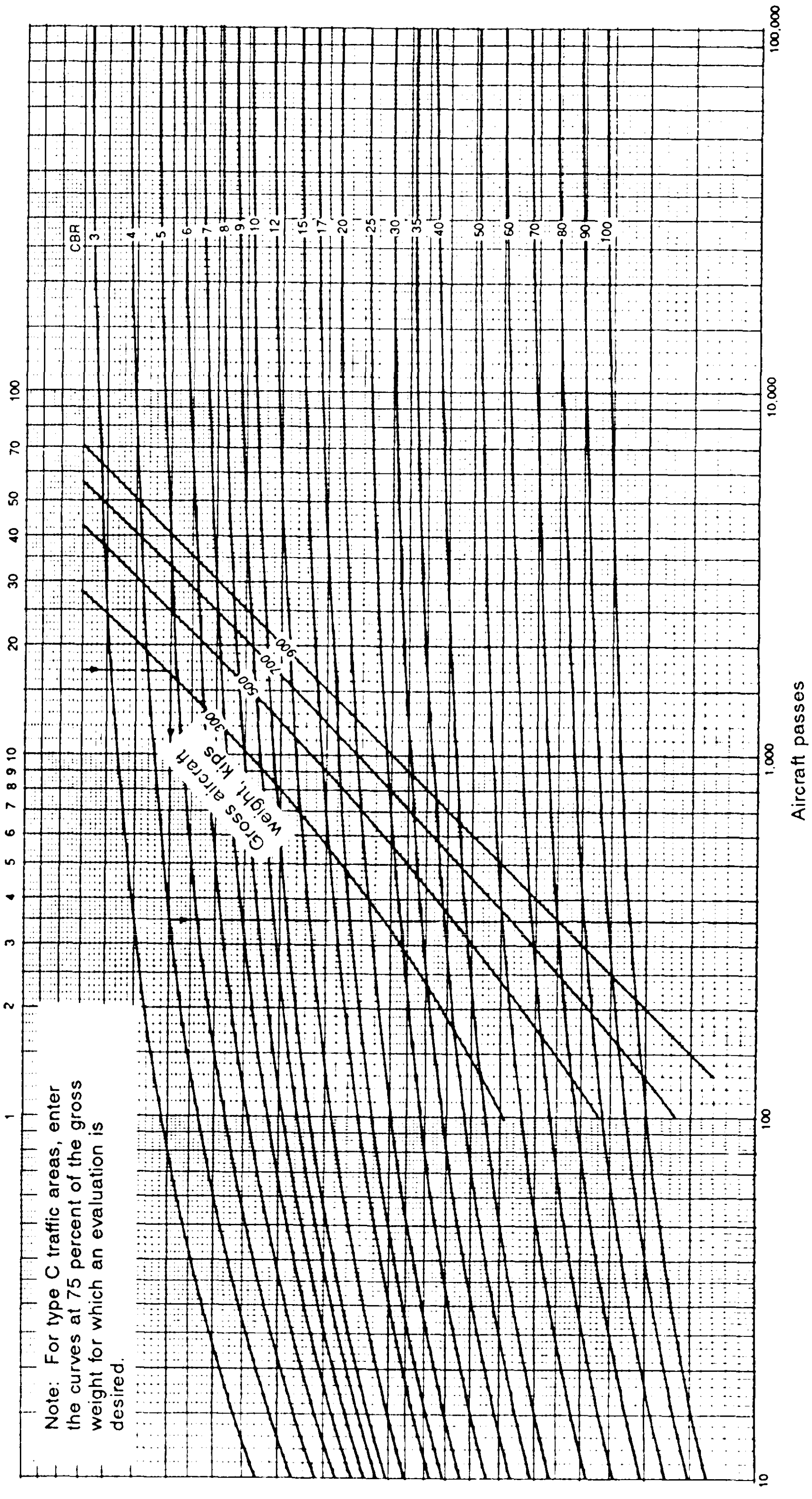


Figure K-19. Flexible-pavement evaluation curves, Group Index X, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-20. Flexible-pavement evaluation curves, Group Index X, Type B and C traffic areas

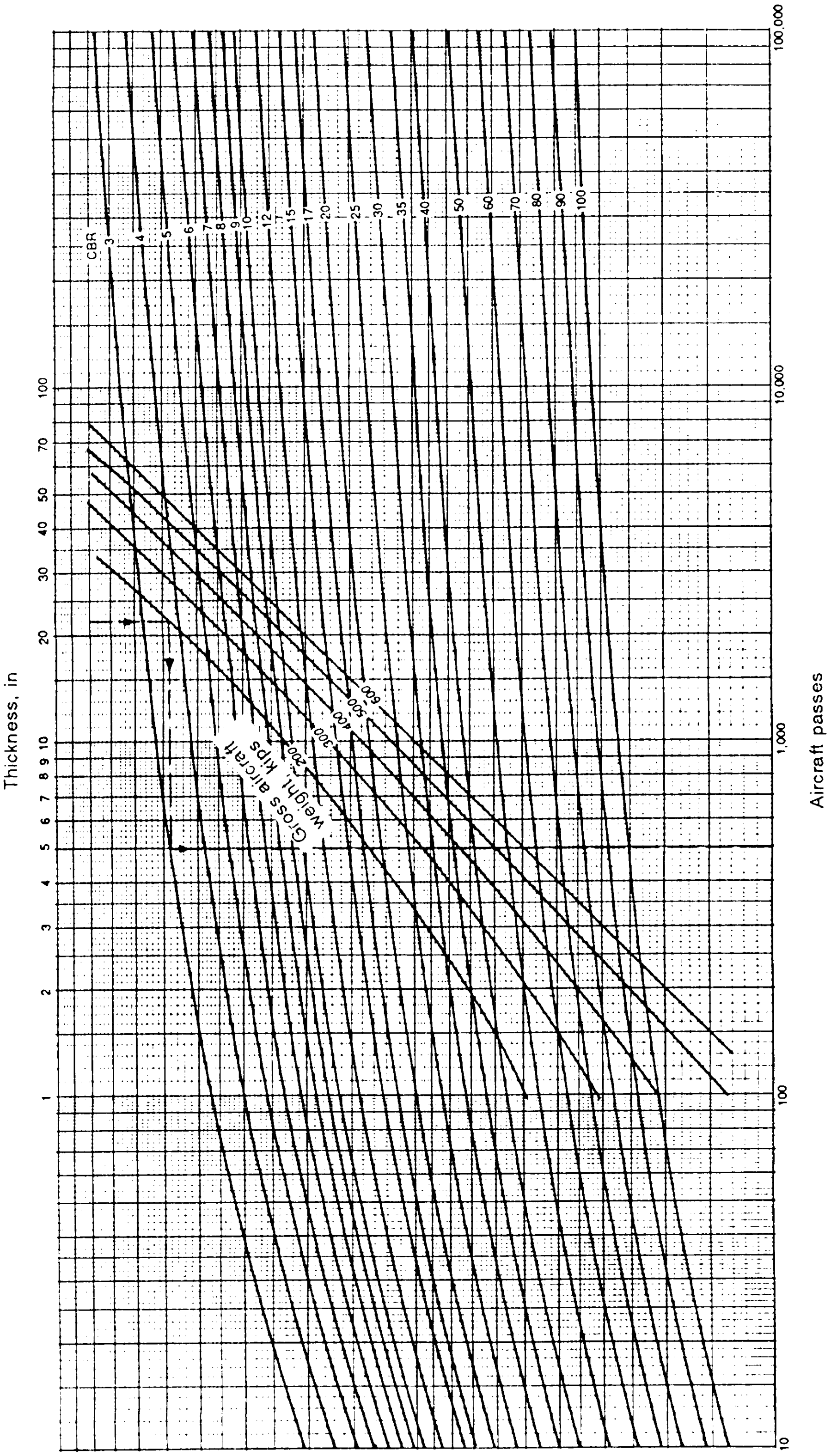
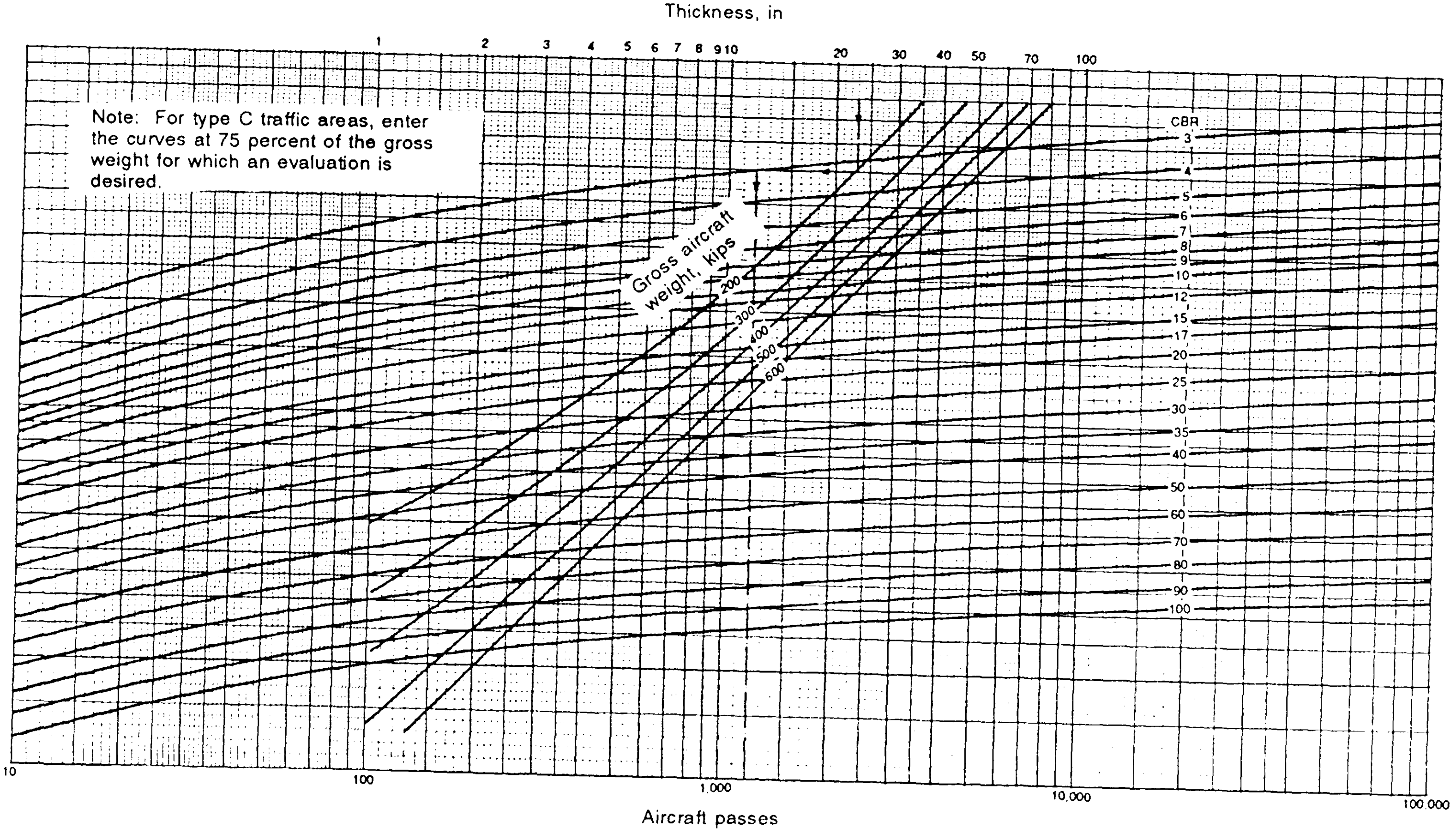


Figure K-21. Flexible-pavement evaluation curves, Group Index XI, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-22. Flexible-pavement evaluation curves, Group Index XI, Type B and C traffic areas

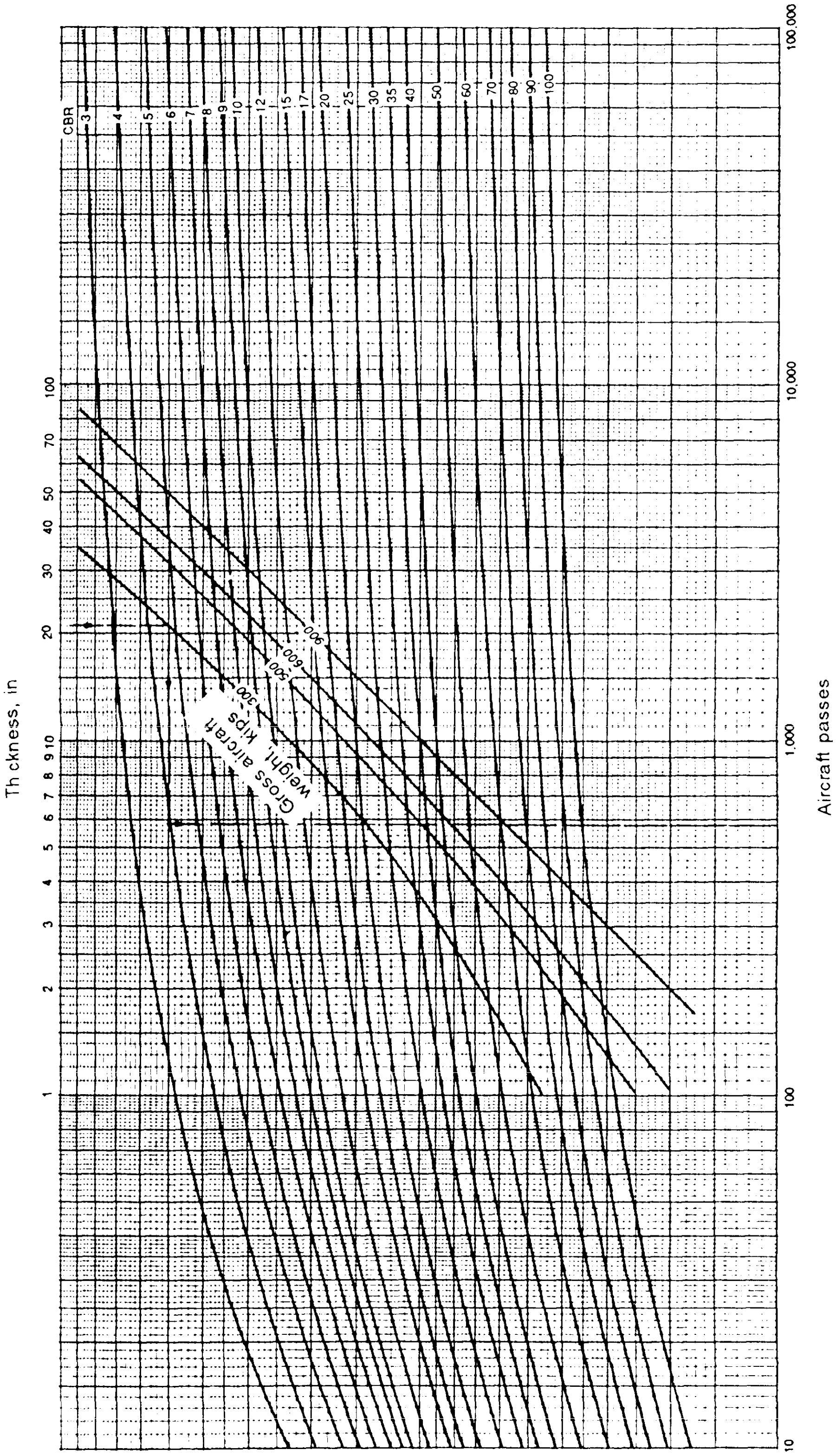
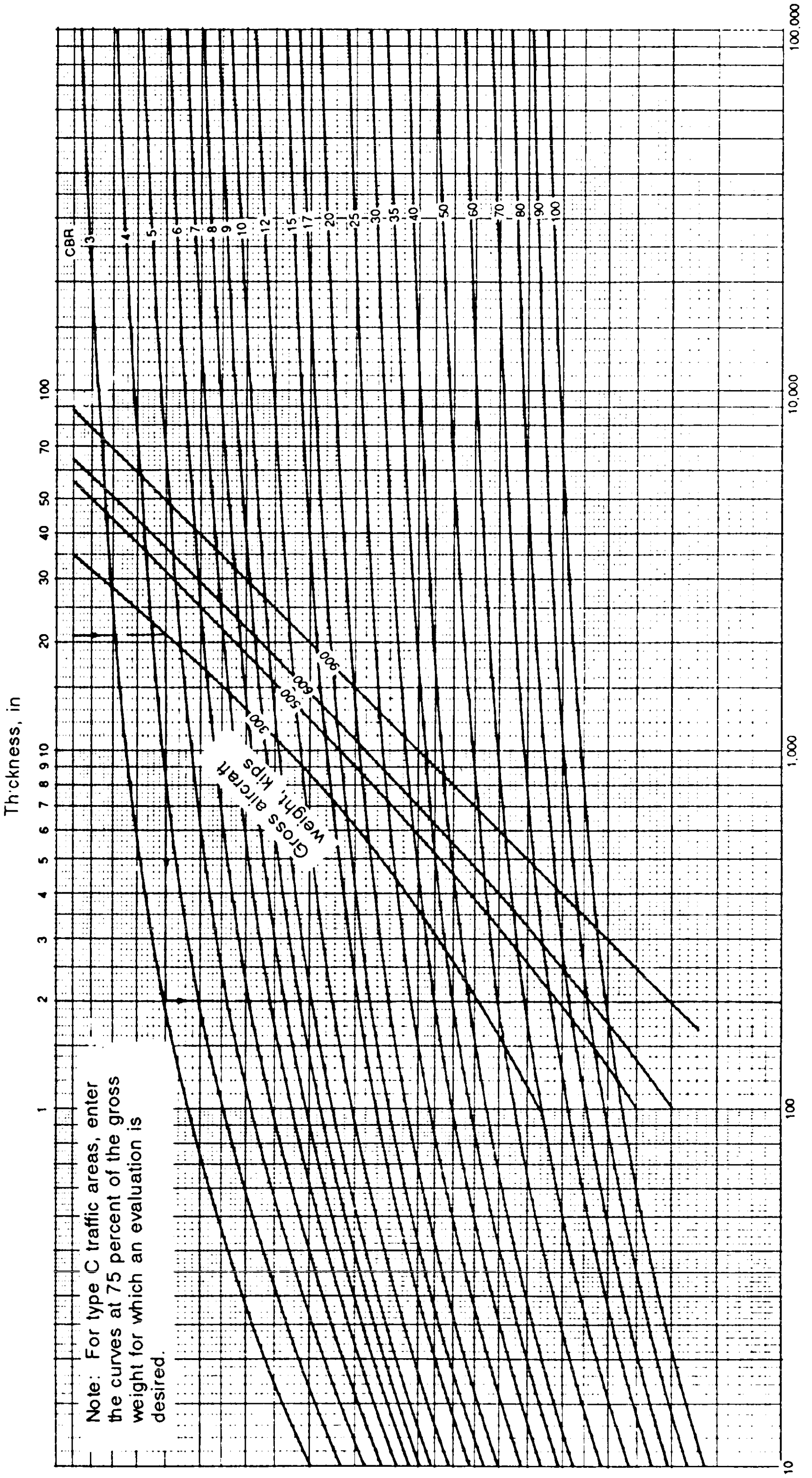


Figure K-23. Flexible-pavement evaluation curves, Group Index XII, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-24. Flexible-pavement evaluation curves, Group Index XII, Type B and C traffic areas

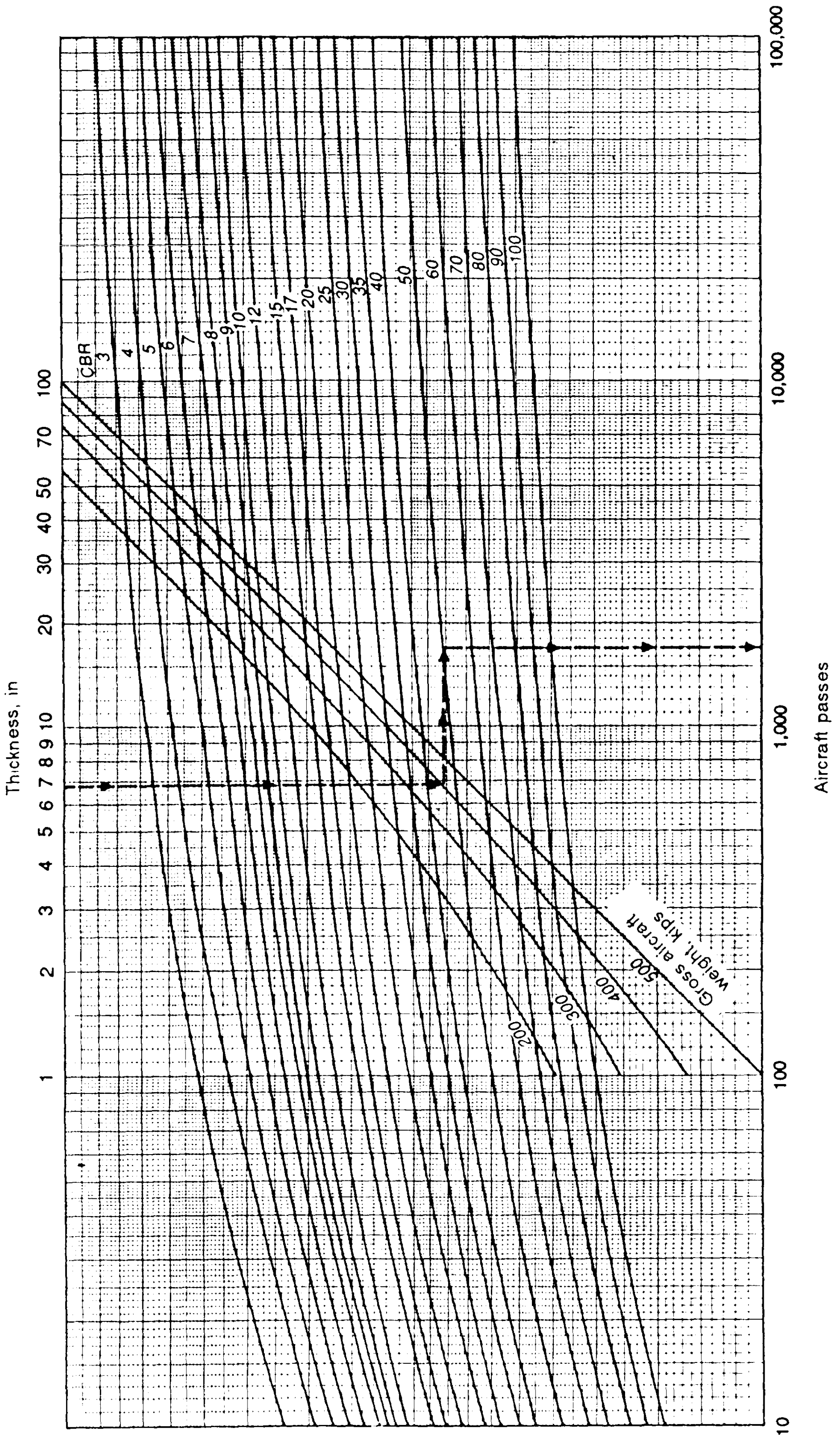
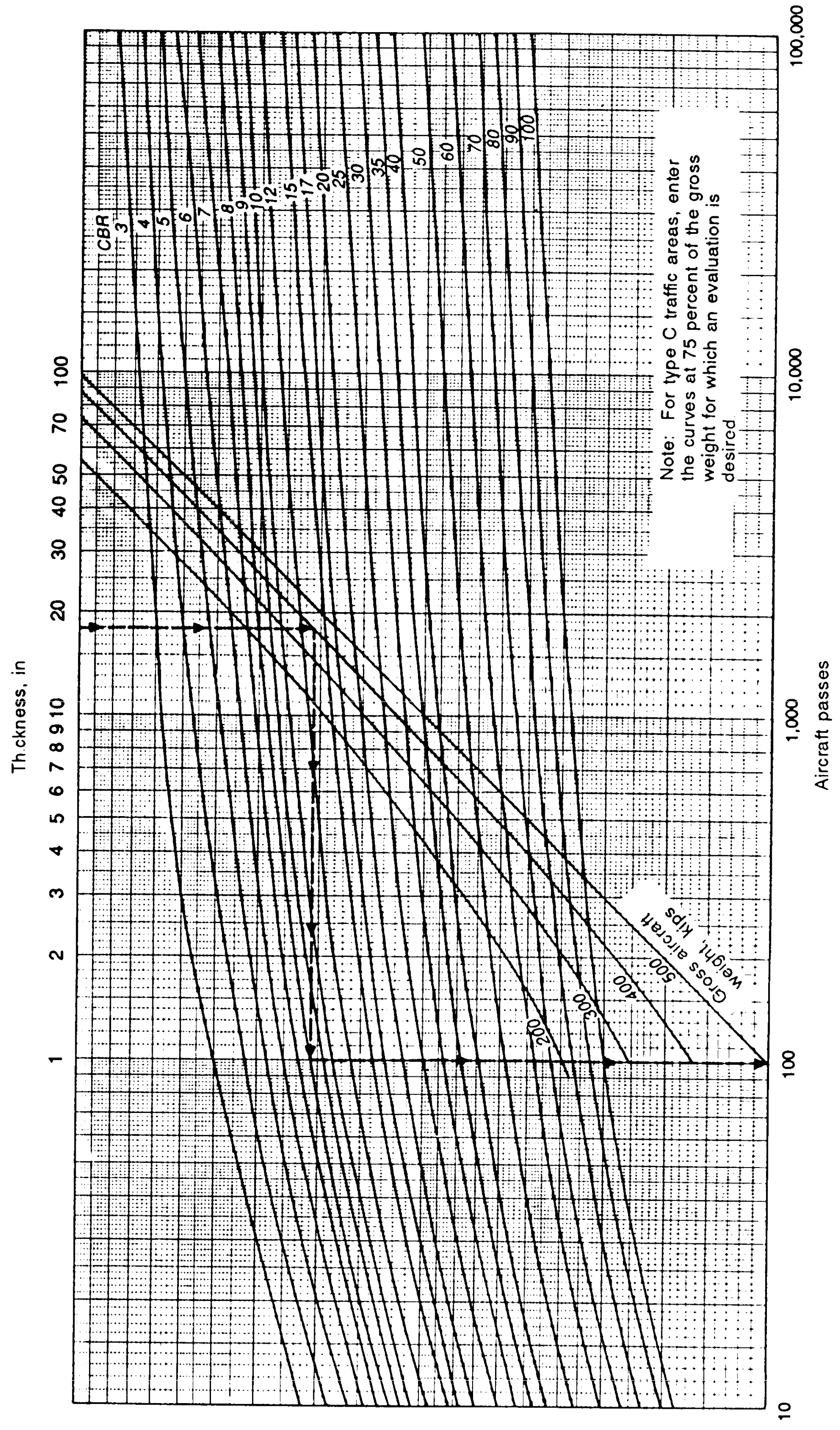


Figure K-25. Flexible-pavement evaluation curves, Group Index XIII, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired

Figure K-26. Flexible-pavement evaluation curves, Group Index XIII, Type B and C traffic areas

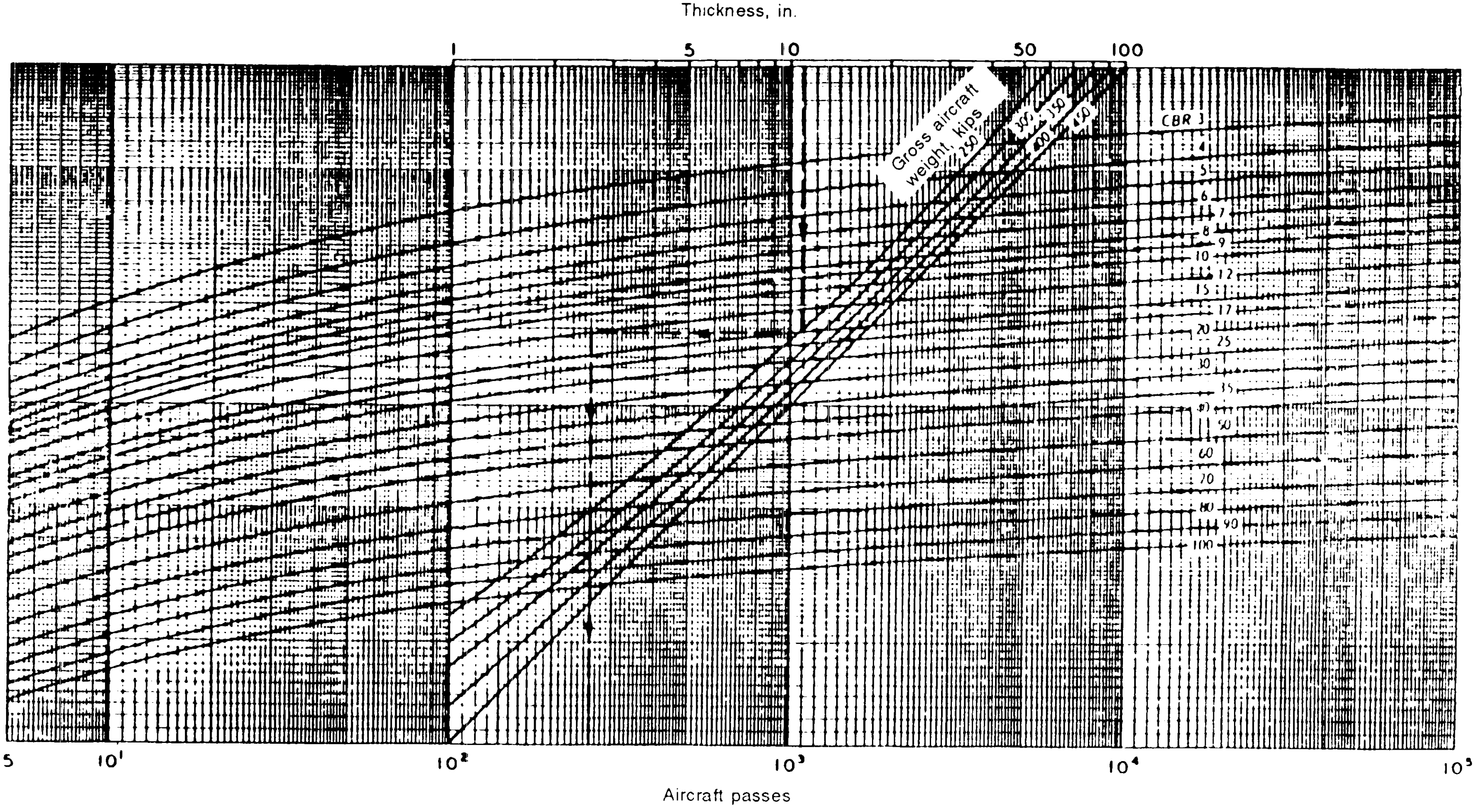
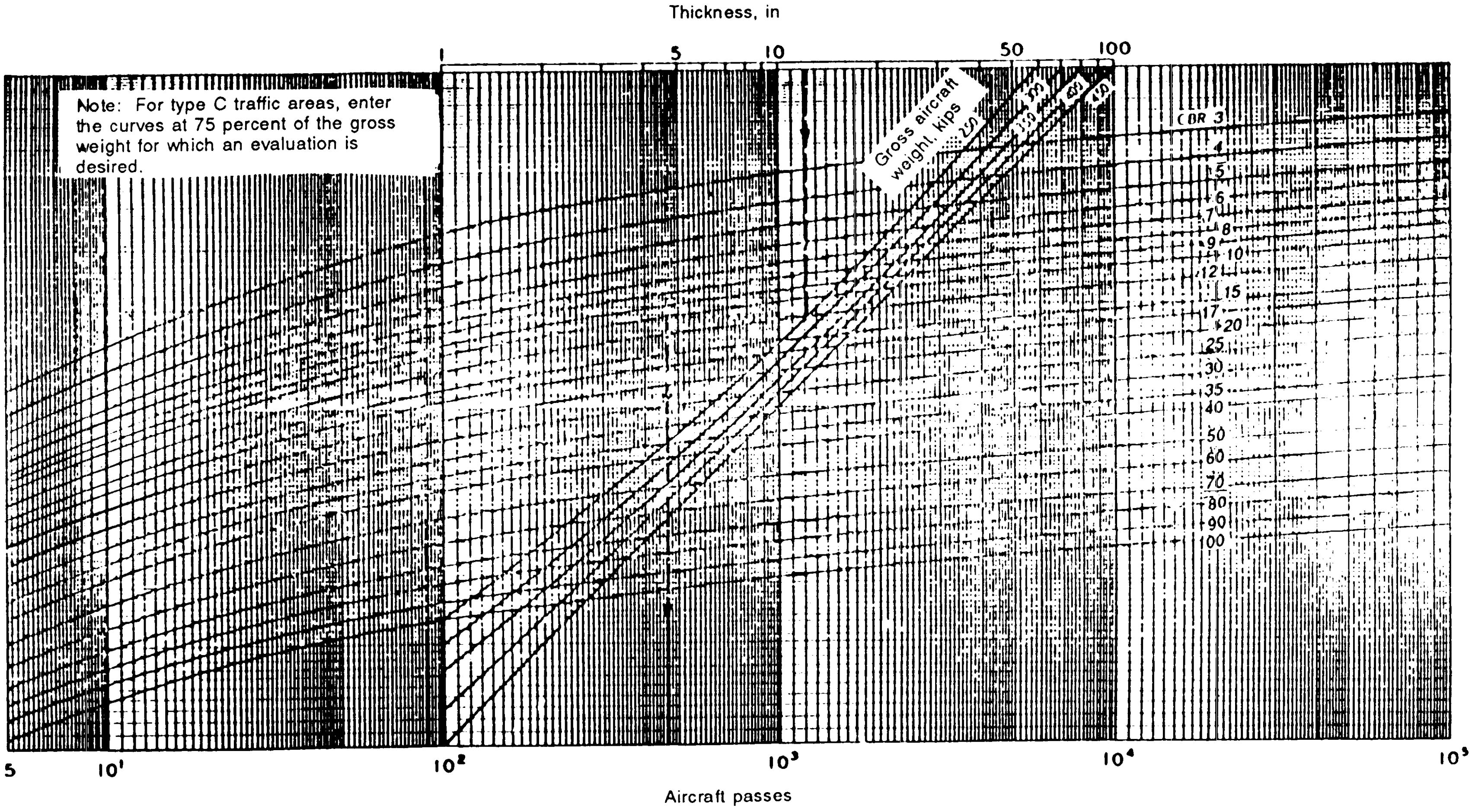


Figure K-27. Flexible-pavement evaluation curves, B-1, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-28. Flexible-pavement evaluation curves, B-1, Type B and C traffic areas

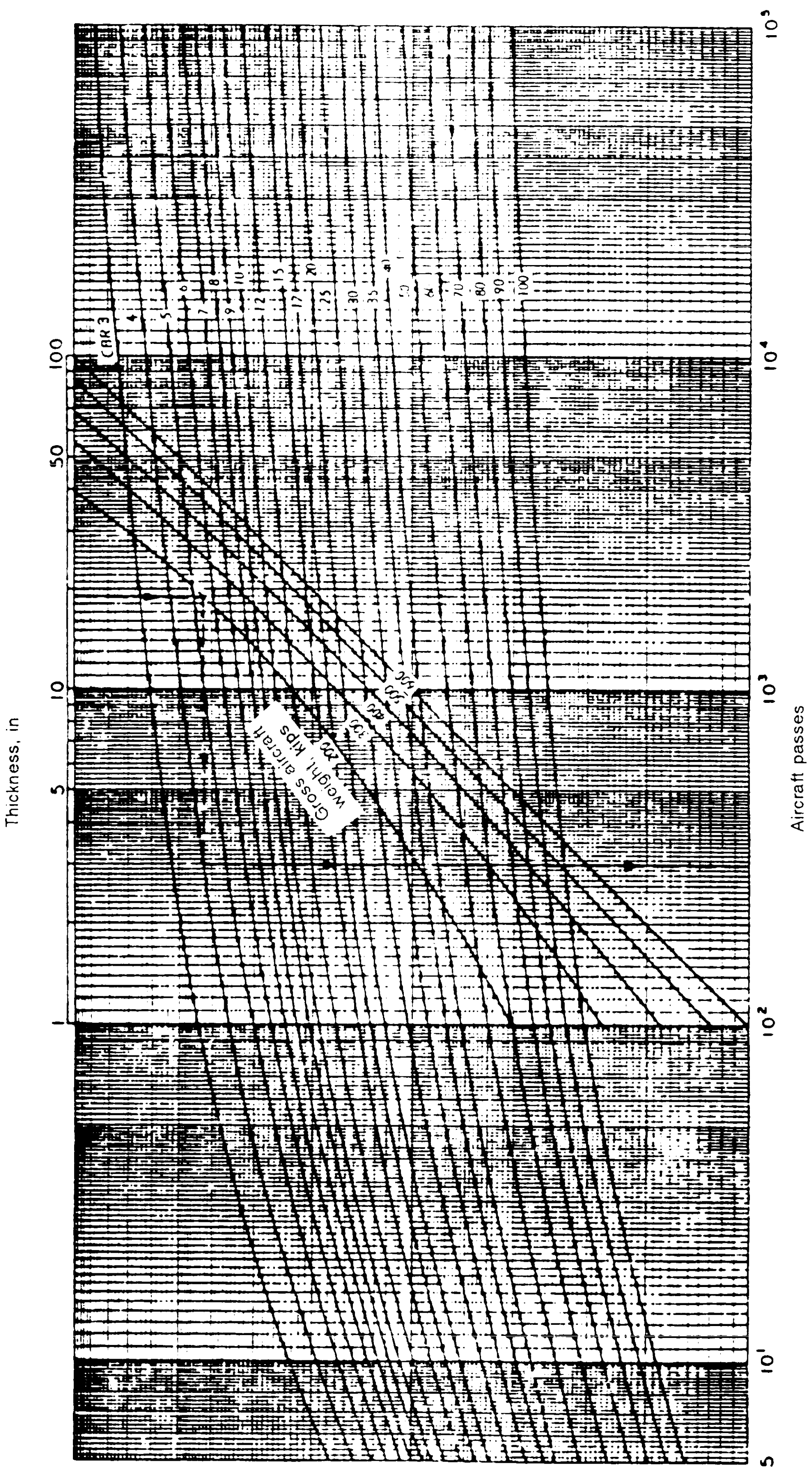
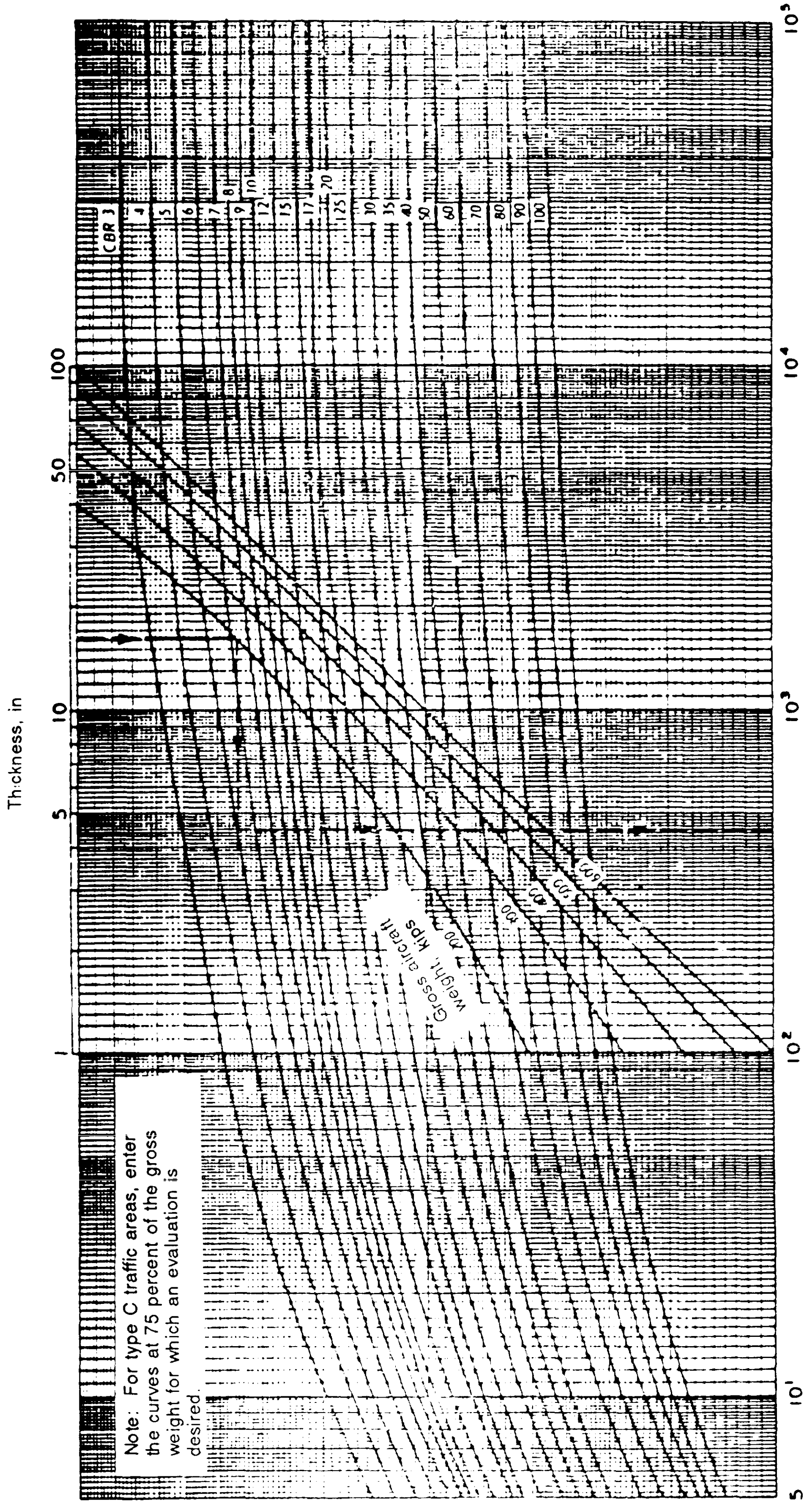


Figure K-29. Flexible-pavement evaluation curves, DC-10-10, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-30. Flexible-pavement evaluation curves, DC-10-10, Type B and C traffic areas

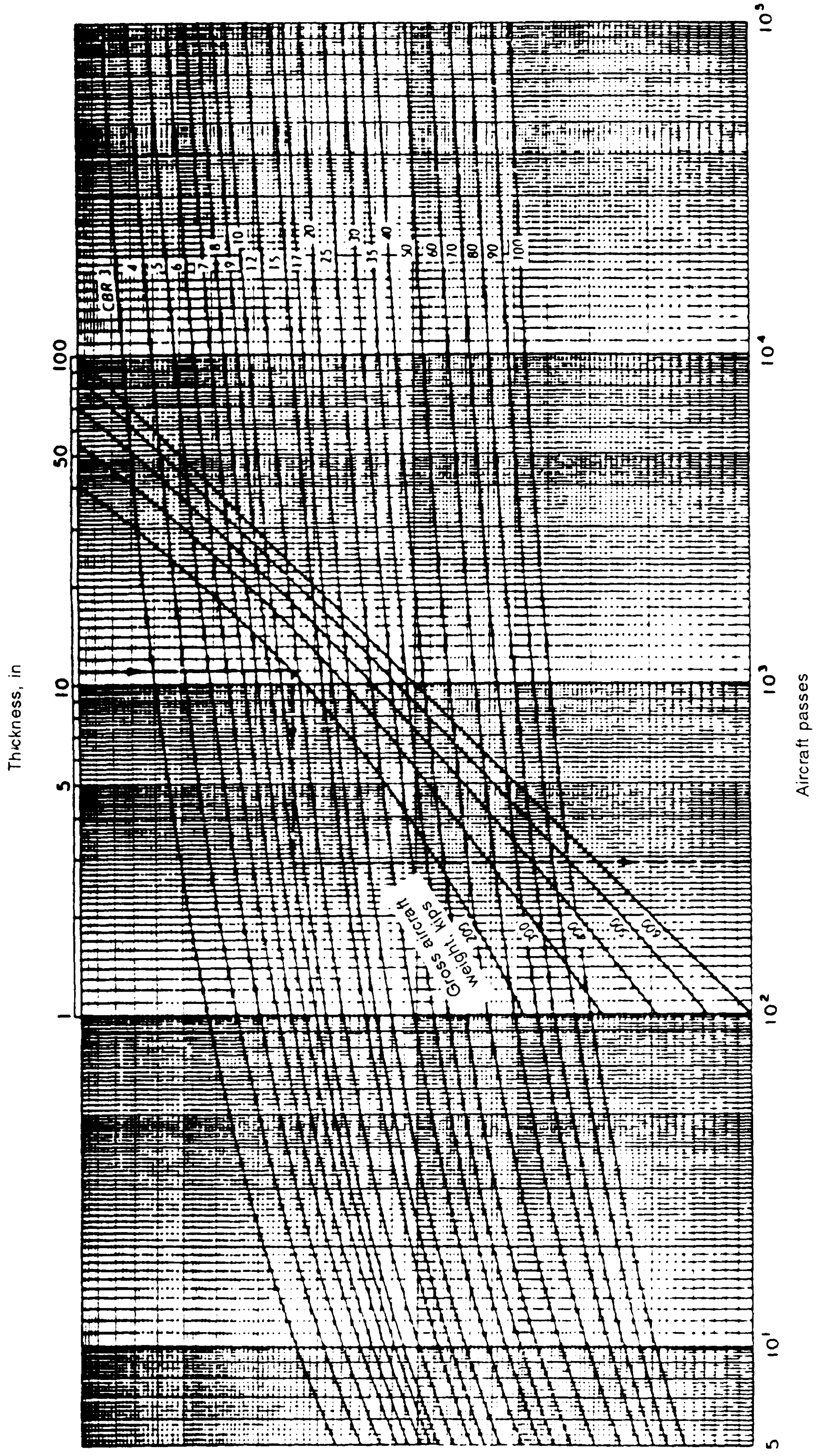
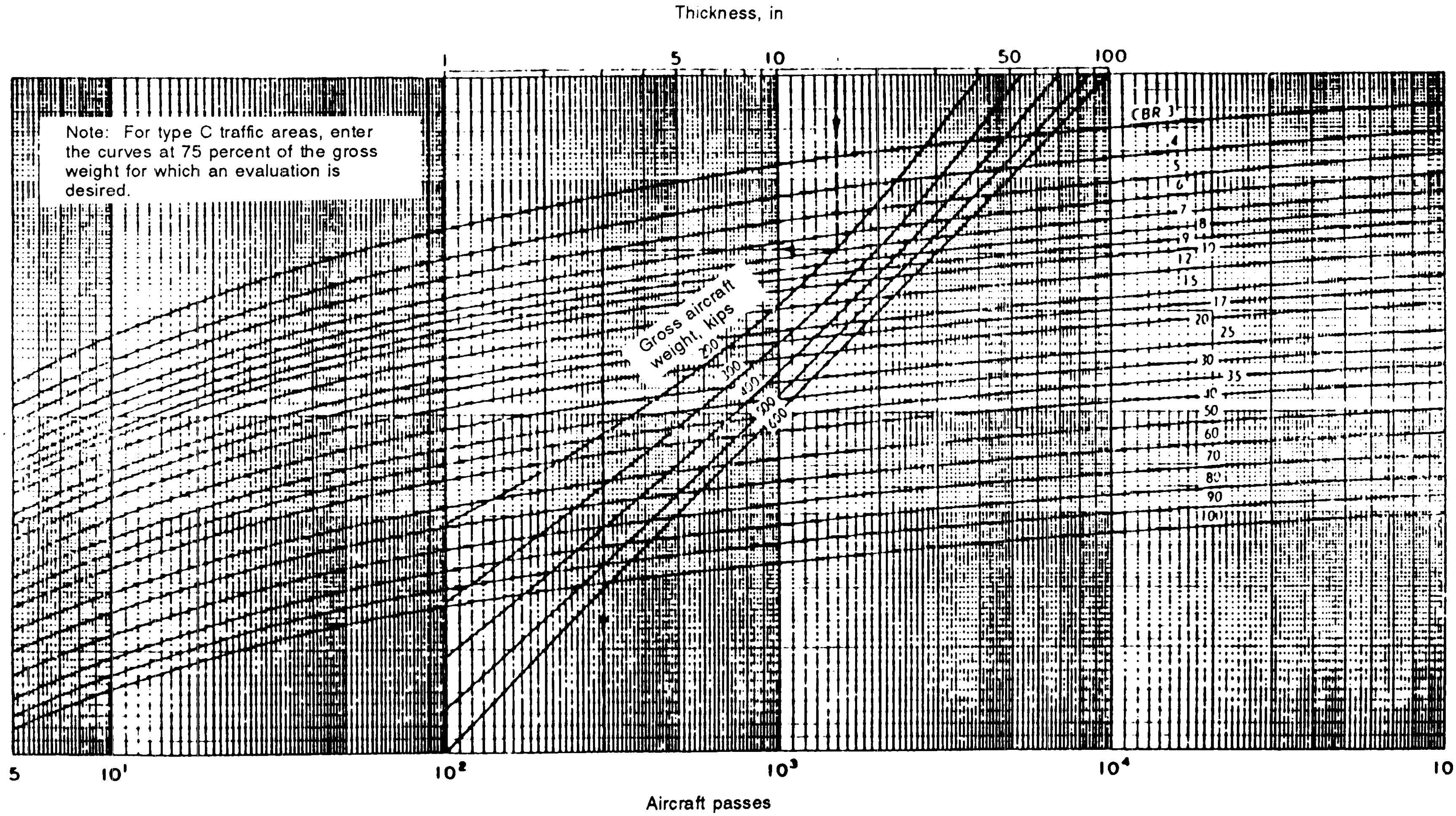


Figure K-31. Flexible-pavement evaluation curves, L-1011, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-32. Flexible-pavement evaluation curves, L-1011, Type B and C traffic areas

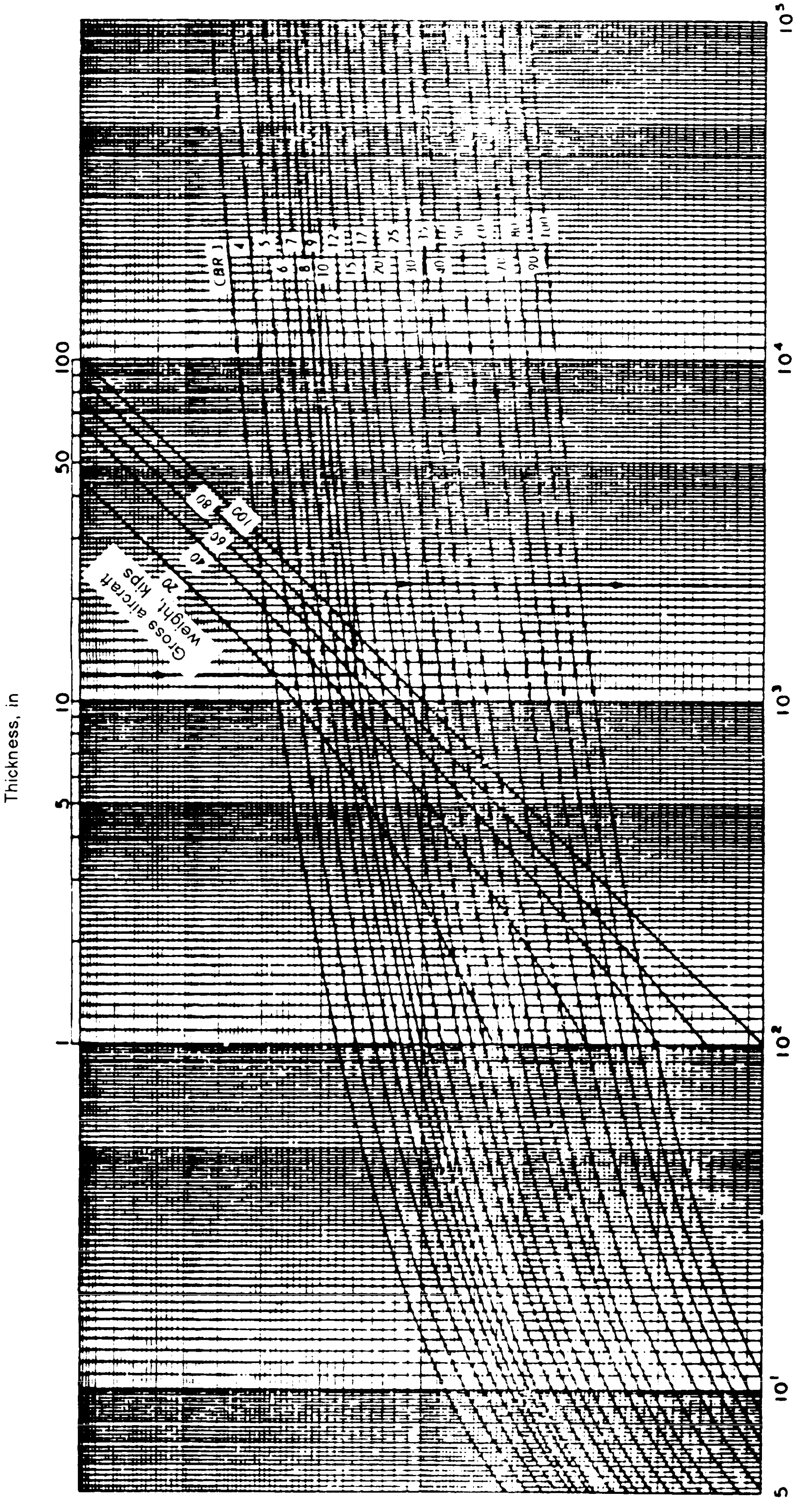
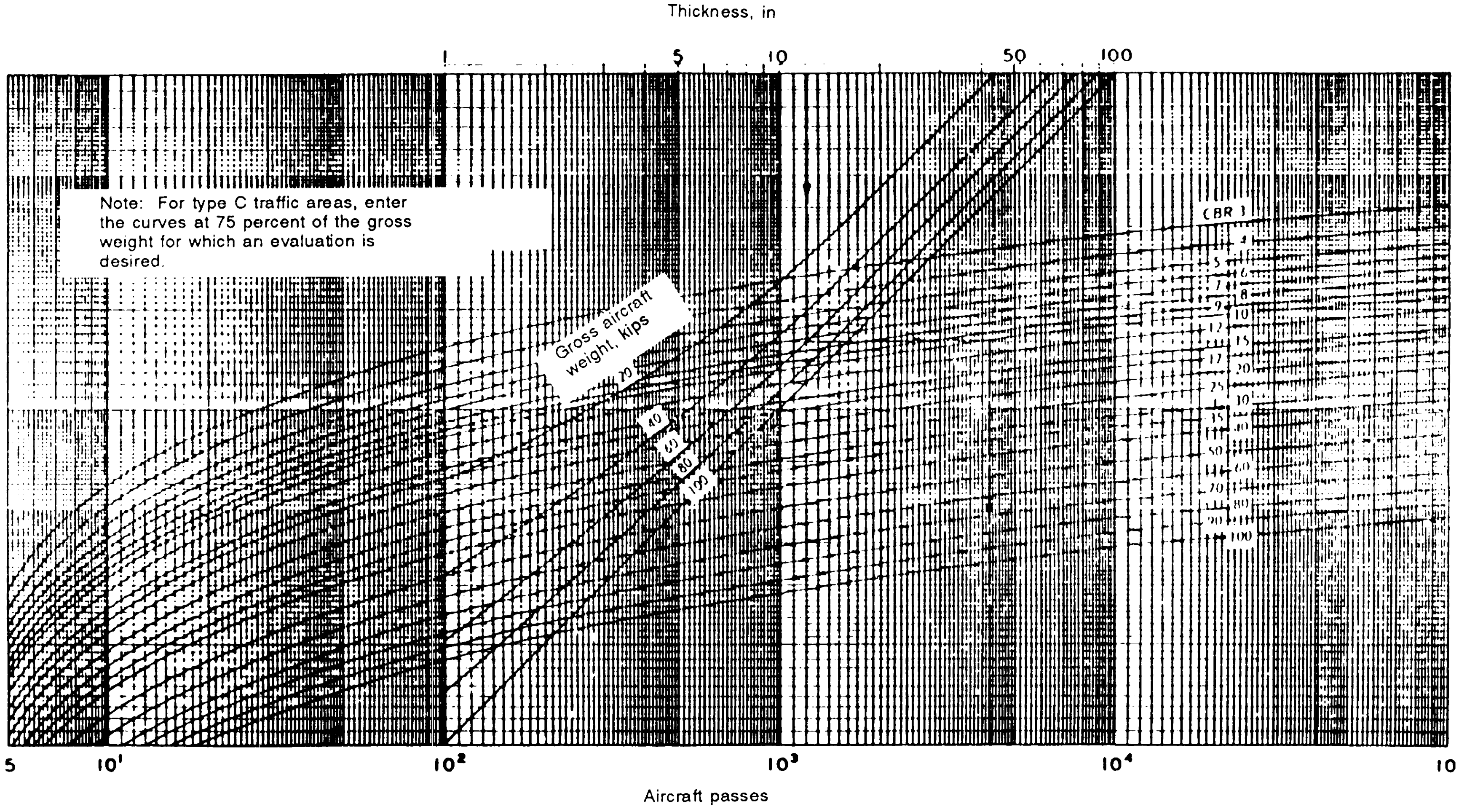


Figure K-33. Flexible-pavement evaluation curves, single curves, single-wheel, 100 sq in, Type A traffic areas



Note: For type C traffic areas, enter the curves at 75 percent of the gross weight for which an evaluation is desired.

Figure K-34. Flexible-pavement evaluation curves, single-wheel, 100 sq in, Type B and C traffic areas

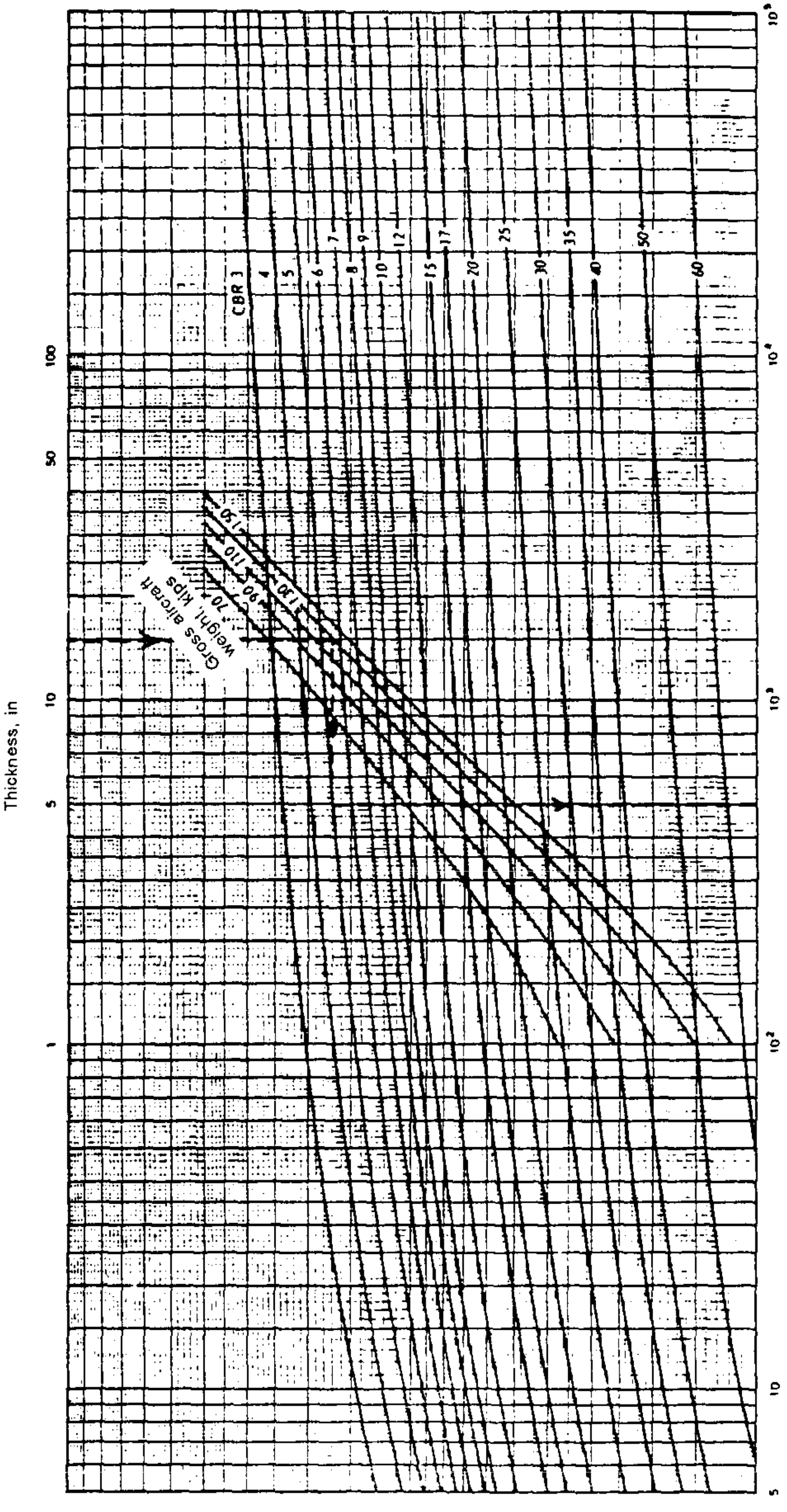


Figure K-35. Flexible-pavement evaluation curves, for roads and streets, crash-rescue vehicle P-15

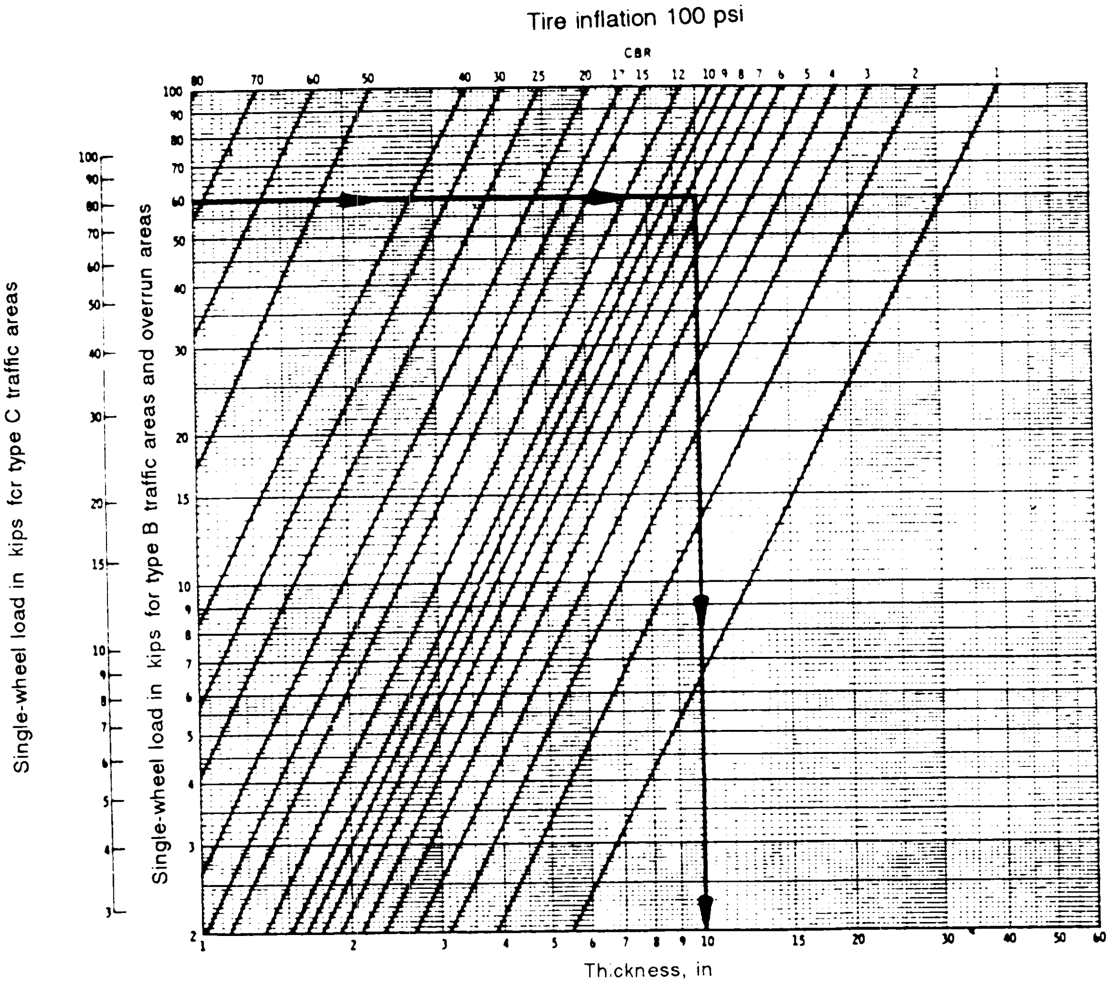


Figure K-36. Flexible-pavement evaluation curves, single-wheel (used for shoulder design)

APPENDIX L

MAT REQUIREMENT TABLES FOR AIRFIELDS

Tables L-1 and L-2 show the number of bundles, the weight, and the volumes of landing mat required to meet the needs of a close battle area or support area airfield.

Table L-1. Mat required for close battle area airfield

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Runway	558	281	521	463
Taxiway	328	165	306	272
Apron, warm-up	112	57	105	93
Overrun	134	68	125	112
Shoulder	417	210	389	346
Apron, parking	335	169	313	278
Total	1,884	950	1,759	1,564
Weight (tons)				
Runway	568.0	354.1	515.8	504.7
Taxiway	333.9	207.9	302.9	296.5
Apron, warm-up	114.1	71.8	104.0	101.4
Overrun	136.4	85.7	123.8	122.1
Shoulder	424.5	264.6	385.1	377.1
Apron, parking	341.0	212.9	309.9	303.0
Total	1,917.9	1,197.0	1,741.5	1,704.8
Cargo Space (cu ft)				
Runway	13,783	23,941	32,302	27,641
Taxiway	8,102	14,058	18,972	16,238
Apron, warm-up	2,767	4,856	6,510	5,552
Overrun	3,310	5,794	7,750	6,686
Shoulder	10,300	17,892	24,118	20,656
Apron, parking	8,275	14,399	19,406	16,597
Total	46,537	80,940	109,058	93,370
Measurement Tons (40 cu ft = 1 measurement ton)				
Runway	344.5	589.5	807.5	691.0
Taxiway	204.5	351.5	474.3	406.0
Apron, warm-up	69.1	121.4	162.7	138.8
Overrun	82.7	144.9	193.7	167.2
Shoulder	257.4	447.3	602.9	516.4
Apron, parking	206.9	360.0	485.2	414.9
Total	1,163.1	2,023.6	2,726.3	2,334.3

Table L-2. Mat required for support area airfield

Bundle Logistics	**Mat Type**			
	M8A1	**M19**	**AM2**	**Truss Web**
Number Required For				
Runway	782	393	730	649
Taxiway	529	266	494	439
Apron, warm-up	103	52	96	85
Overrun	134	68	125	112
Shoulder	566	285	528	470
Apron, parking	1,392	700	1,299	1,155
Total	3,506	1,764	3,272	2,910
Weight (tons)				
Runway	796.1	495.2	722.7	707.4
Taxiway	538.5	335.2	489.1	478.5
Apron, warm-up	104.9	65.5	95.0	92.7
Overrun	136.4	85.7	123.8	122.1
Shoulder	576.2	359.1	522.7	512.3
Apron, parking	1,417.1	882.0	1,286.0	1,259.0
Total	3,569.2	2,222.7	3,239.3	3,172.0
Cargo Space (cu ft)				
Runway	19,316	33,484	45,260	38,745
Taxiway	13,067	22,663	30,628	26,208
Apron, warm-up	2,545	4,430	5,952	5,075
Overrun	3,310	5,794	7,750	6,686
Shoulder	13,981	24,282	32,736	28,059
Apron, parking	34,383	59,640	80,538	68,954
Total	76,602	150,293	202,864	173,727
Measurement Tons (40 cu ft = 1 measurement ton)				
Runway	482.8	837.1	1,131.5	968.6
Taxiway	326.6	566.6	765.7	655.2
Apron, warm-up	63.6	110.8	148.8	126.9
Overrun	82.7	144.9	193.7	167.2
Shoulder	349.5	607.1	818.4	701.5
Apron, parking	859.5	1,491.0	2,013.4	1,723.9
Total	2,164.7	3,757.5	5,071.5	4,343.3

APPENDIX M

MAT REQUIREMENT TABLES FOR HELIPADS AND HELIPORTS

Tables M-1 through M-22 show the number of bundles, the weight, and the volumes of landing mat required to build helipads and heliports.

Table M-1. Mat required for forward area OH-58 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	1	1	1	1
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1	1	1	1
Weight (tons)				
Pad	1.1	1.3	1.0	1.1
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1.1	1.3	1.0	1.1
Cargo Space (cu ft)				
Pad	25	86	62	60
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	25	86	62	60
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	0.6	2.2	1.6	1.5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	0.6	2.2	1.6	1.5

Table M-2. Mat requirecf for forward area UH-1H helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	2	1	2	2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	2	1	2	2
Weight (tons)				
Pad	2.1	1.3	2.0	2.2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	2.1	1.3	2.0	2.2
Cargo Space (cu ft)				
Pad	50	86	124	120
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	50	86	124	120
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	1.3	2.2	3.1	3.0
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1.3	2.2	3.1	3.0

Table M-3. Mat required for forward area CH-47 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	5	3	5	4
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	5	3	5	4
Weight (tons)				
Pad	5.1	3.8	5.0	4.4
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	5.1	3.8	5.0	4.4
Cargo Space (cu ft)				
Pad	124	256	310	239
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	124	256	310	239
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	3.1	6.4	7.8	6.0
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	3.1	6.4	7.8	6.0

Table M-4. Mat required for forward area CH-54 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	10	5	9	8
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	10	5	9	8
Weight (tons)				
Pad	10.2	6.3	8.9	8.7
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	10.2	6.3	8.9	8.7
Cargo Space (cu ft)				
Pad	247	426	558	477.6
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	247	426	558	477.6
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	6.2	10.7	14.0	11.9
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	6.2	10.7	14.0	11.9

Table M-5. Mat required for forward area UH-1H heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	38	19	35	31
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	38	19	35	31
Weight (tons)				
Pad	38.7	23.9	34.7	33.8
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	38.7	23.9	34.7	33.8
Cargo Space (cu ft)				
Pad	938.6	1,618.8	2,170	1,850.7
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	938.6	1,618.8	2,170	1,850.7
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	23.5	40.5	54.3	46.3
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	23.5	40.5	54.3	46.3

Table M-6. Mat required for forward area CH-47 heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	75	38	70	62
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	75	38	70	62
Weight (tons)				
Pad	76.4	47.9	69.3	67.6
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	76.4	47.9	69.3	67.6
Cargo Space (cu ft)				
Pad	1,852.5	3,237.6	4,340	3,701.4
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1,852.5	3,237.6	4,340	3,701.4
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	46.3	80.9	108.5	92.5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	46.3	80.9	108.5	92.5

Table M-7. Mat required for support area OH-58 helipad

Bundle Logistics	Mat Type			
	M8A1	**M19**	**AM2**	**Truss Web**
Number Required For				
Pad	1	1	1	1
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1	1	1	1
Weight (tons)				
Pad	1.1	1.3	1.0	1.1
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1.1	1.3	1.0	1.1
Cargo Space (cu ft)				
Pad	25	86	62	60
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	25	86	62	60
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	0.6	2.2	1.6	1.5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	0.6	2.2	1.6	1.5

Table M-8. Mat required for support area UH-1H helipad

Bundle Logistics	**Mat Type**			
	M8A1	**M19**	**AM2**	**Truss Web**
Number Required For				
Pad	2	1	2	2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	2	1	2	2
Weight (tons)				
Pad	2.1	1.3	2.0	2.2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	2.1	1.3	2.0	2.2
Cargo Space (cu ft)				
Pad	50	86	124	120
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	50	86	124	120
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	1.3	2.2	3.1	3.0
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1.3	2.2	3.1	3.0

Table M-9. Mat required for support area CH-47 helipad

Bundle Logistics	Mat Type			
	M8A1	**M19**	**AM2**	**Truss Web**
	Number Required For			
Pad	5	3	5	4
Taxiway	–	–	–	–
Runway	–	–	–	–
Total	5	3	5	4
	Weight (tons)			
Pad	5.1	3.8	5.0	4.4
Taxiway	–	–	–	–
Runway	–	–	–	–
Total	5.1	3.8	5.0	4.4
	Cargo Space (cu ft)			
Pad	124	256	310	239
Taxiway	–	–	–	–
Runway	–	–	–	–
Total	124	256	310	239
	Measurement Tons (40 cu ft = 1 measurement ton)			
Pad	3.1	6.4	7.8	6.0
Taxiway	–	–	–	–
Runway	–	–	–	–
Total	3.1	6.4	7.8	6.0

Table M-10. Mat required for support area CH-54 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	10	5	9	8
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	10	5	9	8
Weight (tons)				
Pad	10.2	6.3	8.9	8.7
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	10.2	6.3	8.9	8.7
Cargo Space (cu ft)				
Pad	247.0	426	558	477.6
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	247.0	426	558	477.6
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	6.2	10.7	14.0	11.9
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	6.2	10.7	14.0	11.9

Table M-11. Mat required for support area UH-1H company heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	38	19	35	31
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	38	19	35	31
Weight (tons)				
Pad	38.7	23.9	34.7	33.8
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	38.7	23.9	34.7	33.8
Cargo Space (cu ft)				
Pad	938.6	1,618.8	2,170	1,850.7
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	938.6	1,618.8	2,170	1,850.7
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	23.5	40.5	54.3	46.3
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	23.5	40.5	54.3	46.3

Table M-12. Mat required for support area CH-47 company heliport

Bundle Logistics	**Mat Type**			
	M8A1	**M19**	**AM2**	**Truss Web**
Number Required For				
Pad	75	38	70	62
Taxiway	306	154	285	254
Runway	42	22	40	35
Total	423	214	395	351
Weight (tons)				
Pad	76.4	47.9	69.3	67.6
Taxiway	311.5	194.0	282.2	276.9
Runway	42.8	27.7	39.6	38.2
Total	430.7	269.6	391.1	382.7
Cargo Space (cu ft)				
Pad	1,852.5	3,237.6	4,340	3,701.4
Taxiway	7,558.2	13,120.8	17,670	15,163.8
Runway	1,037.4	1,874.4	2,480	2,089.5
Total	10,448.1	18,232.8	24,490	20,954.7
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	46.3	80.9	108.5	92.5
Taxiway	189.0	328.0	441.8	379.1
Runway	25.9	46.9	62.0	52.2
Total	261.2	455.8	612.3	523.8

Table M-13. *Mat required for support area CH-54 company heliport*

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	75	38	70	62
Taxiway	340	171	317	282
Runway	84	43	79	70
Total	499	252	466	414
Weight (tons)				
Pad	76.4	47.9	69.3	67.6
Taxiway	346.1	215.5	313.8	307.4
Runway	85.5	54.2	78.2	76.3
Total	508.0	317.6	461.3	451.3
Cargo Space (cu ft)				
Pad	1,852.5	3,237.6	4,340	3,701.4
Taxiway	8,398.0	14,569.2	19,654	16,835.4
Runway	2,074.8	3,663.6	4,898	4,179.0
Total	12,325.3	21,470.4	28,892	24,715.8
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	46.3	80.9	108.5	92.5
Taxiway	210.0	364.2	491.4	420.9
Runway	51.9	91.6	122.5	104.5
Total	308.2	536.7	722.4	617.9

Table M-14. Mat required for support area mixed battalion heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	151	76	141	125
Taxiway	345	174	322	287
Runway	42	22	40	35
Maintenance apron	298	150	278	247
Total	836	422	781	694
Weight (tons)				
Pad	153.7	95.8	139.6	136.3
Taxiway	351.2	219.2	318.8	312.8
Runway	42.8	27.7	39.6	38.2
Maintenance apron	303.4	189.0	275.2	269.2
Total	851.1	531.7	773.2	756.5
Cargo Space (cu ft)				
Pad	3,729.7	6,475.2	8,742	7,462.5
Taxiway	8,521.5	14,824.8	19,964	17,133.9
Runway	1,037.4	1,874.4	2,480	2,089.5
Maintenance apron	7,360.6	12,780.0	17,236	14,745.9
Total	20,649.2	35,954.4	48,422	41,431.8
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	93.2	161.9	218.6	186.6
Taxiway	213.0	370.6	499.1	423.3
Runway	25.9	46.9	62.0	52.2
Maintenance apron	184.0	319.5	430.9	368.5
Total	516.1	898.9	1,210.6	1,035.7

Table M-15. Mat required for rear area OH-58 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	3	2	3	2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	3	2	3	2
Weight (tons)				
Pad	3.1	2.5	3.0	2.2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	3.1	2.5	3.0	2.2
Cargo Space (cu ft)				
Pad	74.1	170.4	186	119.4
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	74.1	170.4	186	119.4
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	1.9	4.3	4.7	3.0
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	1.9	4.3	4.7	3.0

Table M-16. Mat required for rear area UH-1H helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	6	3	6	5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	6	3	6	5
Weight (tons)				
Pad	6.2	3.8	5.9	5.5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	6.2	3.8	5.9	5.5
Cargo Space (cu ft)				
Pad	148.2	255.6	372	298.5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	148.2	255.6	373	298.5
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	3.7	6.4	9.3	7.5
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	3.7	6.4	9.3	7.5

Table M-17. Mat required for rear area CH-47 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	19	10	18	16
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	19	10	18	16
Weight (tons)				
Pad	19.3	12.6	17.8	17.4
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	19.3	12.6	17.8	17.4
Cargo Space (cu ft)				
Pad	469.3	852	1,116	955.2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	469.3	852	1,116	955.2
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	11.7	21.3	27.9	23.9
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	11.7	21.3	27.9	23.9

Table M-18. Mat required for rear area CH-54 helipad

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	38	19	35	31
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	38	19	35	31
Weight (tons)				
Pad	38.7	23.9	34.7	33.8
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	38.7	23.9	34.7	33.8
Cargo Space (cu ft)				
Pad	938.6	1,618.8	2,170	1,850.7
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	938.6	1,618.8	2,170	1,850.7
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	23.5	40.5	54.3	46.3
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	23.5	40.5	54.3	46.3

Table M-19. Mat required for rear area UH-1H company heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	149	75	139	124
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	149	75	139	124
Weight (tons)				
Pad	151.7	94.5	137.6	135.2
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	151.7	94.5	137.6	135.2
Cargo Space (cu ft)				
Pad	3,680.3	6,390	8,618	7,402.8
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	3,680.3	6,390	8,618	7,402.8
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	92.0	159.8	215.5	185.1
Taxiway	--	--	--	--
Runway	--	--	--	--
Total	92.0	159.8	215.5	185.1

Table M-20. Mat required for rear area CH-47 company heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	298	150	278	247
Taxiway	468	236	437	388
Runway	67	34	63	56
Total	833	420	778	691
Weight (tons)				
Pad	303.4	189.0	275.2	269.2
Taxiway	476.4	297.4	432.6	422.9
Runway	68.2	42.8	62.4	61.0
Total	848.0	529.2	770.2	753.1
Cargo Space (cu ft)				
Pad	7,360.6	12,780.0	17,236	14,745.9
Taxiway	11,559.6	20,107.2	27,094	23,163.6
Runway	1,654.9	2,896.8	3,906	3,343.2
Total	20,575.1	35,784.0	48,236	41,252.7
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	184.0	319.5	430.9	368.6
Taxiway	289.0	502.7	677.4	579.1
Runway	41.4	72.4	97.7	83.6
Total	514.4	894.6	1,206.0	1,031.3

Table M-21. Mat required for rear area CH-54 company heliport

Bundle Logistics	**Mat Type**			
	M8A1	**M19**	**AM2**	**Truss Web**
Number Required For				
Pad	224	113	209	186
Taxiway	362	182	337	300
Runway	101	51	94	84
Total	687	346	640	570
Weight (tons)				
Pad	228.0	142.4	206.9	202.7
Taxiway	368.5	229.3	333.6	327.0
Runway	102.8	64.3	93.1	91.6
Total	699.3	436.0	633.6	621.3
Cargo Space (cu ft)				
Pad	5,532.8	9,627.6	12,958	11,104.2
Taxiway	8,941.4	15,506.4	20,894	17,910.0
Runway	2,494.7	4,345.2	5,828	5,014.8
Total	16,968.9	29,479.2	39,680	34,029.0
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	138.3	240.7	324.0	277.6
Taxiway	233.5	387.7	522.4	447.8
Runway	62.4	108.6	145.7	125.4
Total	424.2	737.0	992.1	850.8

Table M-22. Mat required for rear area mixed battalion heliport

Bundle Logistics	Mat Type			
	M8A1	M19	AM2	Truss Web
Number Required For				
Pad	603	303	563	500
Taxiway	514	259	479	426
Runway	67	34	63	56
Maintenance apron	298	150	278	247
Total	1,482	746	1,383	1,229
Weight (tons)				
Pad	613.9	381.8	557.4	545.0
Taxiway	523.3	326.3	474.2	464.3
Runway	68.2	42.8	62.4	61.0
Maintenance apron	303.4	189.0	275.2	269.2
Total	1,508.8	939.9	1,369.2	1,339.5
Cargo Space (cu ft)				
Pad	14,894.1	25,815.6	34,906	28,850.0
Taxiway	12,695.8	22,066.8	29,698	25,432.2
Runway	1,654.9	2,896.8	3,906	3,343.2
Maintenance apron	7,360.6	12,780.0	17,236	14,745.9
Total	36,605.4	63,559.2	85,746	73,371.3
Measurement Tons (40 cu ft = 1 measurement ton)				
Pad	372.4	645.4	872.7	746.3
Taxiway	317.4	551.7	742.5	635.8
Runway	41.4	72.4	97.7	83.6
Maintenance apron	184.0	319.5	430.9	368.6
Total	915.2	1,589.0	2,143.8	1,834.3

APPENDIX N

MEMBRANES AND MATS

Mats and membranes are used to improve existing assault-type airfields or to construct new airfield surfaces in all areas of the world where field commanders require expedient surfacing or support of air mobile operations.

Initial selection of the airfield site should be made by utilization of available data, such as topographic maps, aerial photographs, and geological and climatological data. Final selection is based on the in-place or the average in-place soil bearing strength and its capacity to support anticipated aircraft traffic. Chapter 10 discusses the number of traffic cycles versus bearing strength for mats and membranes.

MEMBRANES

TYPES

Membranes consist mainly of coated fabrics intended for use as airfield surfacing to dustproof and waterproof soil subgrades. Currently, there are two types of membranes that meet acceptable standards—heavy-duty and medium-duty.

The WX- 18 heavy-duty membrane is a neoprene-coated, four-ply, nylon fabric that is woven from continuous filament nylon yarns. The membrane is 5/64 inch thick, and a runway section is 66 feet wide by 53 feet long and weighs about 0.5 pound per square foot. It was developed as a result of the T-17 medium-duty membrane's failure to support C-130 braking action. The medium-duty membrane is made of the same material as the heavy-duty membrane except that it is only a two-ply fabric and weighs approximately 0.33 pound per square foot.

Heavy-Duty Membrane

The WX-18 heavy-duty membrane is capable of withstanding the braking action of C-130 aircraft. The WX-18 can be used in two configurations to support C-130 operations, either all heavy-duty membrane for the entire airfield or with T-17 medium-duty membrane. In this configuration, the initial 500 feet at each end of the runway will be heavy-duty membrane while the remainder will be T-17 membrane.

To provide adequate braking during inclement weather, a nonskid compound has been applied to the middle 32 feet of the heavy-duty membrane that will be used for the traffic areas of the airfield. The nonskid compound is a polka-dot pattern; white stripes are painted on the membrane surface to outline the nonskid treated area, provide alignment of the surfacing during placement, and serve as runway marking for aircraft operations. Table N-1, page N-2, shows a detailed listing of the components contained in each heavy-duty membrane set.

Medium-Duty Membrane

The T-17 is a medium-duty membrane that is capable of withstanding operations of helicopters and light, fixed-wing aircraft. When used in conjunction with the heavy-duty membrane, the T-17 membrane can be used to support C-130 operations. T-17 mem-

Table N-1. WX-18, heavy-duty membrane set components

NSN	Number	Description
5680-173-6828		**Part I. Membrane Outfit, Heavy-Duty, Runway/Heliport, WX-18** **(Approximate weight: 26,650 pounds; approximate volume: 523 cubic feet)**
8040-921-5761	20	Adhesive, membrane, 5-gallon pail
5680-782-6894	280	Anchor, disc-type, membrane
8020-682-6491	12	Cover, paint roller, 9 inches long, vinyl-acrylonitrile copolymer material, 26 to 28 ounces weight per square yard, 3/8 inch pile height
5120-679-5655	12	Gun, caulking, metal, half barrel, cradle or drop-in type for spouted cartridge
7920-682-6512	12	Handle, wood, acme thread (thd) end, 48 inches long, 3/4-inch axial, long thread end, 11/16 inch (outside diameter (OD)) thd, 6 thd per inch, stainless steel thd end cap
5120-221-1536	12	Knife, putty, flexible, Class 1, blade 3 1/2 inches long by 1 1/4 inches wide
5680	10	Roll, membrane, 3 feet X 66 feet
8020-753-4915	12	Roller, paint, open bird cage or tension cylinder with cover, dip-type, dynel flush, knitted fabric, 9 inches long with 3/8-inch pile height
	60	Sealant, white, 1/10-gallon cartridge (Brand: Weatherban 101)
5680	10	Section, membrane, 53 feet long by 66 feet wide
5680-173-6829		**Part II. Membrane Outfit, Heavy-Duty, Taxiway Surfacing** **(Approximate weight: 17,500 pounds; approximate volume: 462 cubic feet)**
8040-921-5761	10	Adhesive, membrane, 5-gallon pail
5680-782-6894	280	Anchor, disc-type, membrane
8020-682-6491	12	Cover, paint roller, 9 inches long, vinyl-acrylonitrile copolymer material, 26 to 28 ounces weight per square yard, 3/8-inch pile height
5120-679-5655	12	Gun, caulking, metal, half barrel, cradle or drop-in type for spouted cartridge
7920-682-6512	12	Handle, wood, acme thd end, 48 inches long, 3/4-inch axial, long thread end, 11/16-inch OD thd, 5 thd per inch, stainless steel thd end cap
5120-221-1536	12	Knife, putty, flexible, Class 1, blade 3 1/2 inches long by 1 1/4 inches wide
5680	10	Roll, membrane, 3 feet by 66 feet
8020-753-4915	12	Roller, paint, open bird cage or tension cylinder with cover dip-type, dynel flush, knitted fabric, 9 inches long with 3/8-inch pile height
	36	Sealant, white, 1/10-gallon cartridge (Brand: Weatherban 101)
5680	10	Section, membrane, 53 feet long by 42 feet wide
5680-173-6831		**Part III. Membrane Outfit, Heavy-Duty, Parking-Apron Surfacing** **(Approximate weight: 89,440 pounds; approximate volume: 2,333 cubic feet)**
8040-921-5761	100	Adhesive, membrane, 5-gallon pail
5680-782-6894	1,248	Anchor, disc-type, membrane
8020-682-6491	24	Cover, paint roller, 9 inches long, vinyl-acrylonitrile copolymer material, 26 to 28 ounces weight per square yard, 3/8-inch pile height
5120-679-5655	12	Gun, caulking, metal, half barrel, cradle or drop-in type for spouted cartridge
7920-682-6512	12	Handle, wood, acme thd end, 48 inches long, 3/4-inch axial, long thread end, 11/16-inch OD thd, 5 thd per inch, stainless-steel thd end cap

Table N-1. WX-18, heavy-duty membrane set components (continued)

NSN	Number	Description
5120-221-1536	12	Knife, putty, flexible, Class 1, blade 3 1/2 inches long by 1 1/4 inches wide
5680	70	Roll, membrane, 3 feet by 66 feet
8020-753-4915	12	Roller, paint, open bird cage or tension cylinder with cover, dip-type, dynel flush, knitted fabric, 9 inches long with 3/8-inch pile height
	372	Sealant, white, 1/10-gallon cartridge (Brand: Weatherban 101)
5680	48	Section, membrane, 53 feet long by 42 feet wide
5680-164-3372	**Part IV. Membrane Outfit, Heavy Duty, Warm-Up Apron Surfacing (Approximately weight: 28,317 pounds; approximate volume 559 cubic feet)**	
8040-921-5761	30	Adhesive, membrane, 5-gallon pail
5680-782-6894	260	Anchor, disc-type, membrane
8020-682-6491	12	Cover, paint roller, 9 inches long, vinyl-acrylonitrile copolymer material, 26 to 28 ounces weight per square yard, 3/8-inch pile height
5120-679-5655	6	Gun, caulking, metal, half barrel, cradle or drop-in type for spouted cartridge
7920-682-6512	6	Handle, wood, acme thd end, 48 inches long, 3/4-inch axial, long thread end, 11/16-inch OD thd, 5 thd per inch, stainless-steel thd end cap
5120-221-1536	6	Knife, putty, flexible, Class l, blade 3 1/2 inches long by 1 1/4 inches wide
5680	20	Roll, membrane, 3 feet by 66 feet
8020-753-4915	6	Roller, paint, open bird cage or tension cylinder with cover, dip-type, dynel flush, knitted fabric, 9 inches long with 3/8-inch pile height
	84	Sealant, white, 1/10-gallon cartridge (Brand: Weatherban 101)
5680	10	Section, membrane, 53 feet long by 66 feet wide
5680-173-6832	**Part V. Membrane Outfit, Heavy-Duty, Helipad/Replacement Surfacing (Approximately weight: 3,427 pounds; approximate volume: 73 cubic feet**	
8040-921-5761	4	Adhesive, membrane, 5-gallon pail
5680-782-6894	52	Anchor, disc-type, membrane
8020-682-6491	12	Cover, paint roller, 9 inches long vinyl-acrylonitrile copolymer material, 26 to 28 ounces weight per square yard, 3/8-inch pile height
5120-679-5655	6	Gun, caulking, metal, half barrel, cradle or drop-in type for spouted cartridge
7920-682-6512	6	Handle, wood, acme thd end, 48 inches long, 3/4-inch axial, long thread end, 11/16-inch OD thd, 5 thd per inch, stainless-steel thd end cap
5120-221-1536	6	Knife, putty, flexible, Class 1, blade 3 1/2 inches long by 1 1/4 inches wide
5680	4	Roll, membrane, 3 feet by 66 feet
8020-753-4915	6	Roller, paint, open bird cage or tension cylinder with cover dip-type dynel flush knitted fabric, 9 inches long with 3/8-inch pile height
	20	Sealant, scotch-seal brand industrial (for wet weather), EC 801/1622, 1-gallon can with accelerator in Class A can container
	24	Sealant, white, 1/10-gallon cartridge (Brand: Weatherban 101)
5680	1	Section, membrane, 53 feet long by 66 feet wide

Table N-1. WX-18, heavy-duty membrane set components (continued)

NSN	Number	Description
5680-173-8296	**Part VI. Membrane Outfit, Heavy-Duty, Maintenance Surfacing** **(Approximate weight: 947 pounds; approximate volume: 24 cubic feet)**	
8040-921-5761	2	Adhesive, runway, 5-gallon pail
5680-782-6894	26	Anchor, disc-type, membrane
5120-679-5655	2	Gun, caulking, metal, half barrel, cradle or drop-in type for spouted cartridge
7920-682-6512	6	Handle, wood, acme thd end, 48 inches long, 3/4-inch axial, long thread end, 11/16-inch OD thd, 5 thd per inch, stainless-steel thd end cap
8020-682-6491	12	Cover, paint roller, 9 inches long, vinyl-acrylonitrile copolymer material, 26 to 28 ounces weight per square yard, 3/8-inch pile height
5610-921-5762	6	Compound, nonskid, 5 1/4-gallon pail
8020-753-4915	6	Roller, paint, open bird cage or tension cylinder, with cover, clip-type, dynel flush, knitted fabric, 9 inches long with 3/8-inch pile height, MIL-R-17987D, Type II
	24	Sealant, white, 1/10-gallon cartridge (Brand: Weatherban 101)
5120-221-1536	2	Knife, putty, flexible, Class 1, blade 3 1/2 inches long by 1 1/4 inches wide
	12	Sealant, scotch-seal brand industrial, EC 801/1622 1-gallon can with accelerator in Class A can container
8020-205-6501	6	Brush, varnish, flat, nylon bristle, 2 inches by 3 inches
5680	2	Roll, membrane, 3 feet by 66 feet

brane is manufactured from two-ply, 5.1-ounce, neoprene-coated, nylon material and weighs 3 pounds per square yard. For adequate skid resistance, a nonskid paint must be applied to the membrane after it is installed.

Packaging

Complete sets of heavy-duty membrane can be ordered using SC 5680-97-CL-E05. Set components and matting sizes differ according to airfield requirements. The T-17 membrane will be available until current stocks are depleted after which only heavy-duty membrane will be available. Membrane sections will be in crates weighing several thousand pounds, and membrane splices will come in rolls similar to tar-paper rolls. A mechanical lifting device should be used to move the crates. Table N-2 shows membrane panel sizes.

Table N-2. Membrane panel sizes

Membrane	Type Package	Size	Principle Use
T17	Roll	3 X 66	Reinforce/repair
	Crate	56 X 100	Helipad/taxiway section
	Crate	78 X 100	Helipad/runway section
Heavy-duty WX-18	Roll	3 X 66	Reinforce/repair
	Crate	66 X 53	Helipad/runway section
	Crate	42 X 53	Helipad/taxiway section

During packing of the membrane at the factory, the sections are folded when placed into crates. Often the membrane will develop wrinkles when folded for a long period of time because of the difference in the residual tension in the nylon. These wrinkles will not affect the usefulness of the membrane to any great degree. Stretching the section will normally remove or reduce the wrinkles.

MEMBRANE ACCESSORIES

Accessories required for constructing, emplacing, securing, maintaining, and repairing the WX-18 heavy-duty and the T-17 membrane surfacing are similar and are as follows:

Anchors

Disc-type, steel anchors are used to expedite placement of the membrane surfacing by securing the surfacing in place. Each anchor consists of a 3/4-inch-diameter steel reinforcing rod approximately 12 inches long that has been arc-welded to a 1/8-inch-thick, shaped steel plate that is 8 inches in diameter. The anchor weighs approximately 3 pounds. These come with the membrane kits or may be locally fabricated.

Adhesive

Adhesive is used to form membrane construction joints and to repair membrane in the field. The adhesive consists of a synthetic rubber resin dispersed in solvent that evaporates rapidly after exposure to air, thus developing the bond strength of the resin. The adhesive used during dry weather is supplied in 5-gallon, tight-head pails with pouring spouts. Each 5-gallon pail of adhesive weighs approxi-mately 40 pounds. Adhesive used for wet weather repairs and replacement of surfacing is furnished in 1 -gallon pails with accelerator. This adhesive must be mixed in the field (basic cement and accelerator) before use. It has a short pot life and no more of the adhesive should be mixed than that planned for use during a period of two hours. The adhesive and accelerator are packaged in cases. Each case contains four 1-gallon pails of adhesive and four 1-pint cans of accelerator.

Nonskid Compound

Nonskid compound consisting of catalyzed epoxy binder with abrasive particles applied in compartmented
5 1/4-gallon pails provides an adequate braking surface during inclement weather. Each pail of compound weighs approximately 65 pounds.

Paint Rollers, Handles, and Covers

Paint rollers that are 9 inches wide with 48-inch-long wooden handles are used to apply adhesive and nonskid compound. Lamb's wool or synthetic fabric disposable roller covers are provided so that after use, the covers can be removed from the rollers and new covers placed on the rollers before reuse.

Joint Sealer, Caulking Gun, and Putty Knife (Heavy-Duty Membrane Only)

A one-part sealant, which cures upon exposure to air and/or moisture, is supplied in a cartridge for application with a half-barrel-type caulking gun. The sealer is used to seal the edges of the 36-inch-wide reinforcing strip used on adhesive construction joints and for rapid repairs to seams and joints during all weather conditions. To remove excess sealant from areas, a 1 1/4-inch-wide putty knife is used to strike and draw the sealant from the surfacing.

Roll Of Membrane (3 X 66 Feet)

One roll of membrane is supplied per set. The roll of membrane is used to reinforce adhesive construction joints and to provide a single-layer cushion of membrane over the heads of disk-type anchors used in each adhesive construction joint.

MEMBRANE PLACEMENT

The placement of both the T-17 and the WX-18 membrane is similar in nature. The differences occur in the design of the membrane. The minimum size unit required for efficient placement is a platoon and six equipment operators (see Table N-3, page N-6). Troops with any military occupational specialty (MOS) can place and maintain membrane with minimal instruction and on-the-job training.

Table N-3. Minimum crew requirements

Crew	Number	Task
Equipment operators	6	2 motorized graders 3 truck drivers 1 light-wheeled vehicle driver
Placement	18	Unfold, stretch, and place membrane
Joint construction	10	2-pour adhesive 4-roll adhesive on joint 4-roll membrane strip

After a site with adequate average bearing strength for wheel load and antic ipated aircraft traffic has been chosen (Chapter 11), the area should be cleared and grubbed to remove all vegetation. The area should be graded to obtain a crown anti minimum grade changes in accordance with the design aircraft. After the site is prepared. 2-foot-deep, L-shaped anchor ditches should be constructed at one end and on both sides of the area to be surfaced. The remaining end anchor ditch should not be constructed until placement of all membrane sections are complete. This will permit access to the area by vehicles and will also permit an exact determination of the location of the final end anchor ditch. A full 3 feet of membrane will be placed in the ditches before backfilling and compaction (Figure N-1). The side ditches should be parallel to the established centerline.

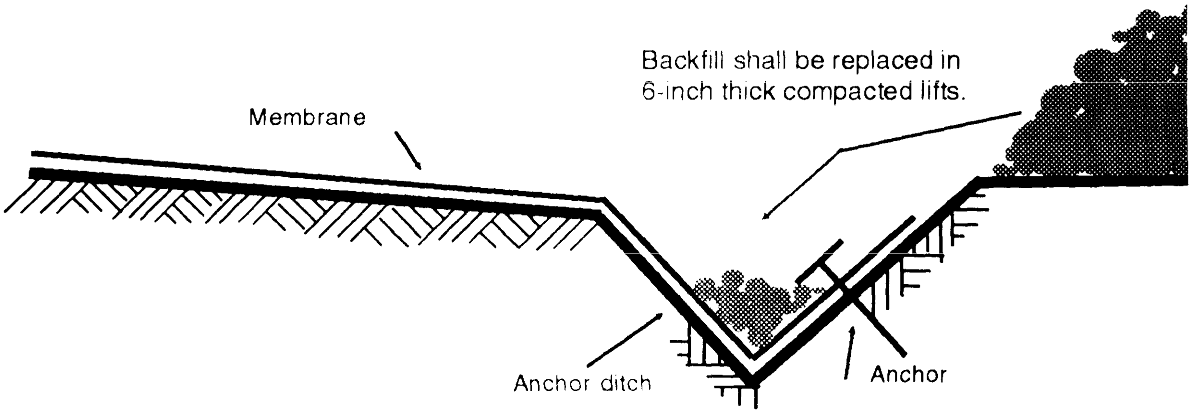
All soil removed from the anchor ditches should be windrowed outside the placement area. and the soil can be used for fill after the membrane has been placed in the ditch. Motor graders are best used to construct anchor ditches, but other pieces of equipment can also perform this function.

Vehicles are required for transporting the wooden crates of membrane to the site and for use during placement. The 5-ton dump truck or any 6x6 cargo truck of at least 2 1/2-ton capacity is suitable for this purpose. After crates have been stockpiled on the placement site, the tops and sides of the crates should be removed just before lifting the skid platform with the banded surfacing on placement vehicles. Medium wreckers can be used to lift the platform.

WX-18 Heavy-Duty Membrane Placement

Placement of the first section of membrane will be initiated by removing approximately 3 feet of the folded surfacing from the skid and placing it in the end anchor ditch that was constructed transversely across the runway. The words top and bottom stenciled on the uppermost surface of the accordion-folded section of surfacing will be disregarded during this stage of placement. Next, the placing vehicle will move slowly along the centerline of the airfield while the membrane surfacing is unfolded from the rear of the vehicle and placed on the ground. Care will be taken by the driver of the vehicle to maintain alignment of the

Figure N-1. Procedure for anchoring membrane in anchor ditch



membrane with the centerline of the area. The placing crew will also exercise care to ensure one edge of the surfacing, as it is being placed on the ground, is aligned with the centerline; the surfacing is placed flat on the ground, and all slack is removed from the surfacing.

When the membrane is first placed on the ground, it will consist of an accordion-folded surfacing that is approximately 48 inches wide and 53 feet long. After the surfacing is unloaded from the vehicle, troops will be stationed at equal intervals along the 53-foot length of the surfacing and will unfold the surfacing to one side of the area and place the edge of the surfacing in a side anchor ditch. Then, the remaining half of the surfacing will be unfolded to the other side of the area and placed in the side anchor ditch. The section of mem-brane will be unfolded so that the side marked top will face upward and the side marked bottom will face downward to contact the soil subgrade. If the section is unfolded incorrectly, the smooth side of the section will face upward, and it will be necessary to turn the section over so that the nonskid treated area faces upward. The section must be repositioned so that alignment of edge and centerline striping is maintained. Every effort will be made to align, position, and remove slack from the surfacing before steel anchors are placed in the surfacing and the ditches backfilled, The anchors will be driven through the factory, single-lap construction joints where the membrane thickness is doubled.

Once the surfacing is positioned on the area and most of the slack removed, steel anchors will be driven through the surfacing in the end anchor ditch approximately 6 inches from the edge of the surfacing (Figure N-1). Eight steel anchors will be used to secure the membrane surfacing in the end anchor ditch. Anchors will be driven in the three alternative factory, single- lap construction joints located immediately on each side of the centerline of the section of membrane and in each corner of the section that is placed in the end anchor ditch. The end anchor ditch will then be backfilled and compacted. Additional slack will be removed from the surfacing by troops pulling on the free end of the surfacing that has not been placed in the anchor ditch. As slack is removed, steel anchors will be driven through alternative single-lap adhesive construction joints on approximately 9-foot centers and 1 foot from the outer edge of the free end of the surfacing. The protective paper on this end of the membrane will not be completely removed during the operation. The top portion will be peeled back to allow the driving of the anchors, and then the paper will be put back on the top portion to protect it against dirt and debris before application of the construction joint. White lines, 1/8 inch wide and located 1 foot from each end of the section of membrane, have been painted on the section to provide alignment for driving the anchors. Steel anchors will then be driven through the surfacing placed in the side anchor ditches on 17-foot centers and approximately 6 inches from the outer edge of the surfacing (Figure N-2, page N-8).

After anchors are driven in the side ditches, backfill will be placed in the ditches in 6-inch lifts and compacted. Loaded 5-ton dumps are suitable for all compaction. If motorized graders are used to compact the lifts, care must be taken to prevent the grader blade from snagging or cutting the membrane. The side ditches will not be backfilled completely to the free end of the section of surfacing because room will be needed to construct the adhesive construction joint. Backfilling of the side ditches will stop approximately 6 feet from the free end of the surfacing. While the side ditches are being backfilled on the first section of surfacing, the next section of surfacing will be unloaded on the area in the manner described previously for the first section of surfacing. Before the second section of surfacing is unloaded on the ground, the vehicle will be positioned and a sufficient amount of surfacing unfolded from the vehicle so that the second section overlaps the first section by approximately 24 inches. The membrane should be unfolded and placed over the area, and the sides should be placed in the side anchor ditches. The

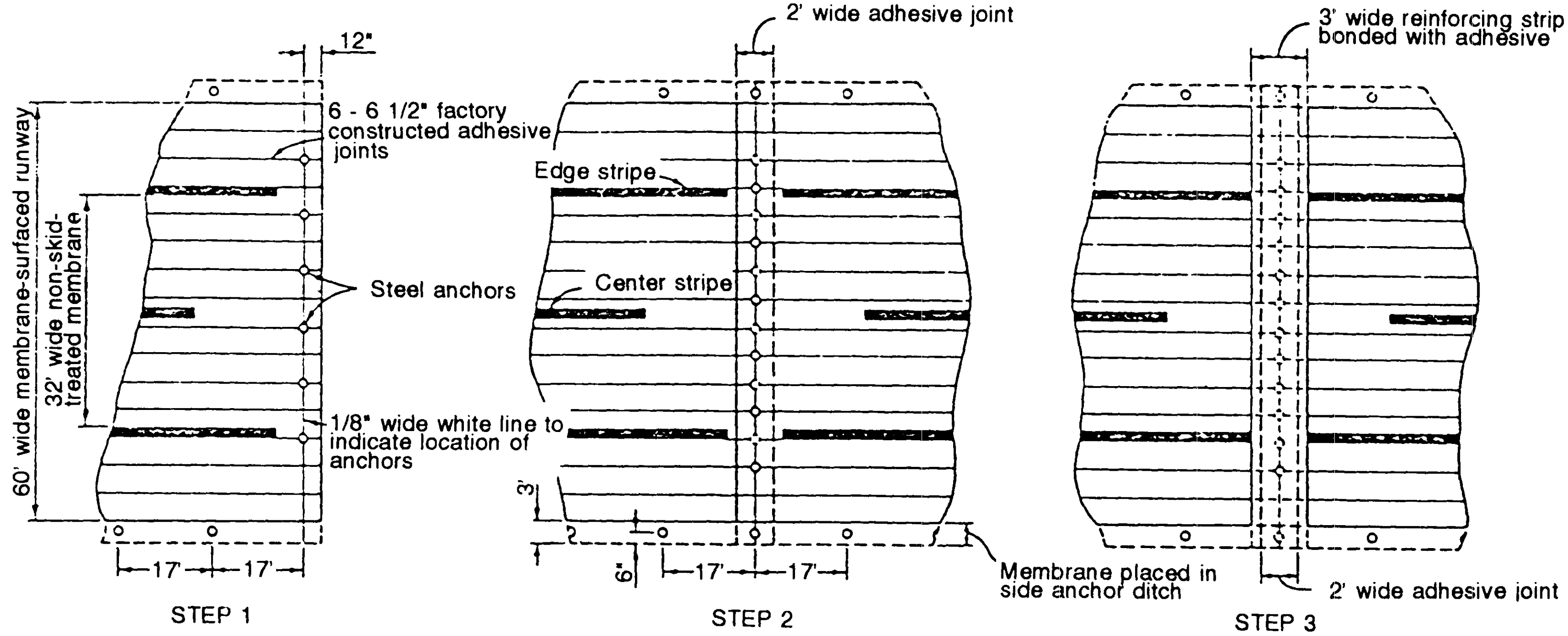


Figure N-2. Anchoring of membrane and construction of adhesive joint protective paper will be removed from the top of the first panel and the bottom of the second panel. The paper from the first panel will be folded out onto the ground and remain in place. This helps keep dirt off the membrane during the application of adhesive when fabricating the construction joint.

After the paper on both sections has been folded back, the overlapping end of the second section will be positioned over the end of the first section so the 1/8-inch-wide white line on the second section will be placed directly over the white line on the end of the first section. The second section will be positioned so the 12-inch-wide white centerline will be aligned with the centerline of the first section. Before any effort is made to remove slack from the second section of surfacing, steel anchors will be driven through the overlapping ends of both membrane sections and into the subgrade to a depth of approximately 6 inches. These anchors will be located between the anchors driven previously through the first section of membrane and will be driven through the overlapping section and positioned on the 1/8-inch-wide white line located 1 foot from the edge of the surfacing (Figure N-2, page N-8). After the anchors are driven through the surfacing, initial slack will be removed from the second section of surfacing, and then anchors will be driven through the factory-constructed, single-lap joints located in the free end of the membrane the same way it was done for the first panel. Anchors will then be driven through the membrane placed in the side anchor ditches on 17-foot centers as they were for the first panel. After the second panel has been anchored, the construction of the adhesive construction point between the first and second panels can be completed. To construct the construction joint, the 2-foot-wide overlapping end of the second section will be raised with 48-inch-long paint-roller handles so adhesive can be poured onto the underlying surfacing. The joint will be constructed in increments approximately every 8 feet along the entire membrane width. Uniform spreading of the adhesive onto the surfacing is accomplished with the long-handled rollers so that the adhesive covers an area that extends approximately 1 foot beyond the anchor heads. Ample time (usually two to five minutes) will be allowed for the adhesive to become tacky to the touch: however, more or less time may be required, depending on weather conditions. When the adhesive becomes tacky, the overlapping ends of the sections will be placed in contact and the anchors driven flush with the surfacing. Care should be exercised to avoid overdriving the anchors. When a snug fit is obtained between the surfacing and anchor head, driving should be stopped.

To reinforce the adhesive construction joint, a 36-inch-wide strip of membrane will be placed over the joint and bonded to the surfacing with adhesive. In placing the strip over the joint, the roll of membrane strip will be aligned so that it straddles the 1/8-inch-wide white line located on the overlapping section. Care will be exercised when placing the reinforcing strip to ensure that the edges of the strip do not extend onto the nonskid-treated area of the surfacing. Adhesive will be spread at intervals of 10 to 12 feet along the joint in a width of approximately 38 inches. After the adhesive becomes tacky, the roll of membrane will be rolled across the adhesive-covered area. Care will be exercised to maintain alignment of the strip and to remove all slack and wrinkles from the membrane. This procedure of applying adhesive and then rolling the membrane across the adhesive-covered area will be continued for the full length of the joint. After the strip has been allowed to set for approximately 15 minutes, the strip may be rolled with a light rubber-tired vehicle. Rolling of the reinforcing strip with a light wheeled vehicle is optional. If a visual inspection of the strip reveals that air pockets exist beneath the strip, then the joint should be rolled to remove these pockets. If no such pockets are found, then rolling the joint is not required. The edges of the construction joint will be sealed with sealant after each reinforcing strip has been allowed to set for approximately 15 minutes and/or has been rolled with a light wheeled vehicle. Sealing of the strips may be delayed until near the end of the working day, but because of the cure time required for the sealant, no traffic of any kind will be allowed on the sealed strips for a minimum period of 48 hours. Any foreign material that may have accumulated adjacent to the edges of the reinforcing strips will be removed before the sealant is applied to the surfacing. A 1/4-inch-wide continuous bead of sealant will be applied to each edge of the reinforcing strip with a caulking gun. The bead of sealant will be beveled with a putty knife in order for the sealant to be flush with the upper surface of the reinforcing strip.

The placement of additional sections of membrane will be accomplished in the same manner as described above. When the last membrane section is placed, the end anchor ditch will be cut in the required location for the membrane placement. The membrane will then be anchored after which the trench will be backfilled and compacted.

T-17 Membrane Placement

The placement of T-17 membrane is very similar to heavy-duty membrane with a few exceptions. T-17 is used with heavy-duty membrane for C-130 capable runways or by itself for fixed-wing rotary aircraft or helipads. When used with heavy-duty membrane, the first 500 feet of both ends of the runway will be heavy-duty membrane and the rest of the airfield can be T-17. Placement of the first section of membrane will be initiated by removing approximately 3 feet of the folded surfacing from the crate and placing it in the anchor ditch that was constructed transversely across the runway. The vehicle should then be driven slowly along the centerline of the runway while the membrane is unfolded from the rear of the vehicle and placed on the ground. Care should be taken to ensure the alignment of the membrane with the centerline of the runway. When the membrane is placed on the ground, it will consist of an accordion-folded surfacing approximately 50 to 60 inches wide and 100 feet long. After the surfacing has been unloaded from the vehicle, troops should be stationed at equal intervals along the length of the surfacing. Half the surfacing should be unfolded to one side and placed in a side anchor ditch. The remaining half of the surfacing should then be unfolded and placed in the other side anchor ditch. There is no top or bottom to this membrane.

After the membrane is aligned and positioned, the initial slack is removed from the surfacing. The end anchor ditch is then backfilled and compacted, and the free end of the membrane is pulled over the area to be surfaced. As slack is removed from the surfacing, the side ditches should be backfilled and compacted to within 6 feet of the free end of the membrane. The side ditches should not be backfilled to the free end of the membrane because space will be needed to join the end of the next section. There is no marking on the T-17 membrane to direct where the placement of the anchors should be. When anchors are used, the locations for the anchors in the end and side ditches should be 6 inches from the outer edge of the membrane on 17-foot centers. On the free end of the membrane, the anchors will be driven on 9-foot centers and 1 foot from the outer edge. A motor grader can be used for compaction but care must be taken to prevent the grader from ripping the membrane. Backfilling of the side ditches should stop approximately 6 feet from the free end of the membrane to allow for construction of the construction joint.

While the side ditches are being backfilled, the second section of membrane should be unloaded onto the area in the same manner as the first section. The placement vehicle should be positioned so that the second section overlaps the first section by approximately 24 inches. The membrane should then be unfolded and placed over the area. The sides should be placed in the side ditches. Anchors should be driven through the overlapping ends of both membranes, between the previously driven anchors, to a depth of 6 inches. Once slack is removed, side anchors and end anchors on the free end of the membrane can be loaded and the construction joint constructed.

To construct the joint, the 2-foot-wide overlapping end of the second section will be raised with 48-inch-long paint-roller handles so adhesive can be poured onto the underlying surfacing. The joint will be constructed in increments approximately 9 feet long. Uniform spreading of the adhesive onto the surfacing will be accomplished with the long-handled rollers. Ample time (usually two to five minutes) will be allowed for the adhesive to become tacky to the touch: however, more or less time may be required, depending on weather conditions. When the adhesive becomes tacky, the overlapping ends of the sections will be placed in contact and the anchors driven flush with the surfacing. Care should be exercised to avoid overdriving the anchors if they are used. When a snug fit is obtained between the surfacing and anchor head, driving should be stopped. To reinforce the adhesive construction joint, a 36-inch-wide strip of membrane will be placed over the joint and bonded to the surfacing with adhesive. In placing the strip over the joint, the roll of membrane should be aligned so that it is centrally located along the edge of the overlapping section.

Adhesive will be spread at intervals of 10 to 12 feet along the joint in a width of approximately 38 inches. After the adhesive becomes tacky, the roll of membrane will be rolled across the adhesive-covered area. Care will be exercised to maintain alignment of the strip and to remove all slack and wrinkles. This procedure of applying adhesive and then rolling the membrane across the adhesive-covered area will be continued for the full length of the joint. After the strip has been allowed to set for approximately 15 minutes, the strip may be rolled with a rubber-tired vehicle. If a visual inspection of the strip reveals that air pockets exist beneath the strip, then the joint should be rolled to remove these pockets. If no such pockets are found, then rolling the joint is not required.

The edges of the reinforcing strip may be sealed with sealant in the same manner as the heavy-duty membrane, but it is not required. Sealant is not part of the T-17 set and must be ordered separately. After sealing the reinforcing strip, no traffic of any kind will be allowed on the sealed strip for a minimum of 48 hours because of the sealant cure time.

Placement of additional sections of membrane will be accomplished in the same manner as above. When the last section is placed, the end anchor ditch will be cut in the required location for the membrane placement. Then, the membrane will be anchored, backfilled, and compacted.

The application of the nonskid compound paint can be accomplished in the same manner discussed in repair of the nonskid compound later in this appendix.

MAINTENANCE, REPAIR, AND REPLACEMENT OF MEMBRANE SURFACING

Maintenance and Repair of Membrane

Service tests have indicated that repair and maintenance of membrane surfacing for operation of current US Army aircraft will be minor. However, more repairs and maintenance can be expected for traffic with maximum-loaded C-130 aircraft. Most, if not all, repairs will be needed in the first 300 feet of surfacing at each end of the runway. The size of the repair and maintenance crew will be determined by the size of the area surface. For airfield complexes, a crew of six men is normally adequate. The surfacing should be inspected thoroughly just before initiation of sustained aircraft operations to determine the condition of the surfacing and to perform essential maintenance. When aircraft operations begin, the surfacing must be inspected by the maintenance crew with binoculars to permit uninterrupted use of the surfacing. If a failure occurs in the surfacing during aircraft operations, the failure should be repaired as soon as aircraft operations permit. Ballooning of the surfacing that has been punctured or torn can occur when air is forced through these openings in the surfacing by the prop wash of aircraft engines causing the surfacing to become airborne. Service tests on the surfacing have shown that small surface failures may be trafficked by aircraft for a limited period without severe damage or ballooning of the surfacing; nevertheless, the best practice is to repair all failed areas as soon as possible. Less time and effort will be required to repair a small area immediately after failure than to risk the small area developing into a major repair problem.

Failures in the traffic area will be repaired by slitting the failed surfacing in the form of a cross and folding the four flaps back. An area approximately 2 feet wide surrounding the failure on all sides will be cleaned to remove dirt or dust that may have accumulated on the underneath side of the surfacing. After the surfacing has been cleaned, the area will be allowed to dry before the adhesive is applied. Adequate membrane surfacing will then be cut and placed beneath the membrane surfacing so that it extends beyond the failed area of surfacing approximately 2 feet on all sides. Adhesive will then be applied to the top of the membrane patch being used for the repair and to the bottom of the surfacing being repaired. After the adhesive becomes tacky (2 to 5 minutes), the flaps that were folded back previously will be placed in their original positions, and the adhesive allowed to set for approximately 15 minutes before rolling the patched areas with a wheeled vehicle. This manner of patching may also be used for areas of surfacing that are not in the main traffic area, but it is permissible to patch these areas on the top side. However, should considerable traffic occur on the area that must be repaired, the patch should be applied to the bottom side of the membrane. If free water is found on the soil subgrade beneath the membrane, patching can be expedited by applying the patch to the top surface of the membrane. When a failure is patched from the top, an area approximately 2 feet wide surrounding the failure will be cleaned to remove all dirt and foreign material. Then adhesive will be applied to the cleaned area and to the swatch of membrane used for the repair. After the adhesive becomes tacky, the adhesive-coated swatch of membrane and the adhesive-coated surfacing will be placed in contact and allowed to set for approximately 15 minutes. The patched area is then rolled with a light wheeled vehicle. If the failure is large or irregular, it may be necessary to use some of the anchors furnished with the maintenance kit to anchor and reinforce the repaired surfacing. When anchors are used to repair the surfacing, care will be exercised to ensure that adequate patching material is used to cover the heads of all anchors completely and extend 2 feet beyond the failed area of surfacing.

Procedures described above for repairs during dry weather are also applicable for membrane repairs during inclement weather with the exception that the surfacing does not have to be dry, but it must be free of mud. The wet-weather adhesive (adhesive furnished in 1-gallon pails) will adhere to wet membrane surfacing, and it can be applied to the surfacing during rains. The bond strength of the wet adhesive usually decreases after a period of two to three weeks; therefore, it will be necessary to replace the wet-weather patch with a dry-weather patch as soon as the weather permits.

The thickness and stiffness of the heavy-duty membrane surfacing are such that it is always necessary to exercise care in the construction of adhesive joints to prevent wrinkled joints. If wrinkles extend the full width of a joint, water will pass through the wrinkles and wet the underlying soil subgrade. Cartridges of sealant are furnished in the maintenance kits that will be used to seal these wrinkles. The sealant will be applied with a caulking gun to the wrinkled joint area. The bead of sealant will be beveled with a putty knife so it will be flush with the upper surface of the membrane.

The minimum crew and equipment required to perform routine maintenance to membrane-surfaced airfields are as follows:

Crew	Number of Personnel	Equipment
Inspect and repair membrane	7 (1 NCOIC, 2 truck drivers, and 4 soldiers to make repairs)	Two 5/4-ton trucks

Maintenance and Repair of Nonskid Compound

When 25 percent or more of the original factory-applied nonskid compound has been removed from the membrane surfacing, it will be necessary to apply nonskid compound to the surfacing. The nonskid compound will be applied to the surfacing with paint rollers at a rate of 80 to 100 square feet per gallon. The compound consists of two components: the accelerator, which is contained in a steel compartment located in the top of the 5 1/4-gallon pail, and the basic compound located in the lower part of the pail. The nonskid compound will be mixed by pouring the accelerator into the pail with the basic compound and thoroughly mixing these components for a minimum period of 15 minutes. One of the 1x4-inch braces on the maintenance kit can be used to mix the nonskid compound. When the components are mixed adequately, the compound will be allowed to set for a period of 45 minutes before it is applied to the membrane surfacing. Paint rollers with 48-inch-long handles will be used to apply the nonskid compound to the surfacing. It will be applied to provide complete coverage of the surfacing in the traffic area. A minimum cure time of 24 hours will be allowed for the nonskid compound before traffic is resumed on the surfacing.

The minimum crew and equipment required to apply nonskid compound to membrane surfacing are as follows below:

Crew	Number of Personnel	Equipment
Inspect and apply nonskid compound	7 (1 NCOIC, *1 truck driver, 1 to mix nonskid compound, 2 to pour compound on surfacing, and *3 to apply nonskid compound)	One 5/4-ton truck
*Same individual; dual tasks.		

Replacement of Membrane Surfacing

Replacement kits are provided so that one or more sections of membrane surfacing can be replaced.

These kits will be used only when it is not feasible to perform expedient repairs to an installed section of surfacing. A failed section of membrane surfacing will be removed by first cutting it at the sides parallel to and approximately 6 feet from the side anchor ditches and end anchor ditches if the panel is the first or last panel in the pad. These cuts will extend to the 3-foot-wide construction joint located at the ends of a section. The surfacing will also be cut free at each end where the edge of the reinforcing strips joins the section of membrane. The failed section of membrane surfacing will be removed after it has been cut free on all four side. The reinforcing strip at each end of the removed section will also be cut approximately 6 feet from the side anchor ditches. Although the full width of the strips will be cut, extreme care will be exercised so that only the reinforcing strip is cut and not the underlying surfacing. After the strips are cut, they may be removed by peeling one end loose by hand for a length of 4 to 5 feet and then attaching the loose end to the bumper of a vehicle. The vehicle will be moved slowly so that the remaining length of the strip is peeled loose. The steel anchors will be exposed when the strip is peeled loose. These anchors will be pried out of the ground with picks and/or shovels. The 2-foot-wide piece of membrane from the failed panel forming the construction joint at the ends will also be cut and removed.The replacement section of the membrane surfacing will be unfolded and positioned on the runway in the same manner as that described for membrane placement and will overlap the cutaway areas or adjacent membrane panels. Care will be exercised to ensure that the centerline of the replacement section is aligned with the centerlines of the adjacent sections of membrane. Transverse construction joints will be constructed on both ends of the replacement section in the same manner as in membrane placement. The sides of the replacement section ill be lifted and adhesive will be spread at intervals 10 to 12 feet long and approximately 2 feet wide. After the adhesive becomes tacky, the two sections will be placed together. This procedure will be continued for the full length of the repair. Reinforcing strips are not required for these adhesive joints at the sides. Adhesives supplied in the replacement kits may be used during both dry and wet weather.

The minimum number of personnel and equipment required to replace one or more sections of membrane surfacing are as shown at the bottom of the page.

REPAIR AND MAINTENANCE OF SOIL SUBGRADE

When the soil subgrade beneath the membrane surfacing becomes rutted by aircraft traffic to the extent that the ruts constitute a hazard to aircraft operation, the subgrade will be repaired. If possible, the subgrade will be repaired by leaving the membrane surfacing in place and cross-rolling the rutted area to smooth out the cuts and compact the area. Rolling can be accomplished with a steel wheel roller, rubber-tired roller, or a loaded 5-ton dump truck. If any of this equipment causes the subgrade to pump, it will be necessary to slit the membrane surfacing and fold the surfacing back to provide working room for construction equipment. Sometimes, the subgrade can be dried by scarifying the soil and allowing it to air dry; in other cases, the wet soil will have to be excavated and replaced with dry backfill material. The dry soil will be compacted with one of the pieces of construction equipment listed previously. Operation of construction equipment, especially steel-tracked bulldozers, should be in a direction parallel to the width of the surfacing. This will allow the equipment to enter and leave the area without traversing the membrane surfacing. Once the area has been repaired, the membrane surfacing will be returned to its original position and patched, as discussed previously in the section on membrane maintenance.

RECOVERY OF MEMBRANE SURFACING

When aircraft operations are completed on a membrane-surfaced airfield, the surfacing may be removed from the airfield and installed at new locations. This may be accomplished by two methods—deliberate and hasty.

Crew	Number of Personnel	Equipment
Load crate into 2 1/2-ton flatbed truck and transport to site	4 (2 truck drivers and 2 to sling load crates)	1 wrecker, one 2 1/2-ton truck with flatbed
Unfold, stretch, and anchor membrane	18	Four 12-pound sledgehammers
Apply adhesive to construction joints	5 (2 to pour adhesive, 2 to spread adhesive, and 1 driver to roll)	1 HMMWV or equivalent

Deliberate Recovery

Deliberate recovery of membrane is accomplished in the reverse manner in which it was placed. This method does not damage the membrane and is used to recover 90 to 100 percent of the surfacing. This method is slow and requires careful supervision and much work. The procedure is as follows:

The soil backfill will be removed from the end and side anchor ditches with a motor grader. Approximately 2 to 3 inches of soil should be left in contact with the surfacing to prevent cutting the surfacing with the blade of the motor grader. This leftover soil backfill will be removed from the anchor ditches with hand shovels. The 3-foot-wide strips of membrane that reinforce each adhesive construction joint will be removed first by peeling one end loose for a distance of approximately 5 feet, and then attaching the loose end to the bumper of a vehicle. The vehicle will then be used to pull the 3-foot-wide strip loose from the surfacing. When all backfill is removed from the ditches, anchors that have been exposed in each adhesive construction joint and in anchor ditches will be removed after prying them loose from the subgrade with picks and shovels.

After anchors are removed, one corner of the uppermost section of membrane will be peeled loose by hand for approximately 5 feet, then the loose corner will be wrapped around the bumper of a truck, and the truck will be moved slowly across the runway until the sections are separated. After sections are peeled apart and all anchors removed, they will be turned over so that the dirt and mud that have accumulated on the bottom side of the surfacing can be removed with shovels and brooms. Failures that are found when the underneath side is cleaned will be repaired. The repairs will be made with materials from the maintenance kits. When the supply of membrane material in the maintenance kits is depleted, the 3-foot-wide reinforcing strips that were peeled from the adhesive construction joints will be used to repair additional failures. After the sections are swept clean and repaired, troops stationed at equal intervals along the lengths of the sections will accordion-fold each section of membrane into a bundle approximately 48 inches wide and 53 to 100 feet long. Each folded section will then be accordion-folded onto wood pallets. The end of the folded section will be placed on a pallet and held in place by troops while three 10-foot-long pipes are positioned at equal intervals beneath the membrane surfacing for a distance of 12 to 15 feet. The troops will hold the surfacing with the pipes high enough to clear the pallet while a forklift truck moves the pallet beneath the surfacing. As the forklift truck moves forward, the surfacing will be lifted with the pipes and accordion-folded onto the pallet. Steel straps will be used to secure each section of membrane to the wood pallet.

NOTE: Steel straps are not furnished with membrane kits. Prior to recovery, adequate banding equipment, steel strapping, and nails must be obtained from depot stocks.

Personnel and Equipment

The number of personnel and equipment required to remove the membrane surfacing will be determined by the size of the area that is surfaced. The minimum number of personnel and equipment required to handle sections of membrane and perform tasks are on page N-16.

Hasty Recovery

The hasty recovery is identical to the deliberate recovery except that the membrane is cut at the edges and the portions in the anchor ditches are left in place. The hasty method is faster and requires less supervision, but the width and length of the membrane are shortened by the amount left in the anchor ditches. The shortened membrane can be reused on another field with narrower runway requirements or as a taxiway, warm-up apron, or helipad surfacing.

Crew	Number of Personnel	Equipment
Operate equipment	4 (2 motor grader operators, and 2 to direct motor operators)	2 motor graders
Apply adhesive to construction joint	6 (5 to peel reinforcing strip and membrane section loose, and 1 truck driver)	One 2 1/2-ton truck
Remove anchors	4	
Accordion-fold membrane sections	18 (17 to fold membrane, and 1 forklift operator)	1 forklift, *3 pipes (2 to 3 inches in diameter and 10 feet long)
Band membrane to wood pallets	2	*Steel banding equipment (FSN 3540-565-6244 and 3540-278-1251)
*Not furnished with membrane kits; must be obtained from depot stocks		

STORAGE OF MEMBRANE SURFACING

The crated sections of membrane surfacing and accessories, maintenance kits, and replacement kits can be stored in open or closed depot storage. The crates are constructed so they can be stacked three high in tiers. The materials used to construct the crates will last indefinitely in closed storage and approximately 10 years in open storage. The items contained in the wood crates will last indefinitely in open or closed storage. If the crated sections of membrane are stored in the open, they will be placed on an area that has adequate drainage so rainwater will not puddle under the wood crates, which will shorten the life of the crates.

MATS

LANDING MAT

The use of a landing mat to construct an airfield will depend on many factors. The type of airfield and using aircraft, characteristics of the subgrade, time to construct, and the number of sorties desired will all impact on the decision.

Time is the most critical factor, and it is essential that TO airfields be completed at the specific time requested and remain operational long enough for the pertinent military mission to be completed. The proper use of the items described herein will enable troops to construct an assault airfield in a minimum amount of time.

MAT CLASSIFICATION

There are currently five types of mats available for use as airfields (Table N-4). These have been placed into three classifications based on the following criteria:

Light-Duty Mats

Light-duty mats must be able to withstand 1,000 coverages of a 30,000-pound, single-wheel load with a tire pressure of 100 psi on a subgrade with a CBR value of 4 (AI = 6). These criteria must be met without the occurrence of excessive deflection under load and no more than 10 percent replacement of failed panels. Other requirements are that the mats weigh 3 pounds per square foot or less of usable area and be in sections small enough to be readily placed by hand.

Table N-4. Mat characteristics

	Light **M8A1**	**Medium** **XM18**	**Medium** **M19**	**Medium** **AM2**	**Heavy** **Truss Web**
NSN	5680-00-782-5577	5680-00-089-7260	5680-00-089-5920	5680-00-191-3665	5680-00-107-1703
Bundle dimensions (WXLXD) (ft)	1.896 X 12.021 X 1.083	2.343 X 12.218 X 2.572	4.29 X 4.25 X 4.67	2.28 X 12.58 X 2.16	2.5 X 9.5 X 2.6
Volume of bundle (cu ft)	24.7	74	85.1	62	59.7
Placing area in bundle (sq ft)	268.8	432	534.4	288	324
Area covered (sq ft per cu ft of cargo space)	10.88	5.8	6.28	4.64	5.43
Gross weight of bundle (lb)	2,036	2,400	2,484	1,980	2,180
Number of panels (bundle)	13	16	32	11	18
Number of half panels (bundle)	2	4	0	2	0
Panel placing dimensions (WXL) (ft)	1.625 X 11.8125	2.0 X 12.0	4.008 X 4.16	2.0 X 12.0	2.0 X 9.0
Panel depth (D) (in)	1.125	1.5	1.5	1.5	1.5
Panel weight (lb)	144	120	71	140	112.9
Placing area per panel (sq ft)	19.2	24.0	16.7	24.0	18
Weight (psf)	7.5	4.7	4.25	5.8	6.27

Medium-Duty Mats

Medium-duty mats must be able to withstand 1,000 simulated coverages of a 25,000-pound, single-wheel load with tire pressures of 250 psi on a subgrade with a CBR value of 4 (AI = 6). These criteria must be met without the occurrence of excessive deflection under load and no more than 10 percent replacement of failed panels. Other requirements are that the mats must weigh 4.5 pounds per square foot or less of usable area and be in sections small enough to be readily placed by hand.

Heavy-Duty Mats

Heavy-duty mats must be able to withstand 1,000 simulated coverages of a 50,000-pound, single-wheel load with a tire pressure of 250 psi on a subgrade with a CBR value of 4 (AI = 6). These criteria must be met without the occurrence of excessive deflection under load and no more than 10 percent replacement of failed panels. Other requirements are that the mats must weigh 6.5 pounds per square foot or less of usable area and be in sections small enough to be readily placed by hand.

Preliminary Considerations

Proper evaluation and grading of the subgrade are critical for the proper use of landing mat. A profile to the depth of 24 inches will indicate the soil strength pattern to preclude the possibility of overstress at some point in the underlying subgrade. The length and design of the airfield must be determined from Chapter 11, and the subgrade must be crowned within the proper grades allowable. Mats must not bridge any gaps or a failure may occur.

Membrane must be placed under all landing mat in high-traffic areas, such as runways or taxiways, to waterproof and dustproof the subgrade. The membrane must meet MIL-C-43006D. Type 1 specifications and be at least single-ply, vinyl-coated, nylon cloth weighing approximately 18 ounces per square yard or the equivalent. Current Army membrane is adequate for this. The membrane is not required to be placed in a trench, as with a membrane-only airfield, but it must extend at least 6 inches past the edges of the matting. If two or more sections of membrane overlap, an adhesive joint must be formed or the matting overlapped by 1 foot to prevent water from passing into the subgrade. An adhesive joint is preferred.

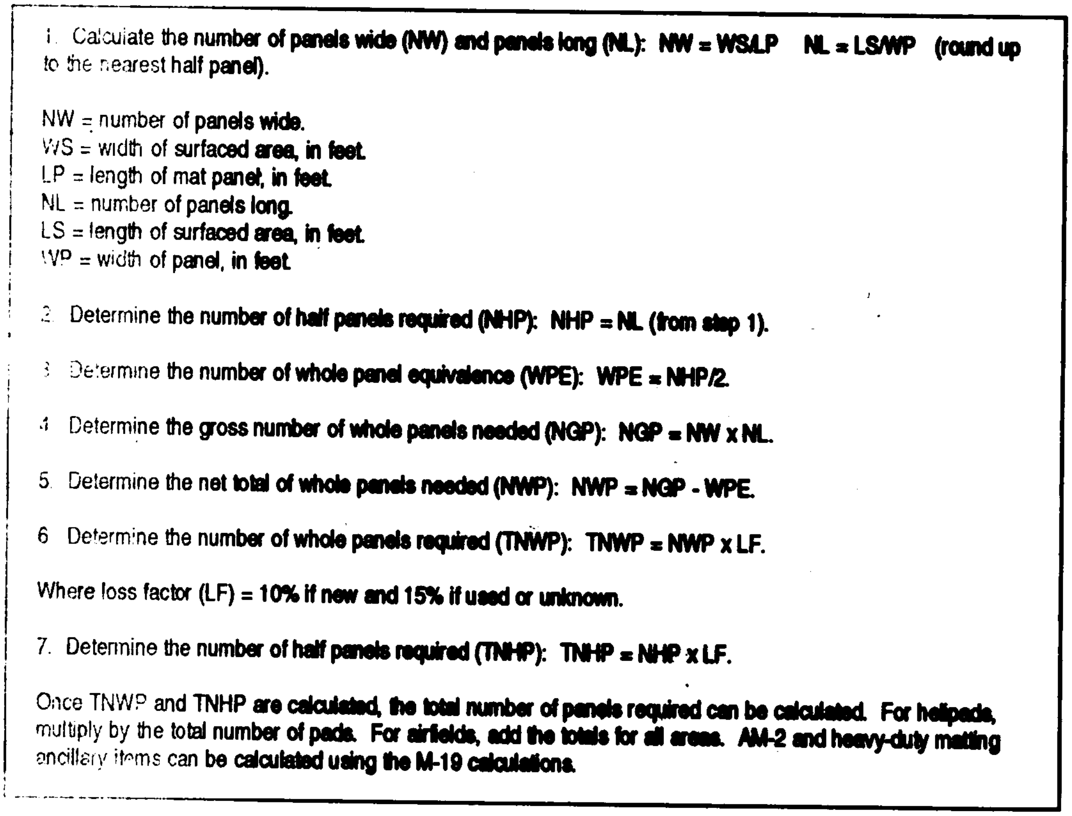
You must also consider and plan for drainage. Placement of culverts and ditches may be required across the airfield and should be emplaced before the landing mat is laid.

Material Requirements

After the airfield or helipad dimenensions have been determined from Chapter 11 or 13, respectively, and the runway length calculated from Chapter 10, the material requirements can be calculated in four steps: width determination, length determination, total panels, and additional ancillary requirements. Table N-5 provides formulas for calculating landing mat requirements for all mats except the M19. Table N-6 provides formulas for calculating landing matting and ancillary requirements for the M19. Table N-6 can also be used to determine the ancillary requirements for all other mats. The matting and ancillary items will be delivered to the airfield on pallets.

Prior to mat placement, the baseline for one edge of the proposed runway should be established by using a transit and should be clearly marked with a string line or stakes. As the laying of the mat progresses, the alignment of the mat edge or sides should be checked periodically to ensure straightness of the runway. This is very important because straightness is necessary for landing aircraft and attaching mat to make 90-degree turns.

Table N-5. Matting requirements for runways and helipads (non-M19)



1. Calculate the number of panels wide (NW) and panels long (NL): NW = WS/LP NL = LS/WP (round up to the nearest half panel).

NW = number of panels wide.
WS = width of surfaced area, in feet.
LP = length of mat panel, in feet.
NL = number of panels long.
LS = length of surfaced area, in feet.
WP = width of panel, in feet.

2. Determine the number of half panels required (NHP): NHP = NL (from step 1).

3. Determine the number of whole panel equivalence (WPE): WPE = NHP/2.

4. Determine the gross number of whole panels needed (NGP): NGP = NW x NL.

5. Determine the net total of whole panels needed (NWP): NWP = NGP - WPE.

6. Determine the number of whole panels required (TNWP): TNWP = NWP x LF.

Where loss factor (LF) = 10% if new and 15% if used or unknown.

7. Determine the number of half panels required (TNHP): TNHP = NHP x LF.

Once TNWP and TNHP are calculated, the total number of panels required can be calculated. For helipads, multiply by the total number of pads. For airfields, add the totals for all areas. AM-2 and heavy-duty matting ancillary items can be calculated using the M-19 calculations.

Table N-6. M19 matting requirements for runways and helipads

1. Calculate the number of panels wide (NW) and the number of panels long (NL): NW = WS/4.08 NL = LS/4.11 (round up to the next whole panel).

WS = width of surfaced area.
LS = length of surfaced area.

2. Calculate the number of half panels (NHP):

	Pad	Runway
NHP =	NW	2NW (if NW is even)
NHP =	NW-1	2(NW-1) (if NW is odd)

3. Determine whole panel equivalence (WPE): WPE = NHP/2.

4. Determine the total number of whole panels required (NWP):

Runway: NWP = [(NW x NL) + 4NW - WPE] x LF
Pad: NWP = [(NW x NL) - WPE] x LF

Where loss factor (LF) = 10% if new and 15% if used or unknown.

5. Determine the number of bundles (NBUN) (32 panels per bundle): NBUN = NWP/32 (round up to the next whole bundle).

6. Calculate the number of whole and half starting adapters: NS = NW - 1 and NHS = 2 .

7. Calculate the number of earth anchors (NA):

Runway: NA = (NL) x LF
Pad: NA = (NL + NW) x LF

8. Calculate the total number of edge anchors (NEA):

NEA = NEAM + NEAF + NEAO
NEAM = NEAF = (NL/2) x LF
NEAO = NW x LF (pads only)

NEAM = male anchors.
NEAF = female anchors.
NEAO = overlap/underlap anchors.

9. Calculate the number of maintenance adapters (NMA): NMA = [(LS/100) - 2] x NW x LF.

10. Calculate the number of 15-degree turndown adapters: NT = 2NW x LF.

11. Calculate the number of 90-degree turning adapters (see Figure N-51, page N-60).

Pallet Distribution

The pallets of mat should be distributed along each edge of the proposed runway and in a line equal to two-thirds of the runway width plus 4 feet inside the runway edge that will have the starting row of runway mats (Figure N-3). With this arrangement, the longest carrying distance will be slightly more than one-third of the runway width. Pallet spacing can be computed as follows:

$$\text{Pallet spacing}\,(ft) = \frac{\text{no. of rows* of pallets} \times \text{no. of mats/pallets}}{\text{no. of mats in runway width}} \times \text{width of panel}\,(ft)$$

*Rows used for M19, runs for all other matting

Place additional equipment pallets at the edge of the runway at intervals required for best distribution in relation to mat pallets.

Airfield Layout

The determination of the lengths and widths of airfields is discussed in Chapter 12, and sample airfield layouts are given in various figures throughout this section. There are some additional design patterns that may be needed due to terrain and mission requirements.

Fillets. A fillet will normally be used to round off an area where aircraft are required to turn, such as where a warm-up apron meets the taxiway or runway. The purpose of the fillet is to increase the mat-surfaced area to help in preventing aircraft from going off the matting during a turn. In constructing the fillet, the mats are placed to cover the required design area but the edge is left stepped (Figure N-4, page N-22). The matting will also be anchored as required by the mat type.

Oblique taxi ways/ warm-up aprons. Occasionally, it may be necessary to place matting obliquely at an intersection. To do this, the mat is offset for the required design area and the edge is left stepped (Figure N-5, page N-22), The mat is also anchored as required by the mat type.

M8A1 Steel Mat

The M8A1 mat is classified as a light-duty mat formed of 0.125-inch-thick steel plates that can be placed on a crowned subgrade of up to 2 percent. The panels are 11 feet 9 3/4 inches long, 1 foot 7 1/2 inches wide, and weigh 144 pounds (or 7.5 pounds per square foot). The mat is classified as a light-duty mat: however, it does not qualify based on performance or weight. The panels can be placed at a rate of 243 square feet per man-hour. The mat comes in pallets of 13 standard and 2 half panels.

The panels are solid planks, and the end connectors incorporate moment transferring end joints made up of four sliding steel bars that are 3/4 x 3/4 x 10 1/2 inches. A bayonet connector is along one side of the panel, and the other side rolls under the bayonet slots when attached to another panel to form a smooth contour at the subgrade and furnish additional strength along the side. The locking lug can be bent up or down to facilitate removing and replacing (Figure N-6, page N-23).

The two ends of the mat form underlap and overlap edges. When placing panels, the underlap end must be placed on the bottom, and the overlap end is then placed on the top. A reversal of the underlap and overlap positions is not possible because the underlap end ribs will not seat fully and will also prohibit an even surface.

When laying an airfield with M8Al, the first panel to be placed should be the panel in the upper left-hand corner of the field as the crew faces its work, with the bayonet lugs facing away from the laying crew and the slot side adjacent to them. This places the underlap end on the right and the overlap end on the left. After the first panel is placed in the upper left-hand corner of the field, the second panel is joined to the first panel by sliding the four end connector bars into the receiving slots. The remaining panels in the first run are continued in this manner for the entire width.

The first run must be completed for alignment purposes before any other run can be

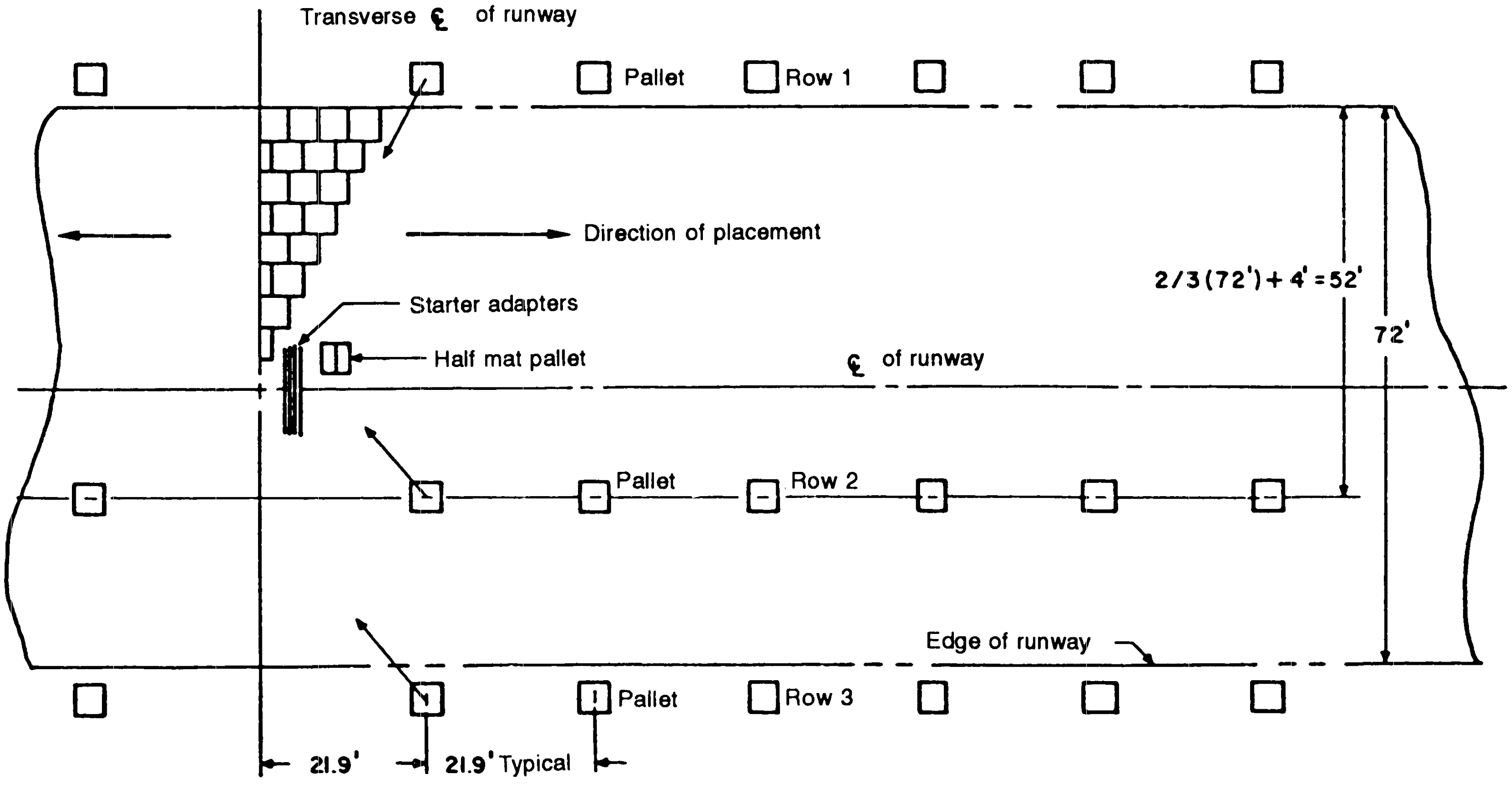
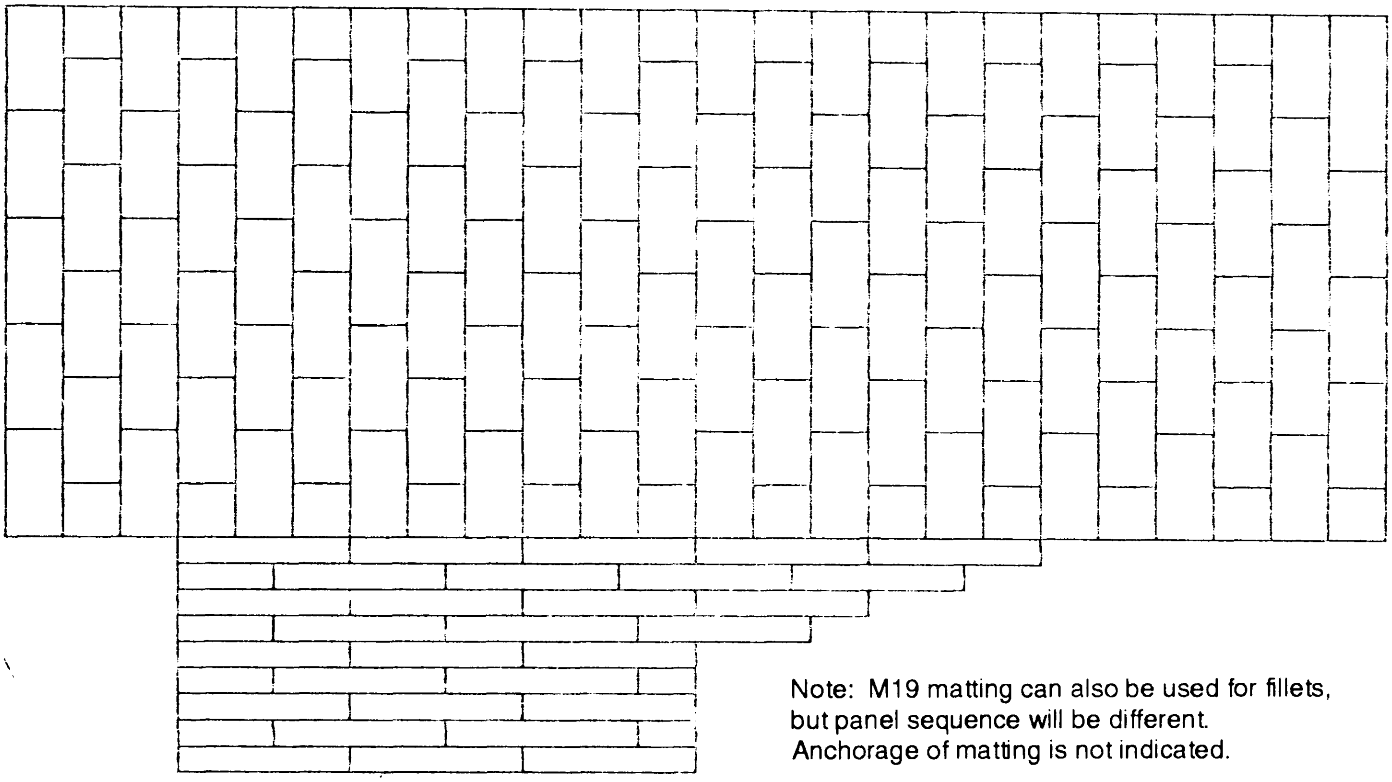


Figure N-3. Typical distribution of pallets for a 72-foot-wide runway using M-19 matting



Note: M19 matting can also be used for fillets, but panel sequence will be different. Anchorage of matting is not indicated.

Figure N-4. Procedure for laying fillet of M8A1, AM-2, and heavy-duty truss web.

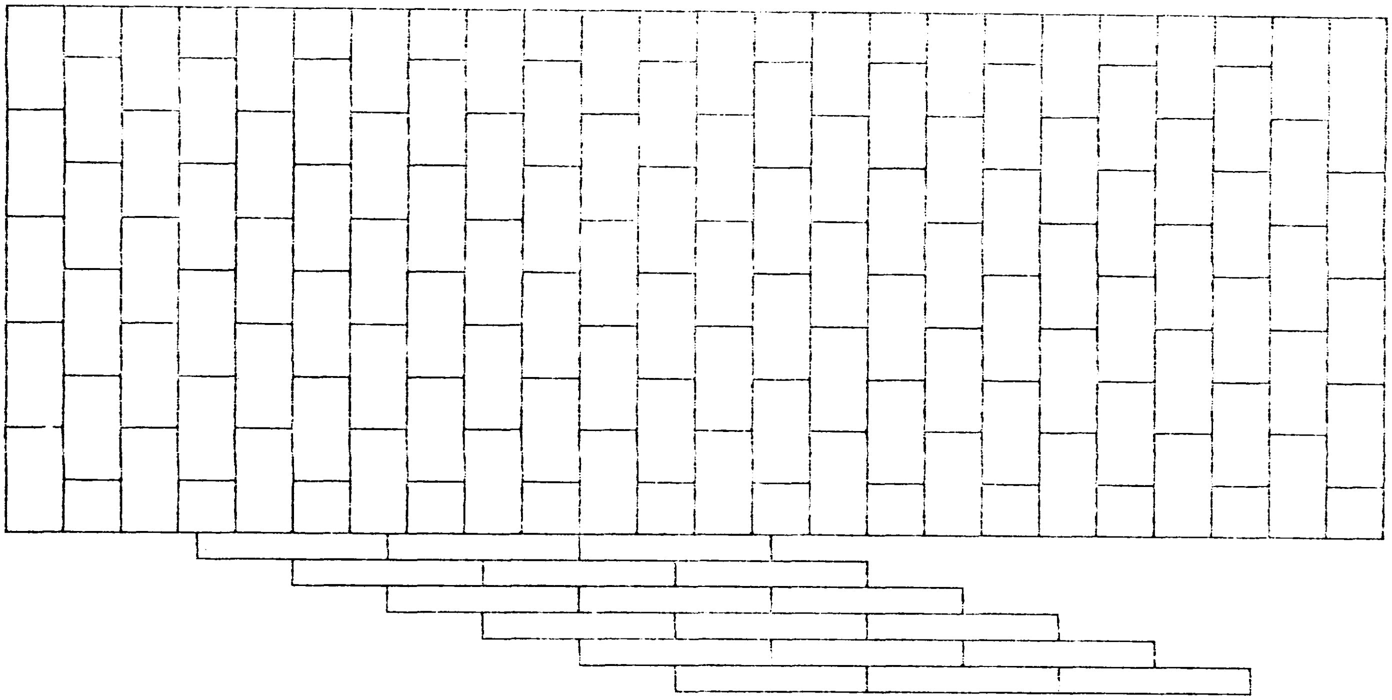


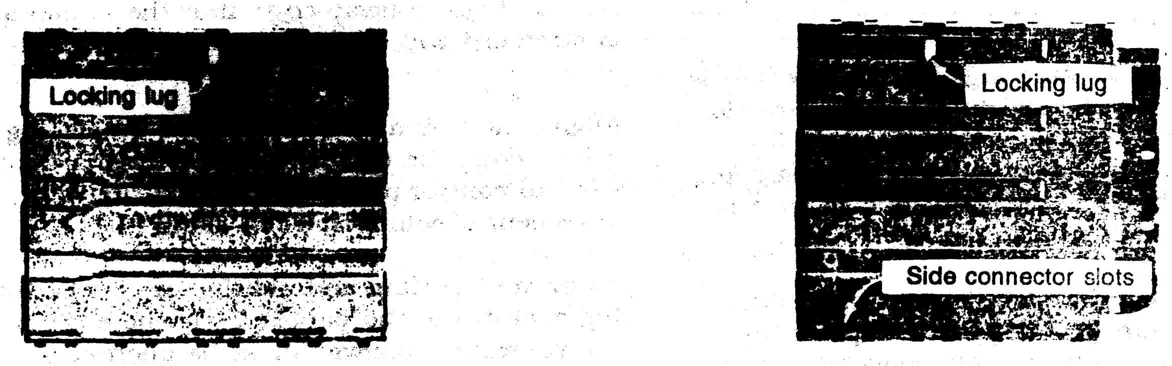
Figure N-5. Sample oblique taxiway

Plan view of panel

Nominal dimensions
1' - 7 1/2" x 11' - 9 3/4"

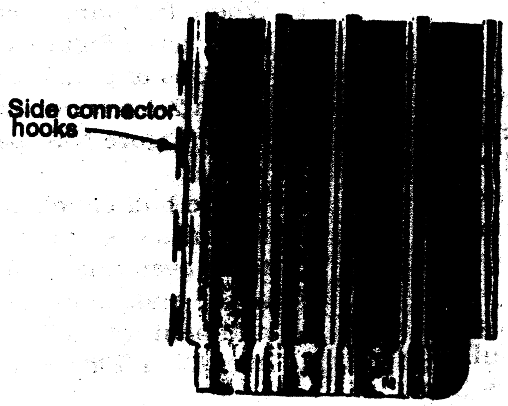
Left end view

Right end view



Details of left end

Details of right end



Bottom view of right end

Figure N-6. M8A1 steel landing mat

started. The second and following runs, however, can be started as soon as enough panels have been laid in a run to allow for the placement of the next run of panels. The follow-on runs, however, may not surpass the previous run since proper locking of the runs together will be impossible.

After the first row of panels has been placed, the second and follow-on rows of panels are placed by holding the panel at approximately a 45-degree angle to the pre-previous row's panel. The bayonet lugs of the panel being laid are engaged in the side slots of the laid panels. The panel is then slid until the bayonet lugs are securely locked in the slots and the locking lug behind the bayonet lugs is positioned in the slots. The locking lug will fit into one of the two locking lug slots of the laid panel to prevent future sliding when the loose plank is lowered back to the ground in its final position.

To make the locking lugs line up, all panels in a run must be slid in the same direction—right or left. Panels in alternate runs are then slid in the opposite direction to maintain edge alignment and to ease removal for maintenance.

M8A1 mat can be placed by using multiple crews. Figure N-7 depicts this procedure. Notice that when multiple crews are used, the mats are welded where the placement crews meet.

The welded juncture may be formed in many ways. The planks of the junction may be cut to form a butt weld, or for a stronger joint, both planks are cut in a rib valley and joined. This joint can also be strengthened by welding short pieces of scrap steel at intervals over the joint.

If the pad should have an even finish, all odd-numbered runs will start with a full panel to ensure staggering of the joints (Figure N-8a, page N-26). All even rows will start and finish with a half panel. If the pad is not required to have an even finish, all even runs will start with a full panel offset from the previous run (Figure N-8b, page N-26).

After every 60 to 70 linear feet of matting has been placed, laying operations are stopped and the mat is stretched tight by using truck winches or other equipment as available. This stretching is necessary to maintain alignment and prevent buckling of panels due to temperature changes.

The placement of panels will continue as outlined until the pad is completed or one crew meets the next crew, whereupon the mat sections are welded.

Runway alignment of the matting must be assured throughout the placement procedure. To assure alignment during placement, the survey party should be available to keep constant check on alignment. This may be accomplished with a transit or by using the 3-4-5 triangle method. Drift or realignment can be corrected at the time the mat is being stretched. The use of temporary anchor stakes at the runway edge after the planking is stretched will assist in maintaining alignment.

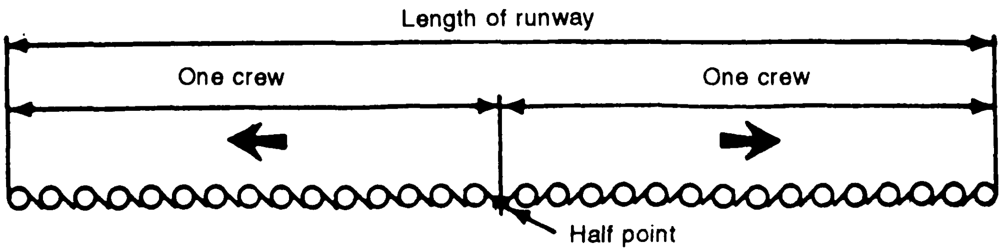
Alignment may also be controlled by placing a line along the centerline. This line is then used to control placement by assuring the alignment of joints that fall along it.

To prevent curling and shifting of panels during operations, the panels along the edge of the runway or taxiway must be anchored. This may be done in several ways.

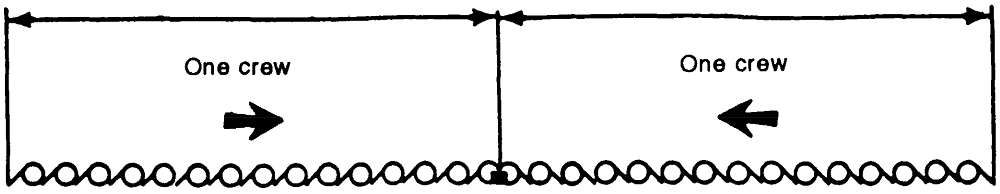
- Where full panels are offset in the even runs, as in Figure N-8b, the extended portions of panels are bent downward into a 2:1 trench, and the trench is backfilled (Figure N-9, page N-27).

- Where half panels are being used to finish the sides of the runway (Figure N-8a) to an even line, a full panel will be used at the ends of every fourth or sixth run and bent into a 2:1 trench and then backfilled (Figure N-9).

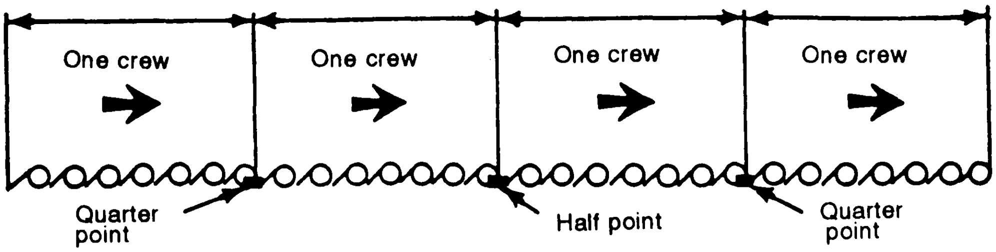
- The extended sections to be buried can be bent by a roller or a truck, Panels may also be bent or beaten into shape with a sledgehammer as required. A cutting torch may be used to cut out a



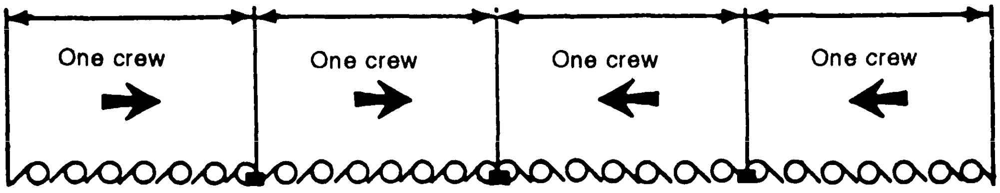
TWO-CREW METHOD



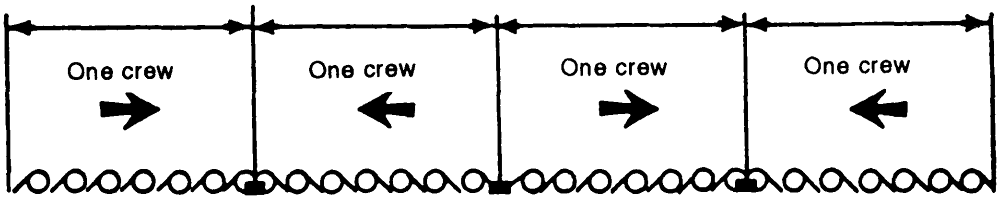
ALTERNATE TWO-CREW METHOD



FOUR-CREW METHOD

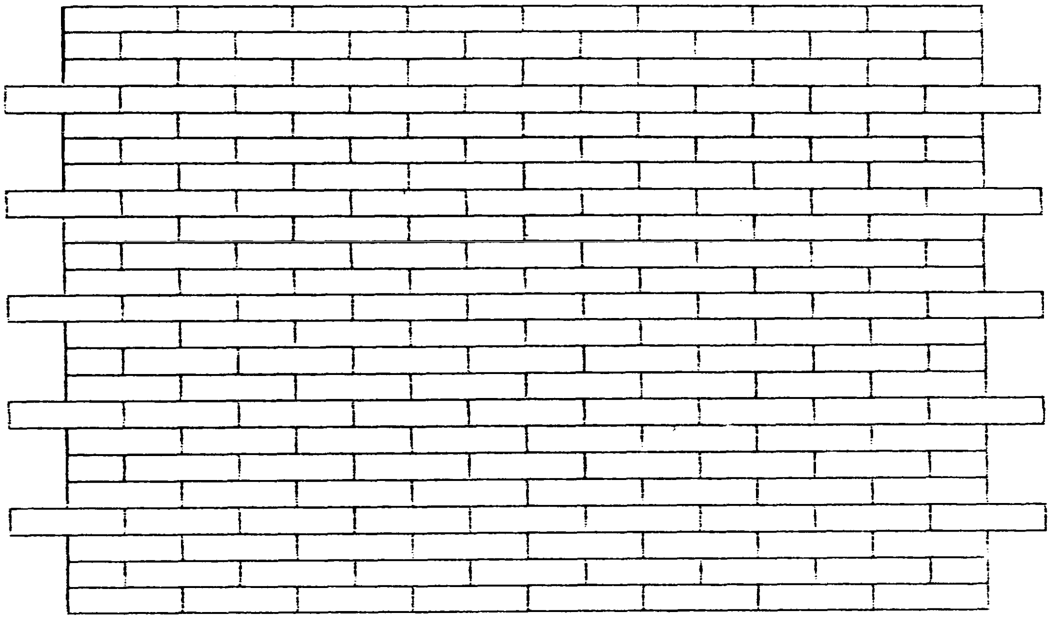


ALTERNATE FOUR-CREW METHOD



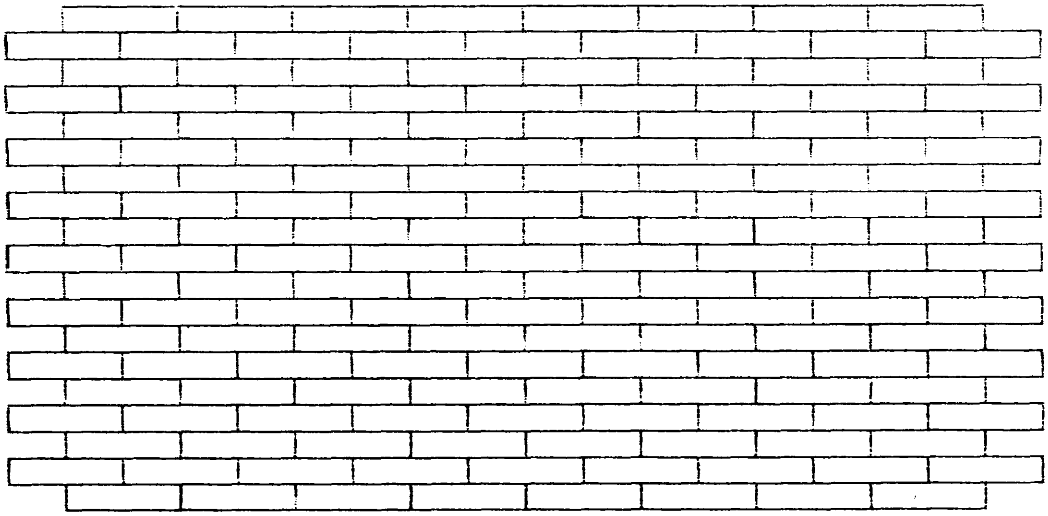
ALTERNATE FOUR-CREW METHOD

Figure N-7. Procedure for laying M8A1 matting with multiple crews



NOTE: Even rows start with a half panel and every 4th or 6th row an offset full panel that will be buried in a 2:1 sloped trench to anchor the pad. Figure shows placement pattern of every 4th row.

Figure N-8a. M8A1 pattern with an even finish



NOTE. The offset full panel in the even rows will be buried in a 2:1 trench to anchor the runway.

Figure N-8b. M8A1 pattern without even finish small notch in the ribs, which will greatly reduce the load required to bend the panel and help in controlling the point of bending.

- Where half panels are used to an even edge, an alternative method is to anchor the mat with cables tied to deadmen buried along the sides. Earth anchors consisting of 3/4-inch reinforcing rod, 40 inches long, are also used to anchor sides of runways, taxiways, or helipads. The top 6 inches of the rod should be bent over the mat.
- At the ends of runways, a 2:1 trench is excavated at each end of the runway across the entire runway width. The panels are continued down the slope of the trench for 6 panels. After the panels are in place, the trench is backfilled and compacted (Figure N-10).

Warm-up Aprons, Hardstands, and Fillets

Construction of hardstands and fillets can be preceded in two ways—by making them an extension of the trafficway or, preferably, by running the panels perpendicular to the line of travel and welding the panels at the junctures. The first method places the panels parallel to the line of travel, but it has advantages such as ease of construction and saving time and material. It is a satisfactory method when traffic will be light.

Warm-up apron panels must be placed perpendicular to the line of travel due to the amount of traffic involved. The juncture of the panels will be welded in the same manner as described for runway/taxiway placement. A fillet may also be used to round off corners.

Staking down of the panels in these areas is generally satisfactory anchorage. When

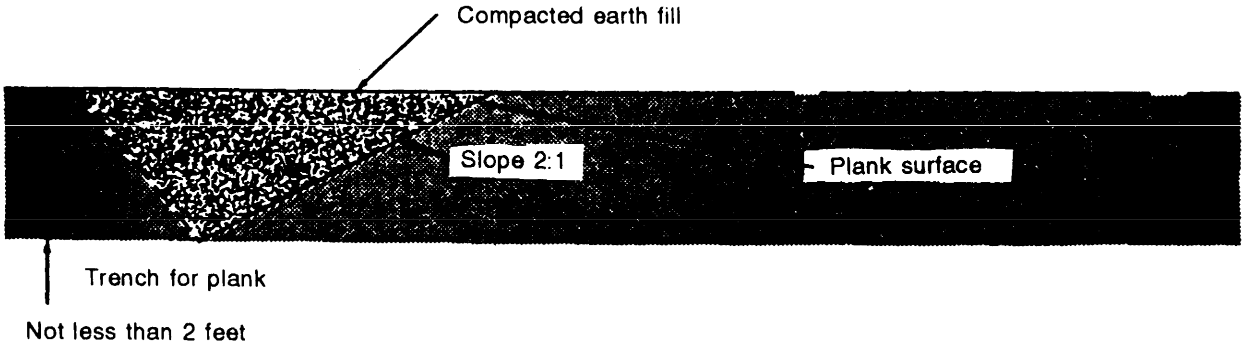


Figure N-9. Trench anchorage for edge of M8A1 matting

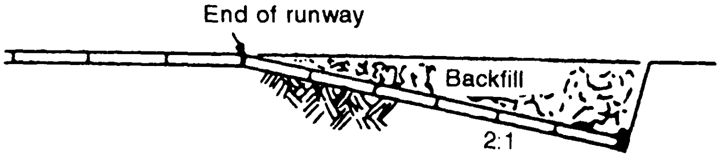


Figure N-10. Anchorage details for M8A1 matting at ends of runway time permits, the edges should be buried in the same manner as for the runway/taxiway to prevent curling.

Recovery, Cleaning, and Bundling of M8A1 Matting

Removing. Generally, the panels will be removed in the reverse order they were placed. The connecting tabs will be unlocked and the panels will be raised to a 45-degree angle with the ground. The panels will be slid about 3/4 inch to the left or right to align the bayonet hook with the hook slot and then removed. It may be necessary to pry a panel from the side connection in order to lift the panel. After two or more panels in a run are removed, removal of the adjacent run's panels may begin, resulting in a stair-step pattern for removal.

Before bundling the panels for shipment, the connecting tabs should be inspected and tack welded as required,

Cleaning. Most of the adhered soil can be loosened from the panels by dropping the panel 4 to 6 feet, flat onto a hard surface, such as a concrete pad or other panels. Bars can be used to loosen the soil by running the bar down the ribs of the panel before or after dropping the panel. Soil must be removed from the connecting edges, or the panels will not connect properly for reuse. It may be necessary to use water under high pressure to remove soil wedged in the female side connection.

Bundling. M8A1 mat is repackaged in bundles containing 13 full and 2 half panels. The panels will be nested in pairs, bottom to bottom, with like panel ends together and the connector protected between the box edge and the first rib of the other panel in the pair. (The two half panels will be stacked with a full panel to make a nested pair, and the pair will be placed in the interior of the bundle.) The nested pairs are then stacked on two 2x4s for skids so that the ends of alternate pairs are reversed. A bundle will be secured with six flat, steel traps. Four of the straps will be placed transversely (to encompass the two longitudinal straps) around the short dimension of the bundle, two of which will be 18 inches from the ends with the interior straps equally spaced. The two longitudinal straps will be at the one-third points, and all straps will be properly tensioned for shipment.

Criteria for Mats to Be Reusable

Used panels can be grouped into three separate classes: Class 1, reusable as is; Class 2, reusable, but in need of minor repair; and Class 3, unusable. The essential factor in deciding if a panel is reusable is whether it will fit together with a new panel (used as a standard gauge). Acceptable panels may have—

- One of the end locking bars missing.
- Four of the bayonet hooks missing. (No two adjacent bayonets may be missing.)
- Minor cracks not exceeding 1 inch in length (no sharp or protruding edges).
- One of the end connector bars (hooks) missing. Bent or slightly deformed bayonets should not cause a panel to be unusable because the bayonets can be easily straightened with hand-tools.

AM-2 Mat

AM-2 mat is a non-Army, medium-duty mat used by the Air Force, Navy, and Marines. Army units can expect to encounter AM-2 in the TO, especially during joint operations.

AM-2 mat is a fabricated aluminum panel that is 1 1/2 inches thick, 12 feet long, and 2 feet wide. It consists of a hollow, extruded, one-piece main section with extruded end connectors welded on each end. The mat weighs 5.8 pounds per square foot, qualifying as a medium mat on performance, not on weight. The panels can be placed at a rate of 163 square feet per man-hour and on a subgrade crowned up to 1.5 percent (Figure N-11).

The connectors of the mat consist of an overlap/underlap on the ends and a male/female hinge joint on the sides. A flat

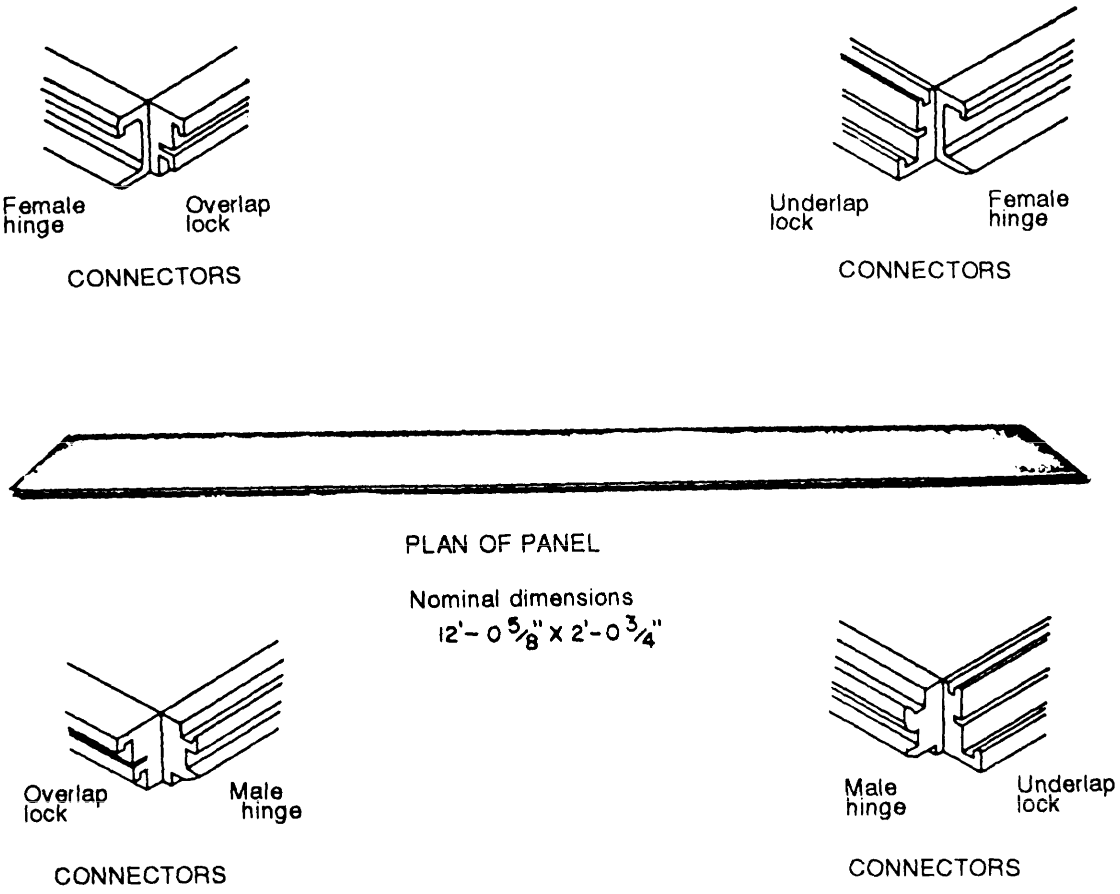


Figure N-11. AM-2 landing mat

locking bar is inserted into the slot common to the panels to form a nonseparable joint (Figure N-12, page N-30).

AM-2 Pallets

Mats and necessary ancillary items are packaged in pallets for movement to the TO.

Standard pallet. The standard pallet contains enough matting to construct three runs (6 feet) on a runway or taxiway that is 72 feet wide.

Ancillary pallets. AM-2 ancillary equipment is packaged by like items, and the sizes will conform to the item sizes.

Ancillary Items

The AM-2 mat uses various ancillary items that are different from other mats.

Keylock adapters are bars that are very similar to the access turning and starter adapters of M19 matting. These are also locked to other keylock adapters by a socket head screw. Five types of keylock adapters are available and listed below:

Starter keylock (Figure N-13, page N-31). A starter keylock is used most often to mate the female ends of an 80-degree adjustable connector and adjoining mats. Starter keylocks are furnished in 3-, 8-, and 12-foot lengths to provide for staggering of joints in matting patterns. The starter keylock is coated with nonskid material.

Typical keylock (Figure N-14, page N-31). A typical keylock is inserted every 100 feet in the pattern to permit the easy removal of sections of mat for multiple mat replacement. Thus, a maximum of 50 feet of any section need only be removed to replace

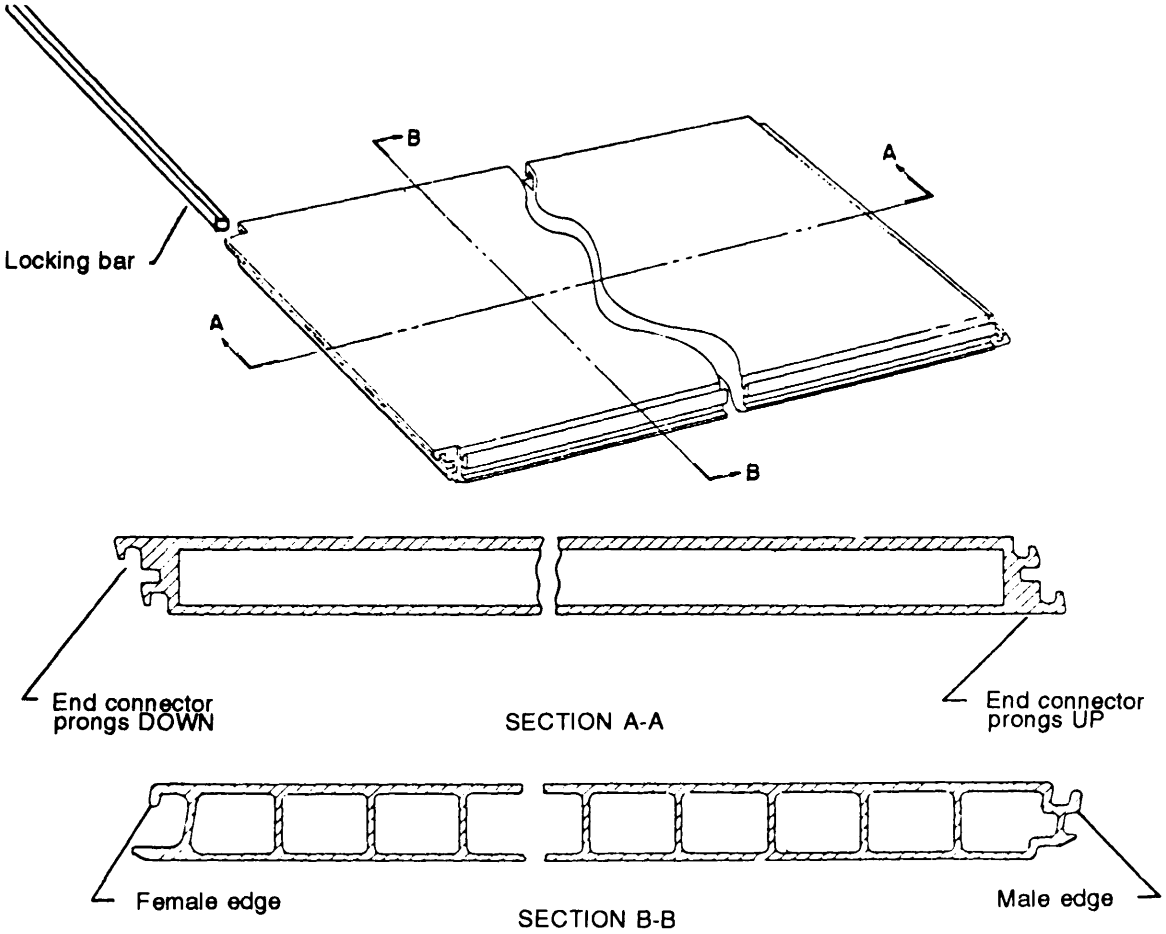


Figure N-12. AM-2 mat configuration

mats that could not economically be replaced as individual units by replacement mats. Typical keylocks are furnished in 3-, 9-, and 12-foot lengths to provide for staggering of joints of mat patterns. The typical keylock is coated with nonskid material. Typical keylocks may also be used alone or in combination with adjustable keylocks and/or spacer mats to fill the last row of replacement mat when the run space is less than 24 inches in width.

Female keylock (Figure N-15). A female keylock is used to join two adjacent male mats. The female keylock is coated with nonskid material.

Adjustable 90-degree connector (Figure N-16). The adjustable 90-degree connector is used to join two mat patterns that are adjacent to each other at a 90-degree angle, such as the main runway and a taxiway. Connectors are 12-foot-long, aluminum sections that can be adjusted in width from 6 1/2 inches to 9 1/2 inches to facilitate the joining of two adjacent matting sections.

Adjustable keylocks (Figure N-17, page N-33). Adjustable keylocks are provided to fill the last run of installed matting when the run space is less than 24 inches wide. These keylocks may be used alone or in combination with typical keylocks and/or spacer mats, depending on the width of the row space. Adjustable keylocks are furnished in 3-, 6-, and 12-foot lengths and can be adjusted to expand from 6 to 9 inches in width. Right and left adjustable keylock assemblies are comprised of a combination of 6-foot, male and female keylock assemblies.

Expansion in width of these keylock assemblies is controlled by a keylock screw in the male keylock assembly that rides in a slot in the female keylock assembly.

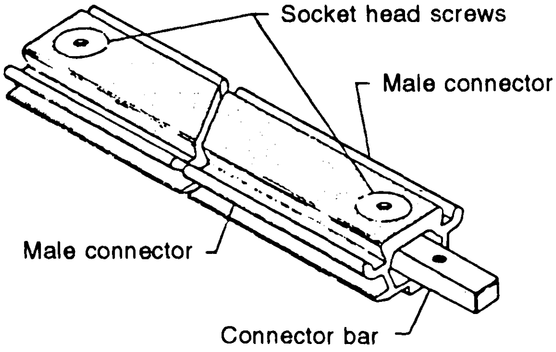


Figure N-13. Starter keylock

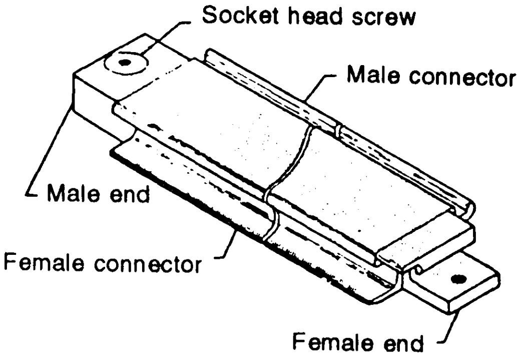


Figure N-14. Typical keylock

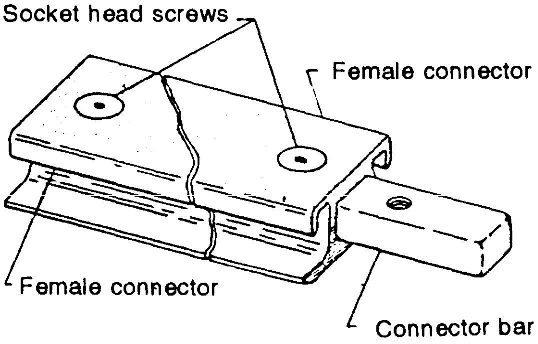


Figure N-15. Female keylock

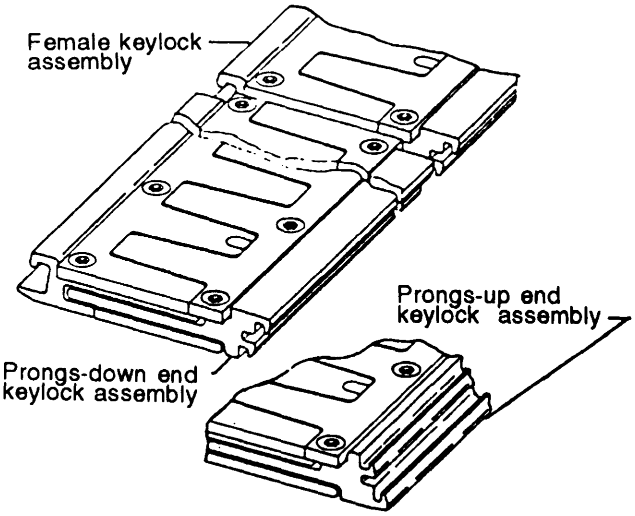


Figure N-16. Adjustable 90° connector

Adjustable keylocks are coated with nonskid material.

Adjustable keylocks provide a dual function—they are used for linear expansion due to temperature change, and they facilitate the joining of previously installed landing mat with adjoining mat.

Adjustable keylocks are not to be used in runway areas. They are to be used on parking and taxiway areas only.

Locking bars. Locking bars are used to interlock the mats and are inserted in the upturned-downturned connection in the mats as the mat is laid. Locking bars come in 2-foot lengths and are 5/8 inch wide.

Blast-deflector adapter (Figure N-18). The blast deflectors are provided to protect the area surrounding the airfield from the blast of the engine exhaust. The deflectors also help to limit the amount of dust caused by jet engines. These deflectors consist of mat sections held at about a 60-degree angle to the horizontal by blast-deflector adapters, which are 2 feet long. They can be installed along the edges of the taxiways and parking areas but are not used along the runway.

The Type I adapter joins to the male edge of the mat and to the female edge of the mat. Type II joins to the prongs-up end of the mat. Type III joins to the prongs-down end of the mat.

Tie-downs (Figure N-19, page N-34). Tie-downs are provided for aircraft anchorage and are bolted in place on the site by drilling and tapping the necessary holes in the AM-2 mats, according to aircraft configuration in the parking areas.

Removable end connectors (Figure N-20, page N-34). Removable end connectors are used to expand the runway width from 72 to 96 feet as required to enlarge an air base. The removable end connectors separate into two halves, which enables the quick replacement of 6-foot mats with 12-foot mats. A flat, locking bar is inserted into the slot common to the removable end connector and the mats to form an inseparable joint.

Mat push-pull fixture (Figure N-21, page N-34). The mat push-pull fixture is used to remove and replace a partial or complete row of mats. Rows of mat are removed for replacing damaged mats and for installing removable end connectors on existing installations. The fixture provides a fork pocket for pushing a single end mat or an entire row with the tines of a forklift. The fixture is provided with shackles to accommodate a wire-rope sling for pulling the mats out of the brickwork pattern.

Replacement mats (Figure N-22, page N-35). Replacement mats allow for the replacement of damaged mats with a replacement item that duplicates the original installation, reestablishes the brickwork pattern, and requires only the removal (by cutting) of the original damaged piece. These mats are complete with a nonskid coating. Replacement mats are prepared from AM-2 mats by cutting off the prongs-up edge and the male-connector edge and welding on adapters. Additional adapters must be bolted on at the Time of installation. In case of site disassembly, replacement mats may be disassembled and used as standard mats without further alteration. They may also be disassembled and saved as prepared replacement mats for the next installation.

Heavy-duty mats (Figure N-23, page N-35). Heavy-duty mats are provided under the arresting gear pendant to eliminate damage during aircraft arrestment procedures. These mats are 6 feet long and 18 inches wide. Heavy-duty mats are painted green, and the top surface is also coated with nonskid material of the same color. Locking bars used to secure heavy-duty mats together are approximately 6 feet long.

Spacer mats (Figure N-24, page N-36). Spacer mats are also provided to fill the last row of replacement matting when the row space is less than 24 inches wide. These mats may be used alone or in combination with typical keylocks and/or adjustable keylocks. Spacer mats are furnished in 6- and 12-foot lengths and are 12 inches wide. The spacer mat is coated with nonskid material.

Edge clamps and stakes (Figure N-25, page N-36). Edge clamps are provided to secure AM-2 mat at aircraft taxiing and parking area turning points. Stakes are driven into the ground to anchor the edge clamps to the mats.

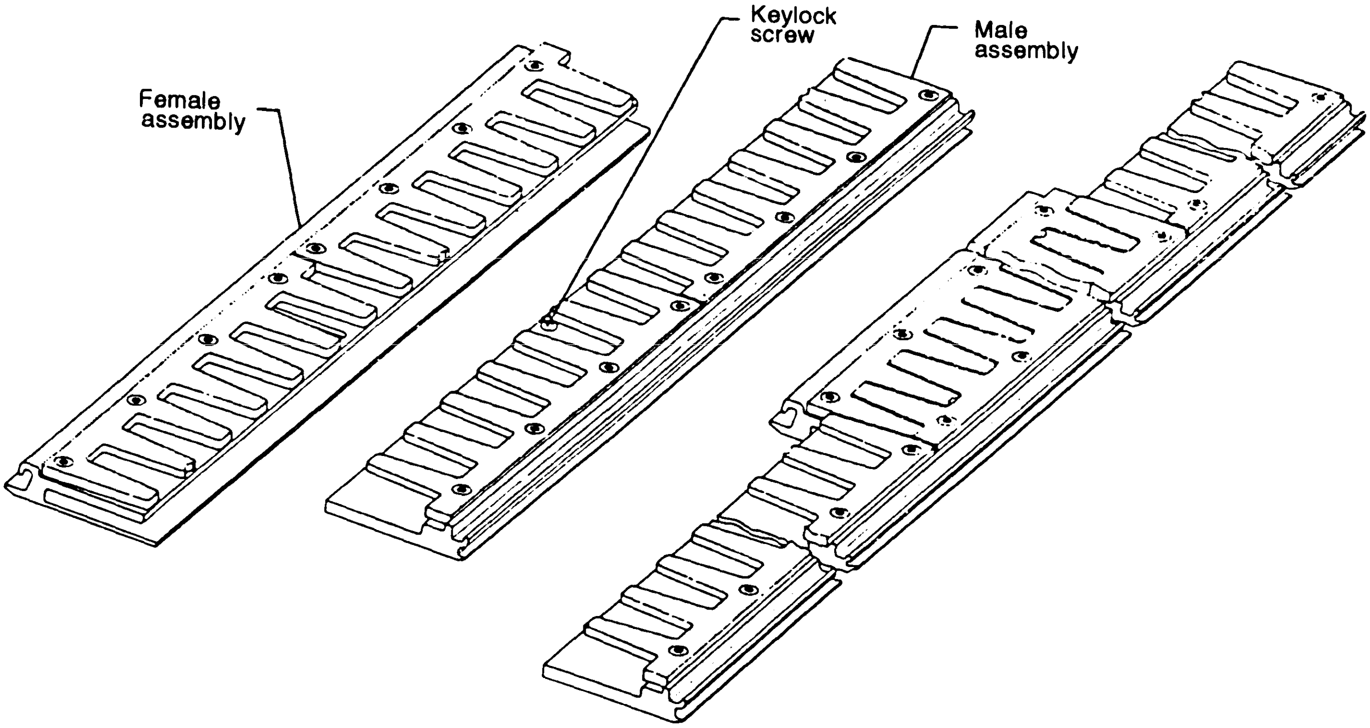


Figure N-17. Adjustable keylock assembly

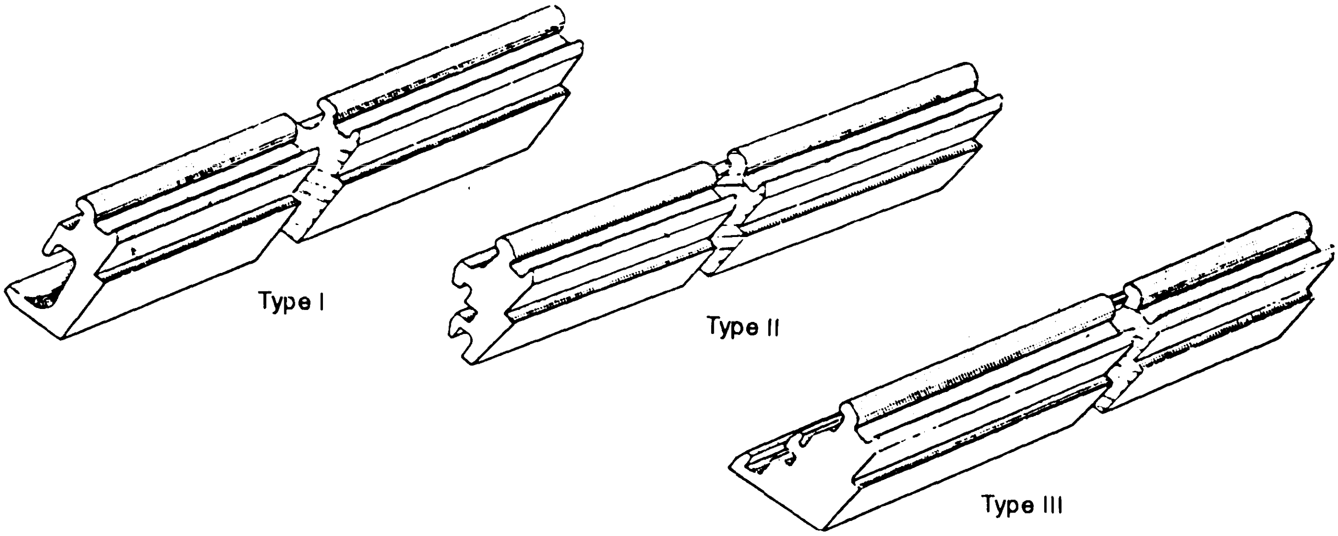


Figure N-18. Blast-deflector adapters

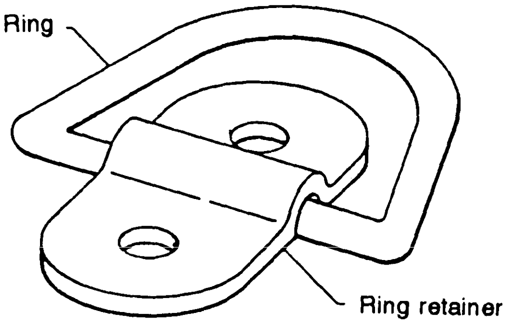


Figure N-19. Tiedowns

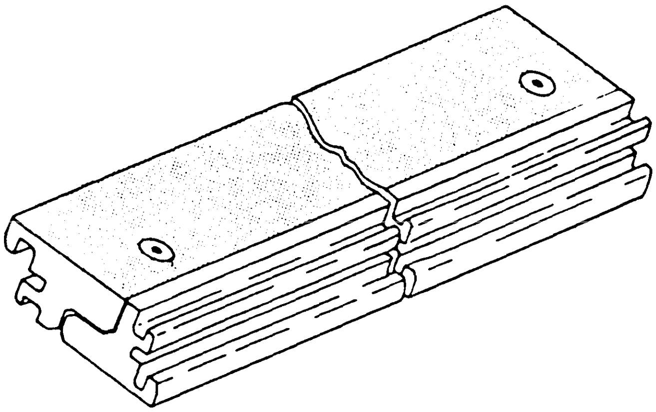


Figure N-20. Remoldable end connectors

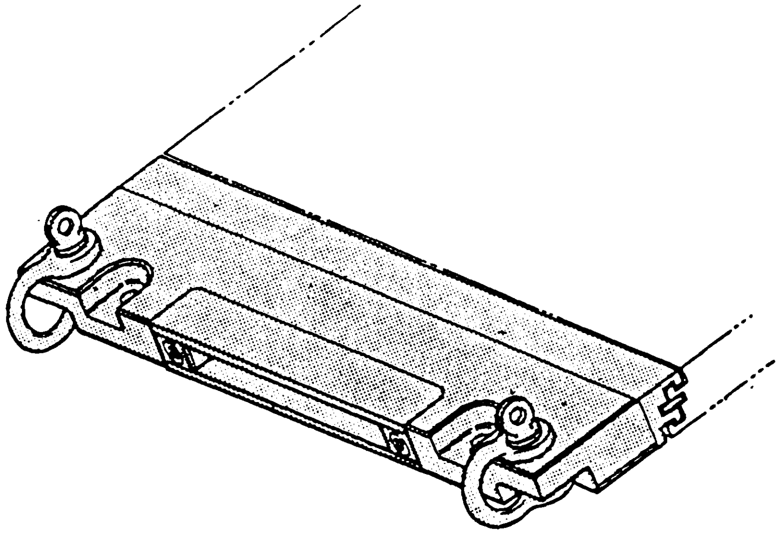


Figure N-21. Mat push-pull fixture

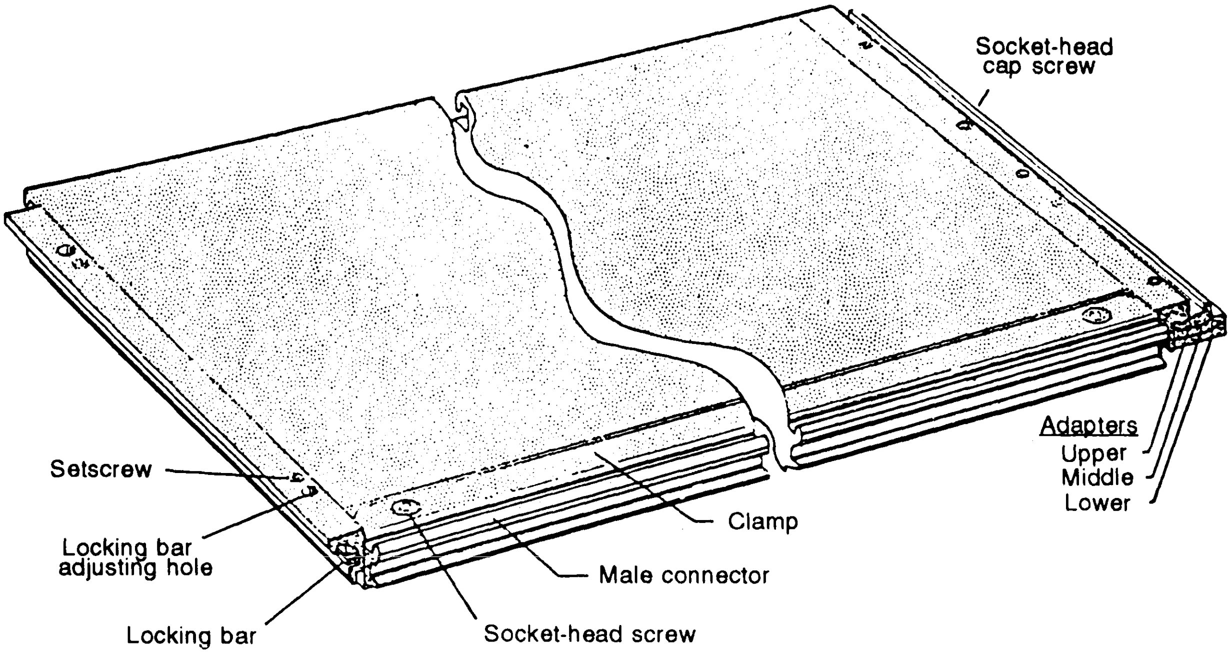


Figure N-22. Replacement mat

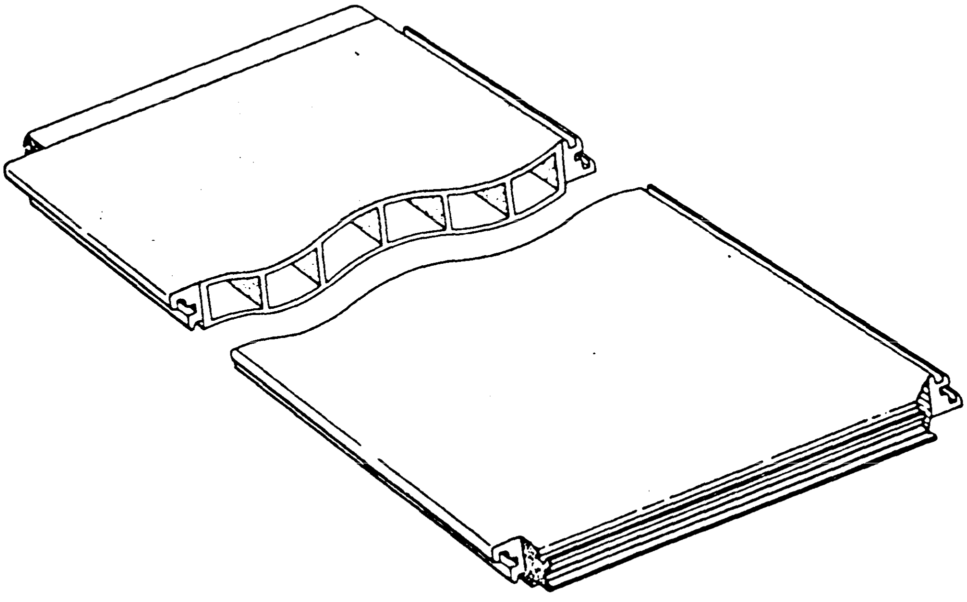


Figure N-23. Heavy-duty mat

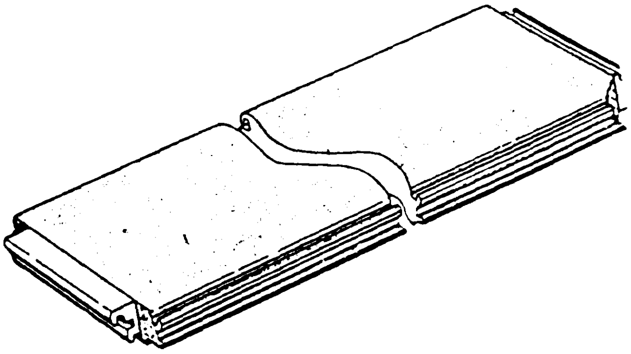


Figure N-24. Spacer mat

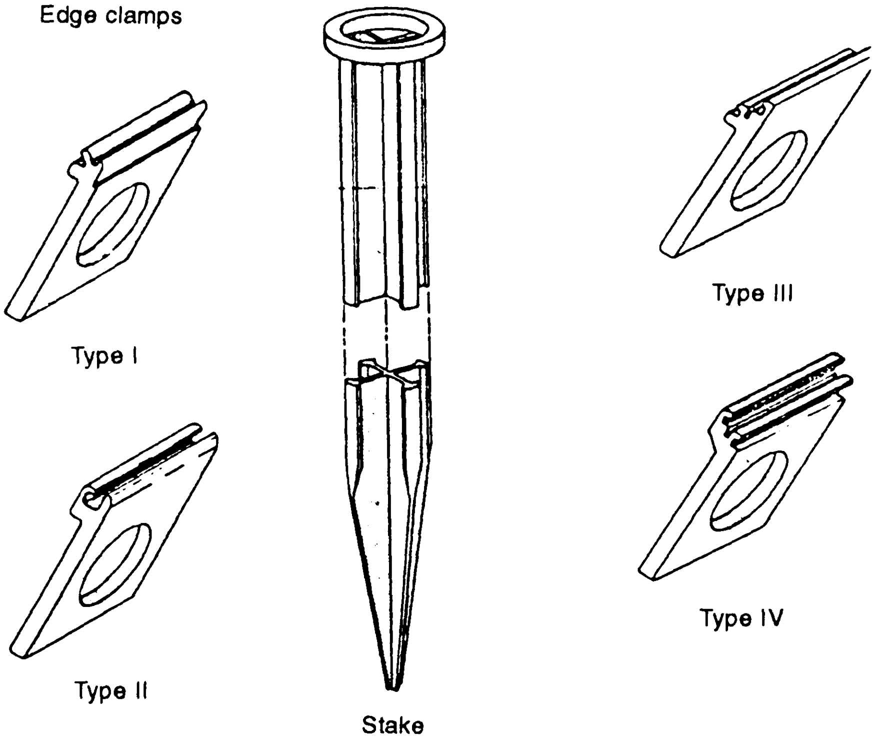


Figure N-25. Edge clamps and stake

There are four types of edge clamps:

- Type I edge clamp anchors female edge of mat.
- Type II edge clamp anchors male edge of mat.
- Type III edge clamp anchors downturned prongs of mat.
- Type IV edge clamp anchors upturned prongs of mat.

Short locking bars are used to secure Type III and IV edge clamps to the mat.

The quantity and location of edge clamps may vary for a specific installation, depending on soil and environmental conditions.

INSTALLATION INSTRUCTIONS

Installation of an AM-2 airfield can be conducted by either starting at one end of the runway and proceeding in one direction down the runway or by starting at the transverse centerline of the runway and proceeding toward each end simultaneously.

A typical placement crew is broken down as shown at the bottom of the page.

The coated side of the mat is always up, and the interlocking prongs on the short (2-foot) edge are always to the right and up. Survey lines are used to ensure longitudinal alignment on at least one edge of the matting section. A typical keylock section is laid every 100 feet to allow easy access to panels for repair and maintenance.

AM-2 airfields are generally designed using two runway width criteria-72 feet and 96 feet. The 72-foot width is designed to meet initial runway standards; its design life is up to 6 months, and it can be easily upgraded to a 96-foot-wide temporary airfield with the use of removable end connectors. The removable end connector cannot be used when laying landing mat in two directions from the transverse centerline but only when the entire airfield has been laid in one direction. The choice of which method to use for laying the matting depends on the mission. While laying mats in two directions at once is faster, airfield upgrade may take longer without the removable end connectors.

INSTALLATION SEQUENCE

The placement of panels for an AM-2 airfield is much the same whether laying a 72- or 96-foot-wide runway or using a starting keylock and laying in two directions at once. Before laying the mats, visually inspect the sides and end connectors for foreign matter. Brooms and brushes should be capable of cleaning the mat.

If placing the mat from one end of the runway to the other, the first panel will be placed on the upper left side of the runway with the nonskid side up, the overlap hinge

Crew	Responsibility
1 NCOIC	Supervises
1 Alignment man	Ensures that the linear alignment of the field is maintained.
2 Prybar men	Adjust individual mats and insert mat-locking bars.
12 Mat installation men (six 2-man teams)	Work with a partner, obtain a mat from the pallet, carry mat to emplacement point, and install mat in field.

on the outside edge, and the male hinge inside the field. The first and all odd runs will start and end with a half panel (Figures N-26 and N-27, page N-40). The next mat placed will be a fill mat on the first run. A locking bar will be inserted in the rectangular slot formed by the joining of the mats (Figure N-28, page N-41). The third mat placed will be the first mat of the second row. The mat is placed by holding the panel at a 45-degree angle to the mat in the preceding run engaging the female connector over the male end and lowered to the ground. The mat placement will continue in the stair-step pattern as shown in Figures N-26 and N-27 until the entire runway is completed. If a 72-foot-wide runway is to be increased to a 96-foot-wide runway later, removable end connectors should be placed between the last full and half panel on every odd run. This will assist in upgrade of the airfield (Figure N-29, page N-41).

When laying a runway in two directions, a starter keylock adapter will be placed transverse to the centerline at the midpoint of the runway. The length of starter adapters to use will be in the same configuration as the typical keylock pattern shown in Figures N-26 and N-27.

The first panel will be placed in position 1 (Figure N-30, page N-42) by holding the panel at a 45-degree angle to the ground so that the female connector is engaged over the male and lowered into position. Subsequent panels will be placed left to right (facing the transverse centerline) in sequence (2, 3, 4, 5, and so forth) in a stair-step pattern as indicated in Figure N-30. Note that a half panel is used in alternate runs to provide a staggered pattern. This pattern will be maintained throughout placement. The ends of panels will be locked by inserting the locking bar in the locking bar slot. After two to four runs have been placed to ensure proper alignment, a second crew can begin placement in the opposite direction (and from the opposite side) using the same placement procedure described above. On the opposite side, however, odd runs will start and end with full mats while even runs will start and end with a half mat (Figure N-30).

For all airfields, a typical keylock will be installed every 100 feet across the entire matting field. The keylock lengths are shown in Figures N-26 and N-27. The keylocks permit the easy removal of matting for multiple mat replacement. After the keylocks are installed, matting placement will continue using the same procedures described above.

At the ends of the runway, five full mats will be buried in a 5:1 sloped trench for the full width of the runway. The trench is then backfilled and compacted to match the original subgrade contours (Figure N-31, page N-43).

Along the edges of mats, edge clamps are used to secure the mat to stakes driven into the ground. There are four types available, and they will be placed in the same pattern as described for truss-web matting. The stakes used for holding the edge clamps into place are driven into the ground with sledgehammers or pavement breakers. An attachment used to prevent the deformation of the head of the stake will permit this (Figure N-32, page N-43).

Heavy-duty, AM-2 mat must be placed under areas where arresting cables will be used. These mats are placed 90 degrees in relation to the placement of the standard AM-2 mats (Figure N-33, page N-44).

When mats are required to make a 90-degree turn (such as for taxiways, warmup aprons, or parking aprons) enough 90-degree adjustable connector will be installed to equal the width of the sections to be joined. Placement of mat will be the same as described above for laying mat from end to end (Figure N-34, page N-45).

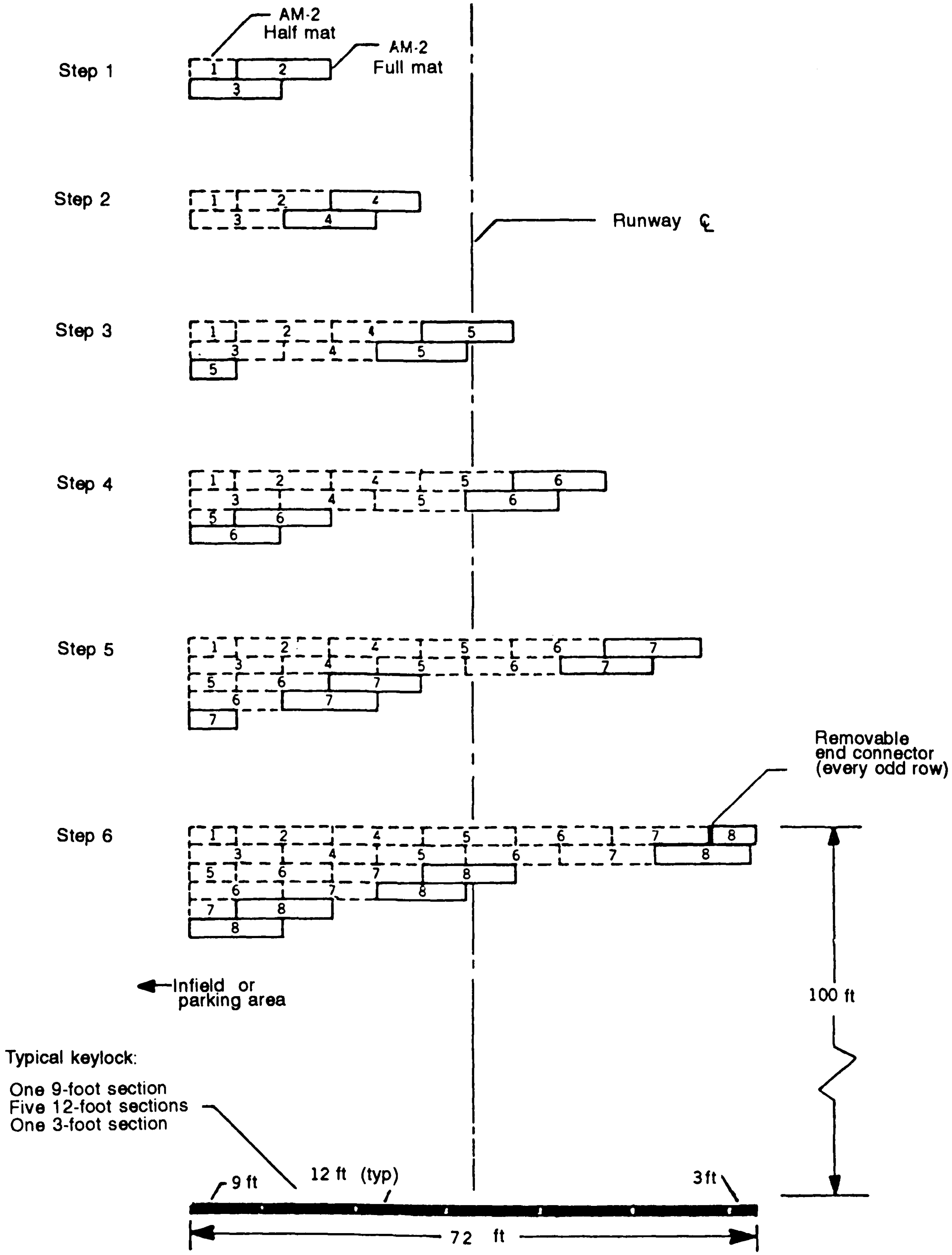


Figure N-26. AM-2 matting sequence for a 72-foot-wide runway proceeding in one direction

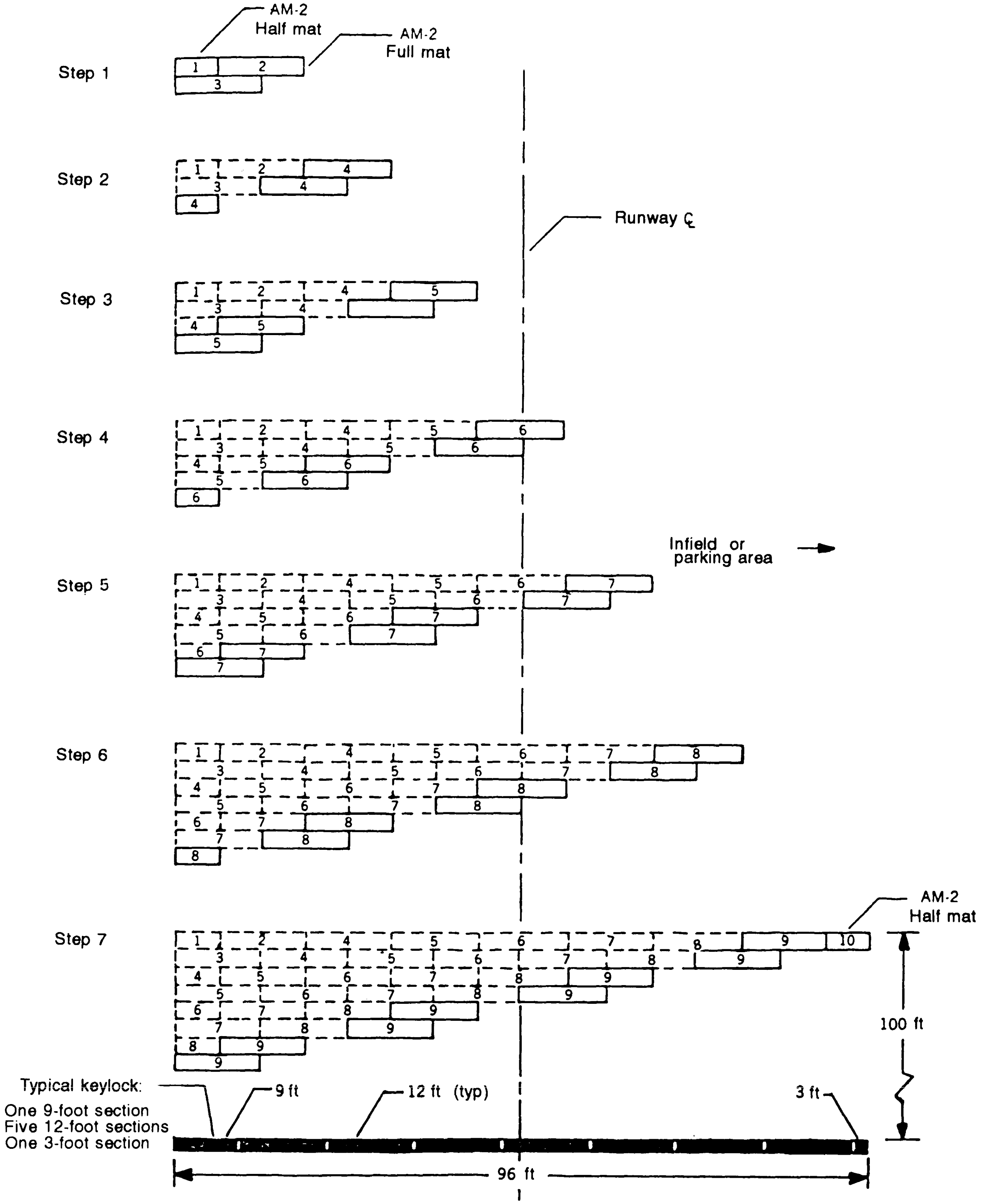


Figure N-27. AM-2 matting sequence for a 96-foot-wide runway proceeding in one direction

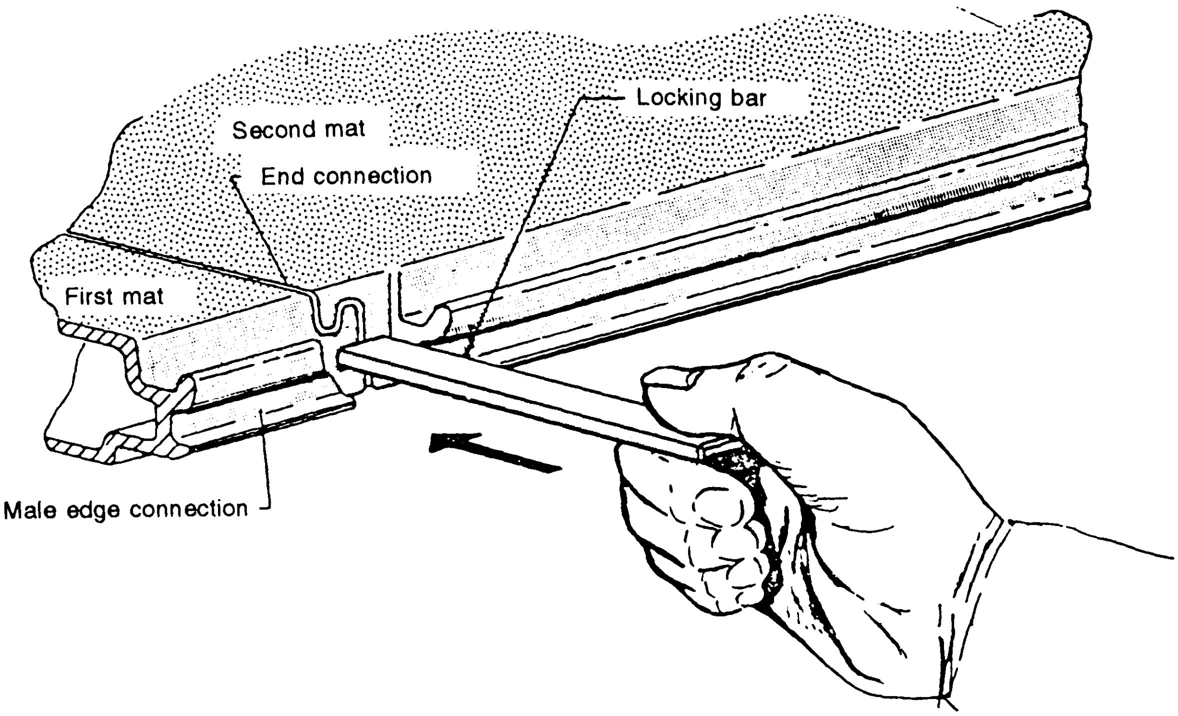


Figure N-28. Inserting locking bar

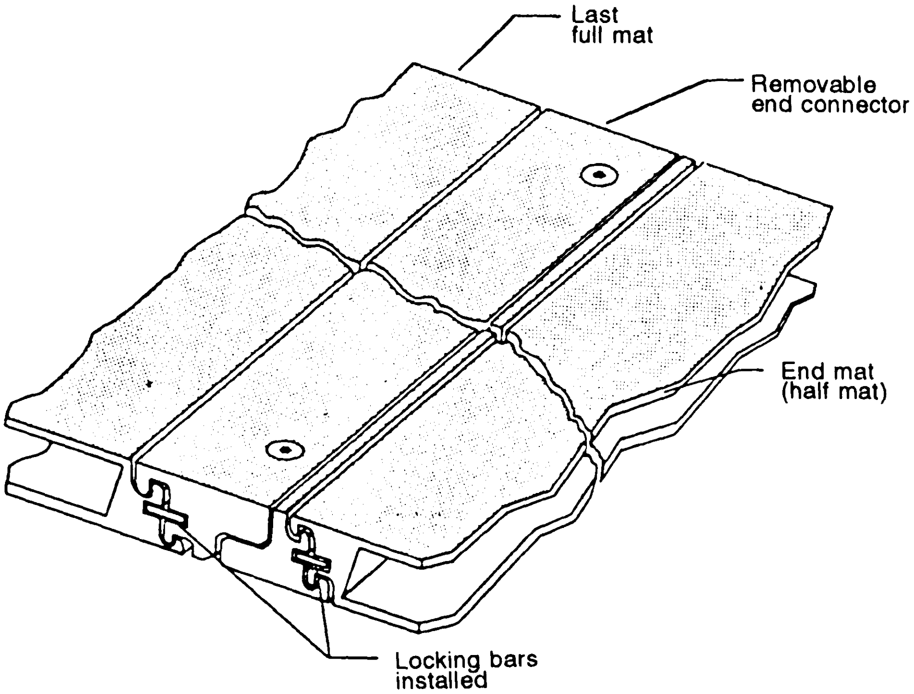


Figure N-29. Installing removable end connectors

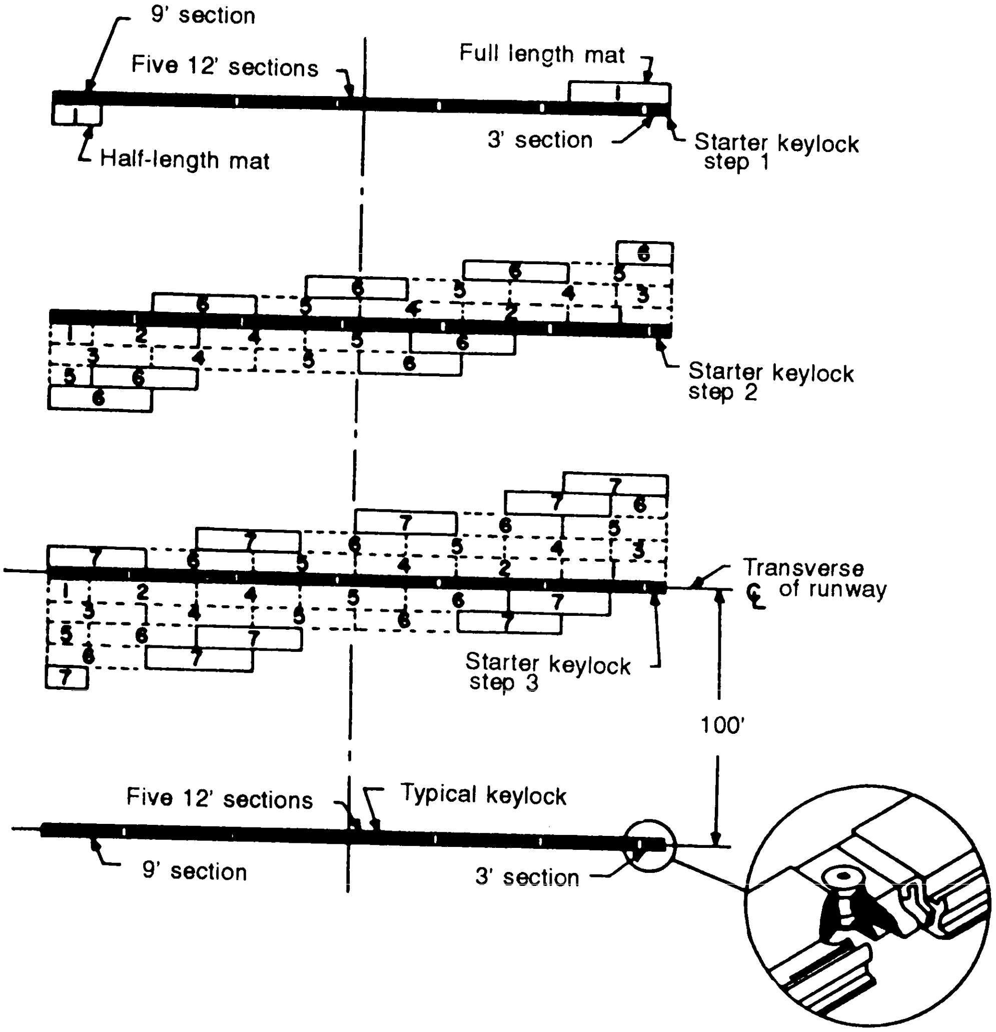


Figure N-30. AM-2 matting sequence for a 72-foot-wide runway proceeding in two directions from the transverse centerline

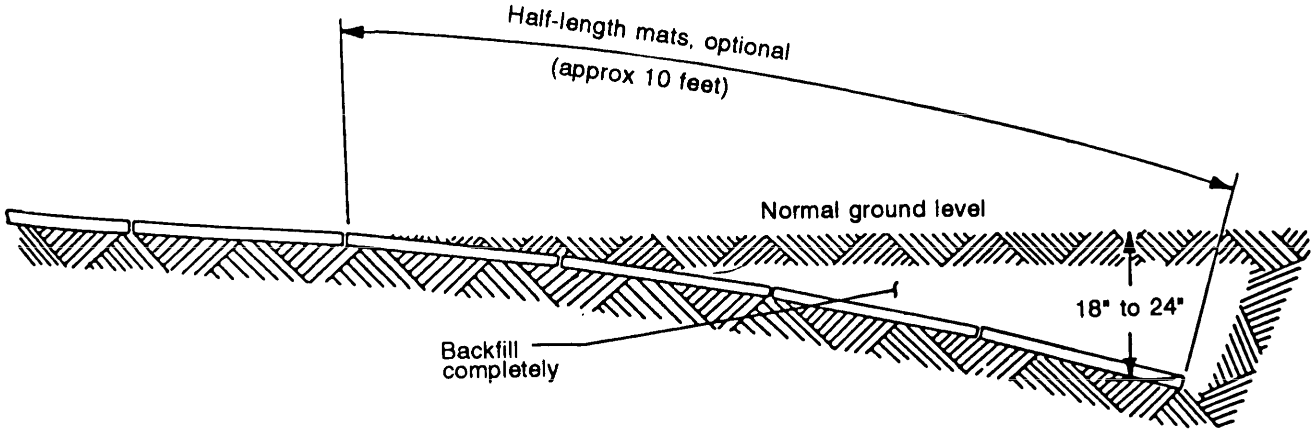


Figure N-31. AM-2 runway end anchorage.

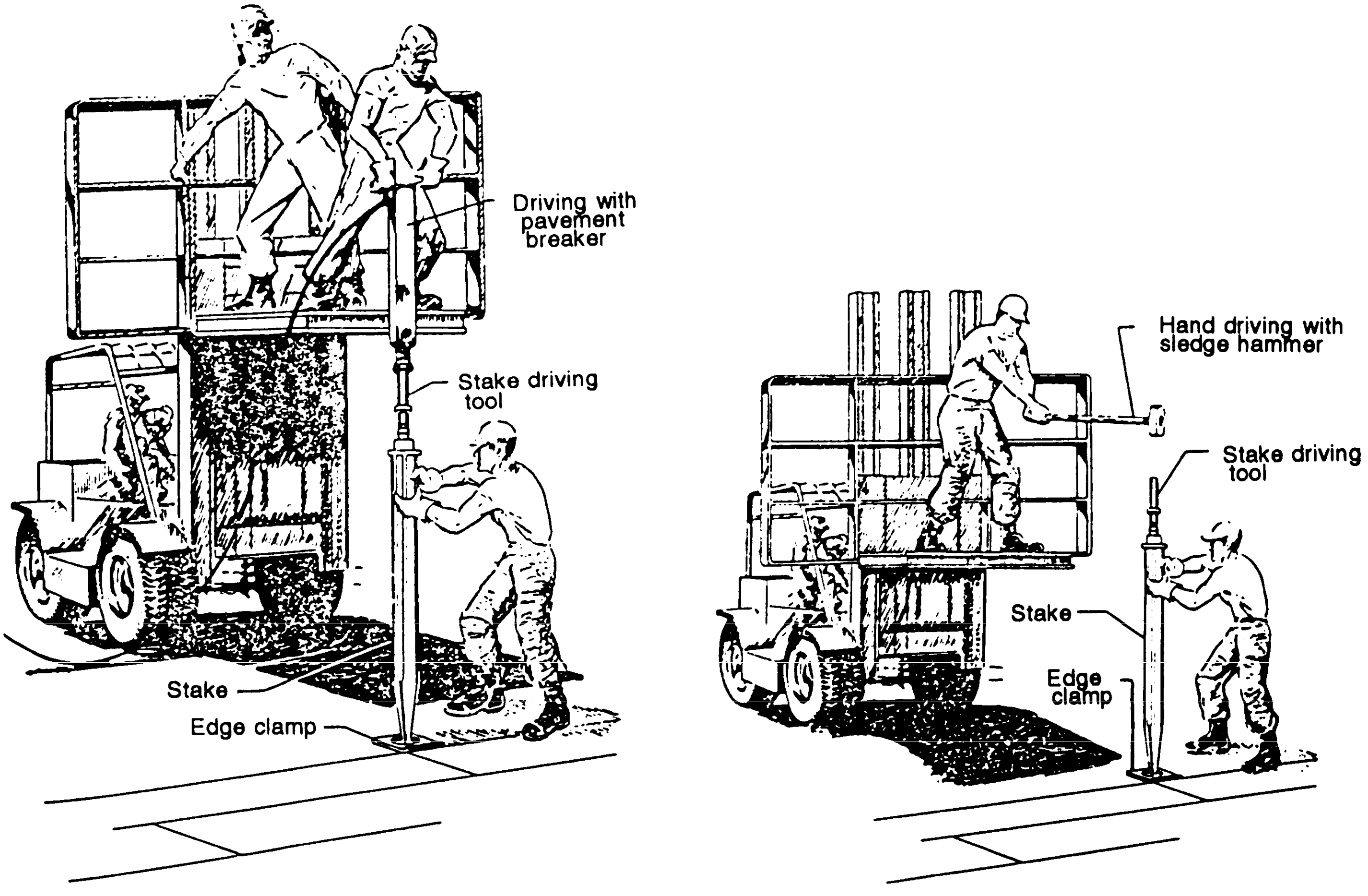


Figure N-32. Methods of emplacing AM-2 edge clamps and stake

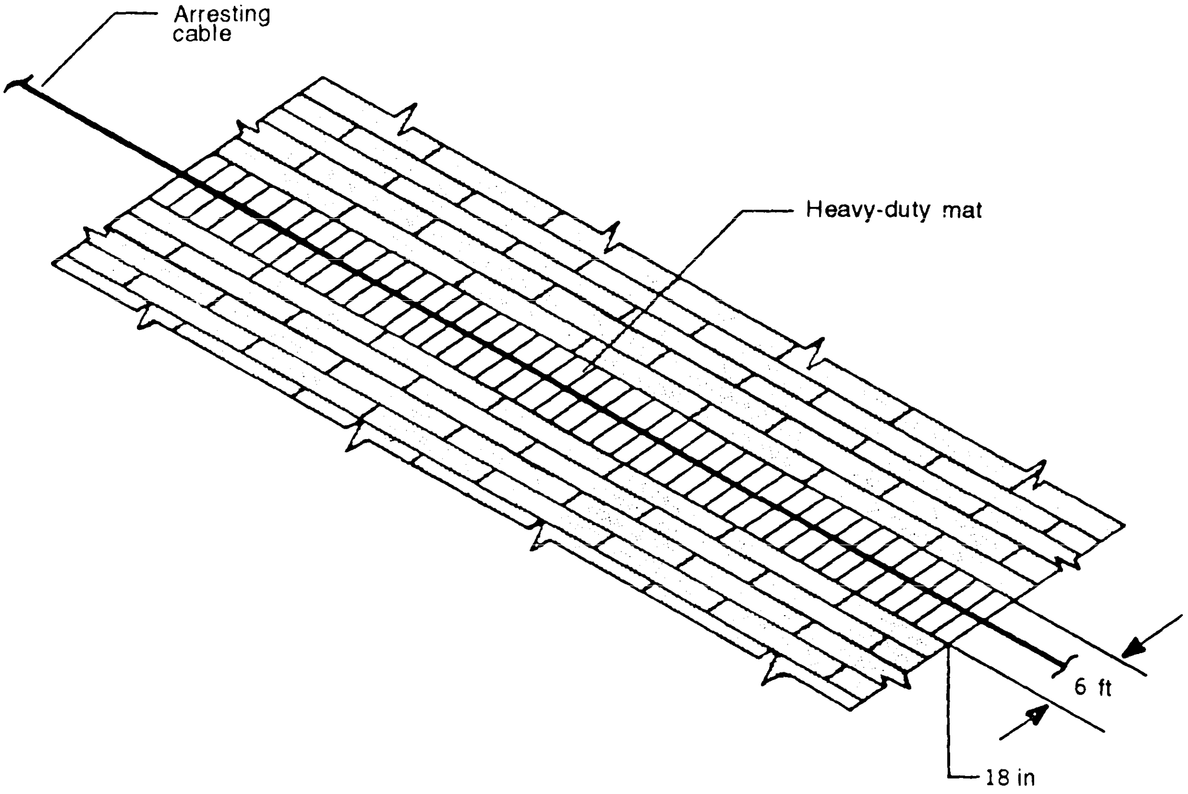


Figure N-33. Placement of heavy-duty AM-2 matting

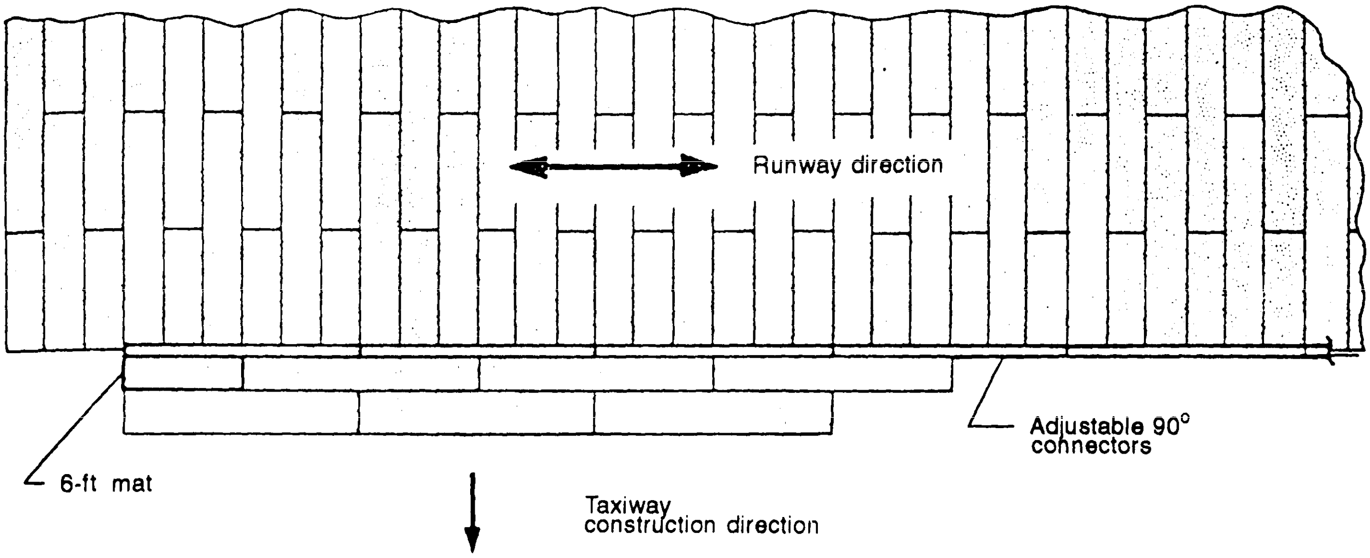


Figure N-34. Installation of 90° connectors

Runway Conversion (72 to 96 Feet Wide)

The following steps outline the procedures for enlarging an existing 72-foot-wide runway. The conversion requires the laying of additional AM-2 mats and can be accomplished in two ways as follows:

With Removable End Connectors

Steps:

1. Remove four socket-head cap screws from the removable end connectors (Figure N-35).

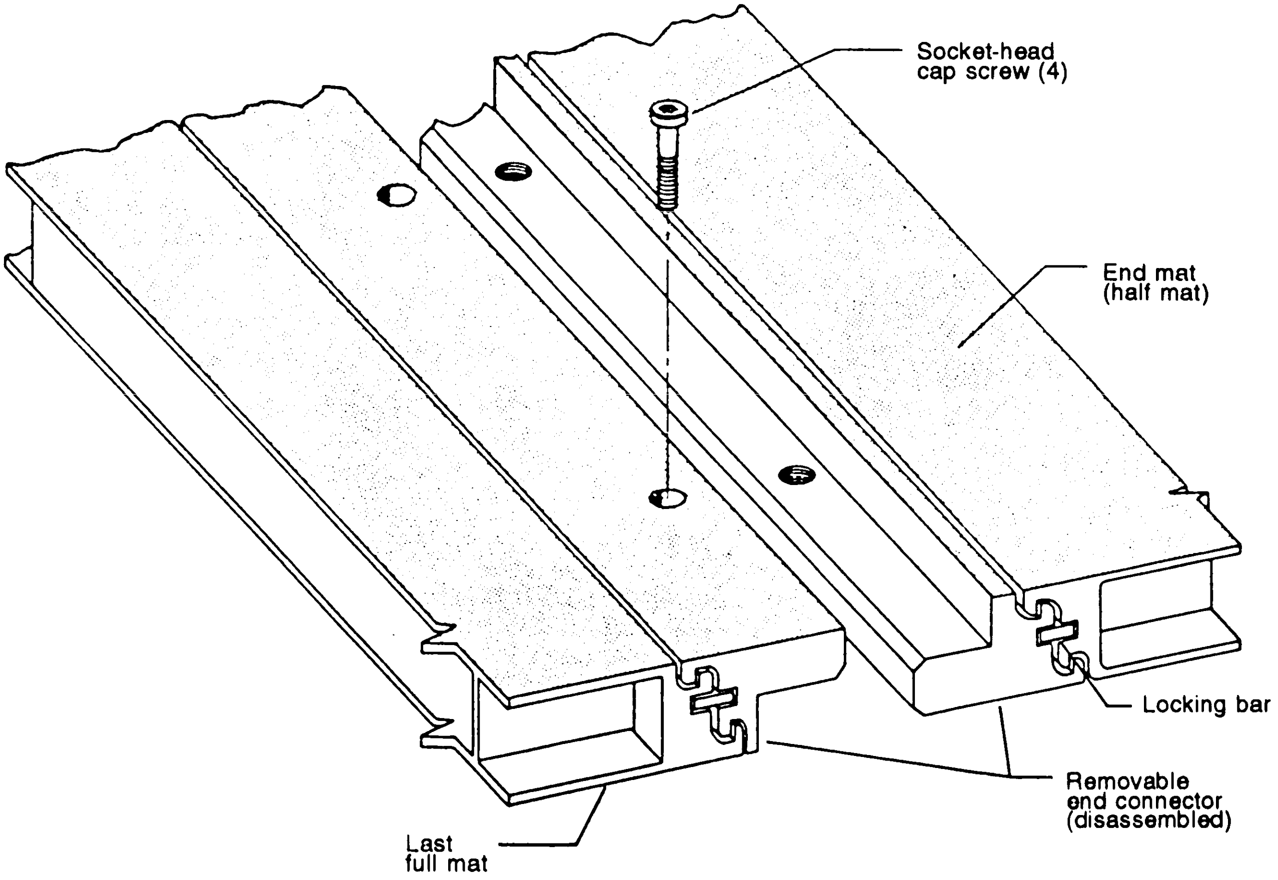


Figure N-35. Disassembly of removable end connectors

2. Remove the half mat with half of the removable end connectors attached (Figure N-36).

3. Remove the locking bar and half of the removable end connector from the half mat.

4. Install the removable end connector to a new, full AM-2 mat.

5. Slide the new mat into the place vacated by the half mat.

6. Install the four socket-head cap screws previously removed.

7. Lay the second mat by mating the downturned prongs with the upturned prongs of the preceding mat. A rectangular slot is formed when two mats are properly engaged.

8. Lock the mats together by inserting a locking bar.

9. Complete the first run of the new AM-2 mats by reinstalling the half mat previously removed.

10. Fill in the second run with two full mats (Figure N-36, step 3).

11. Remove the next half mat and the removable end connector in the third row before installing the next run.

12. Complete each succeeding run as shown. Complete each odd run according to steps 1 through 8 above and each even row according to step 10.

Without Removable End Connectors (Figure N-37)

Steps:

1. Install the mat push-pull fixture (Figure N-21, page N-34) to the first half mat on the side of the runway to be expanded.

2. Attach the wire-rope sling to the mat push-pull fixture and the forklift truck.

3. Pull the entire run of mats out approximately 7 feet, using two other forklift trucks. Remove the wire-rope sling.

4. Remove the locking bar and the half mat.

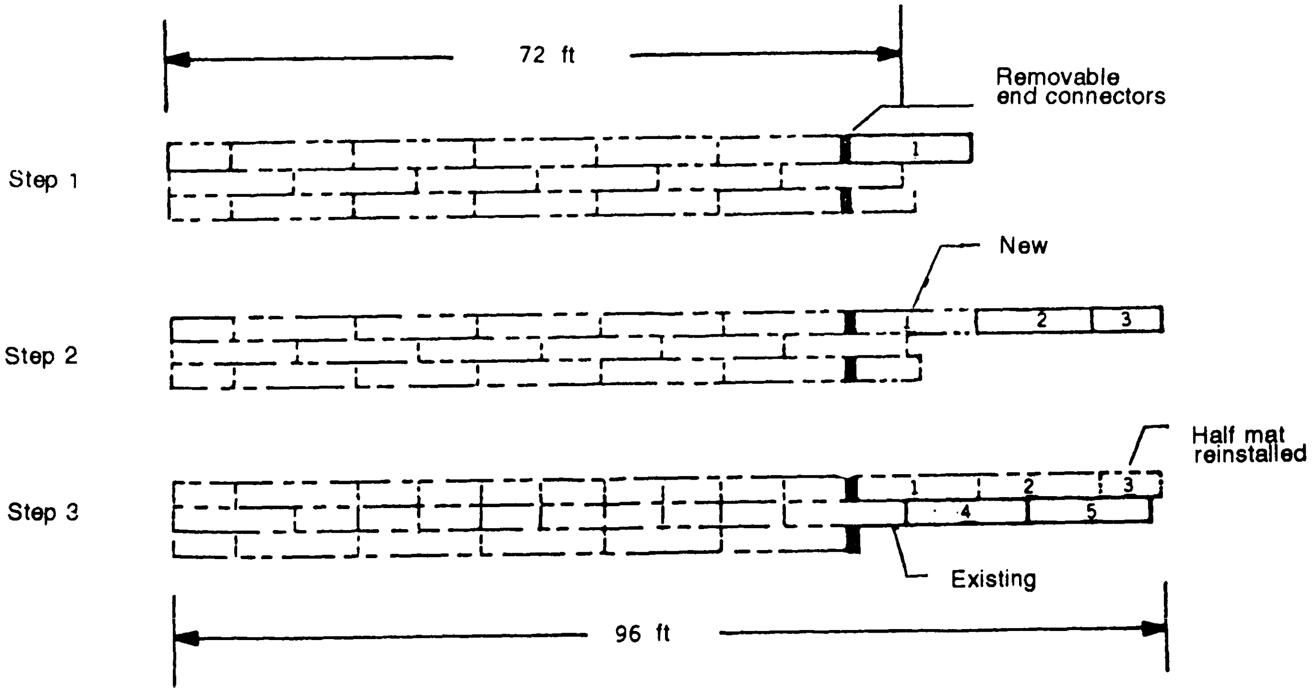


Figure N-36. Runway conversion with removable end connectors

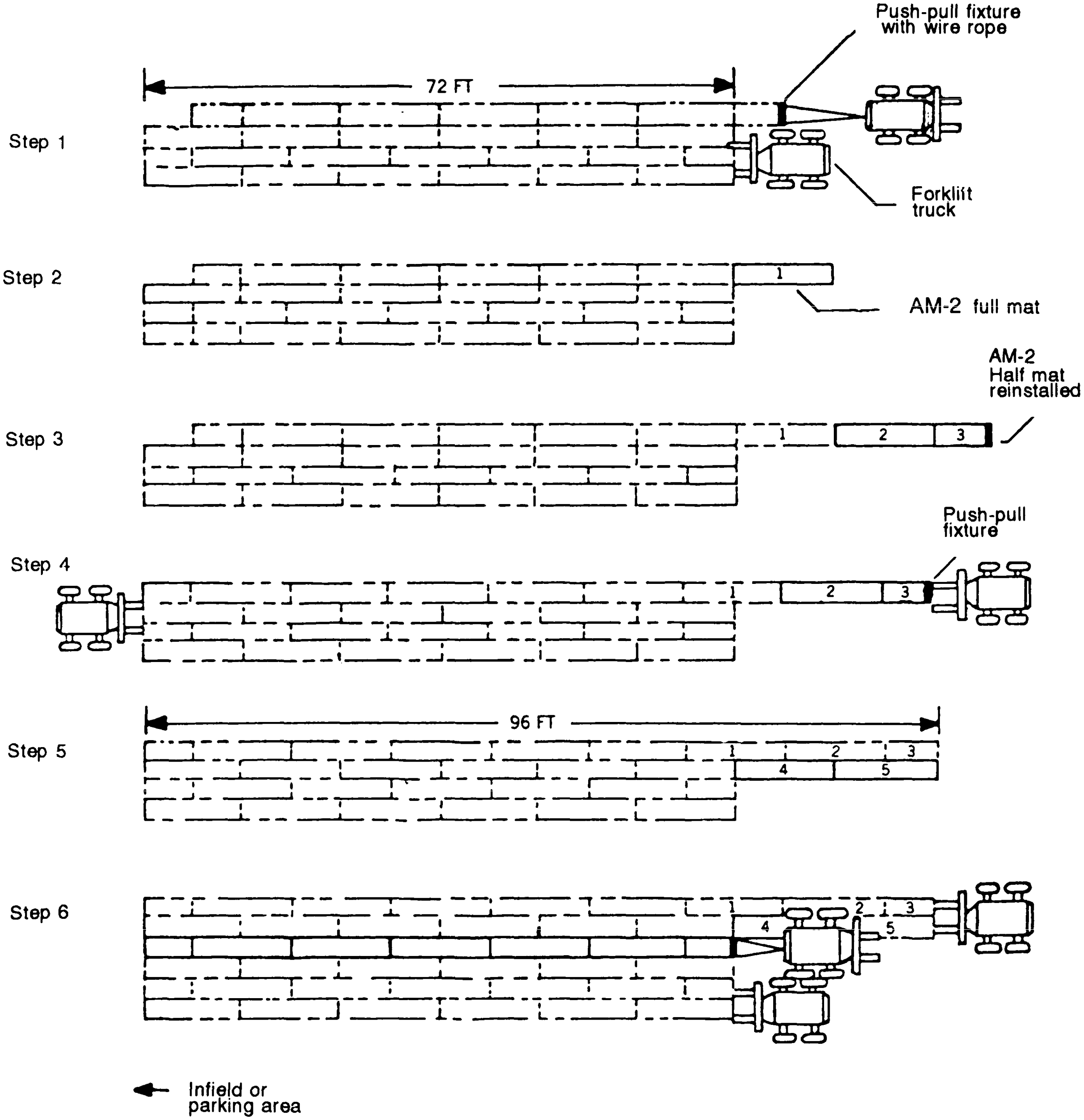


Figure N-37. Runway conversion without removable end connectors

5. Install the new, full AM-2 mat in place of the half mat removed and insert the locking bar.

6. Lay the second full mat and the half mat previously removed to complete the first run. Insert locking bars when required.

7. Push the first row in about 7 feet using mat push-pull fixture and forklift trucks as shown.

8. Remove the push-pull fixture.

9. Lay the two full AM-2 mats to complete the second run of runway expansion.

10. Repeat steps 1 through 9, as required, to complete runway expansion.

Blast-Deflector Installation

To shield the ground area around taxiways and parking areas from the blast effects of aircraft, install blast deflectors as required. Assemble blast-deflector adapters to boundaries of mats, which will be female or male edges, prongs-down ends, or prongs-up ends. Three types of adapters are supplied to fit any one of the four joints. Erect AM-2 mats to the exposed upturned edge of the adapters to provide the blast shield. Use two adapters to support each AM-2 mat. (See Figure N-38.)

Joining AM-2 Matting with M19 Matting

AM-2 and Ml9 can be used together on taxiways and aprons with some additional ancillary items. This is discussed under the M19 section. Mixing of mat is not recommended on the runway.

M19 MEDIUM-DUTY MATTING

The M19 mat is a sandwich-type structure containing a 1.375-inch-thick aluminum, honeycomb core bonded top and bottom to 0.063-inch-thick aluminum skins as shown in Figure N-39, page N-50. Extruded aluminum connectors are bonded to the edge of the core with a potting compound and are welded to the top and bottom skins. Two edges of the panel have overlap- and underlap-type joints that are connected to adjoining panels and locked with an extruded, aluminum locking bar. The other two edges have male- and female-type hinge connections. An exploded view of the mat is shown in Figure N-40, page N-50. The individual panels are 1 1/2 inches thick, 50 1/4 inches long, 49 1/2 inches wide, and weigh approximately 71 pounds. A panel covers approximately 16.7 square feet and weighs 4.25 pounds per square foot of placing area.

The M19 mat is designed to be placed on a subgrade with a strength of CBR 4 (AI 6) or greater and to sustain 1,000 coverages of a 25,000-pound, single-wheel load with 250-psi tire inflation pressure and a contact area of 111.1 square inches. The panels can be placed on a three percent crown at a rate of 350 square feet per man-hour. A basic mat-placing crew consists of seven men (one NCO and six enlisted members (EMs)); however, as many as five crews can lay mat in one direction as work progresses on the runway. The panels are normally laid with the male-female joints parallel to the direction of traffic and continuous along the runway length. The traffic is therefore always applied in a direction perpendicular to the end connector locking bars (Figure N-41, page N-51).

M19 PALLETS

Mats and necessary ancillary items are packaged in crates for shipment to the TO. The crates form skid-mounted pallets for ease of handling with mechanized equipment.

Full-Mat Pallets

Full mats are stacked on four-way-entry, wood skids to make a pallet package of 32 mats. Each mat is supplied with one locking bar placed in the upward facing groove of the underlap edge of the mat plus one additional bar per bundle, making a total of 33 bars per bundle. All sides of the pallet are covered with sheets of plywood, and the corners are protected by angular aluminum strips. The package is bound with steel bands. Gross weight is 2,484 pounds, and bundle dimensions are 51 3/4 x 51 inches wide and 55 inches high.

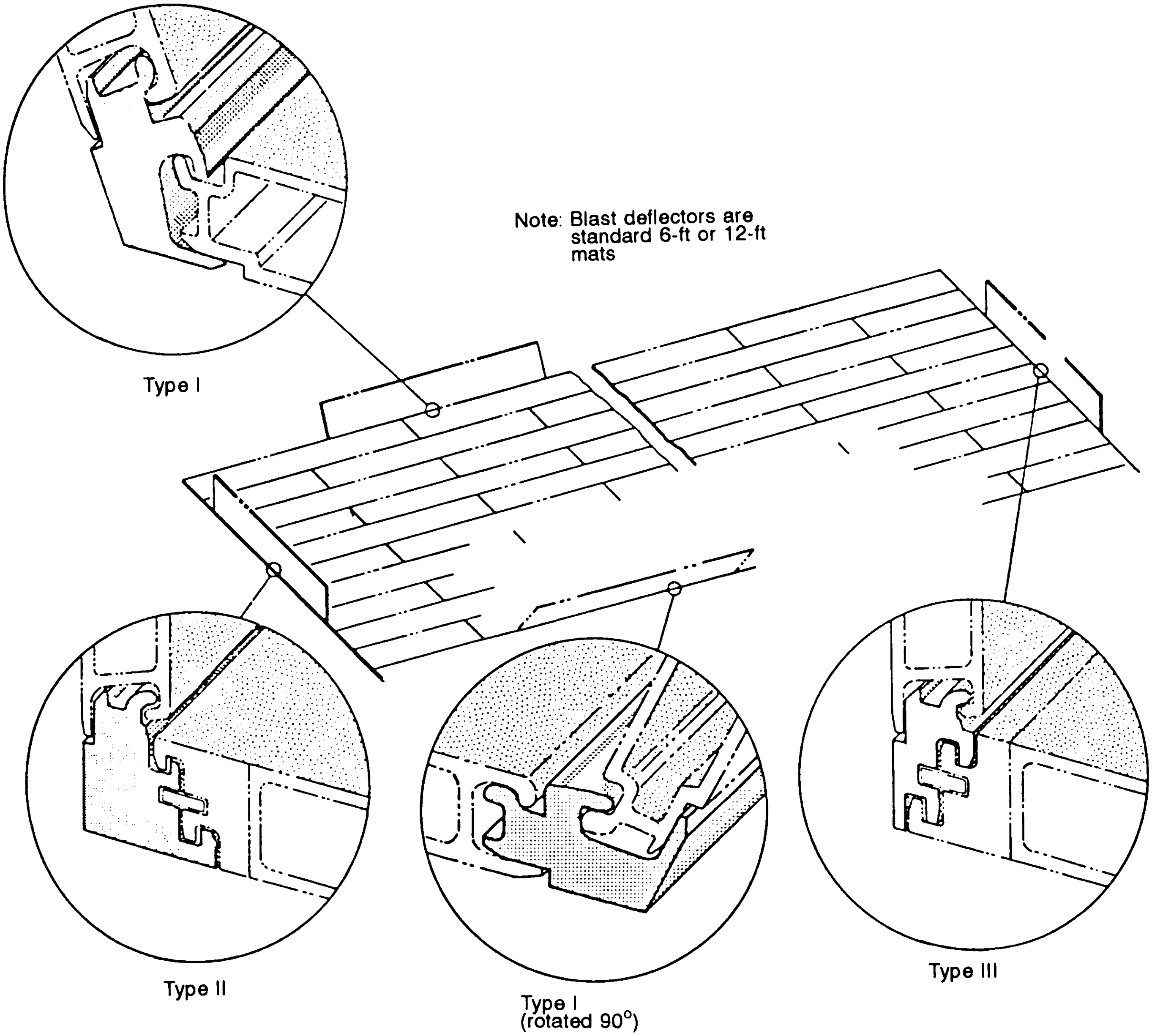


Figure N-38. Blast-deflector installation

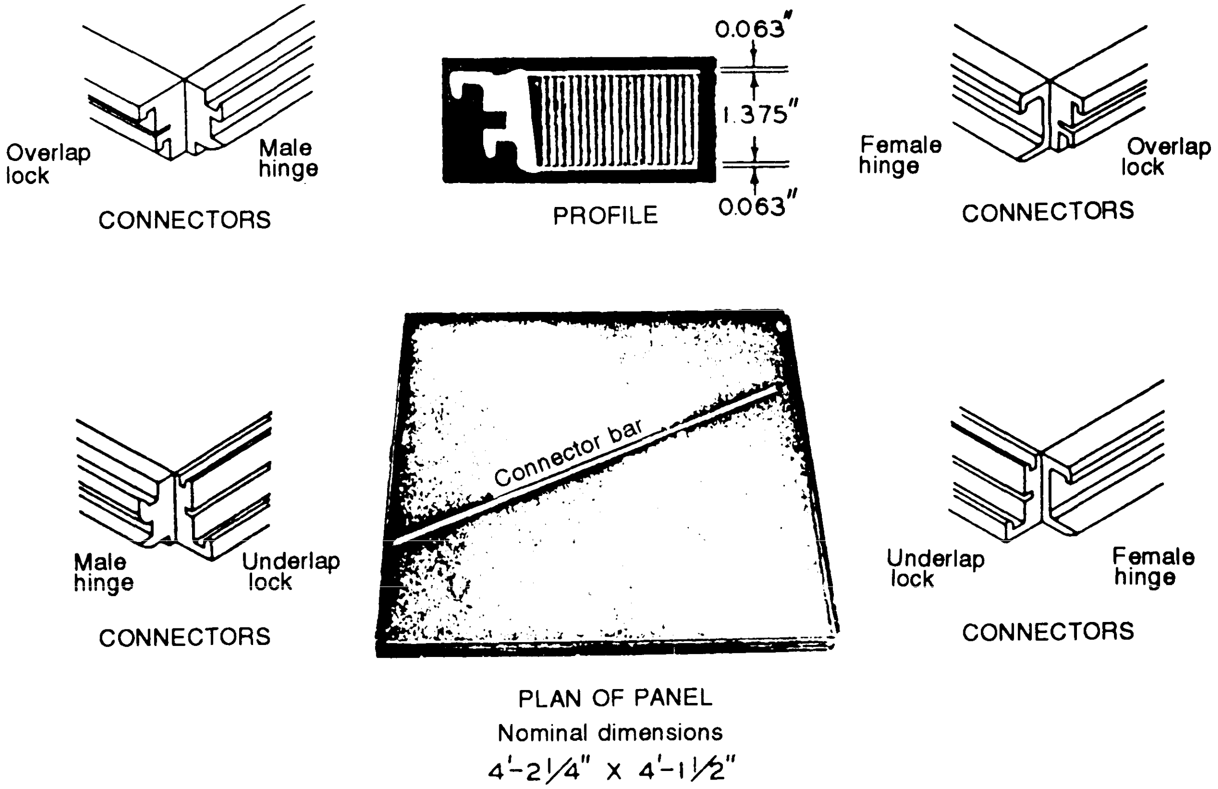
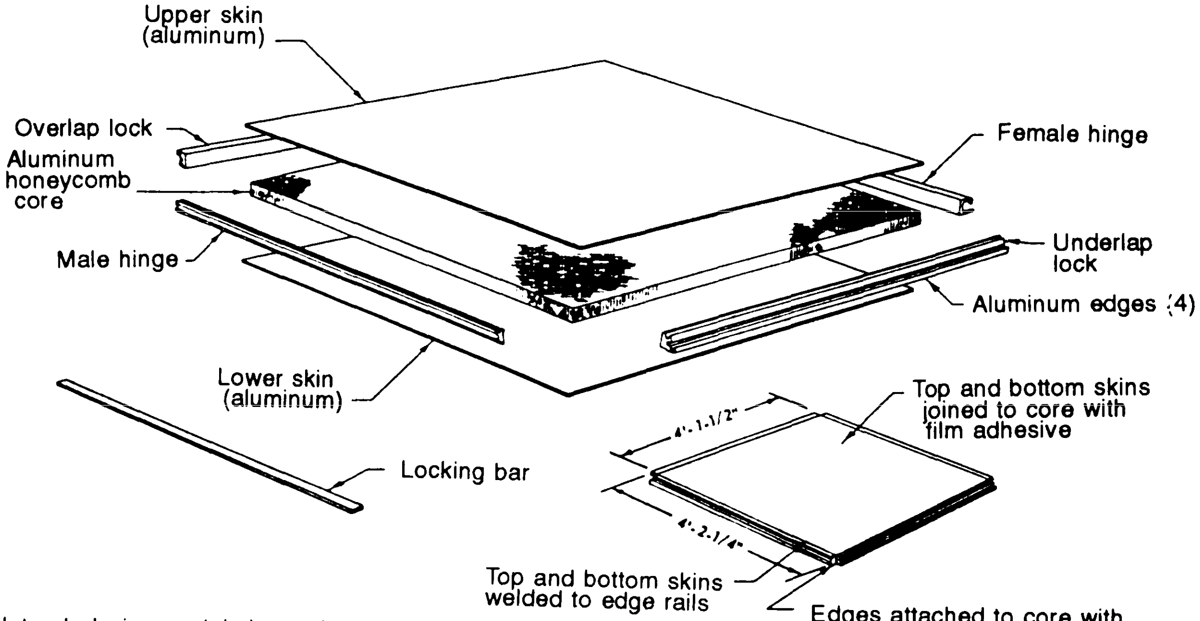


Figure N-39. Composite view of M19 panel



Note: Indexing mark is located at center of male lock.

Figure N-40. M19 exploded view

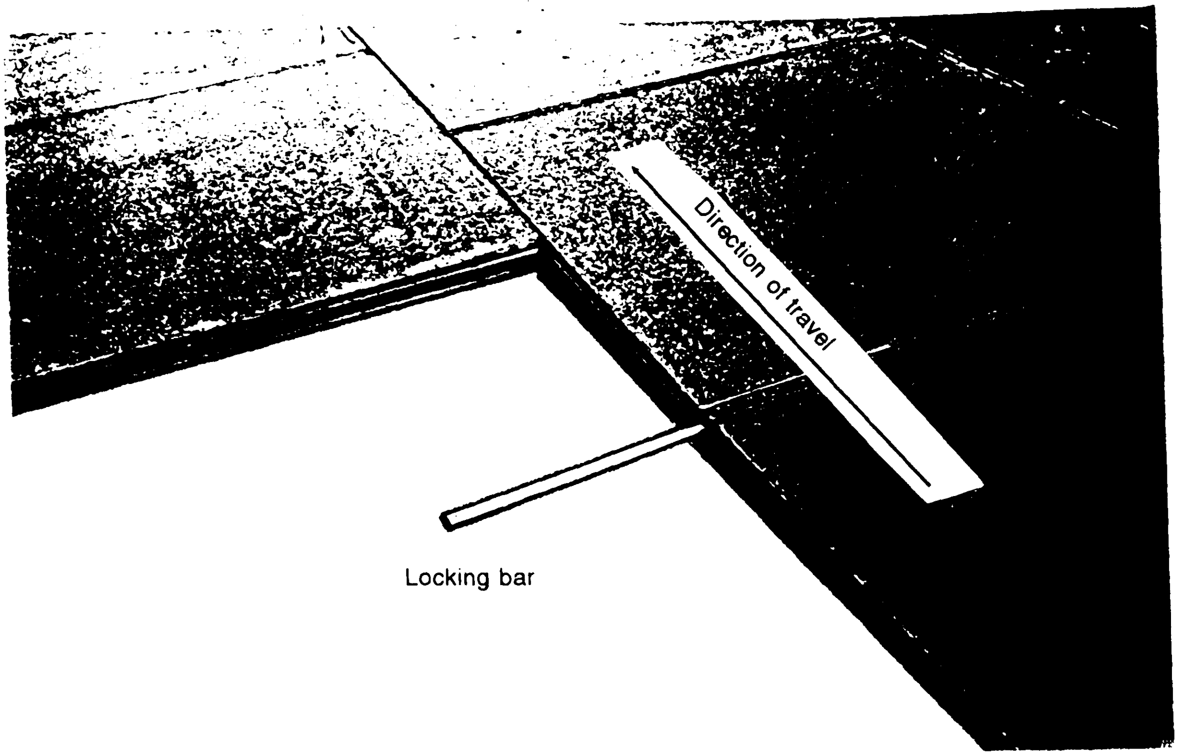


Figure N-41. Direction of traffic in relation to mat panels

Half-Mat Pallets

The specially marked half-mat pallets are similar to the full-mat pallets except that they are approximately half the size of the standard mat bundles. The half panels are bundled in pallets containing 32 half panels and 33 locking bars.

Additional Pallets

The ancillary equipment, such as adapters and anchor attachments, are crated in packages that conform to the sizes of the parts. The specially marked repair mat pallets are similar to the half-mat pallets in size and contain 16 panels.

Ancillary Items

Descriptions of the various ancillary items used in conjunction with the M19 landing mat are given below:

Access adapter. An access adapter is an aluminum alloy bar with an overlap connector formed on one side and an underlap connector formed on the opposite side. The adapters are placed at intervals along the runway to permit easy access into the runway by withdrawing the access adapters from between mats. This allows nondestructive removal and reinstallation of mats in order that the damaged mats can be replaced, the subgrade repaired, and utilities added or repaired. The adapters are 4 feet long, and 25 adapters are shipped with 25 locking bars per bundle.

Anchor attachment. Male, female, and overlap/underlay hinge adapters fabricated from extruded aluminum alloy are used along the runway edges for attaching edge anchors to individual mat panels. The anchor attachments should be spaced every 8 feet (every other panel) along the sides of the field. Overlap/underlap adapters are used along the ends of taxiways and pads but are not required along the ends of the runway.

Edge anchors. Edge anchors are the ball-auger type, fabricated from steel with a 4-inch helix plate. They are 2 feet long. A 1-inch-diameter hole is located in one end in order that a bar, a pneumatic tool, or the opposite end of another anchor can be inserted to screw the anchor into the ground.

Half panels. The half panels are approximately 4 feet long and 2 feet wide and are used in alternate rows at runway ends or are used in conjunction with starter connectors to provide a straight edge across the width of the field while creating a staggered end-joint pattern perpendicular to the direction of traffic.

Repair mats. These mats are used to replace damaged or failed mats. Each panel is fabricated in two pieces with a diagonal overlap/underlap joint between the pieces. Use of repair mats is limited to replacement of damaged mats where it is not practical to take up a section of the runway.

Locking bars. Locking bars, which are used to interlock the mats, are inserted in the underlap/overlap connectors in adjacent mats as each panel is laid. Aluminum alloy bars, 3/16 inch thick by 5/8 inch wide by 48 1/2 inches long, are used with the standard panels. Bars in various other lengths are used in conjunction with the repair mat.

Starting adapter. A starting adapter is an aluminum-alloy bar containing two underlay connectors formed back to back that is used to form a transverse line across the pad from which mat laying is started. The starting adapter allows the mat to be placed simultaneously in two directions. These connectors can be used either to speed the laying of a new field or to extend the length of an existing pad. These adapters come in 2- and 4-foot lengths.

Turn adapters. These are 90-degree adapters and 15-degree turndown adapters, required by changes in the geometry of the mat field and used to form a positive lock between panels being joined. Ninety-degree adapters are used in runways and taxiways to create intersections with cross taxiways and to connect M19 mats to AM-2 mats. Fifteen-degree turndown adapters are used at runway ends to allow burying mats for anchoring the runway. Four 90-degree adapters are available: female/overlap, male/overlap, female/underlap, and male/ underlap.

INSTALLATION INSTRUCTIONS

No special skill is required for emplacing Ml9 landing mat once a well-prepared subgrade has been completed and a baseline has been determined. Panels can be placed on a subgrade crowned as much as 3 percent and at a rate of 350 square feet per man-hour.

Preliminary Inspection

Before the mats are placed in position, they should be given a quick inspection. Any accumulation of dirt, chips, or material left from fabrication in the connectors must be removed since their presence will prevent the proper interlocking of the mat units. Any damaged panels should be removed from the placement area.

M19 Placement

The first step in placing M19 mat consists of placing starting adapters across the runway midpoint, transverse to the centerline of the runway. The starting adapters are placed together, end to end.

Placing mat can only be initially started in one direction from the starting adapter. The first panel will be placed in position 1 (Figure N-42) by engaging the overlap edge of the panel with the underlay edge of the starting adapter. The second panel, position 2, should be held at a 45-degree angle to panel 1, and the female connector should be engaged over the male connector overlap edges of the run. Note that panel 2 is a half panel and that half panels are used to begin alternate rows at the starting adapter to provide a staggered end-joint pattern. A row that starts with a half panel will finish with a half panel. This pattern eliminates a continuous transverse joint across the runway, thereby reducing the bow wave effect.

Subsequent panels in the first row (3, 7, and so on) should be placed in a similar manner as the first panel. This first row of panels can be continued down the length of the runway unimpaired, but alignment must be insured and maintenance adapters must be put in place as required. The panels in the second and successive runs should be connected in the same manner as panel 2 and placed right to left in sequence 4, 5, 6, 8, 9, 10, and so on. This pattern will create a stair-step fashion for maximum placement efficiency. Once a mat has been laid, a lock bar must be inserted into the overlap/underlap connector slot. The panel must be locked together before the next panel of the adjacent row is placed because this operation will be impossible after another row of mat has been laid. The locking bars may stick due to material waviness in the mat panels or unevenness in the subgrade, and it may be required to lift a corner of the mat or to jump on the mat while sliding in the bar. This will help to align the locking bar slots to aid in bar insertion. It may also be required to apply a few light taps with a hammer to drive the bars into their proper positions (Figure N-43, page N-54).

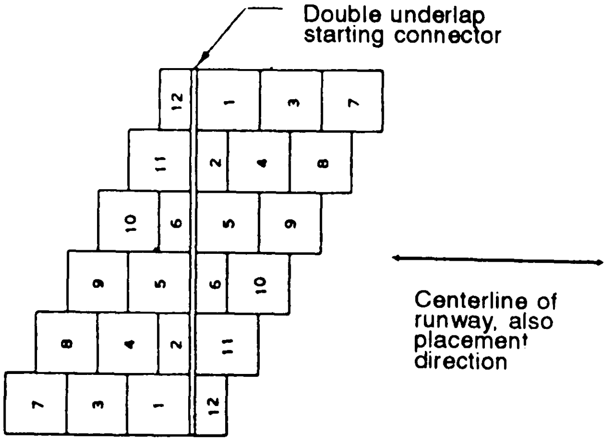


Figure N-42. M19 matting placement

The mats are designed with an apparent loose fit to allow for expansion and also to allow for the natural waviness of individual mats. If misalignment of mat rows occurs from this or any other cause, the mat can be aligned by using bars and sledgehammers or wooden mallets. Always place a wooden block against the mat edge to act as a cushion when using a sledgehammer. Care should be taken to strike only the wooden block and not the mat (Figure N-44, page N-54). Sledgehammer blows directly against the mat edges can deform the edges and make it impossible to connect the next row of mats.

The alignment of the mat may also be lost due to the play of the panels. Alignment should be checked periodically during the placement, and if alignment is off, work should cease and the mat brought back into alignment. This can be accomplished by using vehicles to pull the mat back into alignment.

After four or five runs of mats have been placed in one direction from the starting adapter and proper airfield alignment is assured, a second crew can begin placement in the opposite direction using the same placement procedure as the first direction.

Field access adapters are metal-alloy bars that have an overlap and underlap side placed between panels to allow access into the airfield and to replace panels without taking the entire airfield apart. They are installed in the staggered transverse joints between mats to form a V-shaped line or chevron pattern. The adapters are started every 150 feet and will continue back until the midpoint of the airfield is reached, and then the placement will move forward forming the V-shape (Figures N-45 and N-46, page 5-55).

ANCHORAGE OF MAT

Side Anchors (Figure N-47, page N-56).

After the mat has been laid in the proper position, two to four rows from the starting adapter across the entire width of the run-

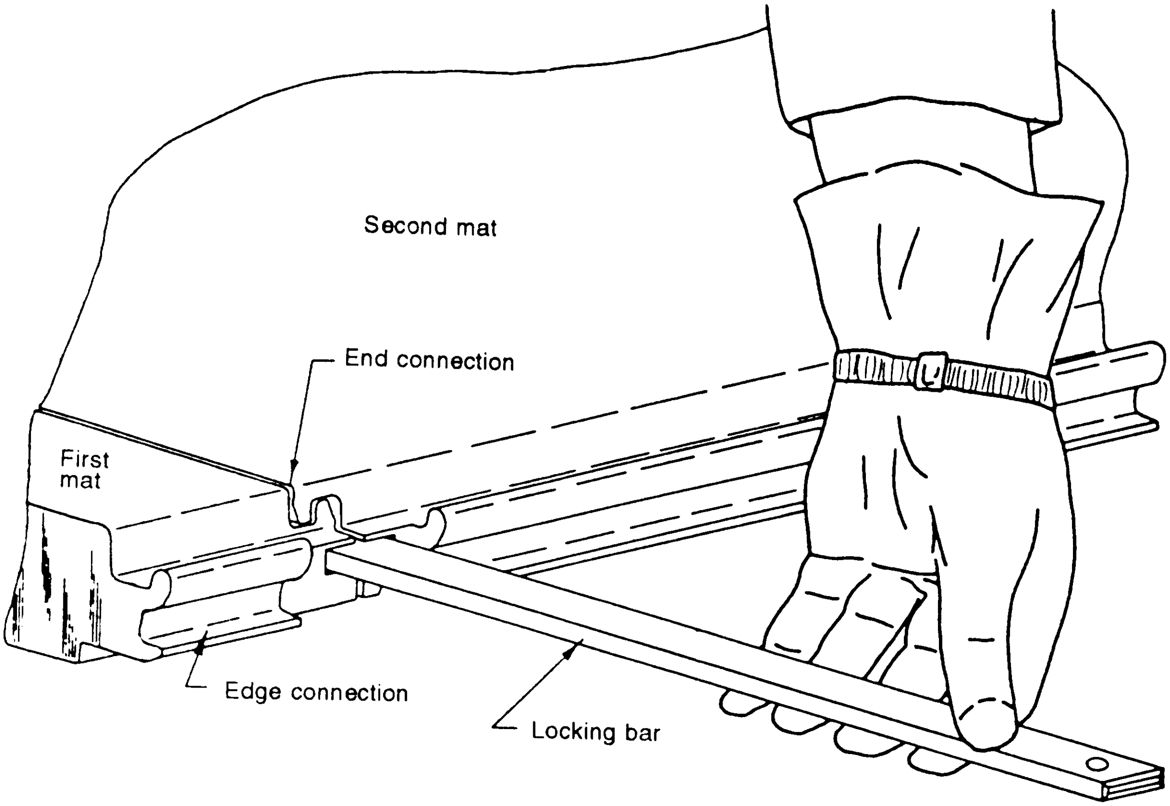


Figure N-43. Locking-bar insertion

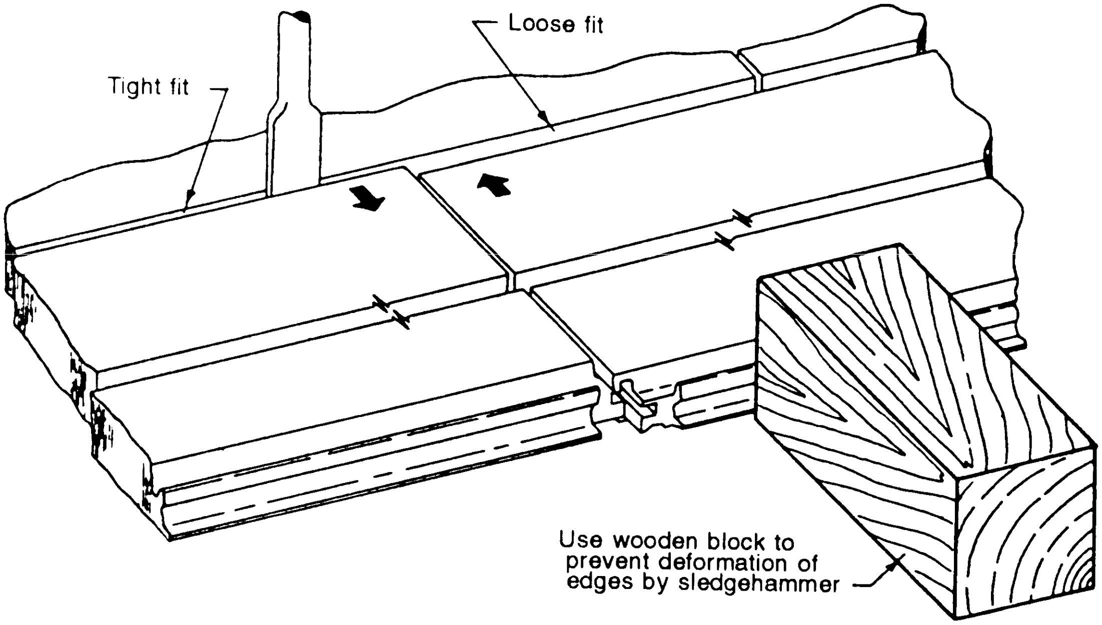


Figure N-44. Correction of mat misalignment

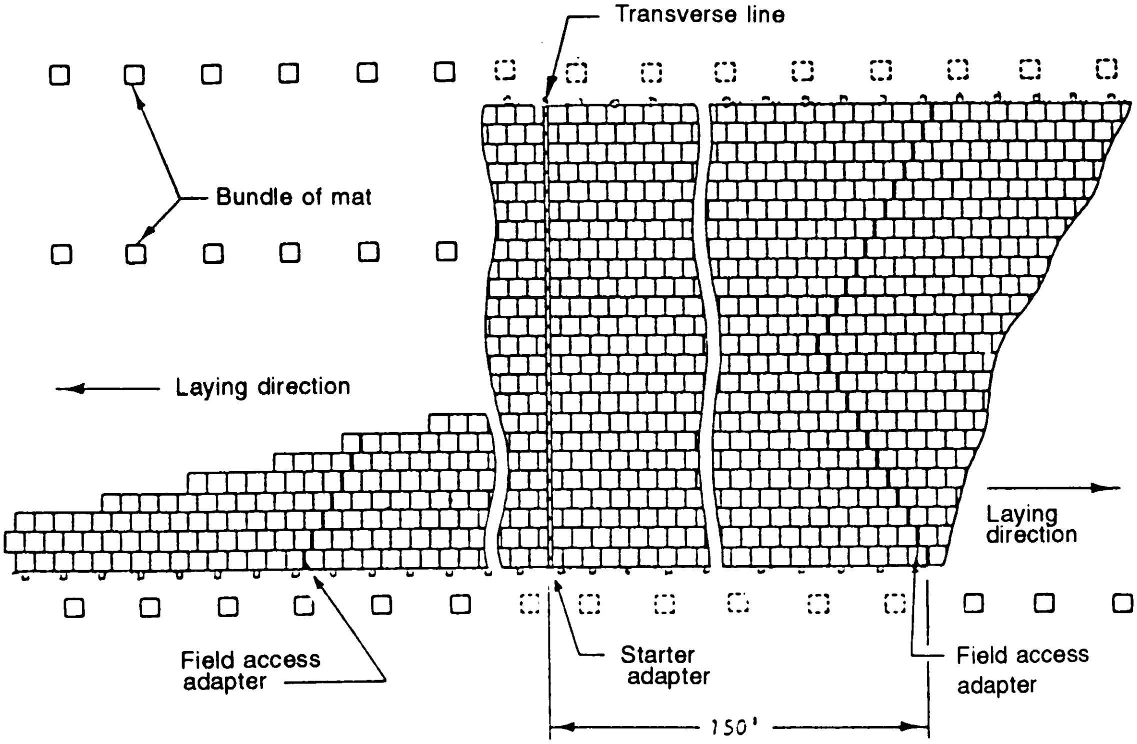


Figure N-45. Field access and starter-adapter placement

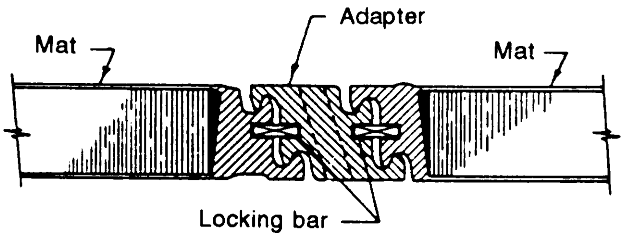


Figure N-46. Field access adapter installation

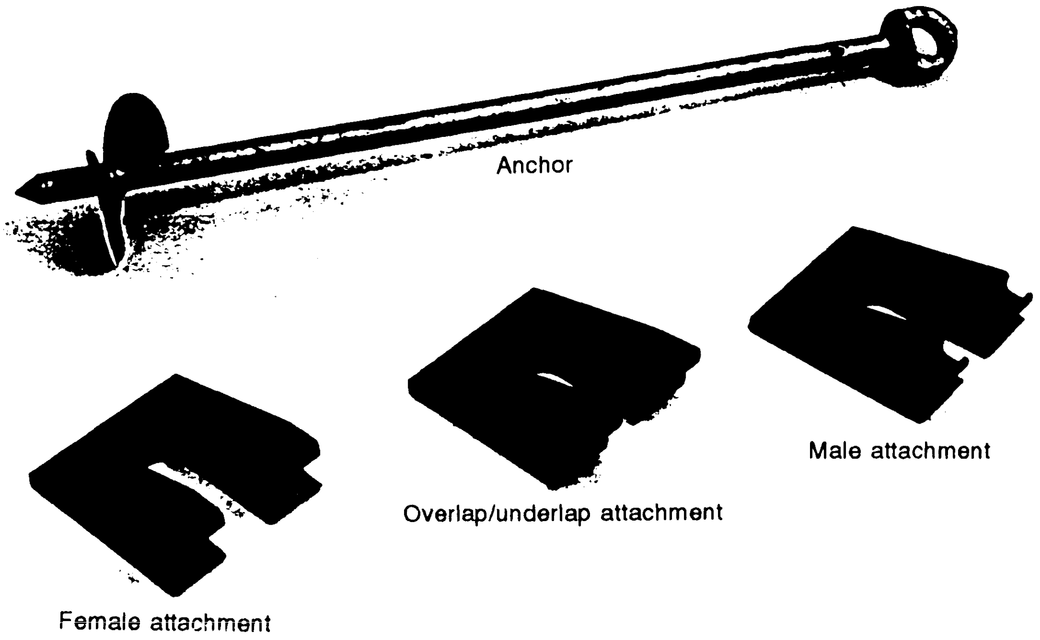


Figure N-47. Earth anchor and attachments

way, installation of earth anchors should begin. These will hold the runway down and prevent lateral clippage. The anchors and attachments should be placed a maximum of 8 feet apart at panel joints on each side of the runway and alternated on each side of the runway so that no two anchors are directly opposite each other (Figure N-48). The 24-inch-long anchor should be screwed into the ground and secured in the anchor attachment slot (Figure N-49).

The following steps should be used in the placement of anchors and anchor attachments:

1. An anchor attachment is placed in position on the edge of the mat. The point of the anchor is then placed in its proper position in the slot of the anchor attachment.

2. The attachment is then removed, and the anchor is screwed into the earth. A power tool equipped for this purpose may be used for ease of operation.

3. After the anchor has been screwed about 12 inches into the soil, the anchor attachment is reinstalled, and the anchor is screwed until it seats itself in the attachment.

Ends of Runway

When the end of the runway is reached, two full rows of panels are buried to anchor the runway by using the 15 turndown adapter (Figure N-50, page N-58). Burying is accomplished by removing enough soil to allow the last two panels of mat in each row to fall in an inclined plane a distance of approximately 18 to 26 inches below the normal ground level. The excavation should be large enough at the ends to allow for mat movement. This will allow the mats to expand without buckling or causing a hump in the mat field. The ground surface should be shaped to provide full soil contact across the bottoms of the anchoring panels. The 15-degree turndown adapter should be used with a locking bar to attach the runway to the anchoring panels, with one locking bar required for each adapter. After the anchoring panels have been placed, the excavation should be backfilled to normal ground level and compacted.

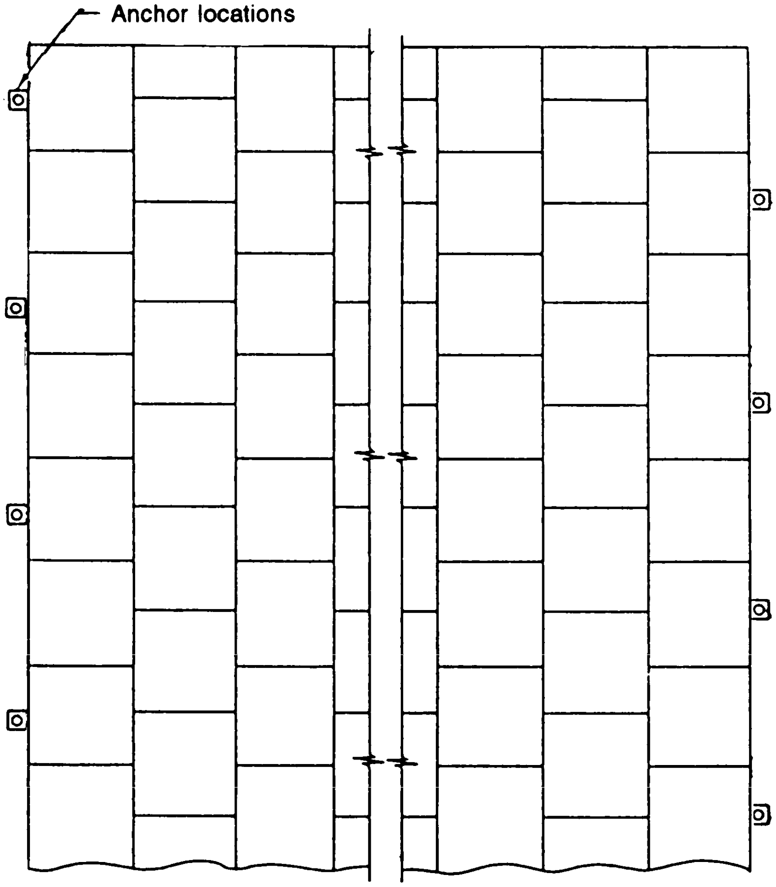


Figure N-48. Anchor locations along matting sides and edges

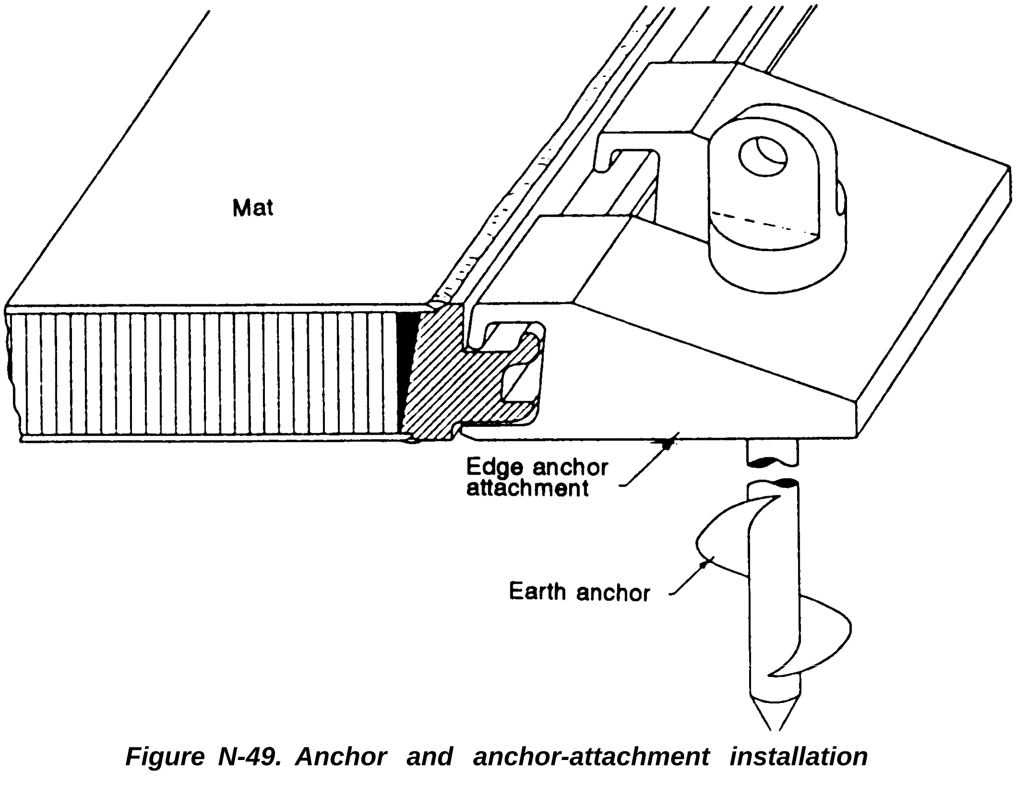


Figure N-49. Anchor and anchor-attachment installation

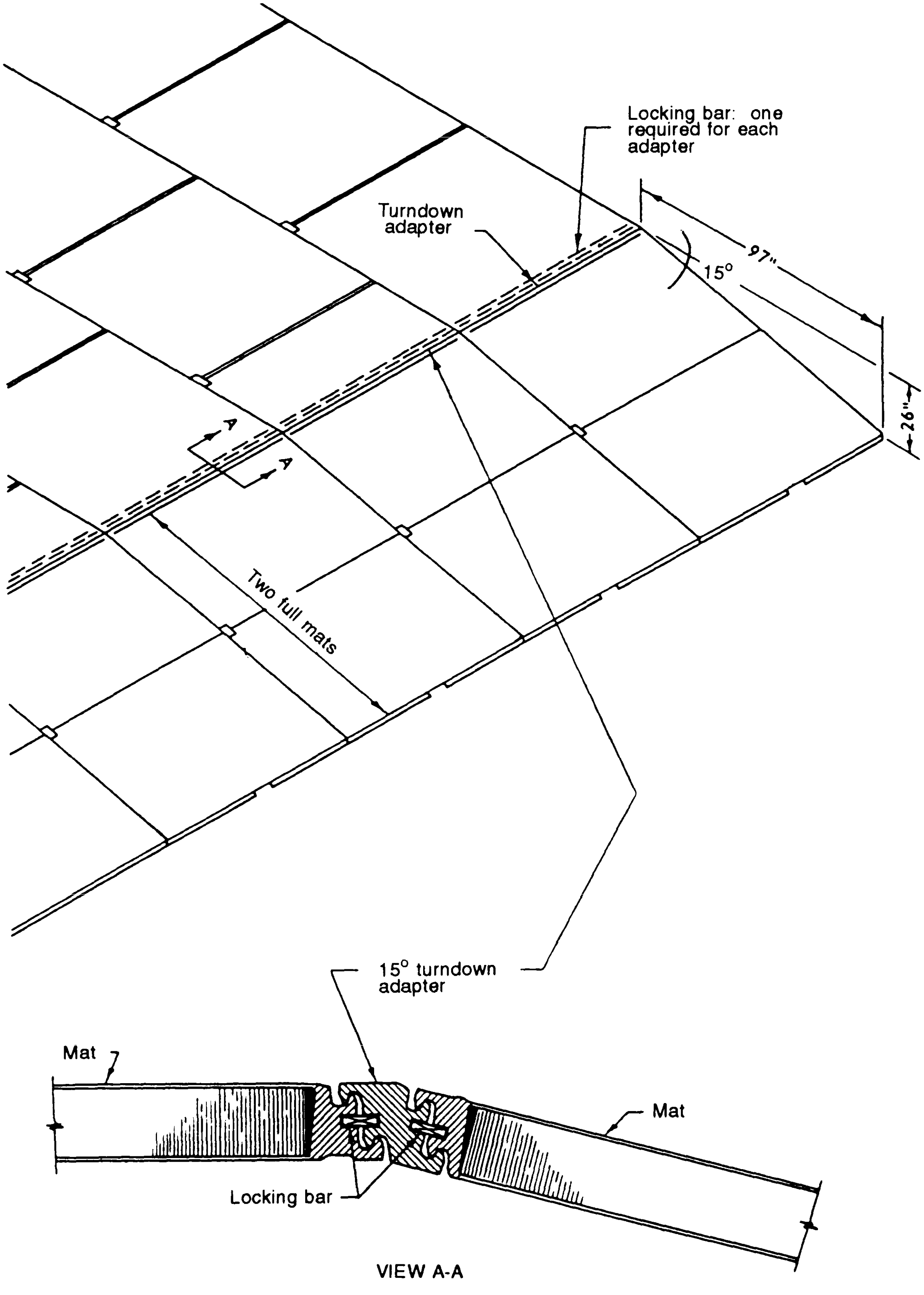


Figure N-50. Turndown-adapter-installation detail

Ends of Pads

Anchors will be used and placed along the edges of mat, such as the taxiway or parking aprons, in the same patterns as for the sides of the runway as discussed earlier. These are not required for the runway since the runway ends will be buried.

Turn Adapters

In the M19 mat set, there are various ancillaries (Figure N-51, page N-60) that provide for a wide range of runway and taxiway combinations in rapid airfield construction. As the mat field progresses, turn adapters are used to make changes in the lay of the mat as may be desired. The following examples show areas in which the various adapters are used:

- Male/underlap turn adapters are used to start a lay from female roll-in edge of another lay. A locking bar is used to secure the underlap side of the adapter to the overlap edge of the mat in the second lay.
- The male/overlap turn adapters can be used to attach the female edges of a row of mats to the underlap drop-in edges of previously laid mats. A locking bar is required to attach the adapters to the underlap edges of the first lay.
- Female/underlap adapters are used for attachment of an intersecting runway or taxiway to a male edge of the runway. These adapters are installed in the same manner as the male/underlap adapters.
- The H-connector is used to make transitions between M19 and AM-2 mats. Mixing of mat types should not occur on the runway. The H-connector can also be used to extend existing runways or to add taxiways at 90 degrees to the existing runways.

M19 MAT REPAIR

Mat removal may be required for repair of the subgrade, for replacement of damaged mats, or for replacement due to marginal conditions that warrant preventive maintenance. If the damaged area is close to the field access adapters or if an extensive area is to be replaced, access can be gained through these adapters. If damage to a single mat is in an area some distance from the field access adapters, repair mats can be used as replacements for damaged mats.

Mat Removal Through Field Access Adapters and Replacement

Field access adapters have an overlap and underlap side, and only mats on the overlap side of the field access adapters can be removed by the method described below:

- Remove the anchors and anchor attachments as required.
- Remove the locking bars from the access adapter at the edge of the field.
- Slide the adapter from position, using a sharp, pointed tool inserted into the hole in the end of the adapter to aid in removal.
- Remove the locking bar from the opposite overlap/underlap connector.
- Remove the panel.
- Remove the next adapter and mat.
- Repeat this procedure as required until a series of mats can be removed with or without removal of additional adapters to reach damaged area.

After the damaged area has been repaired, the mats and adapters should be replaced as follows:

- Replace the mats in the reverse pattern of that used in removal.
- Install the field access adapters in their original positions as mat laying progresses and insert the locking bars.
- Install any anchors and anchor attachments that may have been removed.

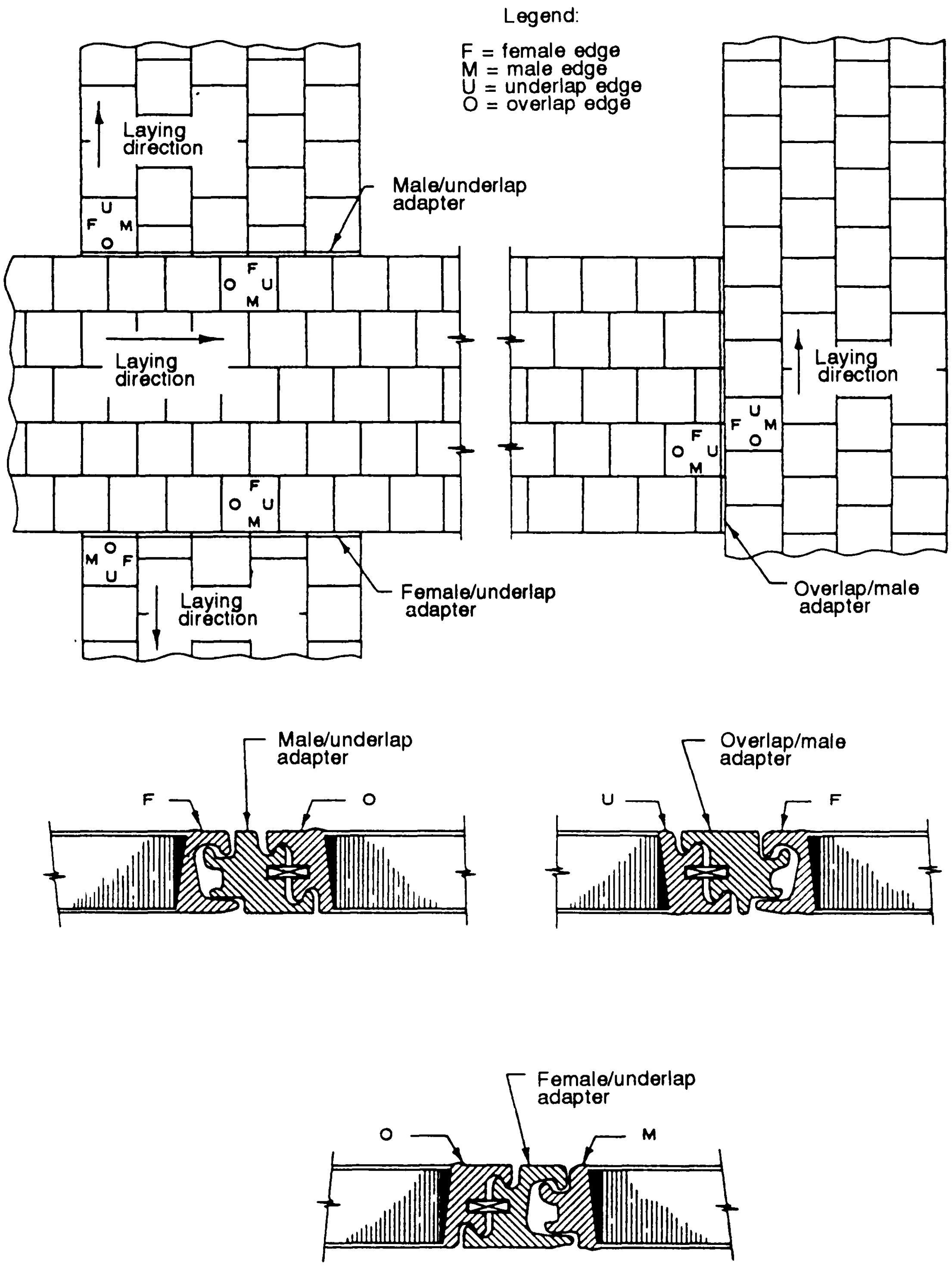


Figure N-51. Turn-adapter installation

Removal of Isolated Mat(s) and Installation of Repair Mat

The following steps outline the procedures used to cut a mat in order that a single failed panel can be removed without requiring access through field access adapters. When a mat is removed by this method, a repair mat is installed in its place.

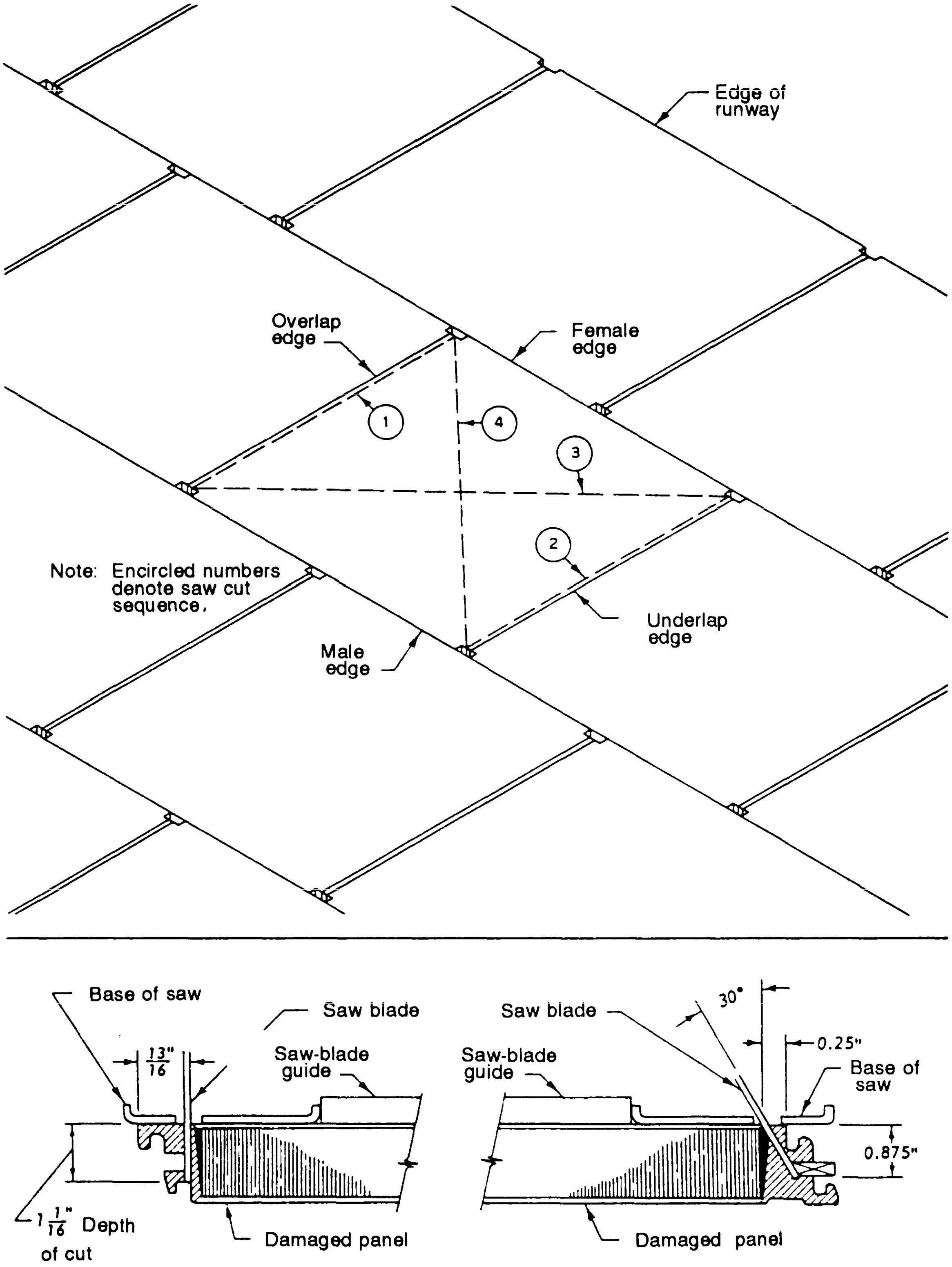
- Cut the mat with a portable saw as shown in Figure N-52, page N-62. Use a saw with a carbide-tip blade, lubricated to prevent chips from sticking to the blade. Make the first cut on the overlap edge of the mat along line 1, with the saw blade set to make a cut 1 1/16 inches deep, located 13/16 inch from the edge of the rail flange. A guide, such as a strip of plywood, should be used to obtain an accurate cut. If cut deviates towards the edge, the blade may become jammed when it contacts the loose locking bar in the joint. If the cut deviates from the edge, the locking-bar pocket will not be exposed, resulting in additional work to remove the bar. Be sure not to cut into adjacent mats.
- Make the second cut along line 2 (Figure N-52). Set the saw to cut 7/8 inch deep, with the blade at a 30-degree angle. Start the cut 1/4 inch from the edge of the upper surface of the mat. With this setup, the saw will penetrate the locking-bar cavity and permit the lower lip of the underlap rail to be rolled out of its groove.
- Set the saw to a depth of 1 1/2 inches, with the blade at an angle of 30 degrees. Cut through the mat along lines 3 and 4 (Figure N-52).
- Pry up the triangular section, the section that contains the female connector and the triangular section adjacent to cut 2. It will be necessary to break some of the materiaI at the ends of the cuts.
- Pry the remaining two triangular sections out of the male hinge connection and overlap joints.
- Pry out the locking bars and flanges of the drop-in joints with a small pry bar.

The following steps should be used for the installation of M19 repair mats:

- The repair mat section incorporating the underlap edges should be installed first, as illustrated in Figure N-53, page N-63 Engage the male edge of the mat with the female edge at the edge of the opening, and lower the mat to the ground. The side underlap rail of the repair mat will not be engaged. To engage this joint, lift the adjacent mats 3 inches off the ground with a pry bar and a suitable block at the corner where the two underlap rails of the repair panel intersect. While the adjacent mats arc elevated, slide the repair mat section under the matching underlap rail, then lower the adjacent mats.
- To install the remaining part of the repair panel, engage the female and male hinge connectors, then lower the panel to engage the overlap and underlap connectors. To lock the mat into position, first loosen the nine socket-head set screws one-half turn. Shift the locking bars into the locked position with the aid of the pointed end of a small pry bar, working through the 3/8-inch-diameter access holes adjacent to the set screws. Tighten the set screws approximately five turns to hold the locking bars in a locked position.

REPAIR OF ANTISKID SURFACE

The antiskid coating can be easily replaced in the field with an ordinary paint brush or roller if care is taken to prevent segregation of the abrasive particles within the binder during application. Follow the sequence on page N-64.

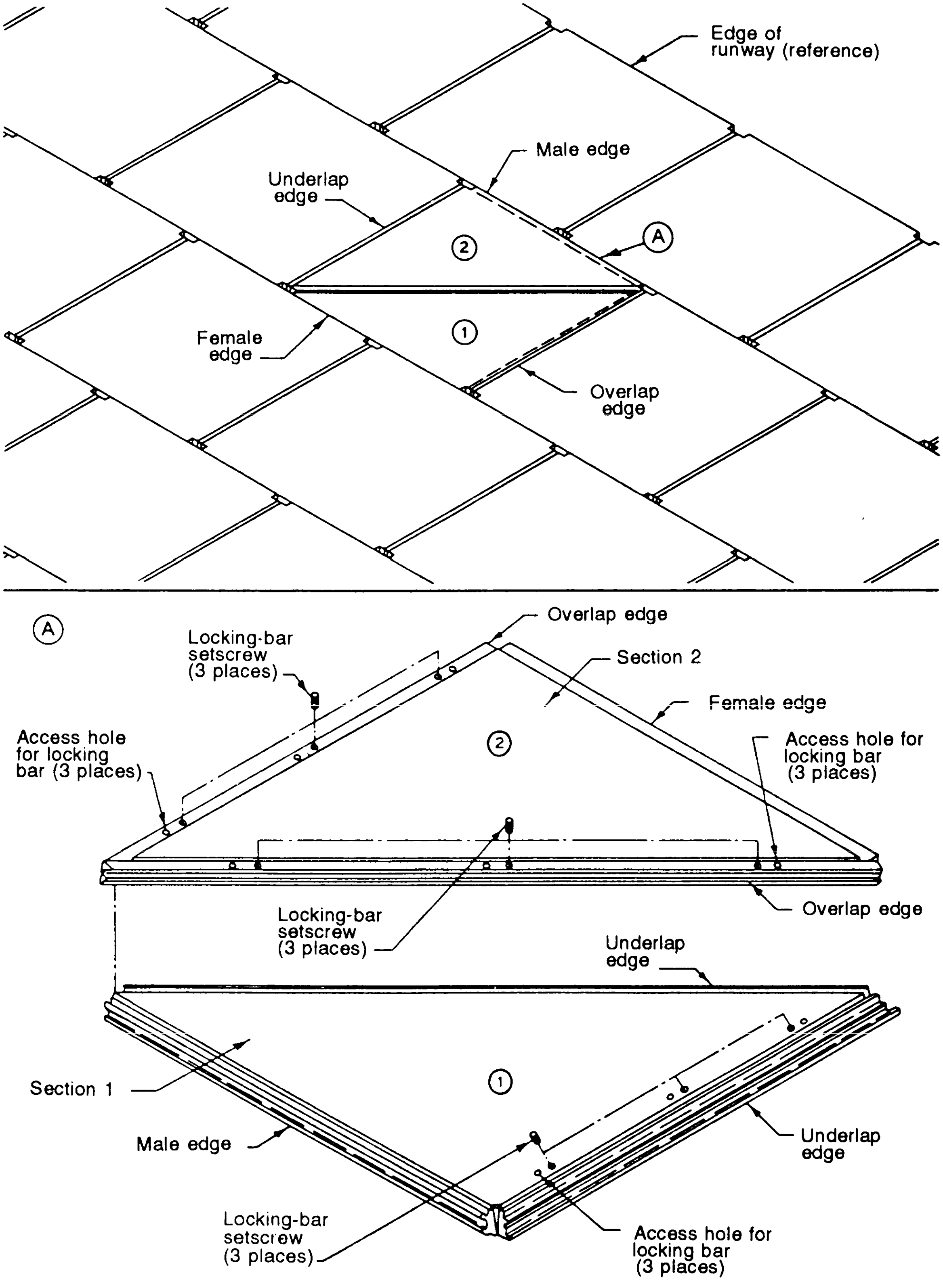


Note: Encircled numbers denote saw cut sequence.

CUT 1

CUT 2

Figure N-52. Isolated-mat removal



Note: Section 1 of the repair mat must be installed first.

Figure N-53. Repair-mat-installation detail

1. Clean the mat surface with a cloth saturated with toluene or an equivalent solvent.

2. Recoat the bare areas with a suitable antiskid coating, agitating the antiskid material periodically.

REMOVING, CLEANING, AND BUNDLING PANELS FOR REUSE

When the airfield is no longer needed, M19 panels can be removed, cleaned, and bundled for reuse at another location. When the mat field is removed, care should be taken not to break or bend the locking bars or damage the mat or any of the ancillary equipment. Upon removal, individual panels should be visually inspected in detail to determine the extent of damage, if any, that has occurred as a result of prior use.

Mat Removal

Panels should be removed from the two outside rows on the runway end where the last panels were placed. A locking bar should be removed by first engaging the hole in the bar with a hook or a sharp, pointed bar and then applying force. Vise-grip pliers can be used to grip the bar and pull it out. The panel can then be raised to an angle of about 45 degrees. The hinge connector will then disengage, and the panel will be free for removal. Next, the adjacent panel in the same row should be removed in the same manner.

Mat removal can also begin wherever access adapters are located in the mat field by first removing the adapters then the panels.

Cleaning

The connecting and locking features must be free of excess soil. Soil should be removed from the surface of the panels with a hoe, square-end shovel, or similar tool. Connecting and locking edges can be cleaned with a locking bar or a pointed tool, but they may require washing with water under pressure.

Bundling

Bundles should be about the same size as those of the original shipment. Half, full, and repair panels should be bundled separately. Each bundle should be tightly strapped with four straps, two over each edge. The straps should be spaced at the quarter points and placed over 2x4s used as skids to facilitate handling.

Criteria for Determining if M19 Mat is Reusable

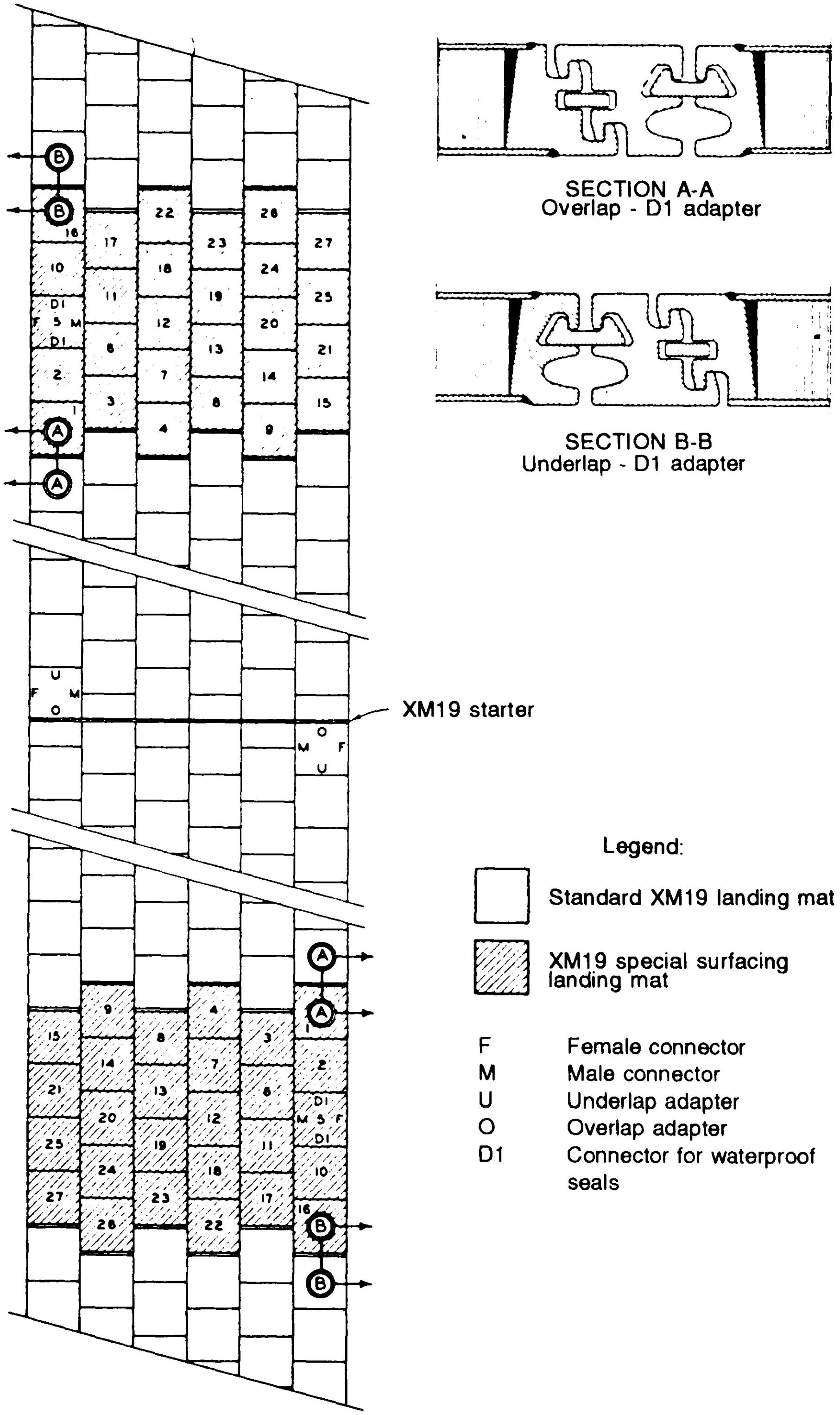
Panels will be considered reusable if they will fit together at the sides and ends with a new panel. The panel should not have any tears or breaks that present a tire hazard. Panels with core failure that are permanently deformed more than 0.6 inch when measured across the transverse direction are considered unsuitable for reuse.

M19 SPECIAL SURFACING LANDING MAT

In the TO environment, it is likely that an expedient airfield using matting may require the use of an arrester system. Therefore, it has been determined that an additional requirement for medium-duty matting is that it be able to sustain two aircraft arresting hook impacts in the same spot and withstand 20 rollovers of an F-4C aircraft loading on the 1-inch-diameter hook arresting cable without structural failure due to the rupture of the top surface of the mat. Standard M19 mat did not meet the requirement, so an M19 special surfacing landing mat was developed for use where these types of operations may occur.

M19 Special Surfacing Mat Placement

Figure N-54 shows the pattern for placement of M19 special surfacing mat within a standard M19 mat field. After laying the standard M19 mat from the M19 starter to the critical area, it is desirable that the special surfacing panels be placed in the order indicated by the panel numbers shown.



Legend:

☐ Standard XM19 landing mat

▨ XM19 special surfacing landing mat

F	Female connector
M	Male connector
U	Underlap adapter
O	Overlap adapter
D1	Connector for waterproof seals

Figure N-54. M19 special surfacing mat placement.

At the junction of the two types of mats, an overlap/D1 adapter should be placed on each row of standard mats (Figure N-54, page N-65, Section A-A). The adapter to the standard mat is secured with a standard lock bar. Panel 1 of the special surfacing mat should then be placed in alignment and flush with the overlap/D1 adapter. The lock bar for the D1 connector (Figure N-55) is then inserted to lock the adapter and the special surfacing mat together. Subsequent panels in the first row (panels 2, 5, 10, and so on) are placed in a similar manner. The panels in successive rows are placed in a stair-step pattern beginning at the first row (note sequence of panel numbers in Figure N-54). The panels are held at a 45-degree angle to the ground to engage the female connector over the male connector of panels in the previous row. The panel is then dropped to the ground with the D1 connector flush with panels already in place. The D1 lock bar is then inserted to secure the panels.

The installation of lock bars, tight and loose spacing of panels, subsequent adjustments, and the installation of side anchors is similar to the procedures for standard mat.

It is anticipated that the standard M19 panels will be placed from the critical area to the end of the runway. At the junction of special surfacing mat and standard mat, a D1/underlap adapter (Figure N-54, Section B-B) will be required. The standard placement pattern and methods will then be continued to the end of the runway.

It is not anticipated that turns or taxiways will be adjacent to the M19 special surfacing. However, should the need exist for such configurations, the standard 90-degree turn adapters (male/overlap, male/underlap, female/overlap, and female/underlap) can be used since the male and female connectors of the M19 special surfacing mat and the standard M19 panels are interchangeable. (It is assumed that only stan-dard M19 mats will be used in the turns and taxiways and not M19 special surfacing mat.)

Mat Removal

It should be noted that access-type adapters are not required with the special surfacing because of the transverse joint configuration. This configuration allows panels to be removed from both edges of the runway after the D1 lock bars are removed. By using a pyramid removal pattern, any M19 special surfacing panel(s) in the interior of the runway can be removed and replaced from either edge of the runway, without any undue effort or damage to panels. After bars are removed, a panel can be hinged out by raising it to about a 45-degree angle with the ground and disengaging the male/female connection. The outer rows of the mat should be removed first, and adjacent rows should be removed as the D1 lock bars are exposed and removed.

Maintenance and Repair

All methods of evaluation and maintenance, such as repair of antiskid surface, cleaning, and rebundling panels for reuse, and determination of mat reusability, are the same as standard M19 unless stated differently in the above section.

TRUSS-WEB, HEAVY-DUTY MAT

The truss-web mat panel is a one-piece, extruded section with extruded end connectors welded to each end (Figure N-56, page N-68). The side connectors are integral parts of the basic extrusion. The basic section is partially hollow. The panel is approximately 1 1/2 inches thick, 2 feet wide, and 9 feet long and comprises 18 square feet of placing area. Half panels are 2 feet wide and 4 1/2 feet long. The truss-web mat, fabricated from aluminum alloy, weighs 6.3 pounds per square foot. This mat is painted Marine Corps Green, Number 23, and the top surface is coated with antiskid material of the same color.

The side connectors (female and male) are constructed to interlock with a rotating motion. The end connectors are symmetrical I-lock connectors. The end connectors of adjacent panels are locked together by a locking bar, which is inserted into the slot formed by the two end connectors (Figure N-57, page N-68).

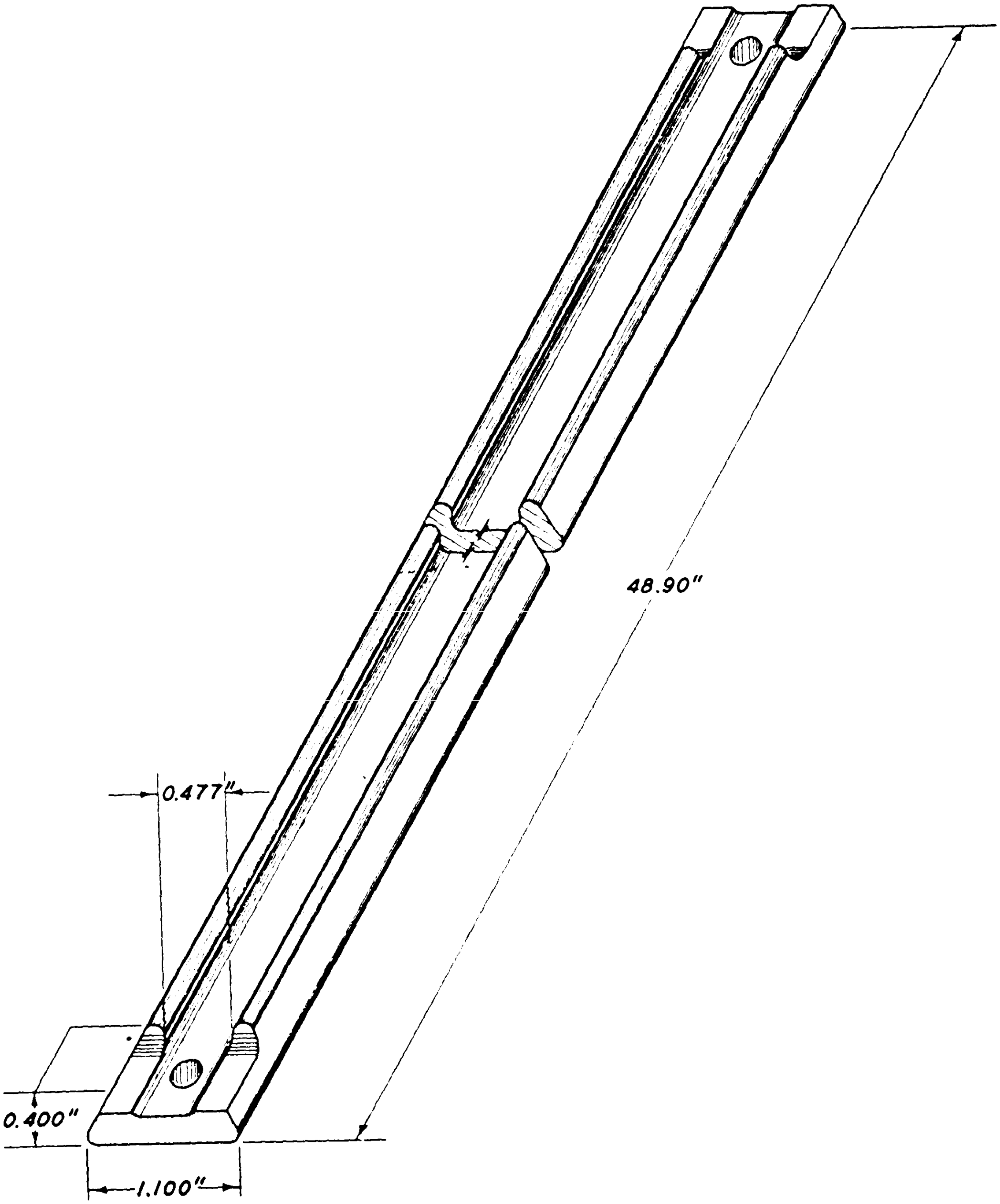


Figure N-55. Lock bar for the D1 connector

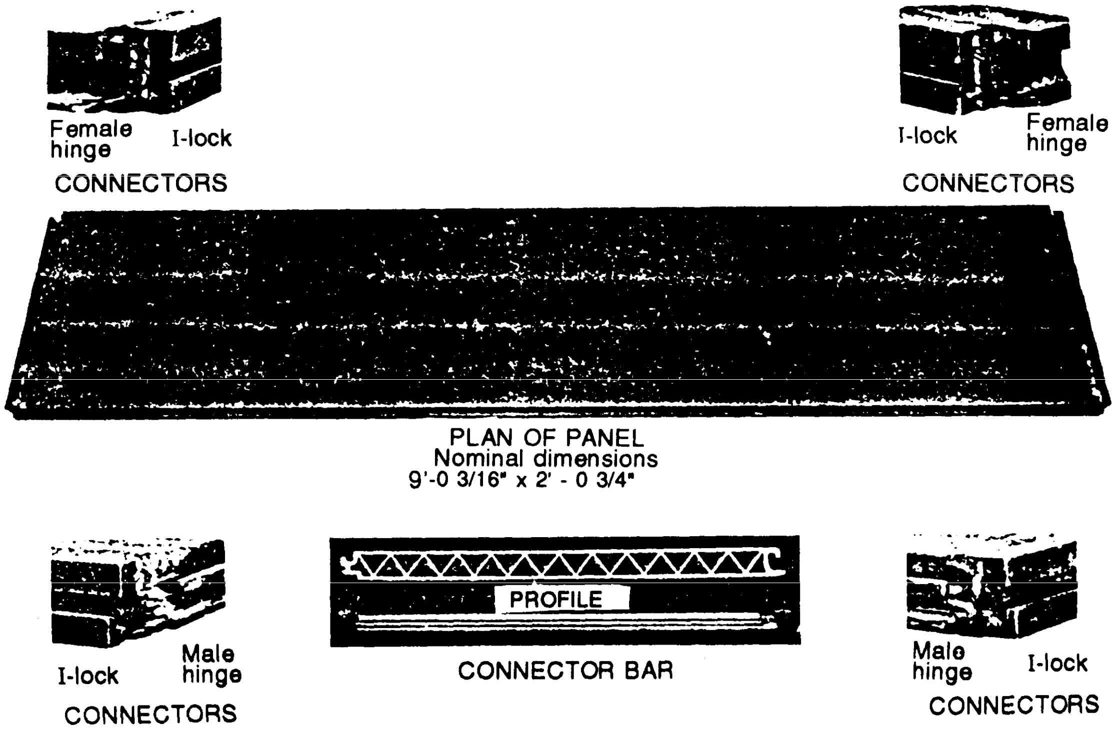


Figure N-56. Heavy-duty truss web matting

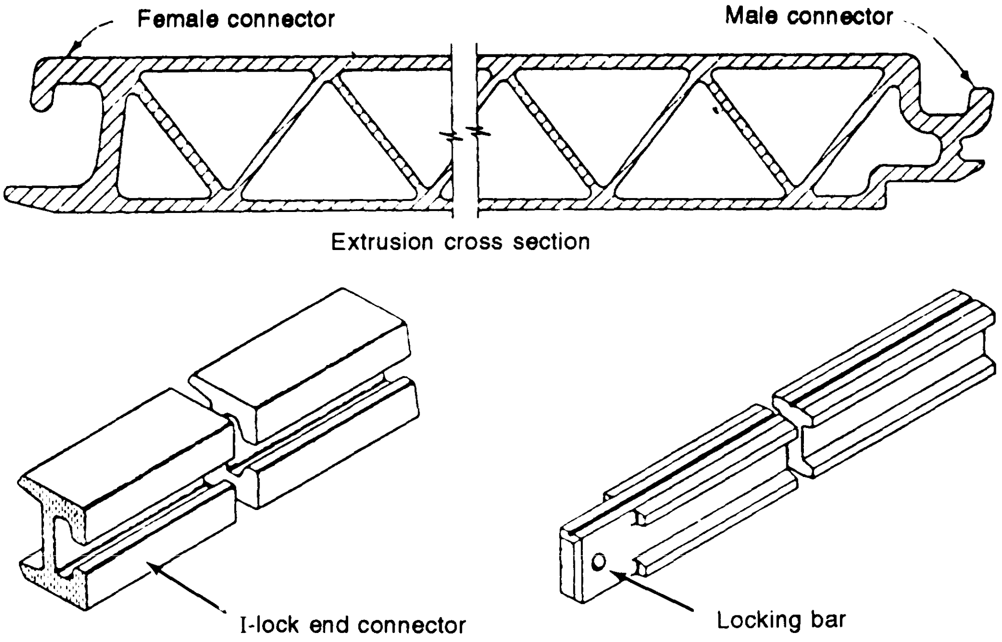


Figure N-57. Truss web connectors

One locking bar per panel of mat is included in each mat bundle. The truss-web mat is laid with the male-female joint perpendicular to the direction of traffic.

Ancillary Items

Descriptions of the various ancillary items used in conjunction with the truss-web landing mat are as follows:

Starting connector. A starting connector is a small, extruded aluminum-alloy section with a male connector on each side (Figure N-58, page N-70). This connector is approximately 3 inches wide, 1 1/2 inches thick, and 108 inches long. The starting connectors are used to form a transverse line across a runway or taxiway from which mat laying is started. The use of these starting connectors per mits the number of laying crews to be doubled since two crews can begin placing mat in opposite directions from the connector toward each end of the runway or taxiway.

Access adapter. An access adapter is a small, extruded aluminum-alloy section with a female connector on one side and a male connector on the other side (Figure N-59, page N-70). This adapter is approximately 2 1/2 inches wide, 1 1/2 inches thick, and 108 inches long. A hole is provided near each end for use in sliding the connector out of the mat field. The adapters are placed every 100 feet in the runway and taxiway to permit nondestructive removal and reinstallation of mats in order that damaged mat panels can be replaced or the subgrade can be reprocessed.

Turn adapters. A turn adapter is a small, extruded aluminum-alloy male or female I-lock connector (Figure N-60, page N-70). These adapters are approximately 1 3/4 inches wide, 1 1/2 inches thick, and 24 inches long. The adapters are used to make 90-degree turns from a runway to a cross taxiway or to connect a taxiway to a parallel taxiway. Through use of these adapters, the mat on a cross taxiway can always be laid in such a way that aircraft traffic is applied on the mat perpendicular to the internal ribs, as it is on the runway. Two-foot locking bars are used with these adapters to make a positive connection with the mat. H-adapters can also be used to construct 90-degree turns. Although this adapter does not provide a positive connection between the mats, it can be used to construct 90-degree turns or connections between different types of mat where the other connectors are not compatible. H-sections can be used to allow slight misalignment between the adjoining sections of mat. These adapters are 6 inches wide, 2 1/4 inches thick, and 144 inches long.

Anchor attachment. An anchor attachment connects to the edges of a mat-surfaced runway or taxiway and is used to secure the edge anchor to the mat along the edges. The type used to secure the edge anchor to the truss-web mat is an I-lock attachment (see Figure N-61, page N-71).

Edge anchor. Edge anchors (Figure N-61) are used in conjunction with anchor attachments to secure the perimeter of the mat. The anchor, fabricated from carbon steel, is approximately 26 inches long. The helix, which is 4 inches in diameter, is attached to a 3/4-inch-diameter shaft. The head of the anchor has a 1-inch-diameter hole through it and a flange surface to aid in installation. One anchor per attachment is required along the runway and taxiway edges.

Repair panel. A repair panel is a special panel that is used to replace a single, damaged mat panel within a mat field without removing adjacent panels. The outside dimensions of the panel are the same as those of the basic section of a full panel, but other features are different. The repair panel is heavier than the standard truss-web mat panel. The female connector is similar to the female connector on a standard panel. The male and I-lock connectors consist of several parts separate from the repair mat extrusion (Figure N-62, page N-71). These parts are placed before placement of the main body of the repair panel. The panel is then put into place, and the parts connected to the main body with cap screws, thus completing the panel.

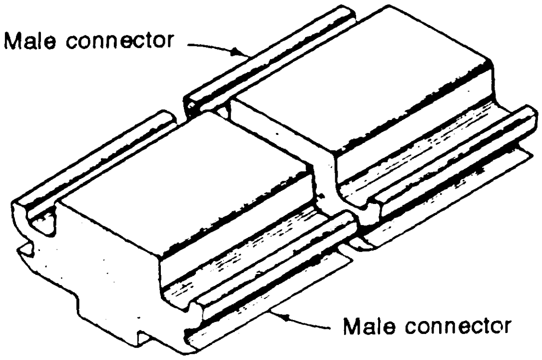


Figure N-58. Starting connector

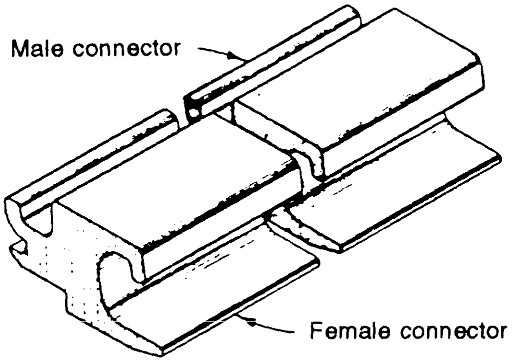


Figure N-59. Access adapter

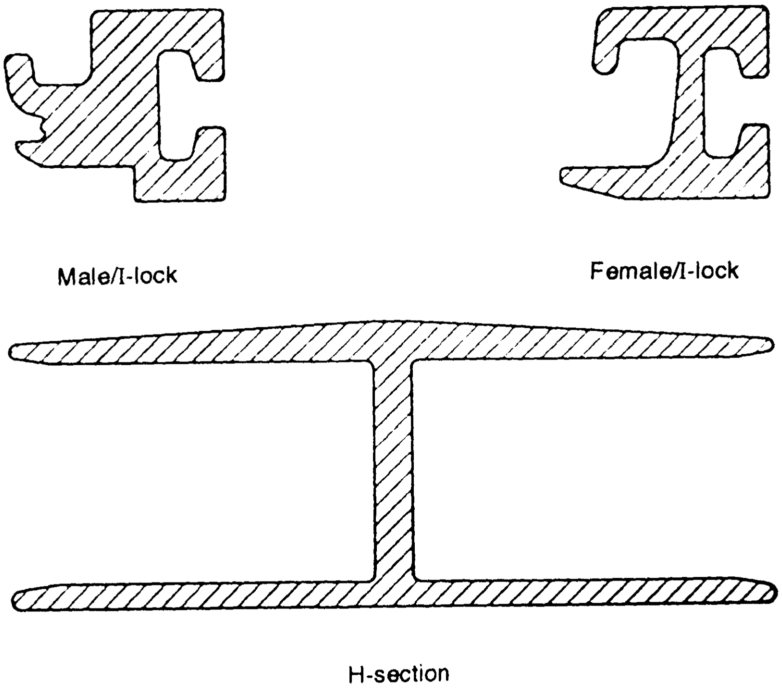
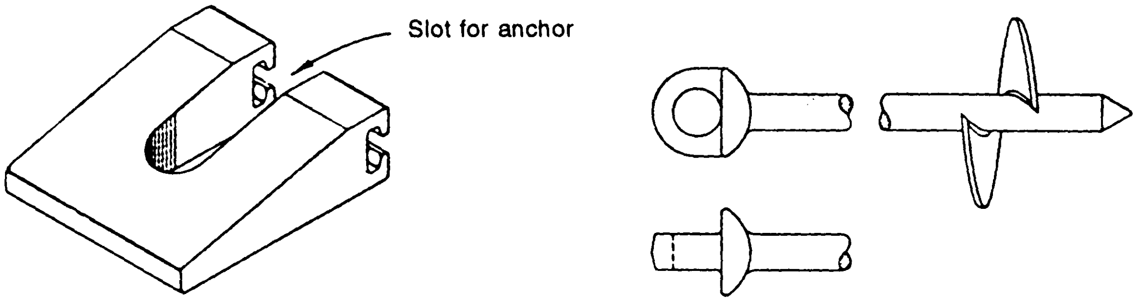


Figure N-60. Turn adapters



I-lock attachment

Edge anchor

Figure N-61. Anchor and anchor attachment

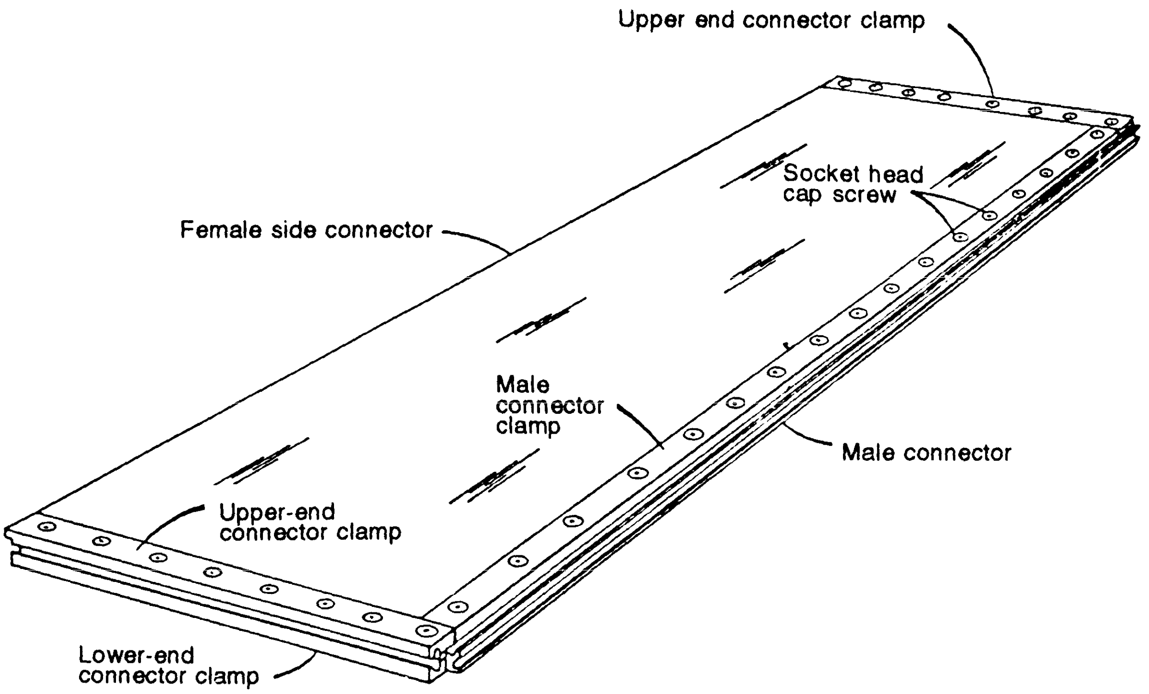


Figure N-62. Repair panel

Installation Instructions

No special skill is required for emplacement of truss-web landing mat once a well-prepared subgrade has been constructed and a baseline has been established.

On a flat subgrade, the mat can be placed in a normal brickwork pattern (Figure N-63) at the rate of 748 square feet per man-hour. The ends of alternate runs are offset by a minimum of 2 inches so the locking bars that connect the anchor attachments to the ends of the mat panels can be installed after the mat has been placed.

On a subgrade crowned as much as 3 percent, mat panels can be placed in the 1-foot offset pattern shown in Figure N-63 at a field rate of 200 square feet per man-hour. When the mat is installed over the crown, the emplacement mat normally has to be raised to reduce the curvature in order to place the panels that bridge the centerline. Therefore, additional time and effort are required, and the installation rate achieved is lower than that achieved when the subgrade contains little or no crown.

A basic mat-placing crew consists of seven men–one NCO and six enlisted men. As many as four crews can lay mats in one direction as work progresses on the runway.

The general procedure for installing mats on a runway, taxiway, or apron is for placing crews to start at the transverse centerline and lay mats toward each end, simultaneously. Baselines established on each side of the section should be used for mat alignment. The baseline and transverse centerline should be clearly marked with stakes or by other means before mat laying. The starting connectors are laid at the trans-verse centerline, and then individual mats are laid in a brickwork/ stair-step pattern or in a 1-foot offset pattern from left to right when facing the starting connector (see arrows in Figure N-64). The coated side (the side with antiskid material) is placed up. Other sections of the airfield installation can be placed in the same manner and at the same time if baselines have been established, proper alignment of these sections with the runway has been made, mat bundle deployment has been accomplished, and sufficient personnel are available to accomplish the multiple crew mat placement. A run of access adapters should be laid every 100 feet. These adapters are placed in the runway and taxiways to permit nondestructive removal and reinstallation of mats in order that damaged mat panels can be replaced or the subgrade can be repaired. Details of installation are given in the following paragraphs:

Mat Laying Procedure

Brickwork pattern. The starting connectors are laid on the transverse centerline of the runway (Figure N-64). As the starting connectors are placed, they are butted together. After the starting connectors have been placed and aligned, the first mat is placed. On the left side of the runway (facing the starting connector), the first mat panel (a half panel) is aligned with the connector. The female connector is placed over the male connector of the starting connector. For proper engagement of the panel with the starting connector, the panel should be held at an angle approximately 45 degrees to the subgrade. With the top flange of the female connector of the panel engaged over the top of the male connector on the starting connector, the panel is rotated downward to form a joint. The next mat (a full panel) is placed to the right of the first mat. The second mat (a full panel) is placed in the same manner as the first. Once the I-Iock connectors of the first and the second mats have been aligned, a locking bar is inserted (Figure N-65, page N-74) to prevent the mats from separating. Because the bar might be tight in the locking bar slot, a hammer may be required for insertion. The tight condition may be due to waviness of the end connectors or locking bars, or to soil or debris in the connectors.

The third mat (a full panel) can be placed in the second run onto the first two mat panels that have been laid (Figure N-64), This mat is offset from the half panel (panel 1) in the first run by 2 inches so that the locking bar for the anchor attachment can be installed after the mat is placed. The brickwork/stair-step pattern can be con tinued across the runway, allowing more placement crews to work and more mat to be placed in a given amount of time.

The last panel placed in the first run will be a half panel, and the first panel placed in the second run will be a full panel. The first run of panels and each alternate run are laid using half panels at the outer edges and full panels in between. Only full panels are laid in the second run and each alternate run thereafter, and these runs are offset from the adjacent runs by a minimum of 2 inches so the locking bars for the anchor attachments can be installed anytime after the mat is placed. This method allows the end joints in adjacent runs to be staggered for greater mat strength.

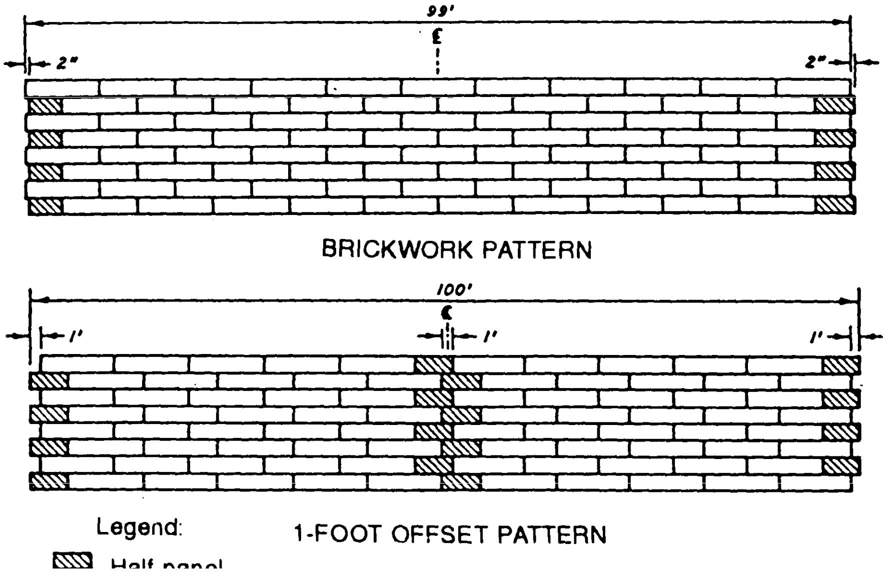


Figure N-63. Laying patterns for truss-web mat

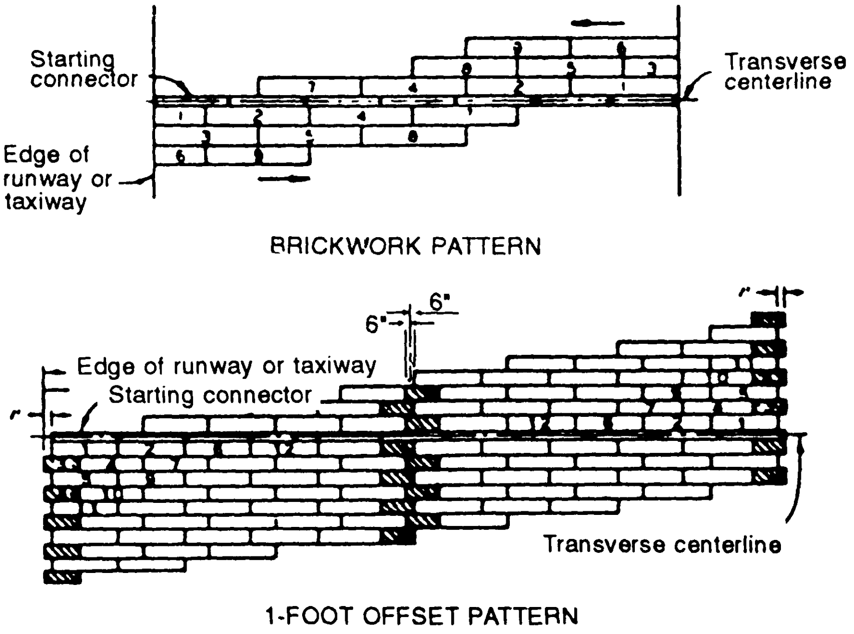


Figure N-64. Starting adapter placement and matting sequence, truss-web mat

After several runs have been placed in one direction and proper alignment has been maintained, placement of the mat can be started in the opposite direction. The procedure for mat placement on the opposite side of the connector is the same as that for placement on the initial side except that the first panel placed is a full panel. All panels in the first run are full panels. Alternate runs thereafter will contain only full panels. The first and last panels in the second run are half panels with full panels in between. Alternate runs thereafter will contain half panels at the outer edges with full panels in between. These runs are offset from the adjacent runs by a minimum of 2 inches so the locking bars for the anchor attachments can be installed anytime after the mat has been placed.

Care should be taken to ensure that alignment with the transverse centerline and with the runway edge is maintained for the first several runs. Then alignment should be maintained with the runway edges as more mat is placed. Any misalignment will cause a displacement of the runway from the planned position at each end of the field.

The truss-web mat panels are designed and fabricated so that when they are placed, there is an apparent loose fit. This allows for mat expansion and for the natural waviness inherent in extruded mat panels, which makes it possible to place a run of mats so misaligned that they prevent the proper engagement of one or more of the mat panels in the following run. The method of correcting misalignment is shown in Figure N-66. Misalignment must be corrected to prevent a zigzag pattern of the mat at the runway edge, which would cause misalignment with the baseline. The runway edge has to be straight at the point where a taxiway is to be laid off the runway in order that the turn adapter will properly engage the mat on the runway. In the area of the runway where the taxiway is to be tied into the runway, the mat panels are not offset. At the ends of the runs opposite the taxiway, locking bars that have been cut in half are installed in alternate runs as the mat is placed. These bars are installed as the mat is placed so that the anchor attachments and anchors can be placed at a later time. If it is necessary to usc a sledgehammer to align the mat, a wooden block should be placed against the mat edge to prevent damage to the panel. After the mat panels have been aligned, the locking bar can be inserted into the locking-bar slot.

One-foot offset pattern. The starting connectors are laid on the transverse centerline of the runway (Figure N-64, page N-73). As the starting connectors are placed, they are butted together. After the starting connectors have been placed and aligned, the first mat is placed. The first mat panel (a full panel is aligned with the connector of the starting connector on the left side of the runway. For proper engagement of the panel with the starting connector, the panel should be held at approximately a 45-degree angle to the subgrade. With the top flange of the female connector of the panel

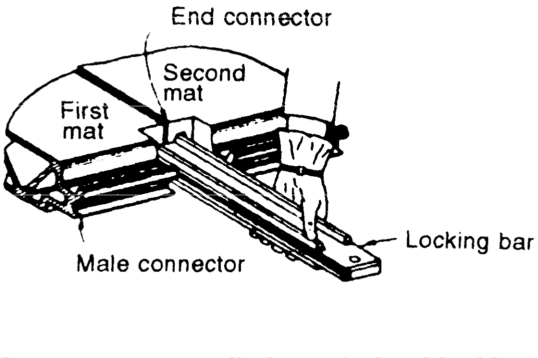


Figure N-65. Installation of the I-locking bar

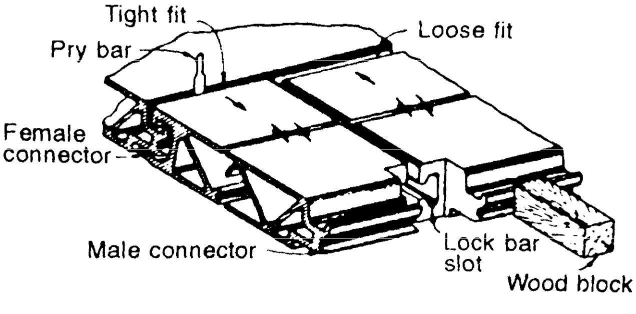


Figure N-66. Correcting mat misalignment engaged over the top of the male connector on the starting connector, the panel is rotated downward to form a joint. The next mat (a full panel) is placed to the right of the first mat. The second mat is placed in the same manner as the first. Once the I-lock connectors of the first and the second mats have been aligned, a locking bar is inserted (Figure N-65, page N-73) to prevent the mats from separating. Because the bar might be tight in the locking bar slot, a hammer may be required for insertion. The tight condition may be due to waviness of the end connectors or locking bars or to soil or debris in the connectors.

The third mat (a half panel) can be placed in the second run onto the first two mat panels that have been laid. This mat is offset from the first full panel in the first run (panel 1) by 1 foot. The fourth mat (a full panel) can be placed adjacent to panel 3 in the second run. Panels 3 and 4 can be connected at the ends with a locking bar. This stair-step pattern can be continued across the runway, allowing more placement crews to work and more mats to be placed in a given amount of time.

The sixth panel placed in runs 1, 3, 5, and so on is a half panel; five full panels are then placed with these runs ending with half panels. The seventh panel placed in runs 2, 4, 6, and so on is a half panel; five full panels are then placed with these runs ending with full panels. The half panels are placed near the center of the runway crown to allow easier mat placement.

After several runs have been placed in one direction and proper alignment has been maintained, placement of the mat can be started in the opposite direction. The procedure for mat placement on the opposite side of the starting connector is the same as that for placement on the initial side. Care should be taken to ensure that alignment with the transverse centerline and with the runway edge is maintained for the first several runs. Then alignment should be maintained with the runway edges as more mat is placed. Any misalignment will cause a displacement of the runway from the planned position at each end of the field. The procedure for correcting any misalignment is the same as for the brickwork pattern. On the area of the runway where the taxiway is to be tied into the runway, the mat panels are to be placed in the brickwork pattern and these panels are not offset at the edges.

Anchorage of Mats

Edge anchors. Anchor attachments and edge anchors are placed every 4 feet along the edges of runways and taxiways. The anchors are placed at the center of the mat panel. However, they are not placed opposite each other on the edges but are staggered 2 feet apart (Figure N-67). A full-length locking bar can be used with the anchor attachment at the ends of the panels where the anchors are to be placed. The full-length bars are used in the ends of the mat runs that are offset either by 2 inches or 1 foot. These anchors and attachments can be placed anytime after the mat has been placed. Along the edge of the mat in the runway opposite the edge where a taxiway ties into the runway, locking bars that have been cut in half are used to connect the anchor attachment to the mat. One of these half bars is inserted in the panel at the end of the run that requires an anchor.

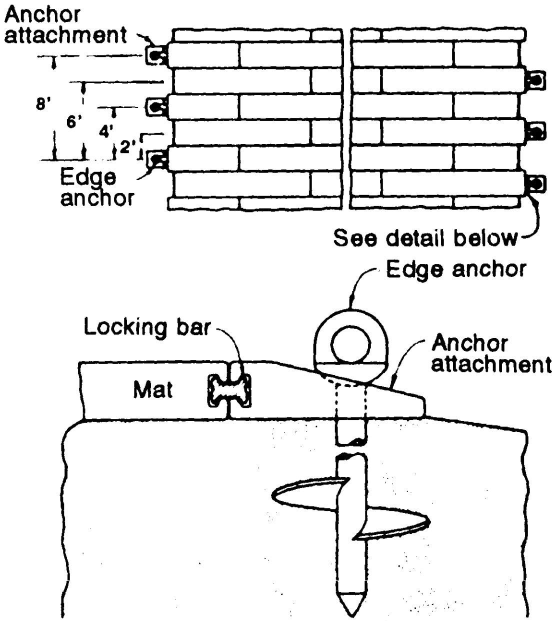


Figure N-67. Anchorage of mat

These bars are installed as the mat is placed since this edge of the runway may end in such a manner that the bars cannot be inserted in the I-lock connector at the runway edge after the mat has been placed. This allows placement of the anchor and anchor attachment anytime after the mat has been placed. When the anchor is placed, it should be completely driven until the anchor head is tight against the anchor attachment.

Ends of runway. In order to anchor the mat at the ends of a runway, a trench is excavated across the entire width of the runway to contain five or six runs of mat (Figure N-68). The trench should slope away-from the end of the runway and at the deepest point should be 24 to 30 inches below the level of the end of the runway. The surface of the trench should be shaped to provide full contact with the bottom of the mat. Five or six runs should be laid in the trench in the normal brickwork/stair -step pattern. The trench should then be backfilled and compacted.

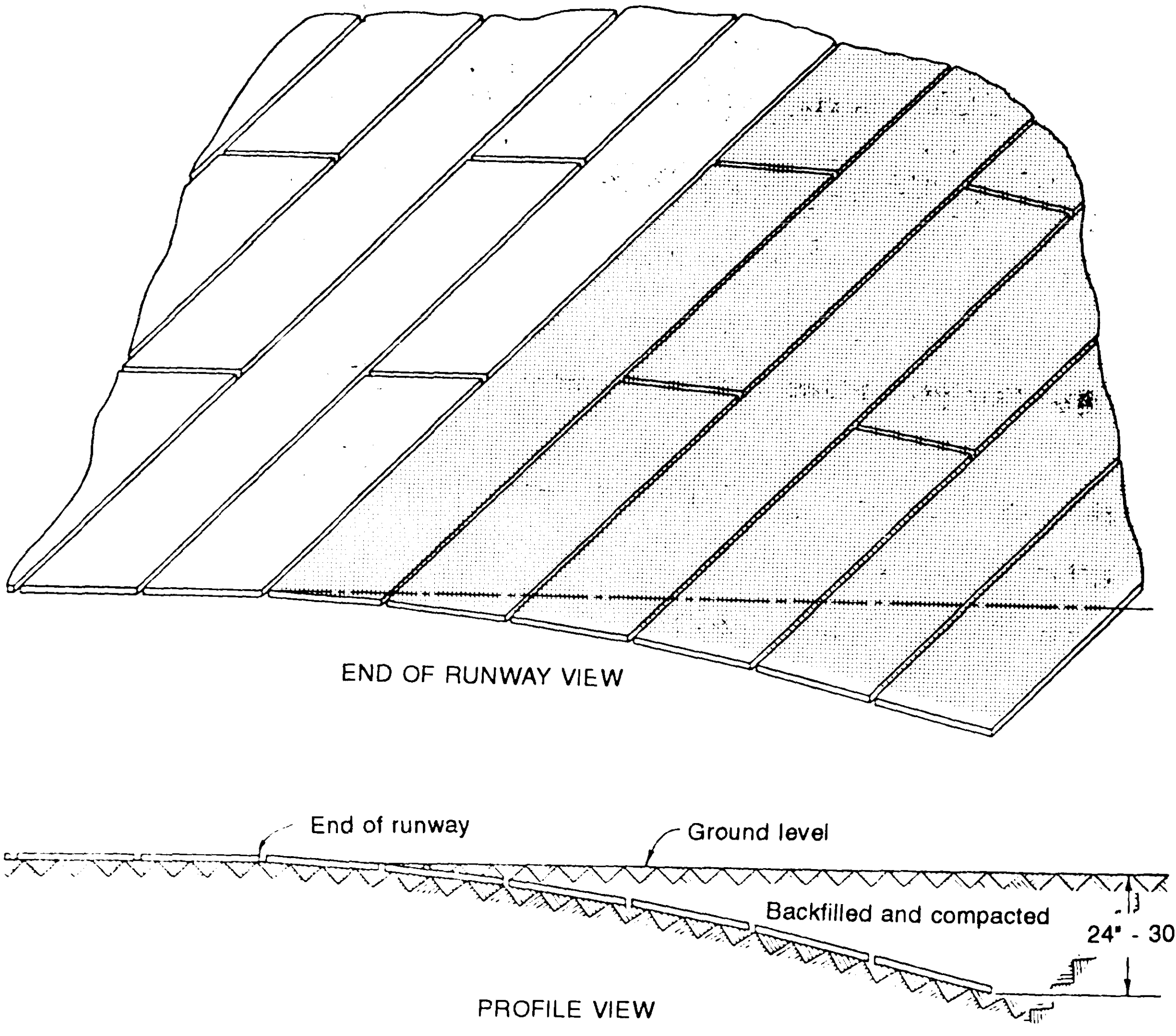


Figure N-68. Anchorage of mat at ends of runway

Field Access Adapters

A run of access adapters is placed every 100 feet in a runway or parallel taxiway. The first access adapter is aligned with the outer edge of the preceding run of mat. The female edge of the adapter is engaged with the male edge of the preceding run of mat. Once the engagement is made, the adapter is rotated downward. The remaining adapters in the run are placed in a similar manner. Adjacent access adapters are butted. After the adapters have been placed, laying of the mat is continued in the brickwork/stair-step pattern described in previous paragraphs.

Turn Adapters

A typical airfield installation is shown in Figure N-69, page N-78. Section A-A shows the starter connectors, which are used in the runway and in the parallel taxiway. Placement of mat from these starter connectors has been described previously. The various junctures formed between the runway, cross taxiways, and parallel taxiways are shown in Figure N-69. Turn adapters used to make the various junctures allow the mat to be positively locked together. As the mat is placed and the juncture areas are approached, care should be taken to ensure that the mat is aligned with the baseline. This is necessary so that the turn adapters will properly connect and the mat on the taxiways can be placed off or on the turn adapters to complete the positive connections. Two-foot-long locking bars are furnished with the turn adapters.

An alternate connector that can be used at the juncture of two facilities is the H-section adapter (Figure N-69, part d). H-sections are generally used to connect different types of mat or to allow for slight misalignment between the adjoining sections of mat and can be installed by either of two methods.

In the first method, the mat is placed on the runway, and then the taxiway mat is laid from the runway at the desired location. In this method, the H-sections are installed on the mat in the runway. As the mat in the first run is placed for the taxiway, each panel is slid into the H-section. After the first panel has been placed in the H-section, the second panel is slid into the H-section. The locking bar between the first and second panels can then be installed. This sequence is used for all the mat placed in the first run. The remainder of the mat to be placed in the taxiway is placed in the brickwork/stair-step pattern as previously described.

The second method that can be used to make the transition between a runway and taxiway with the H-sections is shown in Figure N-70, page N-79. The runway and cross taxiway are placed simultaneously and should be placed so they come to within 1 to 2 inches of each other. This distance has to be carefully controlled so that when the H-section is installed, it will connect the mats effectively. It is suggested that the transverse midpoint of the taxiway be established and the H-sections be installed in each direction from the midpoint. An H-section is placed along the edge of the runway mat. The section is then driven between the runway and taxiway mat with a sledgehammer. A wooden block should be placed against the section to prevent damage. Power equipment such as a forklift or motor patrol can also be used to force the section into place. H-sections can also be used to connect a cross taxiway and parallel taxiway by either of the two methods described above.

Heavy-Duty, Truss-Web Mat Repair

It may be necessary to remove mat due to damage to an individual panel or several panels and/or to repair the subgrade beneath the mat at an existing facility. When individual panels of truss-web mat need to be replaced, they can be cut out and replaced with repair mat assemblies. When several panels or runs of panels need to be removed, the access adapters near the mat that is to be taken out are removed, or a run of mat close to the mat that is to be removed is slid out. The procedures for the two methods of replacement are given in the following paragraphs:

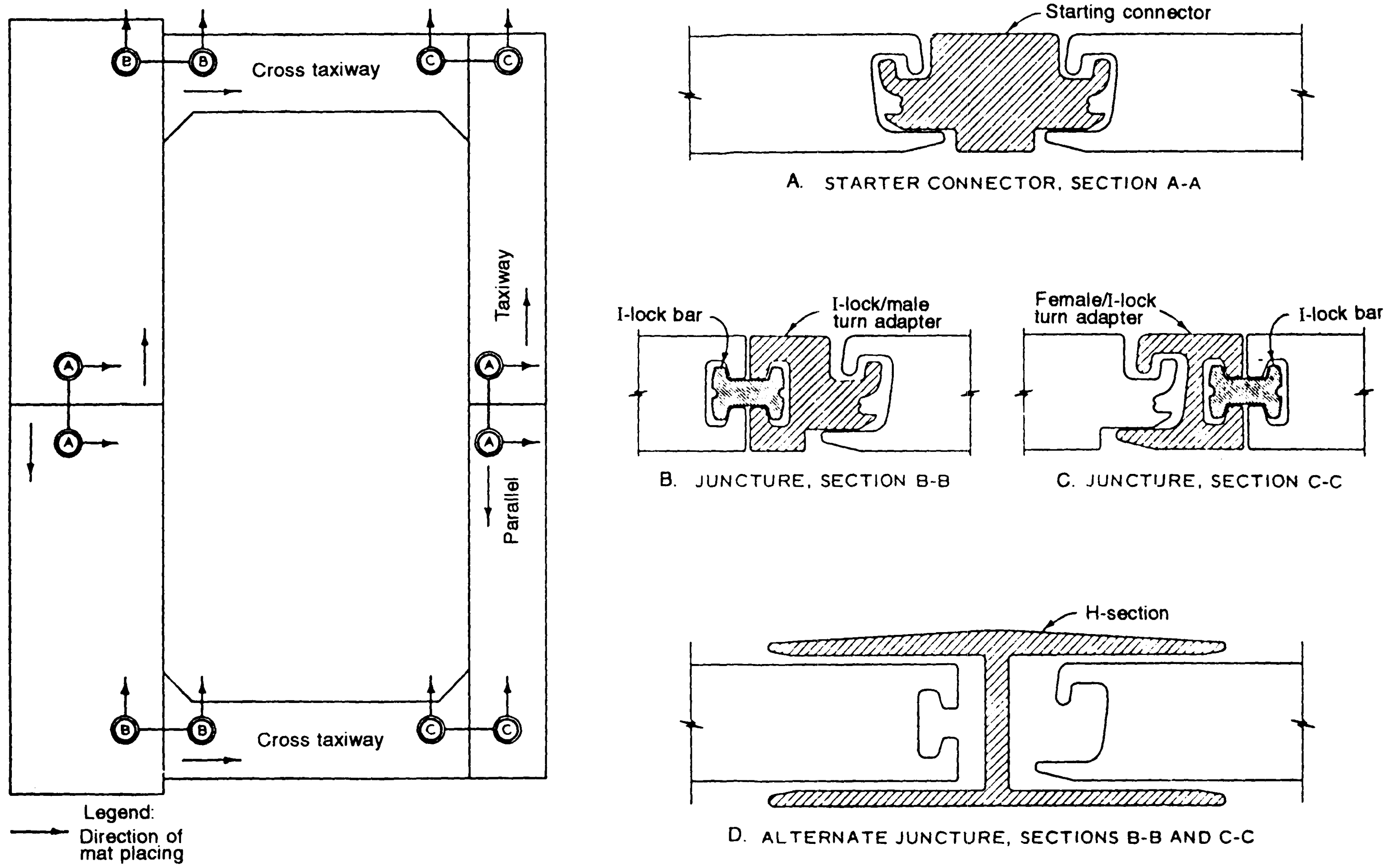
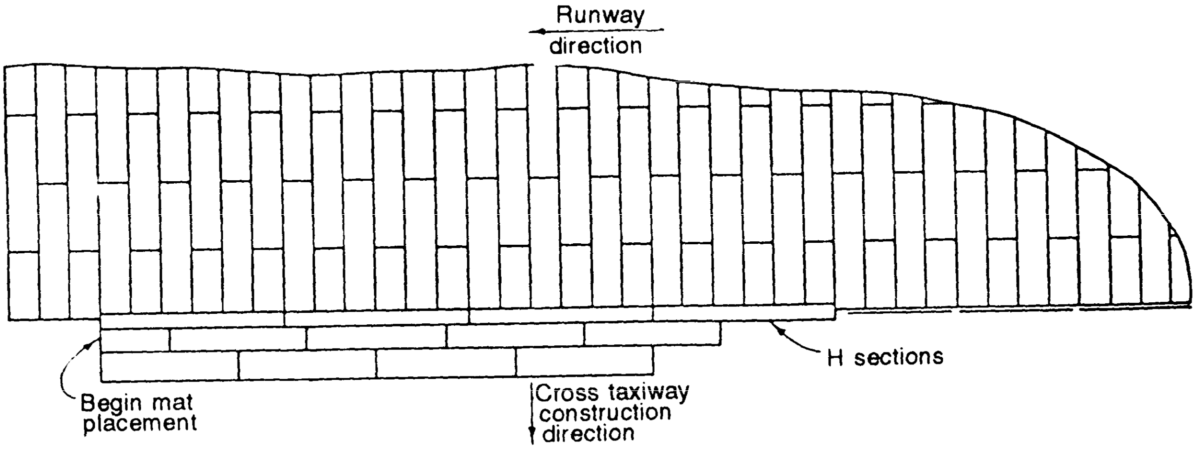
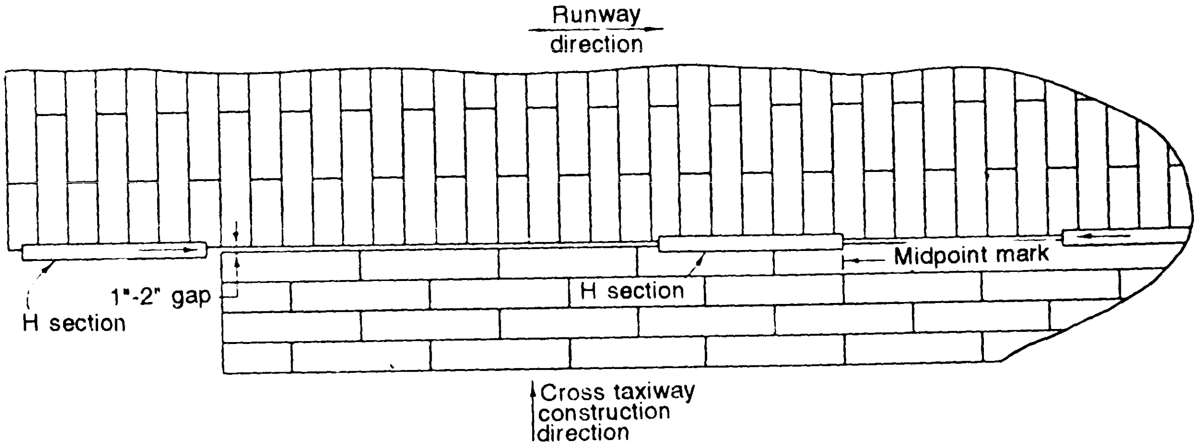


Figure N-69. Heavy-duty, truss-web turning adapters



METHOD 1



METHOD 2

Figure N-70. H-adapter usage

Method 1: Isolated Mat Replacement. As noted earlier, a repair panel is used when it is desired to replace a damaged panel without removing any of the surrounding panels. Tools that can be used in making the individual mat replacement include a power saw, pry bars, a chisel, a 5/16-inch allen wrench, an adjustable wrench, and a hammer. Removal can be accomplished by sawing the damaged panel and removing it in sections (Figure N-71, page N-80). The damaged panel should be cut with a power saw in the sequence shown in Figure N-71. The depth of the cuts and positioning of the saw are shown in Figure N-71. The saw blade should be carbide-tipped for best results. A lubricant added to the saw blade will aid in preventing the chips from sticking. Care should be taken not to cut into the adjacent mat panels and locking bars that will remain engaged with the undamaged panels adjacent to each end of the panel that is to be replaced. It will be necessary to break some of the material at the ends of the cuts, as the cuts will not go completely through the panel that is to be removed. This can be done with a pry bar and/or chisel. After all cuts are made, the small triangular sections (shaded area in Figure N-71) are removed initially to provide access to the larger sections in the removal operation. Then the material at the ends of the cuts is broken. A pry bar should be used to force up section A. This part can then be unhinged and removed. Then section B should be forced up, unhinged, and removed. Prying up section E will help to break off section C, if section C has not already been separated from the rest of the damaged panel. Section C is removed and the adjacent panels can be lifted slightly so that section E can be removed easily. This procedure is repeated for sections D and F. Once all parts of the damaged panel have been removed, all soil or debris that may have collected in the surrounding mat panel connectors and any debris in the area where the repair panel is to be placed should be removed.

The procedure listed should then be followed in the installation of the repair panel (Figure N-72).

- Disassemble the repair panel by removing the 1/2-13UNC (unified coarse thread screw, 1/2 inch long, with 13 threads per inch) with 1 1/2-inch-long socket-head cap screws from the male connector clamp and by removing the upper-end connector clamps at each end of the panel with a 5/16-inch socket-head wrench.
- Position one lower-end connector clamp so that it engages the locking bar that is locked to section A, and one lower-end connector clamp so that it engages the locking bar that is locked to section D.

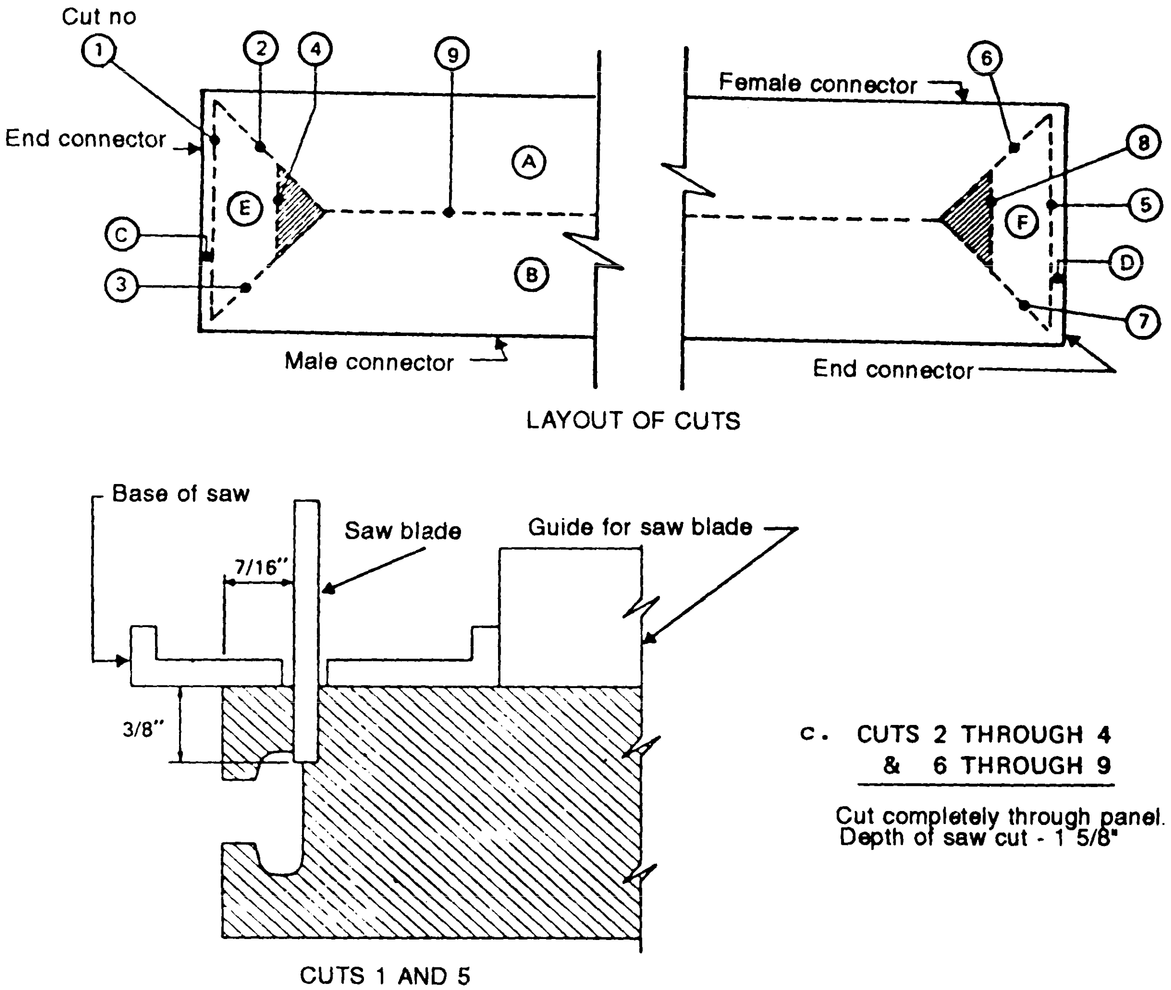


Figure N-71. Sequence for cutting method of individual panel removal

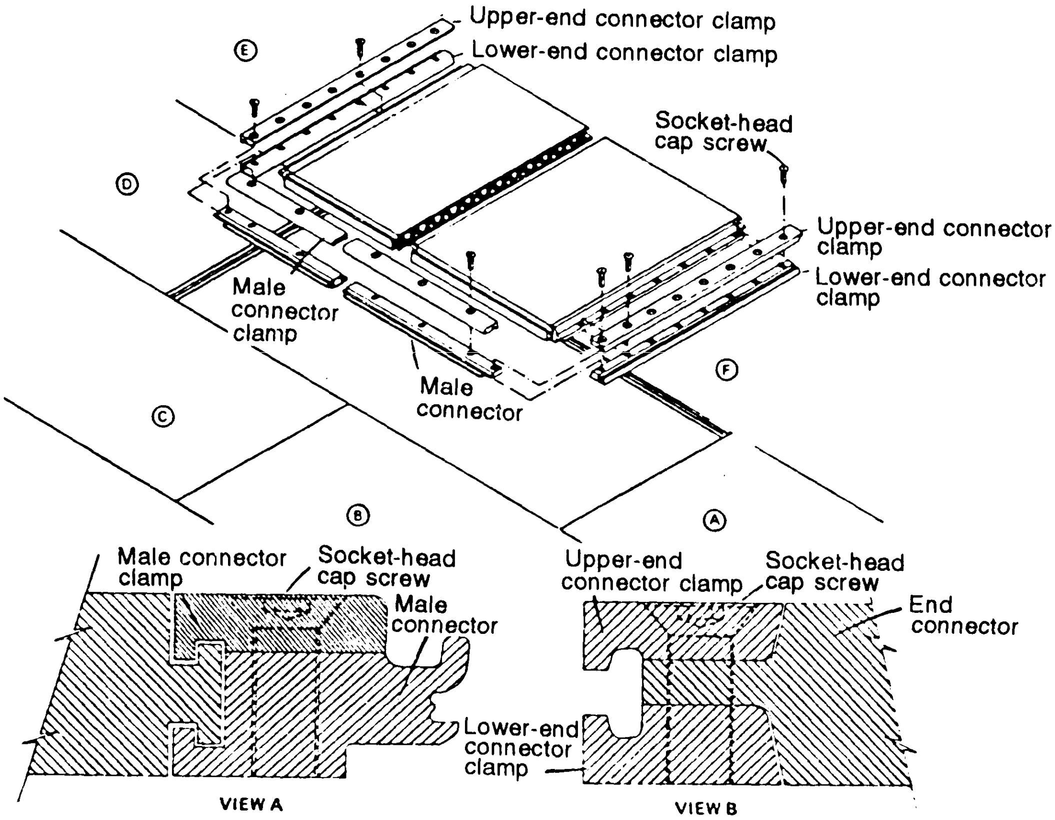
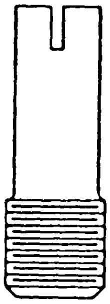


Figure N-72. Typical installation of a repair panel

- To simplify positioning of loose pieces so that the socket-head cap screws can be conveniently installed in the proper sequence, screw one of the threaded locating pins (Figure N-73) four or five turns into the end-threaded hole of the lower-end connector clamp that is nearest sections B and C. Also, screw one threaded locating pin four or five turns into the center hole of each lower end connector clamp. (If these locating pins are not available, a round punch may be used to make the alignment: however, care must be taken not to damage the threads in the male connectors and the lower-end connector clamps.)

Figure N-73. Locating pin



- Position the repair panel male connector on the subgrade so that it engages the female connectors of sections B and C so that the end holes fit over the locating pins that have been temporarily screwed into the end holes in the lower-end connector clamps.
- Hook the female connector of the repair panel over the male connectors of sections E and F and lower into position over the locating pins in the lower-end connector clamps.
- With the aid provided by the locating pins, position an end-connector upper clamp at each end of the repair panel. Install socket cap screws in all open

holes in the end connector and tighten four or five turns.

- Taking care not to disturb any of the repair mat pieces, remove the locating pins at the ends of the end connectors one at a time and replace them with socket-head cap screws.
- Remove locating pins at the center of the end connectors and replace with socket-head cap screws.
- Position the male connector clamp over the repair-mat male connector and over the repair panel. Insert the socket-head cap screws in each hole and tighten gently.
- Tighten each screw in the repair mat assembly.

Method 2: Mat Replacement by Removing Access Adapters. When it is necessary to remove one or many panels to replace damaged mats or to repair the subgrade, mat removal and replacement can be accomplished by sliding out an adjacent run of either access adapters or mat panels. The methods used to remove the access adapters or a run of panels are described in the following paragraphs:

- *Access adapter removal method.* With a tooth of the scarifier on a motor grader or other power equipment, engage the end of the access adapter and push out the entire run of adapters. If a binding condition exists, it may be necessary to slide out only one or two adapters at a time. The binding condition may be caused by distortion of adj scent mat and/or the access adapters or by debris that has migrated into the connectors. A light application of oil poured along the sliding joints will assist in removal.

  Once the access adapters have been removed, the first run of mat panels that is to be removed must be raised high enough to slide out the locking bars. This can be done with blocking and pry bars. It is necessary to raise this run of mat panels only high enough to slide the locking bars out over the adjacent parallel run of mat on the runway. The bars can be removed by inserting a piece of wire or a sharp, pointed instrument into the locking bar holes and pulling the bars out.

  The remaining mat panels that must be removed in order to gain access to the damaged area are then taken up. If necessary, the subgrade is repaired. The mat is replaced in the manner previously described for mat placement until the run is in place. The mat in the last run must be raised with pry bars to permit the installation of the locking bars. The access adapters are then replaced in reverse order from which they were taken out.

- *Mat panel removal method.* A run of mat near the area where repair or replacement is necessary can be removed in the manner described for removal of a run of access adapters. As the panels are slid out, the locking bars are removed. A light application of oil along the sliding joints will assist in the removal. Once this run of the mat has been removed, the rest of the mat panels that must be taken up in order to gain access to the damaged area can be removed. After the repair has been completed, the mat is replaced in the manner previously described for mat placement until the last run is replaced. At this point, the mat in the last run is slid back into the runway with the aid of power equipment. As the panels are slid back into position, the ends of adjacent panels are connected with locking bars.

Replacement of Antiskid Coating

Replacement of antiskid coating on the truss-web mat is necessary when the original coating has been removed, loosened, or charred regardless of cause. The antiskid coating should be applied as follows:

- Before application of the antiskid coating, all loose coating should be removed by brushing the surface of the mat thoroughly with a stiff-bristled brush. All loose matter should be removed from the brushed area by wiping thoroughly with a clean, lint-free rag or by sweeping with a clean broom. Any grease or oil should be removed with denatured alcohol (specification MIL-A-9061C) applied with a clean, lint-free rag. The alcohol should be confined to the metal surface to be cleaned and must not contact any undamaged antiskid coating.

- The application of the antiskid coating should not be started or completed if (1) the ambient temperature is under 40° F, (2) the area to be coated is wet, or (3) rain or snow is expected to fall within 24 hours after the start of the repair. A dry period of 24 hours is necessary before the recoated mat can be used. Any rain or snow during this 24-hour period will necessitate the removal of the repair coating using methyl ethyl ketone (specification TT-M-261B) and the repetition of the repair procedure.
- The antiskid compound should be thoroughly stirred before application and agitated periodically to ensure that the abrasive particles remain in suspension. The compound should be brushed, sprayed, or troweled on at a thickness of approximately 1/16 inch and allowed to cure for at least 24 hours before the repaired area is subjected to any kind of traffic.

Removing, Cleaning, and Bundling Panels for Reuse

When an airfield is no longer needed, the mats can be removed, cleaned, and bundled for reuse at another location. When the mat field is removed, care should be taken not to break or bend the locking bars or damage the mat or any of the ancillary items. Upon removal, individual panels should be examined in detail to determine the extent of damage, if any, that has occurred as a result of prior use.

Mat removal. The anchors and anchor attachments should be detached prior to mat removal. The most efficient removal procedure requires disassembly of the mat in reverse order of placement. However, in order to expedite the operation, an entire run of mat or a run of access adapters can be slid out in several places, and at each location, two crews can take up the mat in the opposite order of placement, but the other crew would have to hinge the male connectors out of the female connectors, requiring more time and effort.

While the mat in the interior of a facility is being removed, a crew with earthmoving equipment can remove the backfill at the ends of the runway. Once the backfill has been removed, a crew can then begin removing the mat from each end of the runway toward the transverse centerline.

To remove a mat panel, first the locking bars should be removed by engaging the holes in the bars with a sharp, pointed instrument or wire and then pulling the bars out. Because of binding, it may be necessary to use vise-grip pliers in order to remove some of the bars. This binding may be caused by panel connector deformation and/or debris that has worked its way into the connectors. Once a bar has been removed, the panel can be raised. The side connection is hinged out when the panel is raised to about a 45-degree angle with the ground. The adjacent panel in the same run can be removed next in the same manner. After two or more panels in the same run have been removed, the end panel in the adjacent run can be removed. By continuing this procedure, a stair-step pattern is established during removal.

Cleaning. The connecting and locking features must be essentially free of soil. The soil can be removed from the panels with a hoe or a square-end shovel. Connecting and locking edges may require washing with water under high pressure.

Bundling. Bundles should be about the same size as those of the original shipment of mat and ancillary items. Half, full, and repair panels and the ancillary items should be bundled separately. Steel strapping should be used to secure the bundles.

Criteria for Determining if a Mat is Reusable

The following can be used as a general guide for determining whether the mat can be reused:

Panels will be considered reusable if they will fit together at the sides and ends with a new panel.

Reusable panels may not have any tears or breaks that will present a tire hazard. Panels with ribs that are permanently deformed more than 0.6 inch across the transverse direction are considered unserviceable.

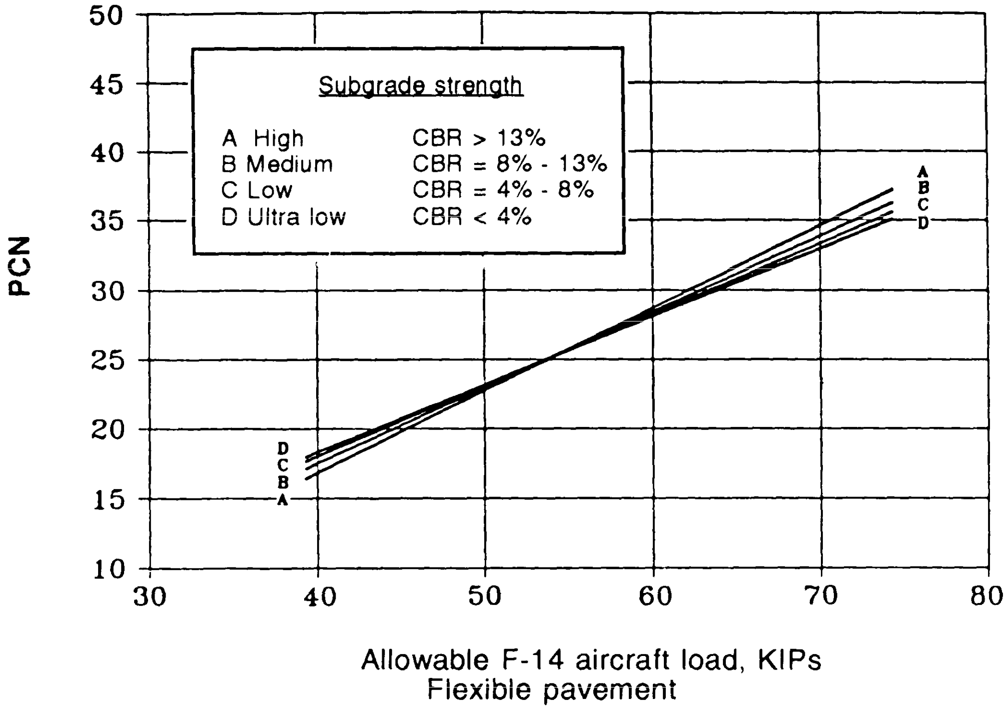
Panels with weld failures at the end connectors are considered unserviceable and must be repaired if the failure is 6 inches long or longer or occurs in two places that together total 6 inches or more in length.

APPENDIX O

PAVEMENT CLASSIFICATION NUMBER (PCN) GRAPHS

Figures O-1 through O-43 are used in determining the PCN values for rigid and flexible pavements, and can be used in determining the ACN for selected aircraft as listed below:

Aircraft	Page
F-14	O-2
P-3	O-3
C-130	O-4
C-141	O-5
C-5A	O-6
C-123	O-7
F-4	O-8
F-111	O-9
C-9	O-10
T-43	O-11
B-727	O-12
E3/KC-135	O-13
KC-10	O-14
B-E4/747	O-15
B-52	O-16
B-1	O-17
OV-10A	O-18
CH-54	O-19
A-300	O-20
B-767	O-21
C-12	O-22
C-17A	O-23
C-20	O-24
C-21	O-25
C-22	O-26
C-23	O-27
C-137	O-28
C-140	O-29
SR-71A	O-30
T-33A	O-31
T-37B	O-32
T-38A	O-33
T-38B	O-34
CT-39	O-35
OA-37B	O-36
A-10	O-37
A-7	O-38
F-5	O-39
F-16	O-40
F106A/B	O-41
F-100	O-42
EC-18	O-43
F-15	O-44



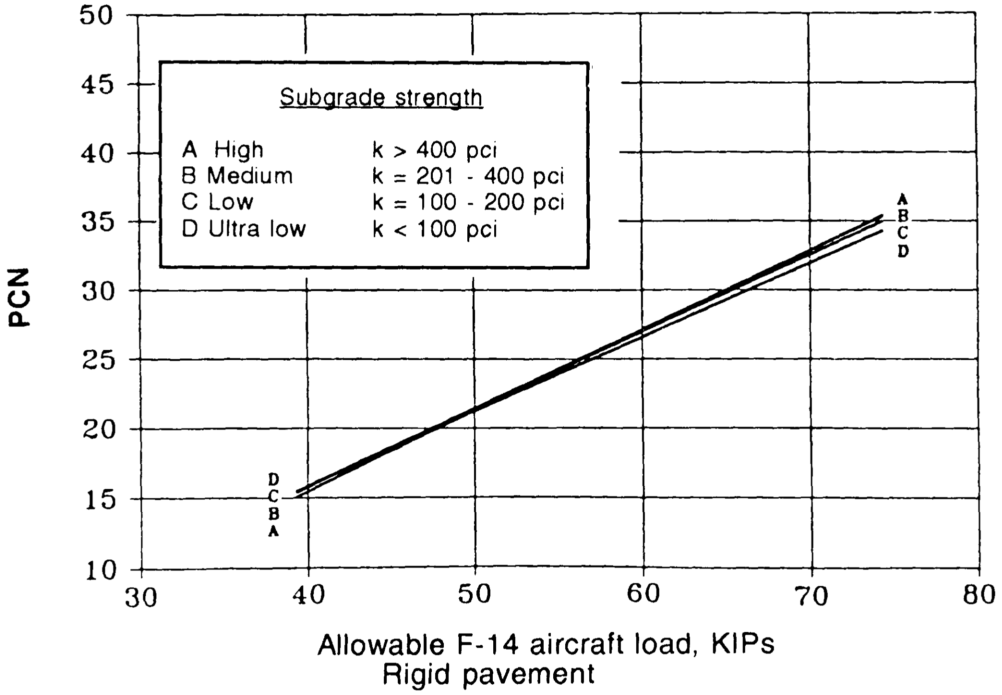
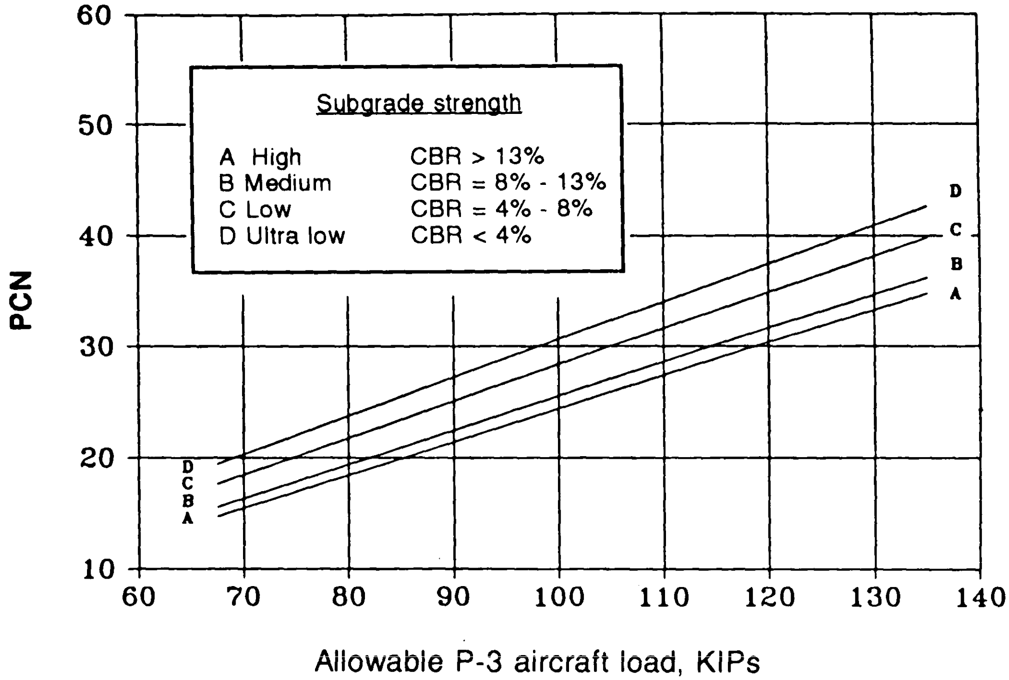
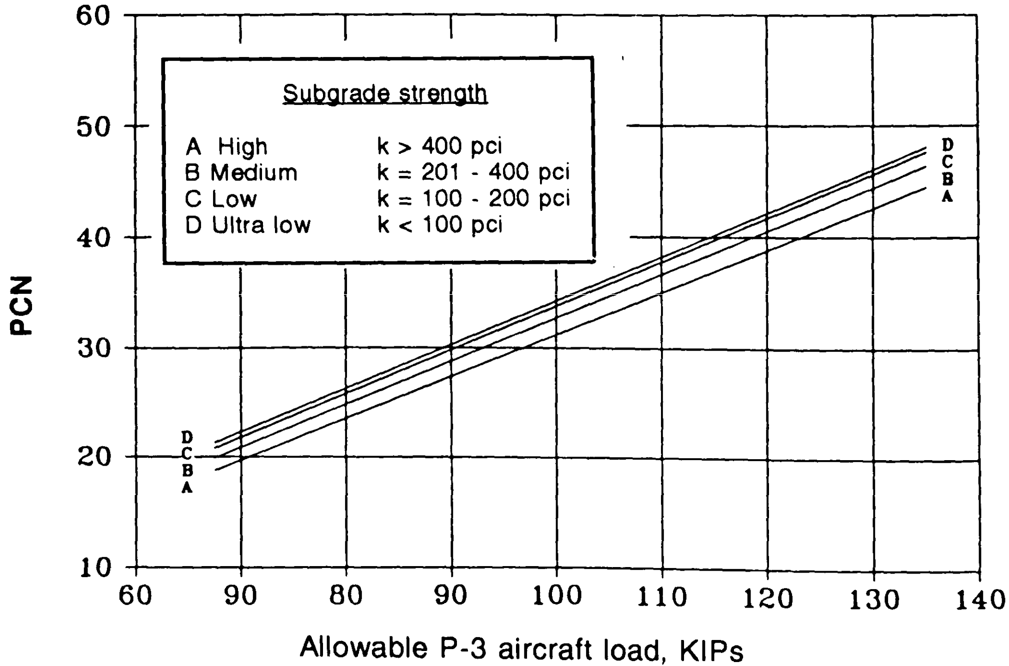


Figure O-1. PCN graphs for F-14

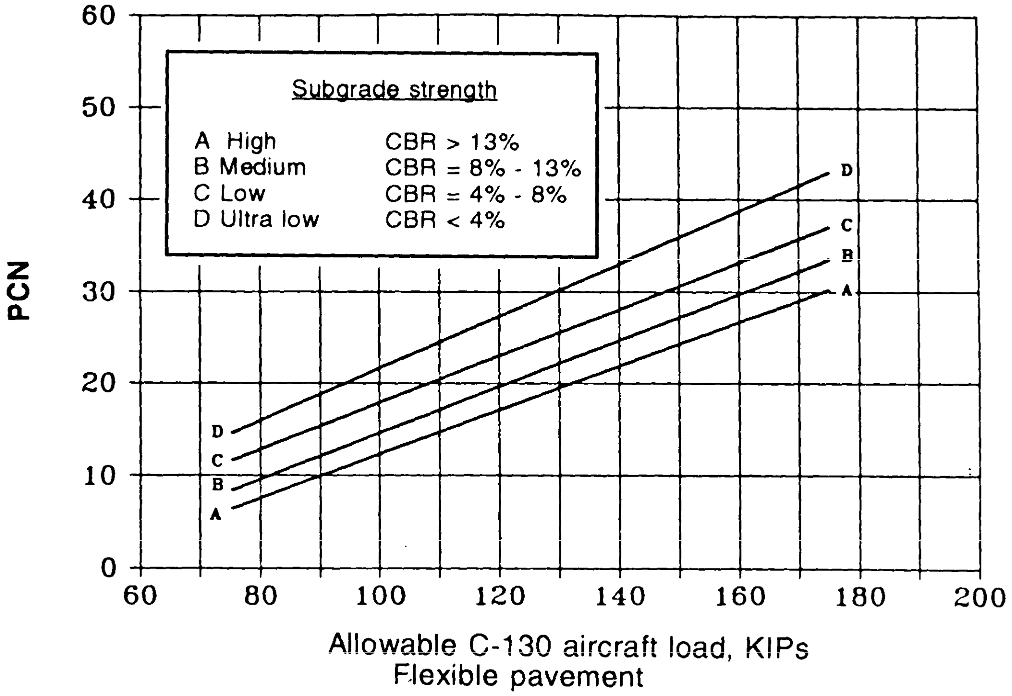


Flexible pavement



Rigid pavement

Figure O-2. PCN graphs for P-3



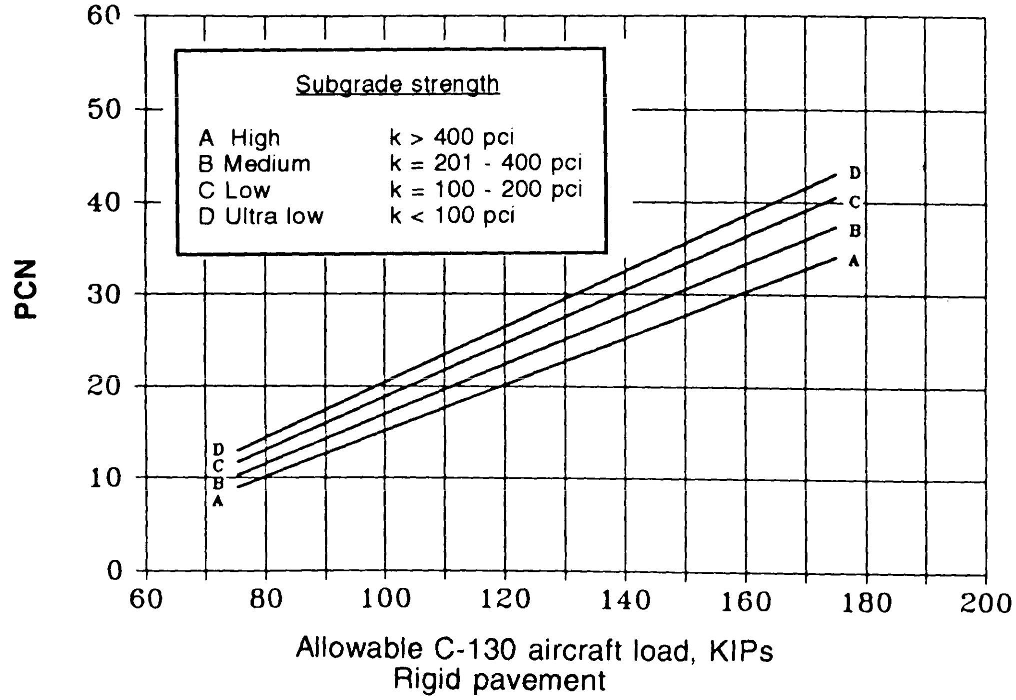
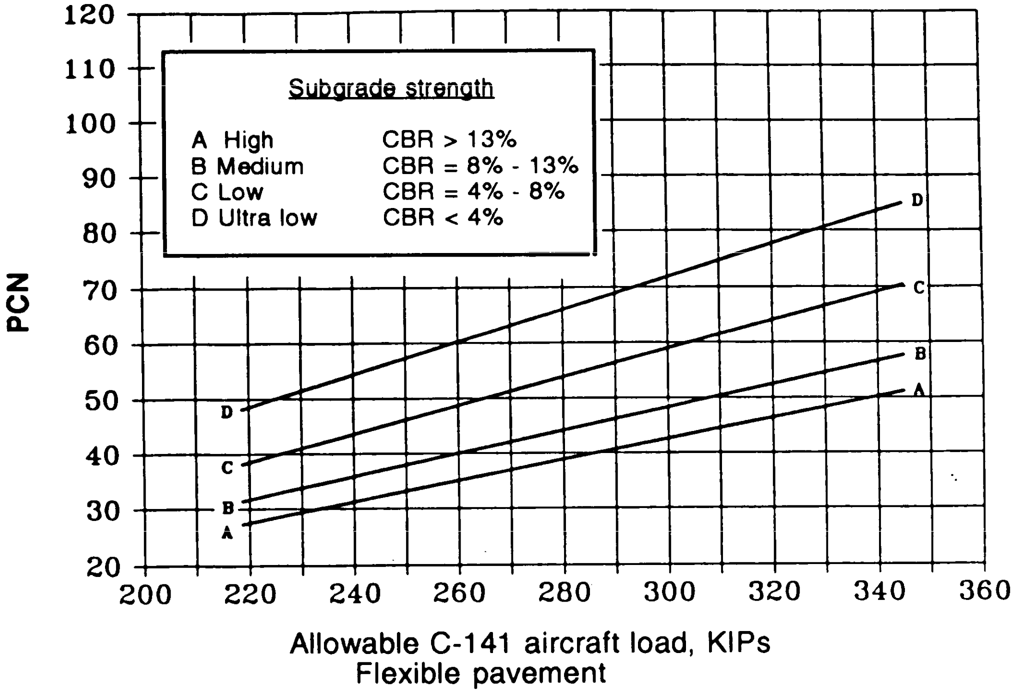


Figure O-3. PCN graphs for C-130.



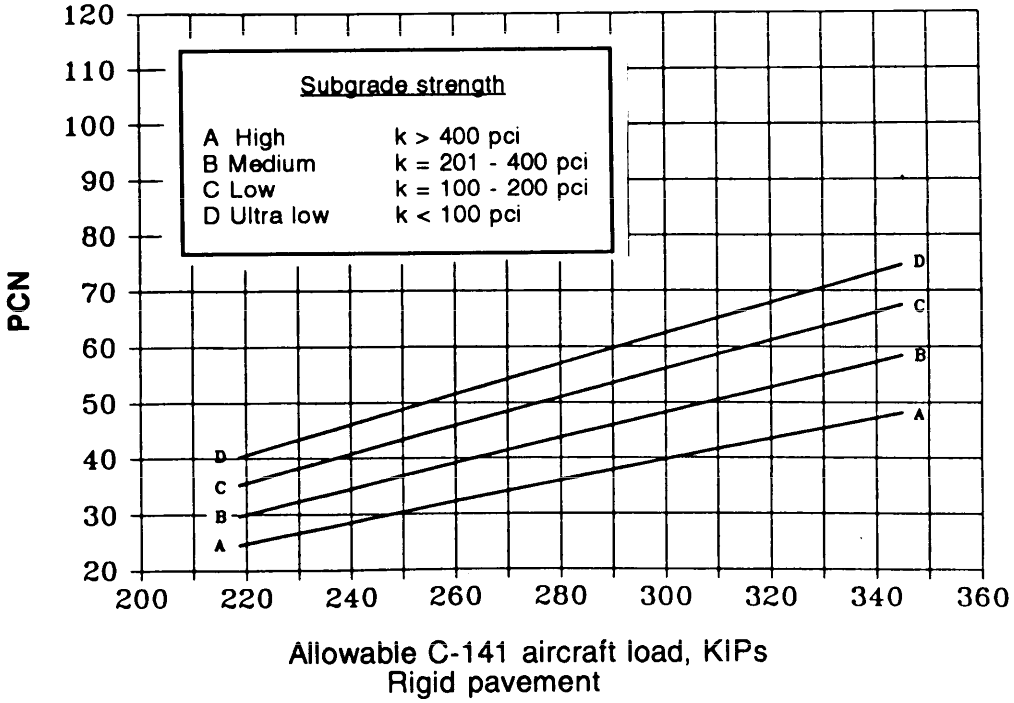
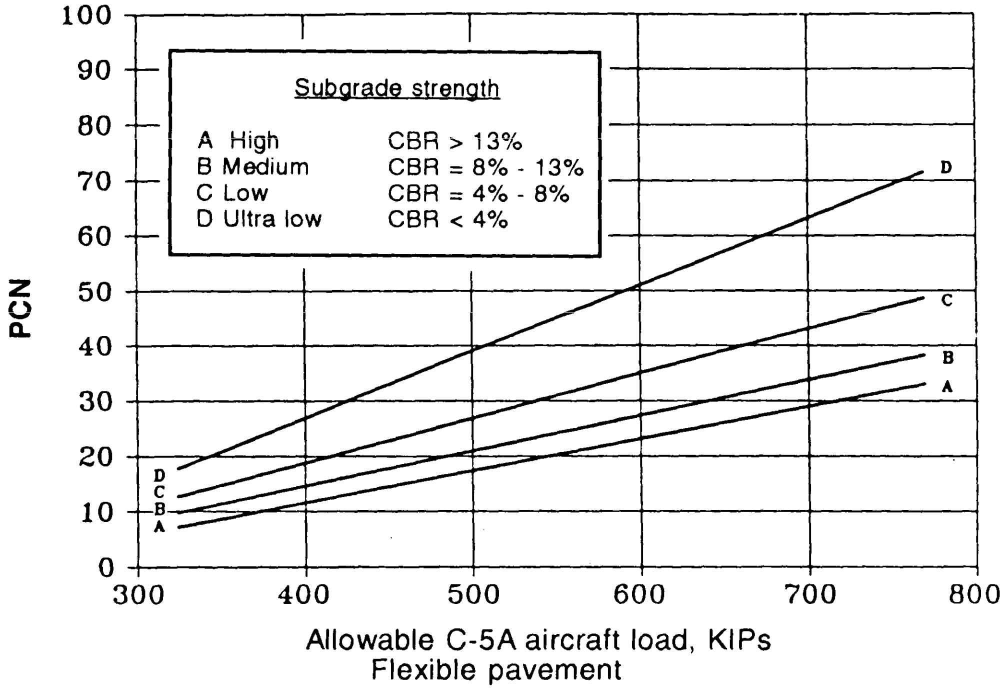


Figure O-4. PCN graphs for C-141



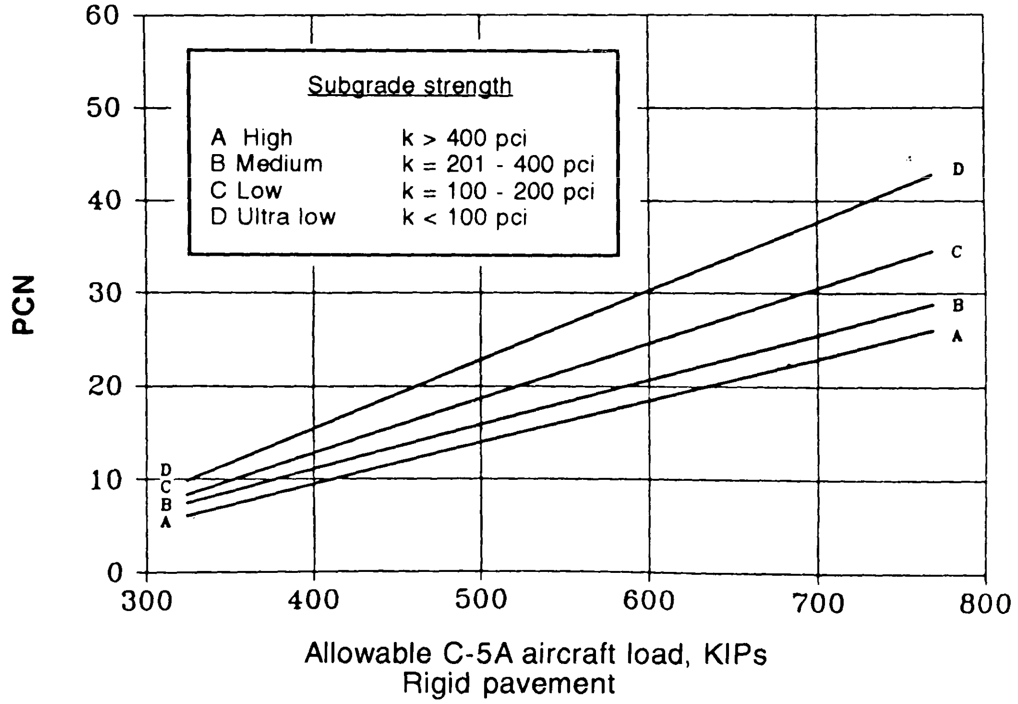
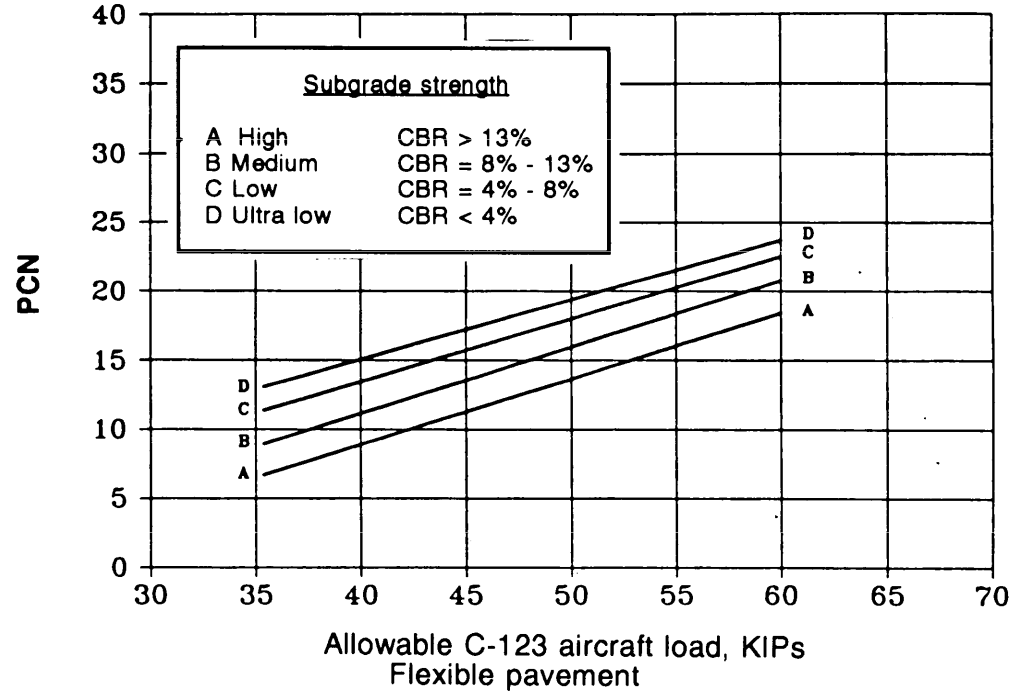


Figure O-5. PCN graphs for C-5A



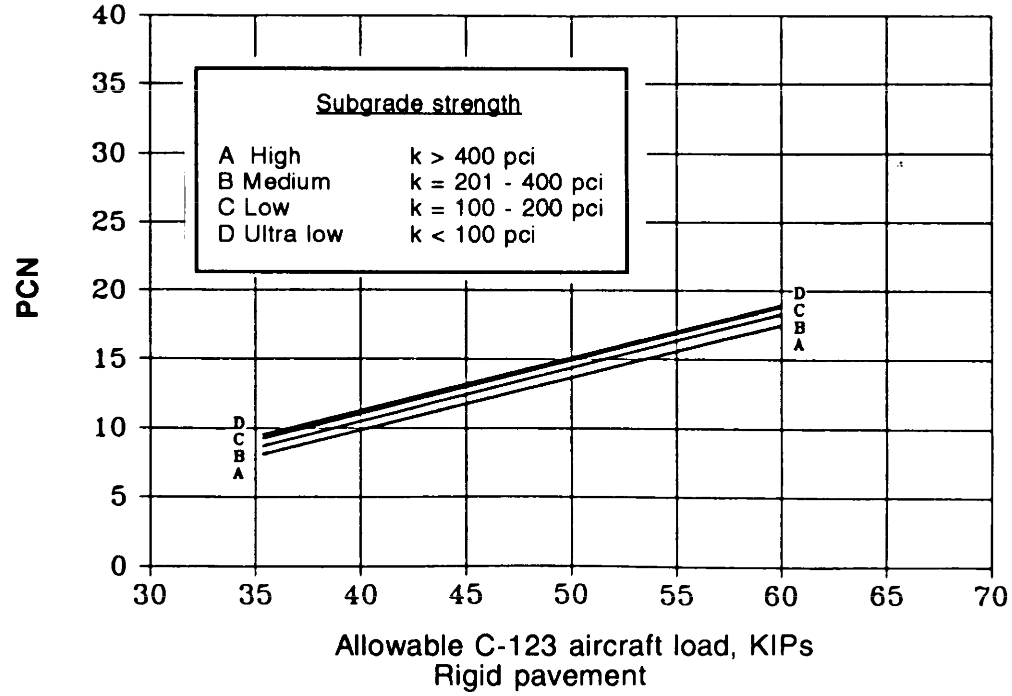
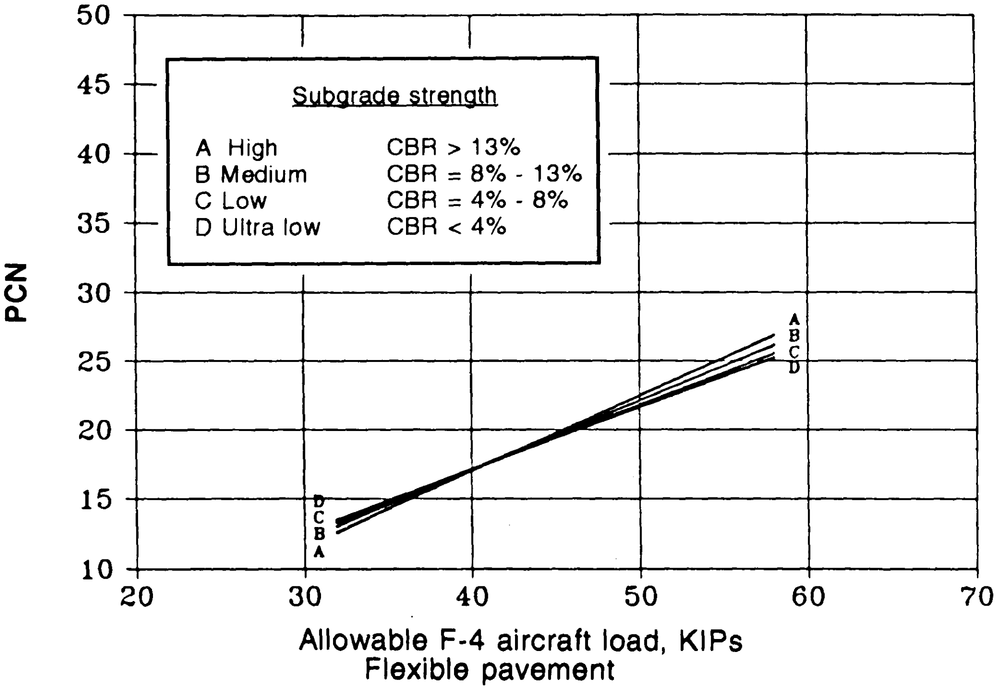


Figure O-6. PCN graphs for C-123



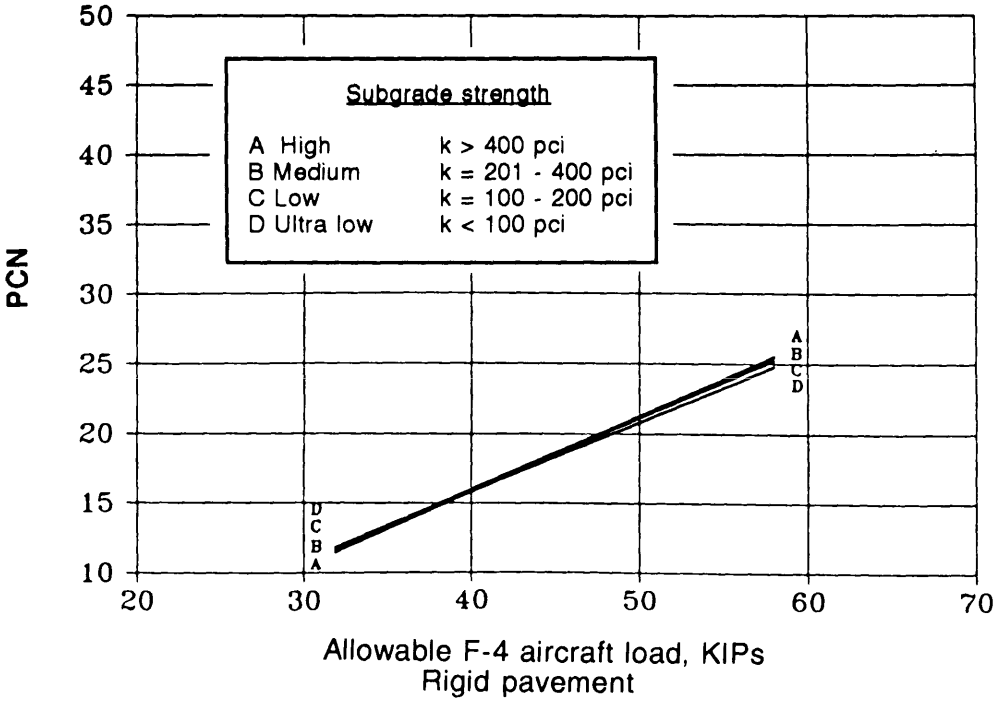
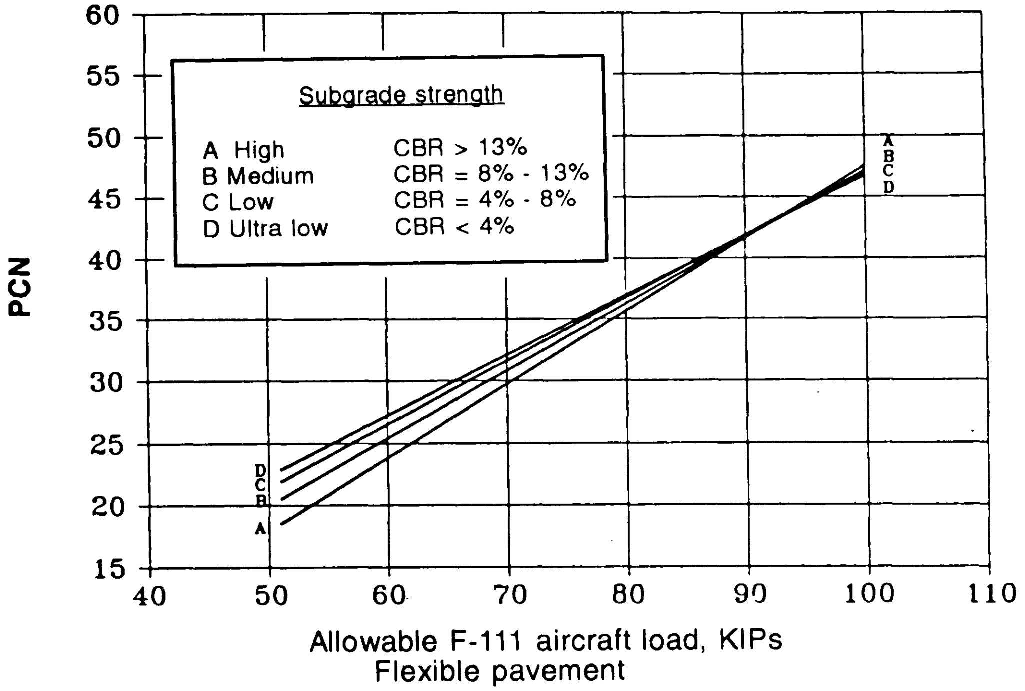


Figure O-7. PCN graphs for F-4



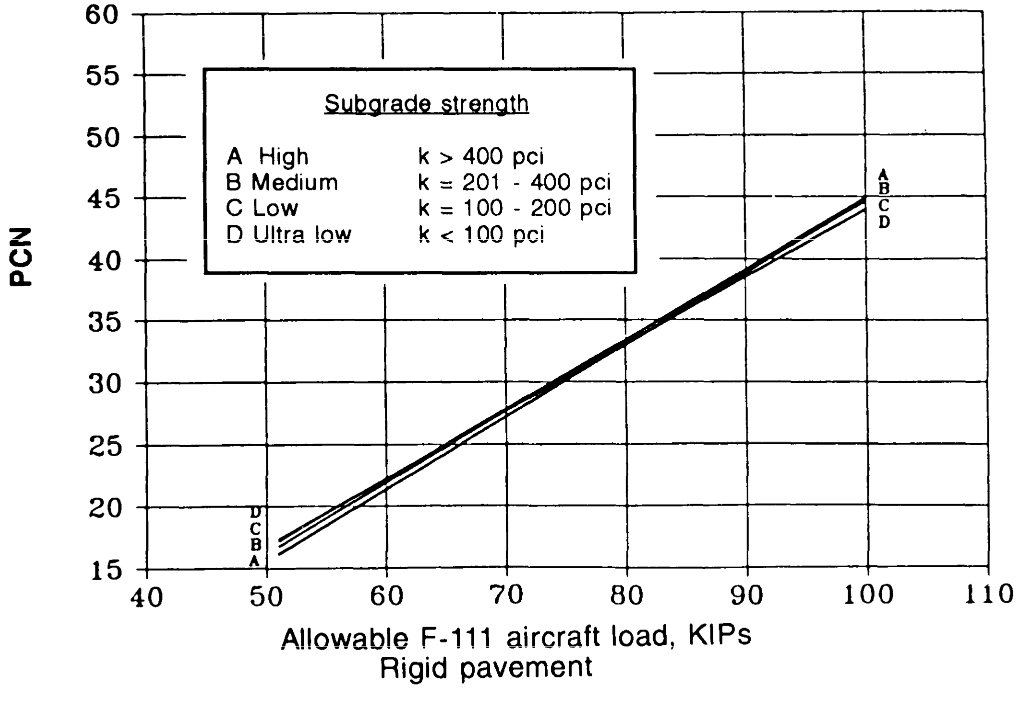
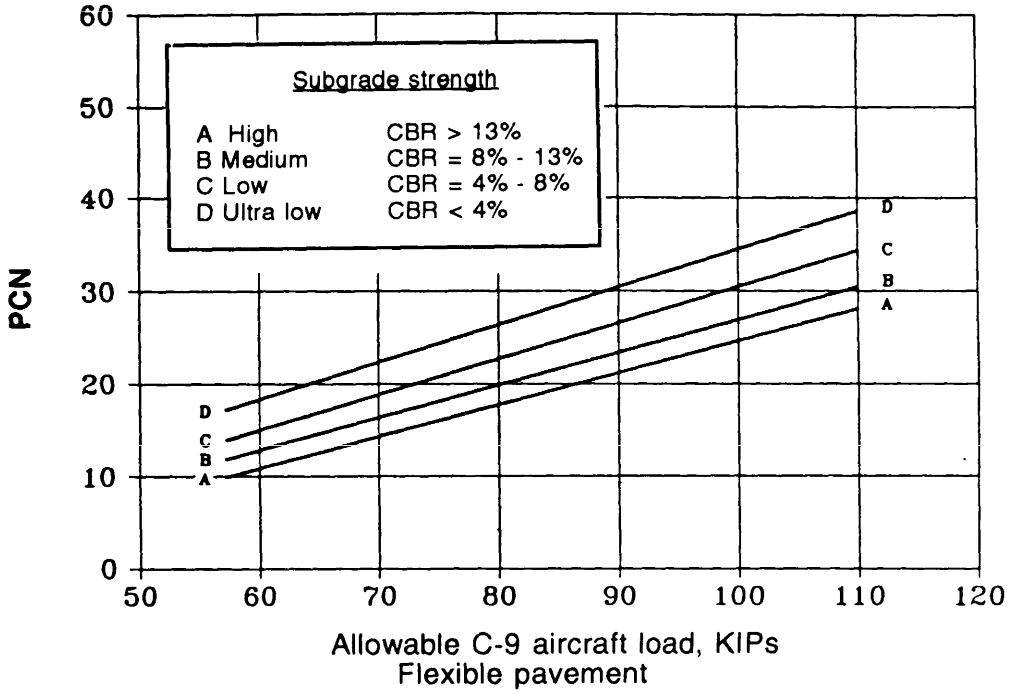


Figure O-8. PCN graphs for F-117



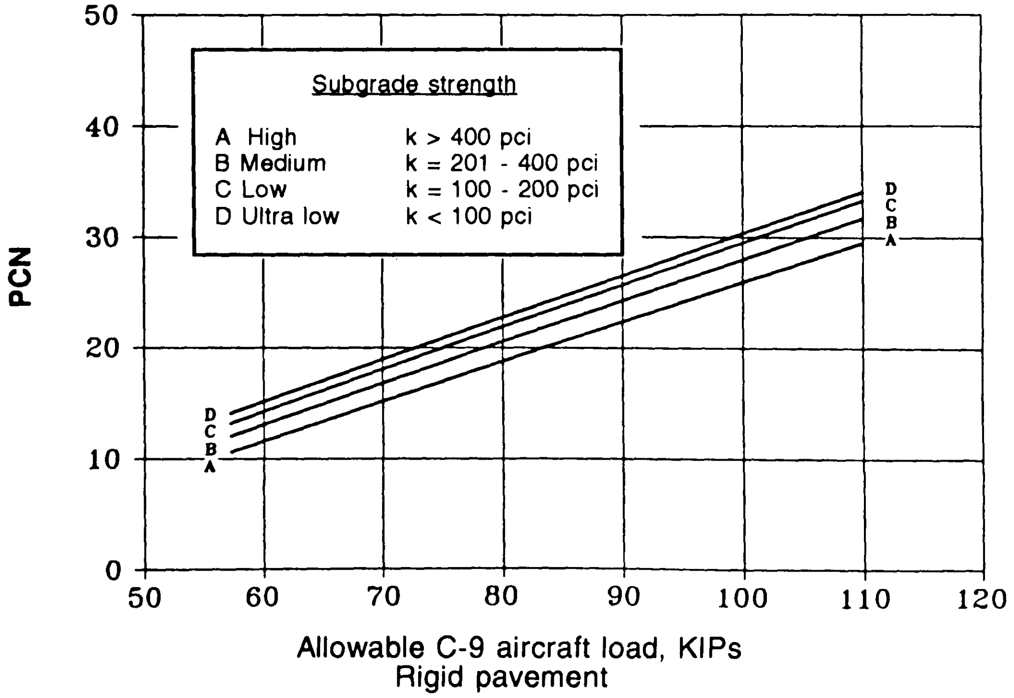
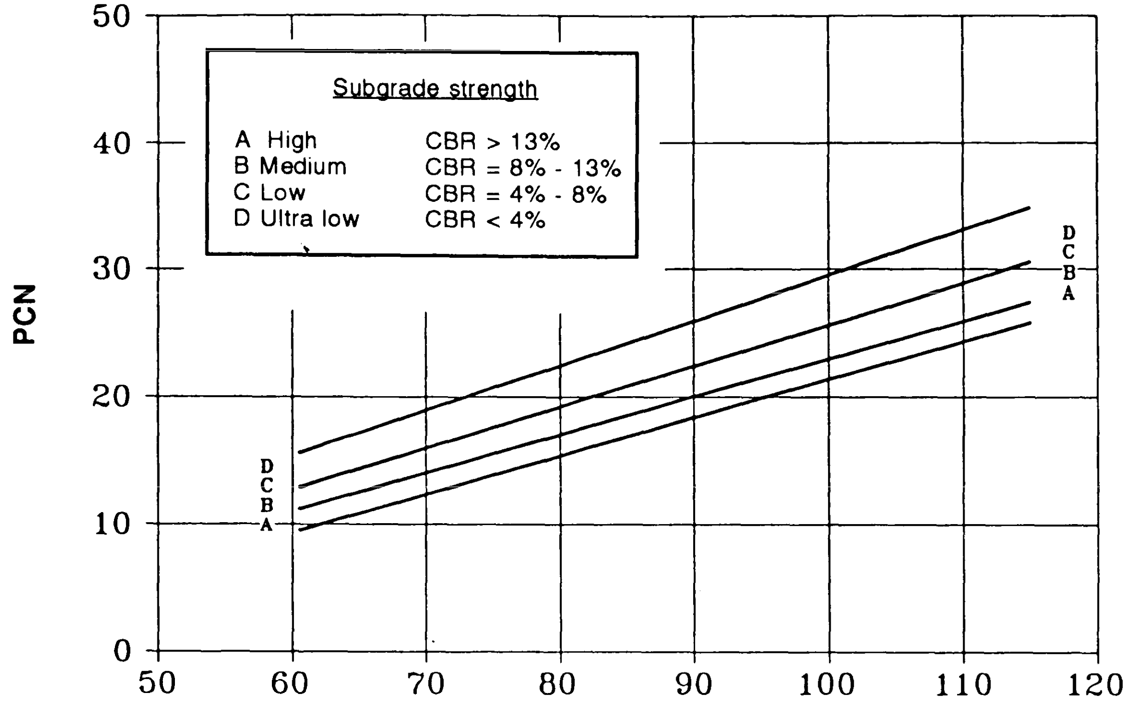
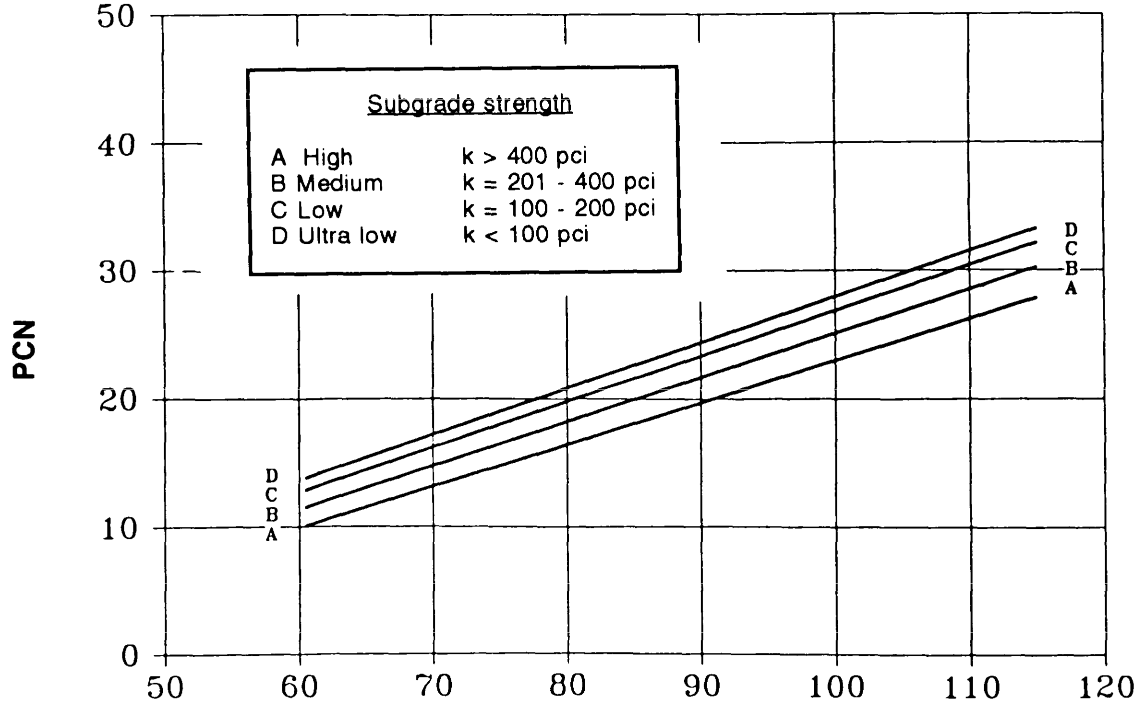


Figure O-9. PCN graphs for C-9

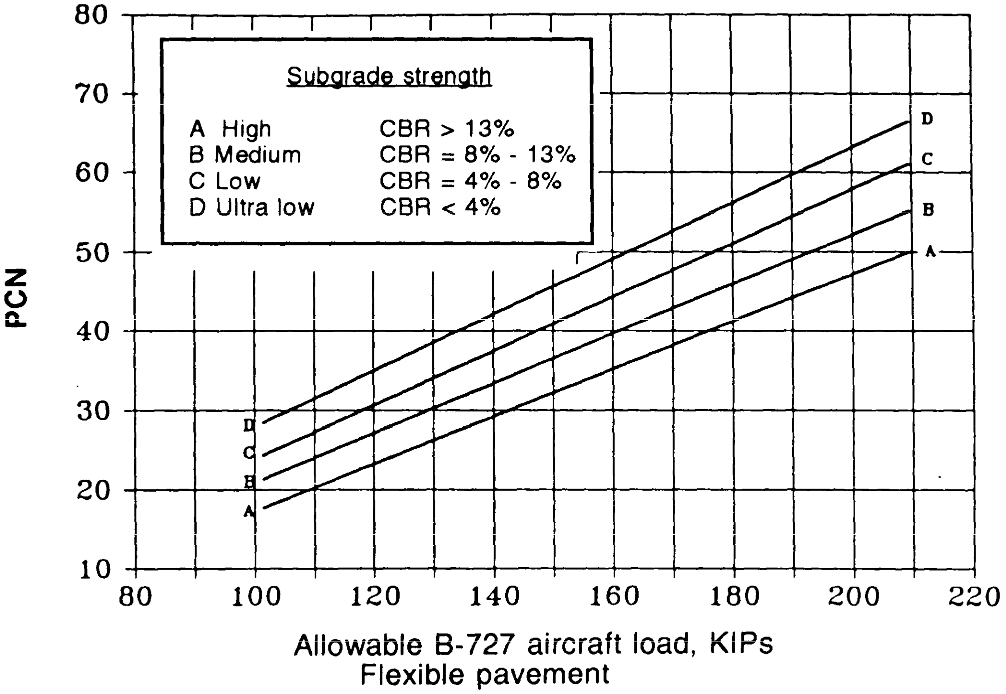


Allowable T-43 aircraft load, KIPs
Flexible pavement



Allowable T-43 aircraft load, KIPs
Rigid pavement

Figure O-10. PCN graphs for T-43



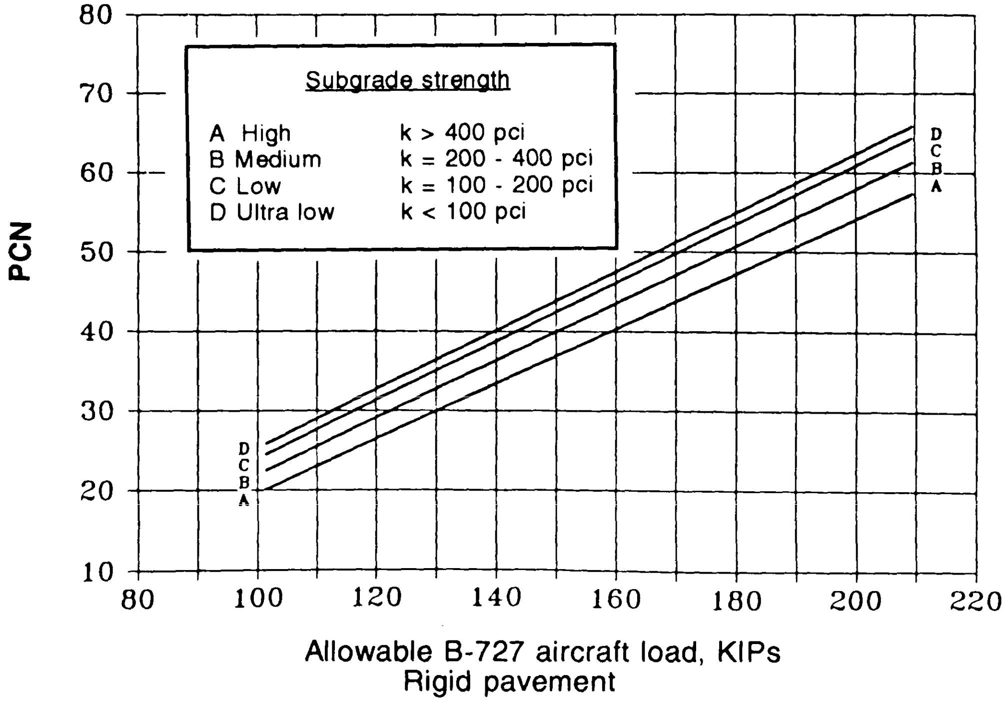
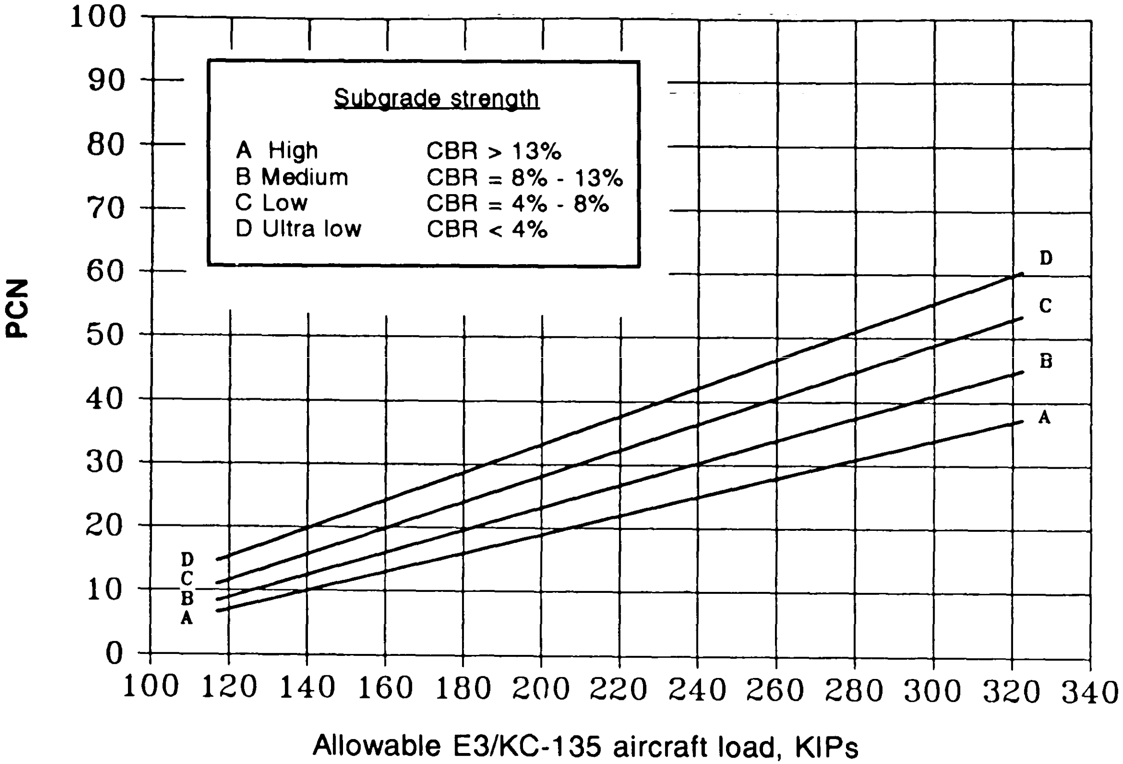
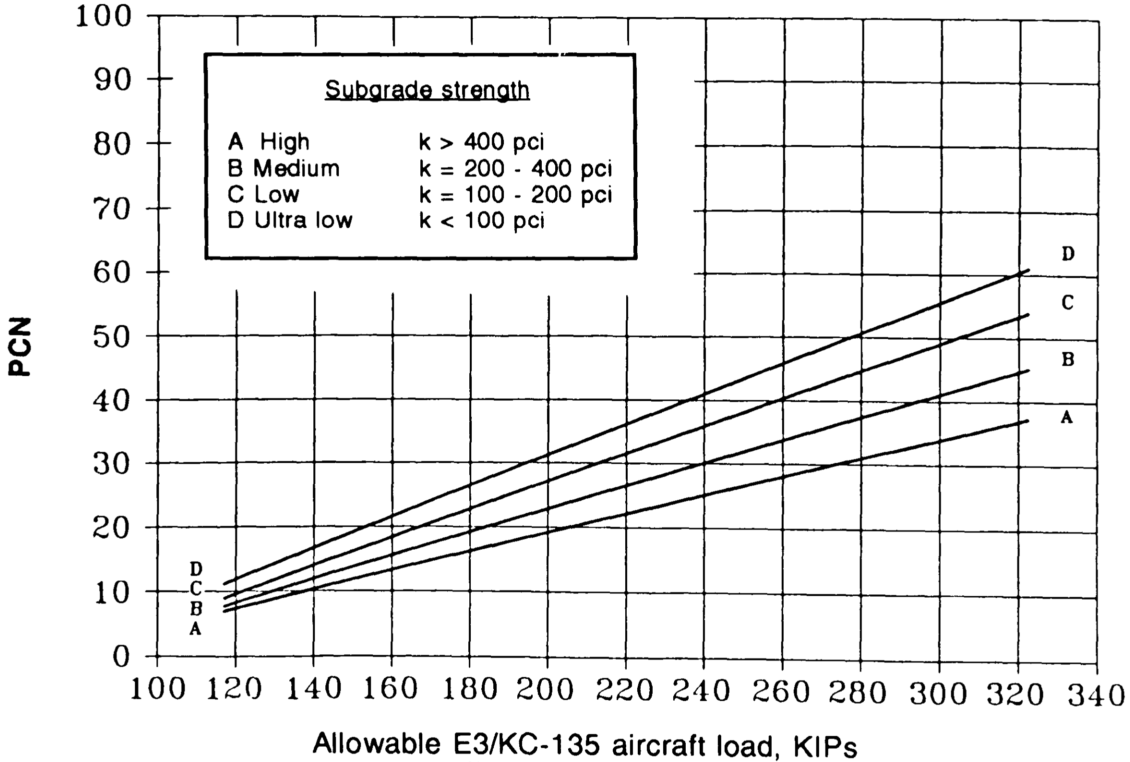


Figure O-11. PCN graphs for B-727

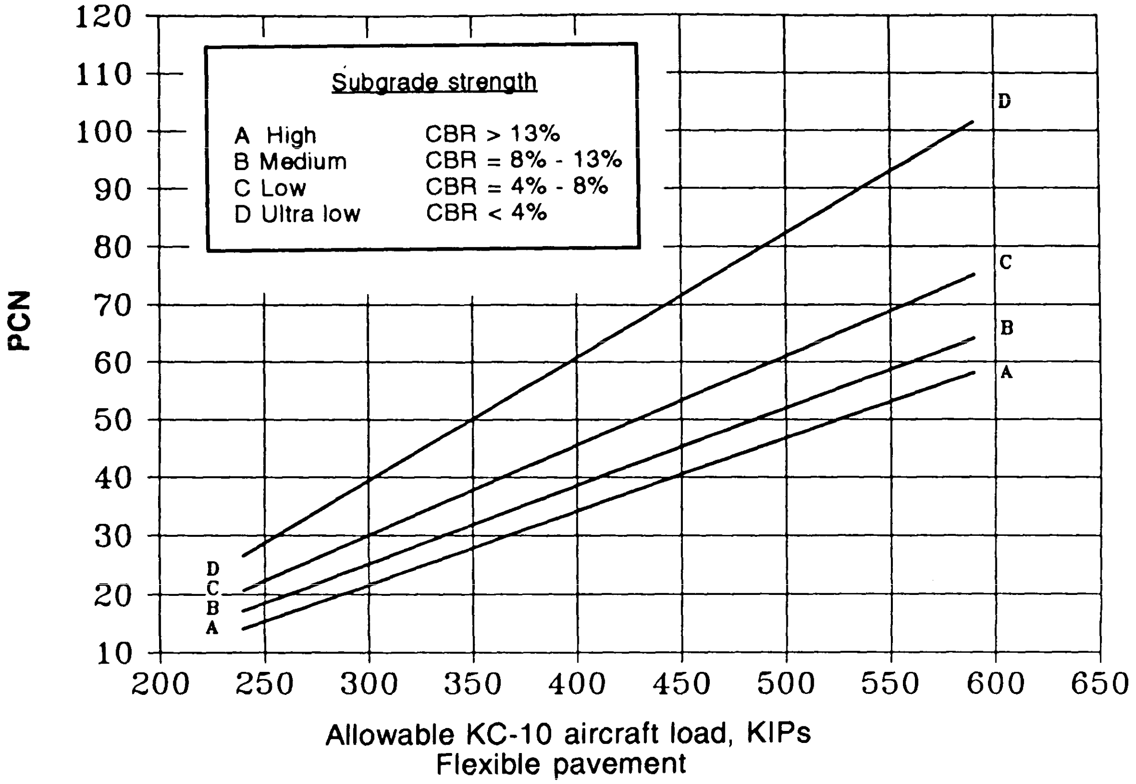


Flexible pavement



Rigid pavement

Figure O-12. PCN graphs for E3/KC-135



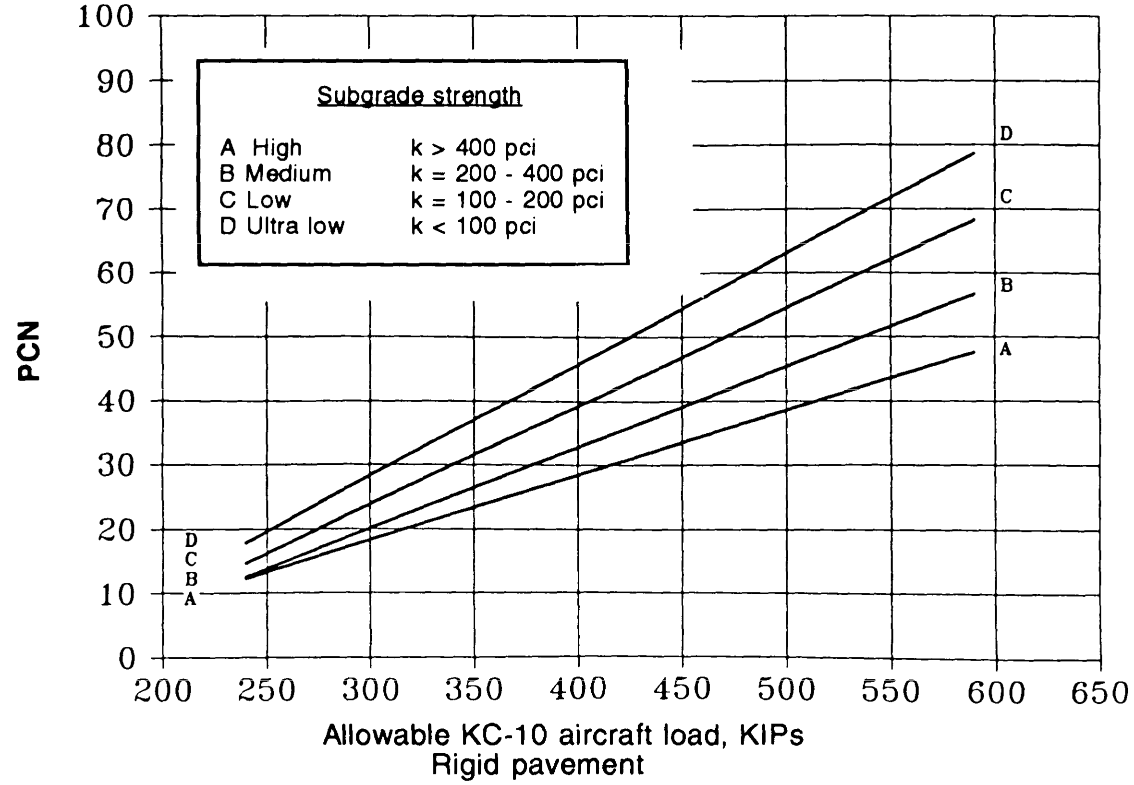
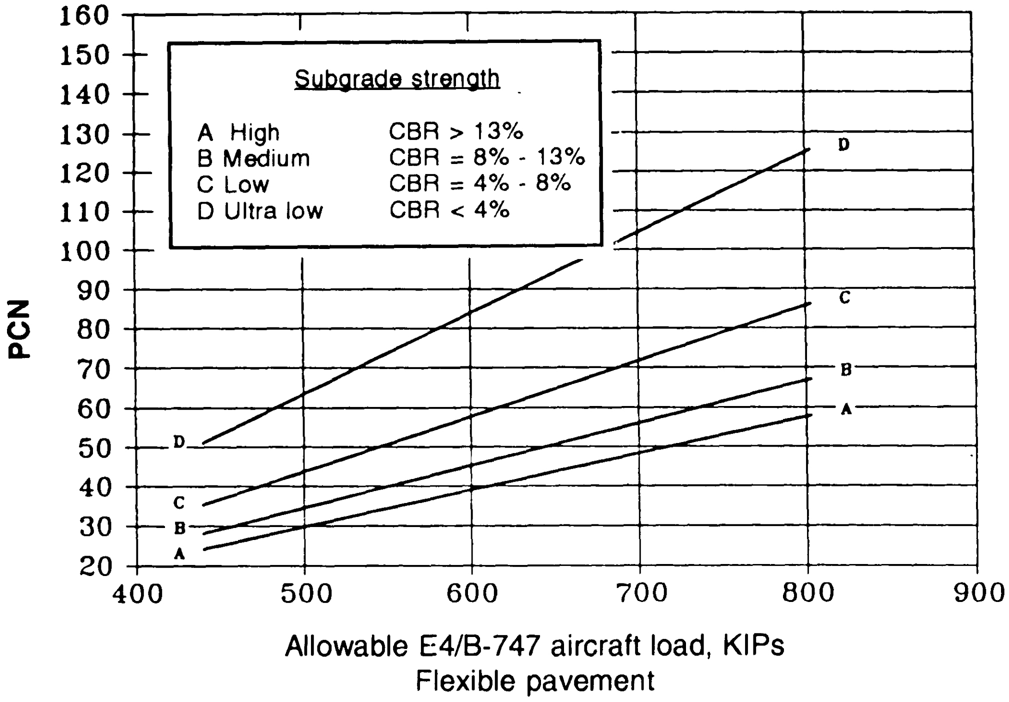


Figure O-13. PCN graphs for KC-10



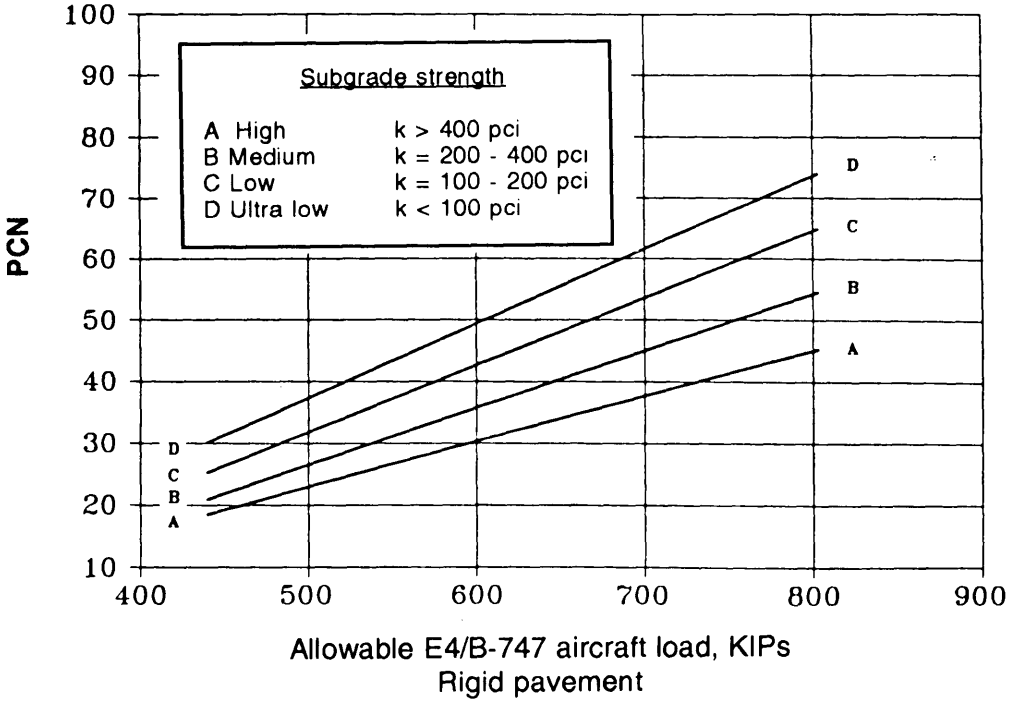
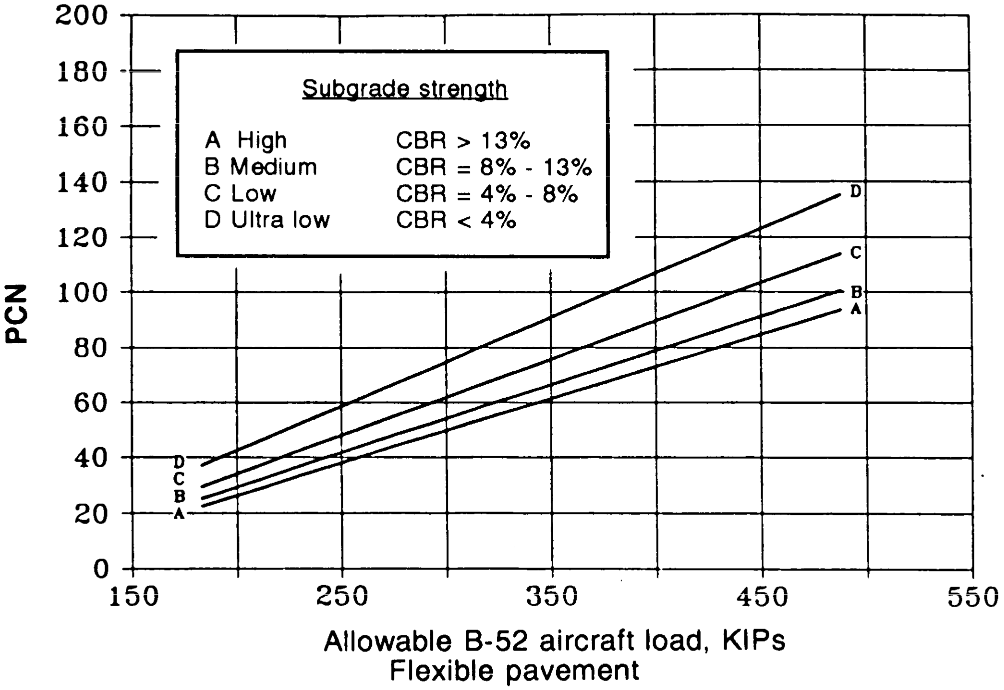


Figure O-14. PCN graphs for E4/B-747



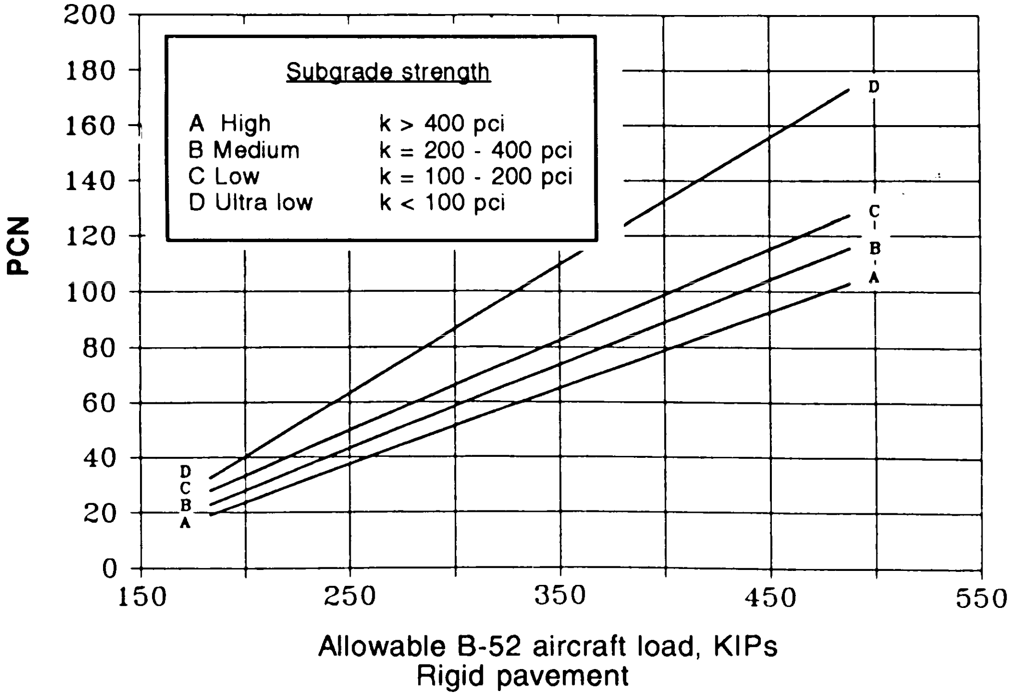
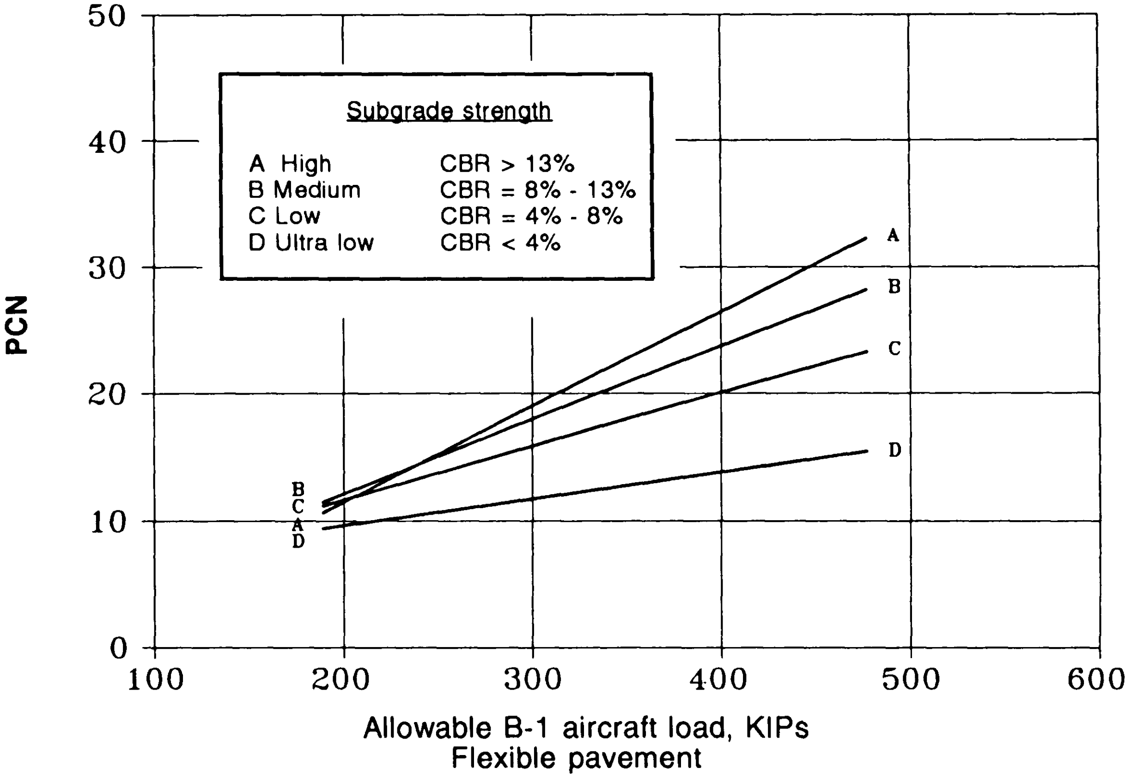


Figure O-15. PCN graphs for B-52



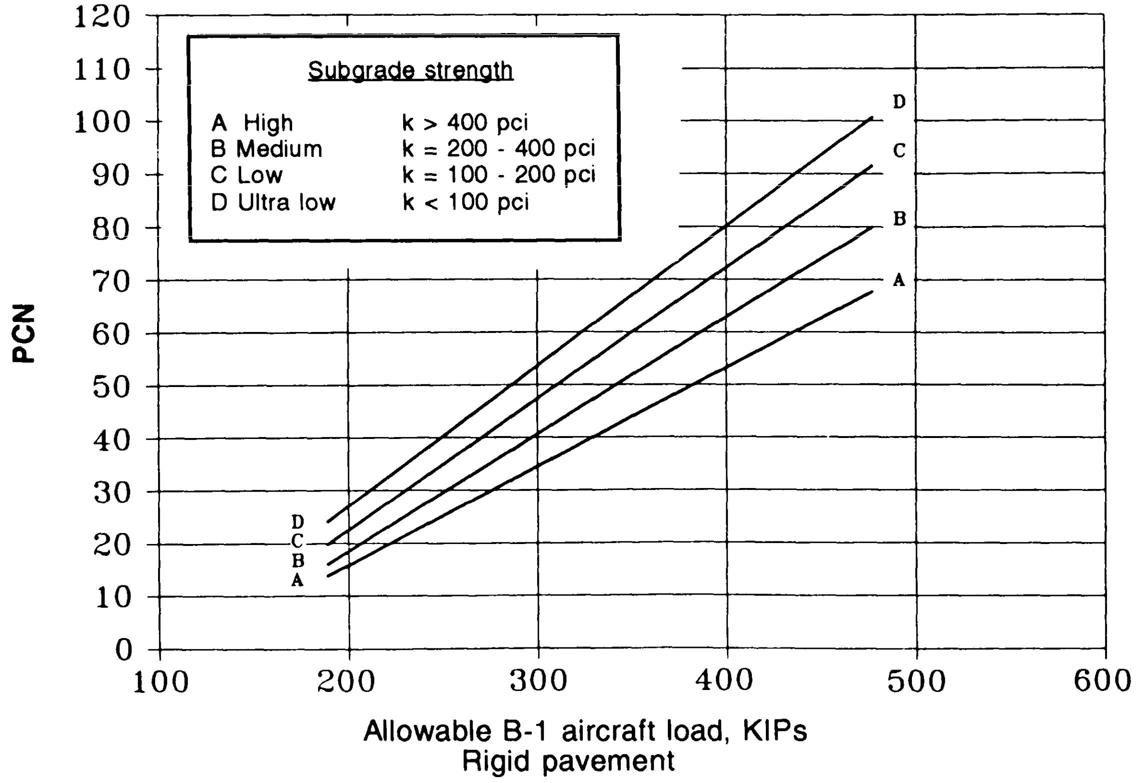
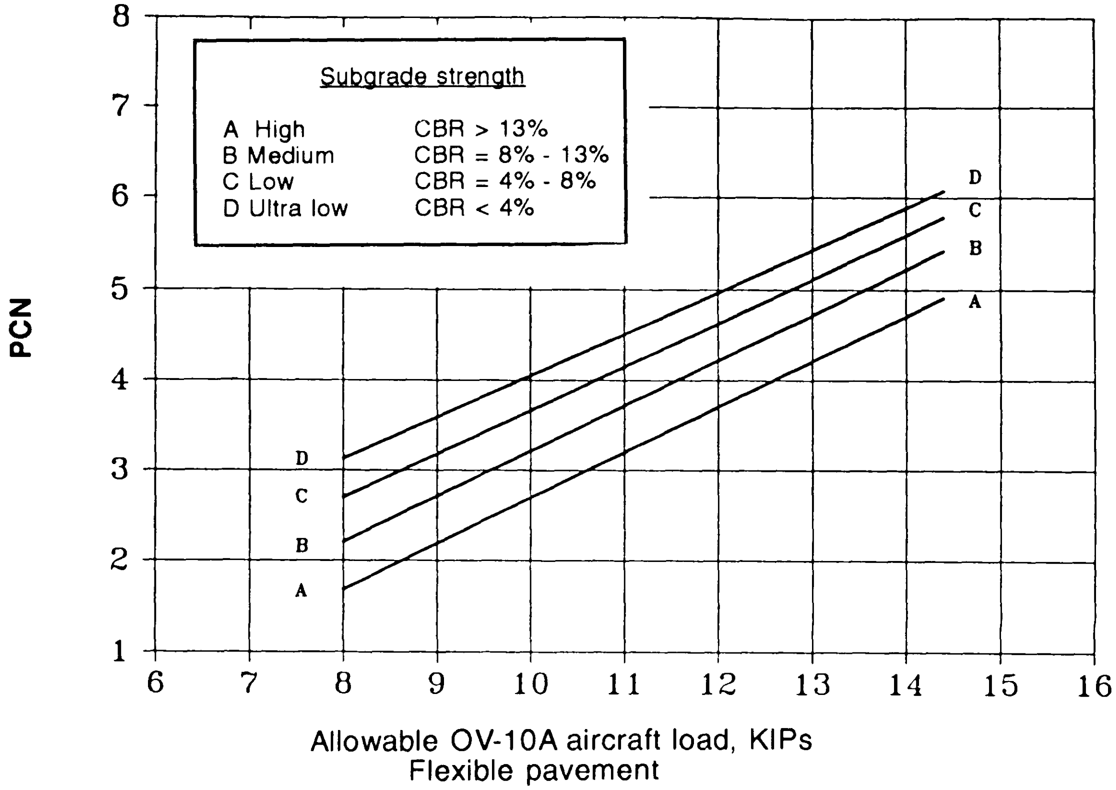


Figure O-16. PCN graphs for B-1



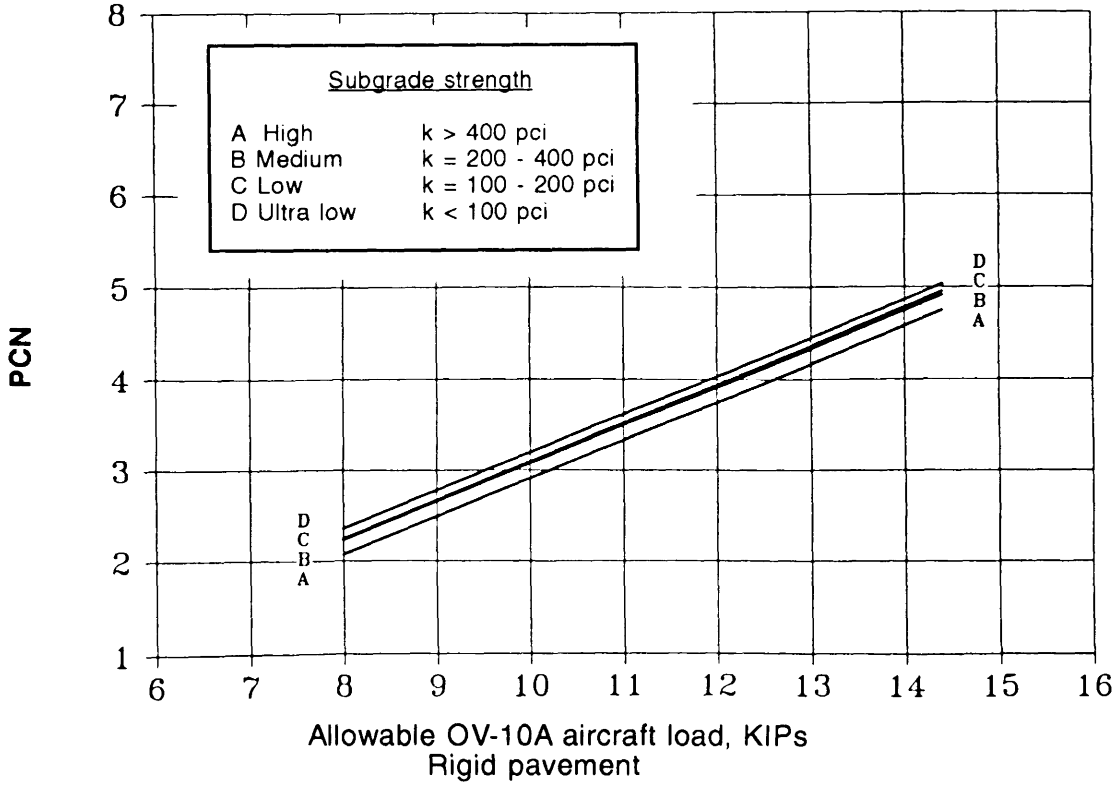
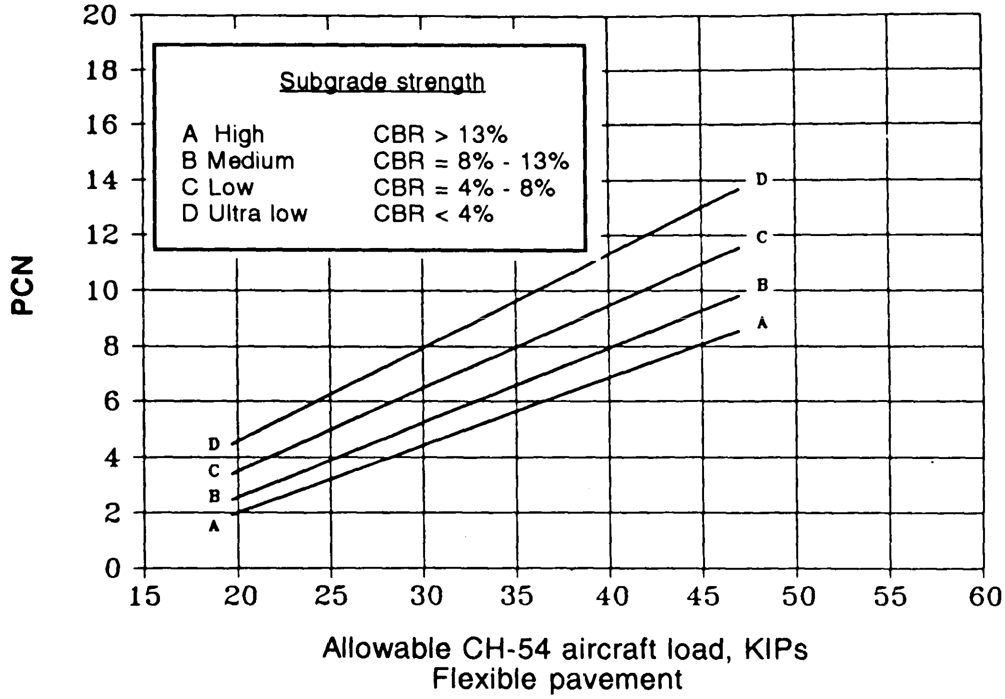


Figure O-17. PCN graphs for OV-10A



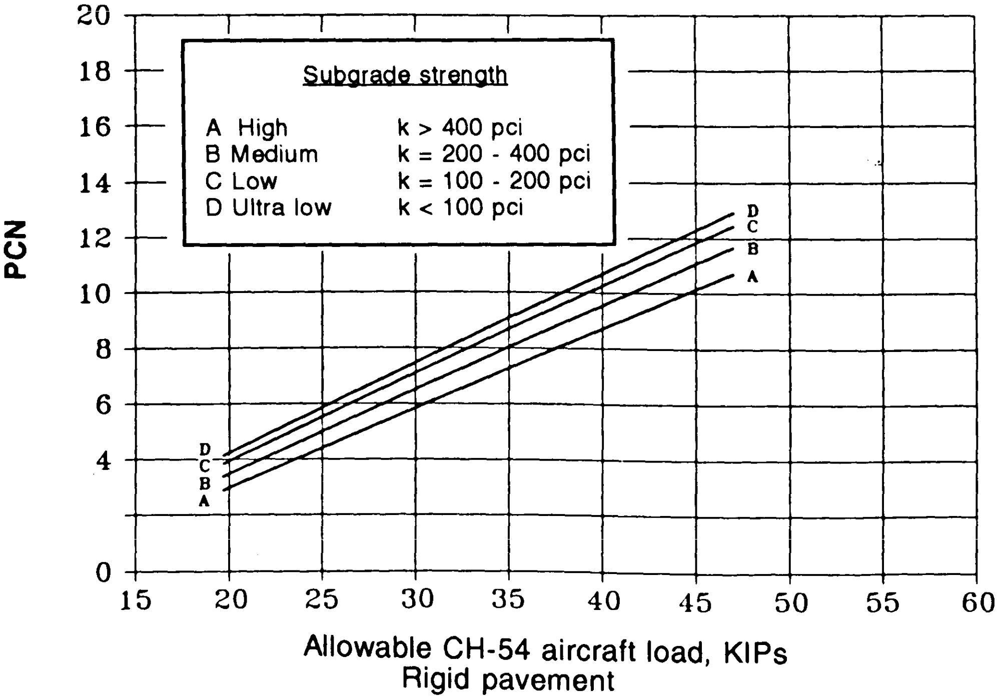
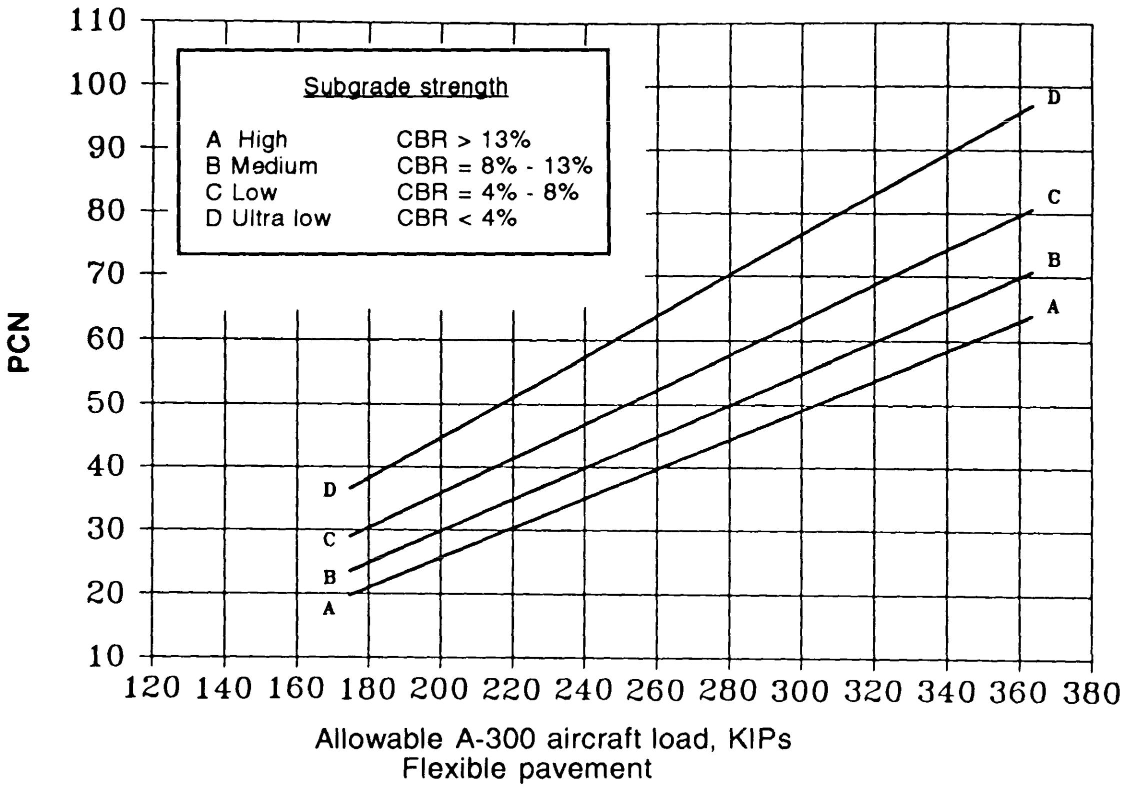


Figure O-18. PCN graphs for CH-54



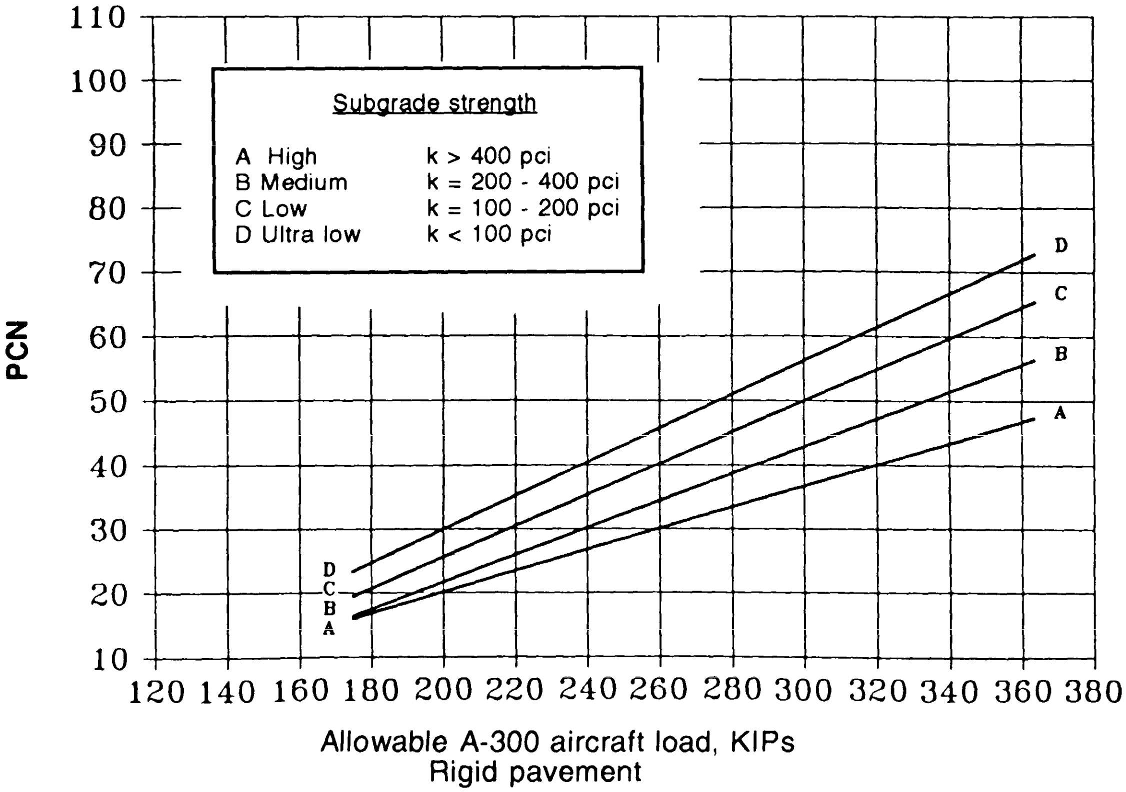
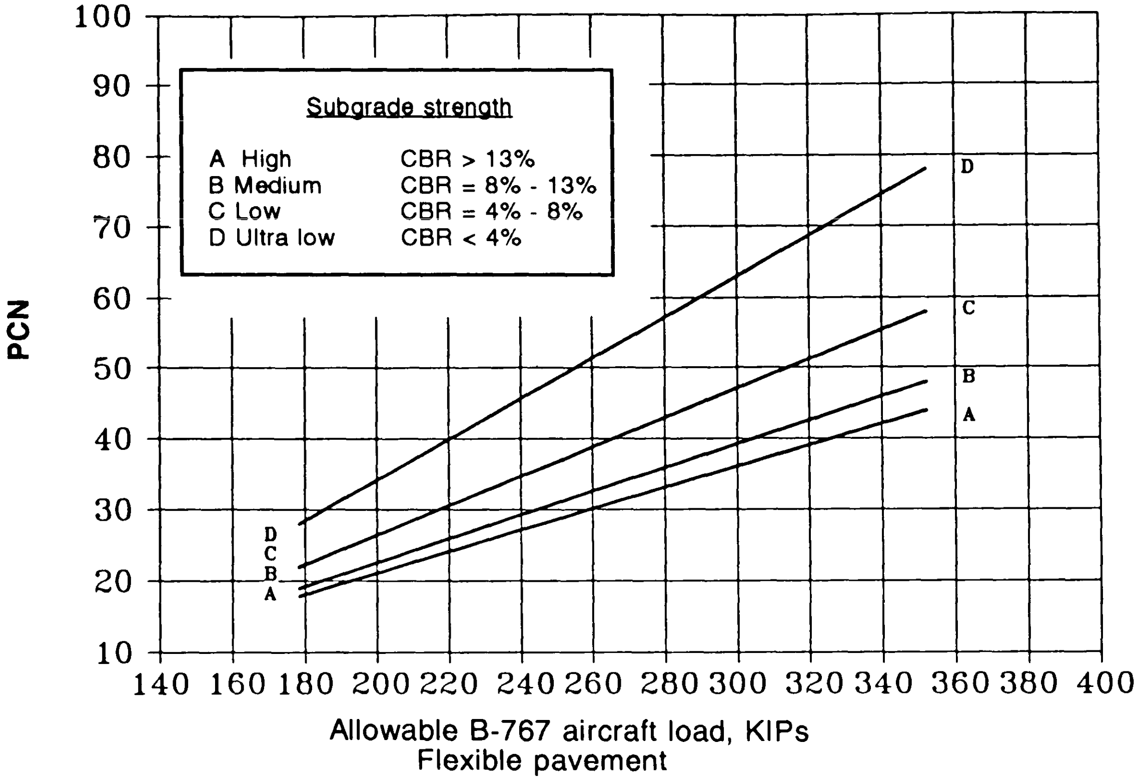


Figure O-19. PCN graphs for A-300



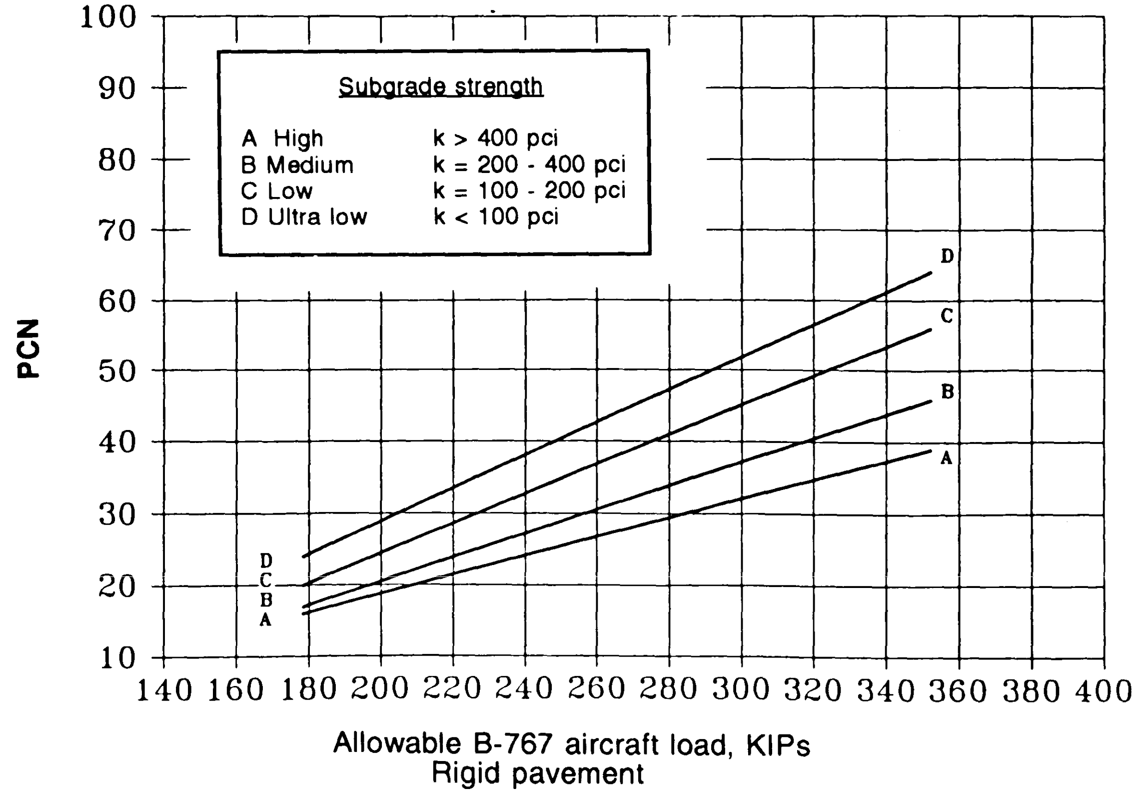


Figure O-20. PCN graphs for B-767

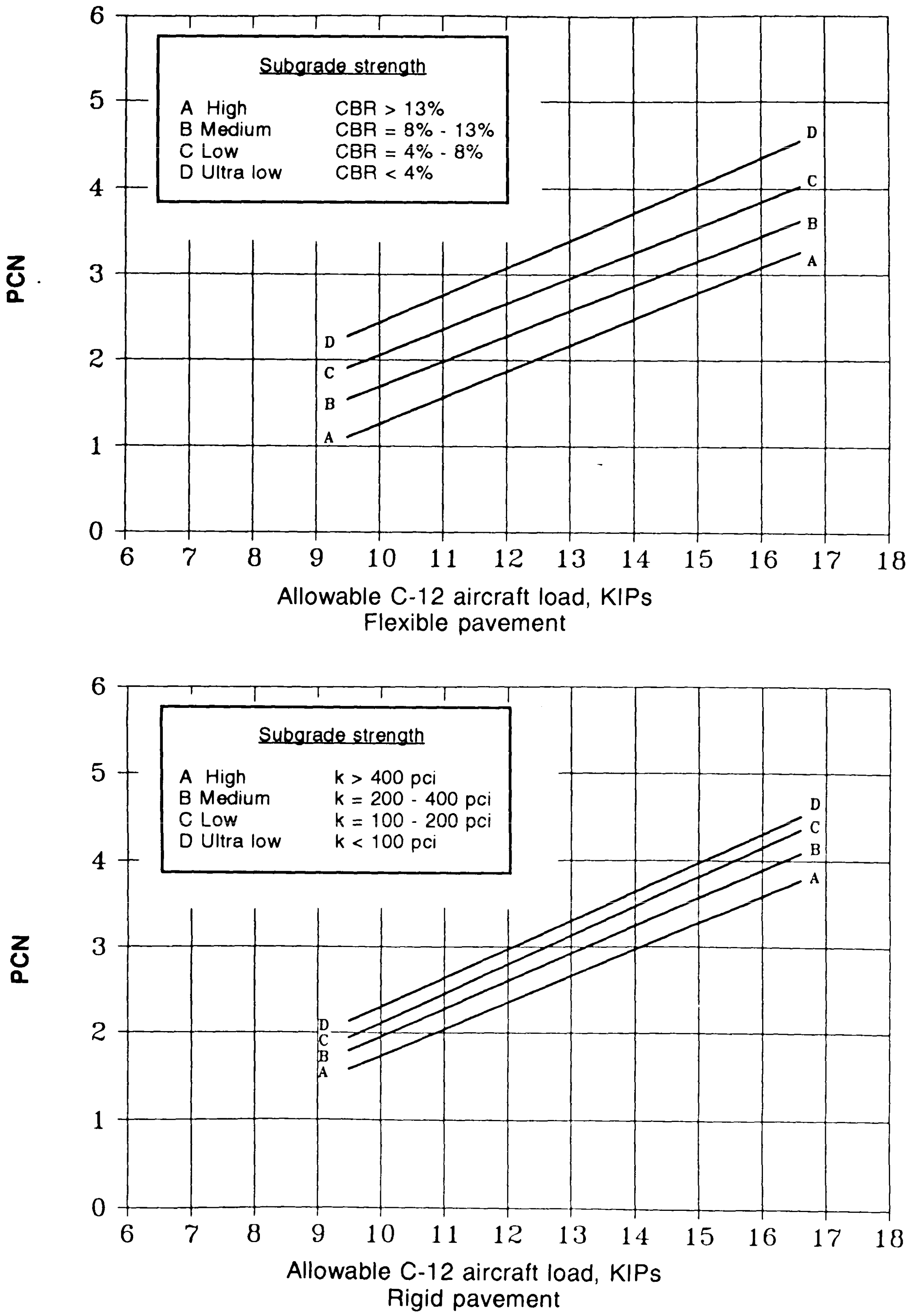
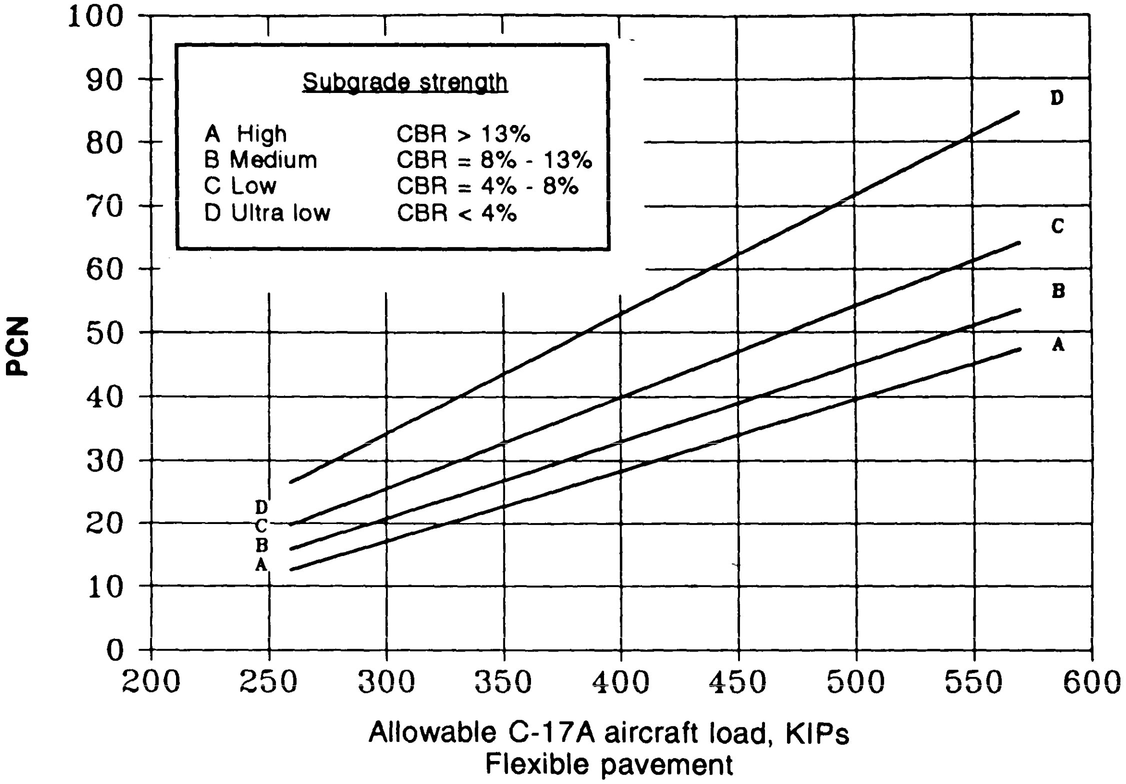


Figure O-21. PCN for C-12



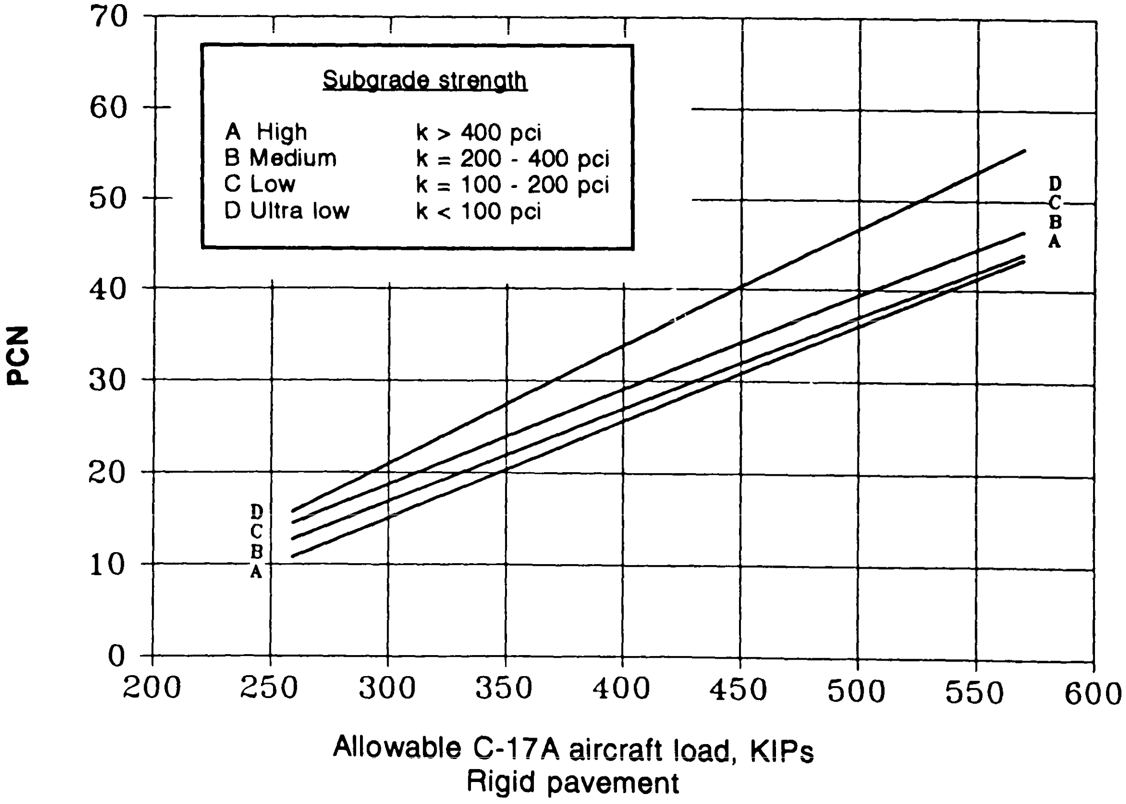
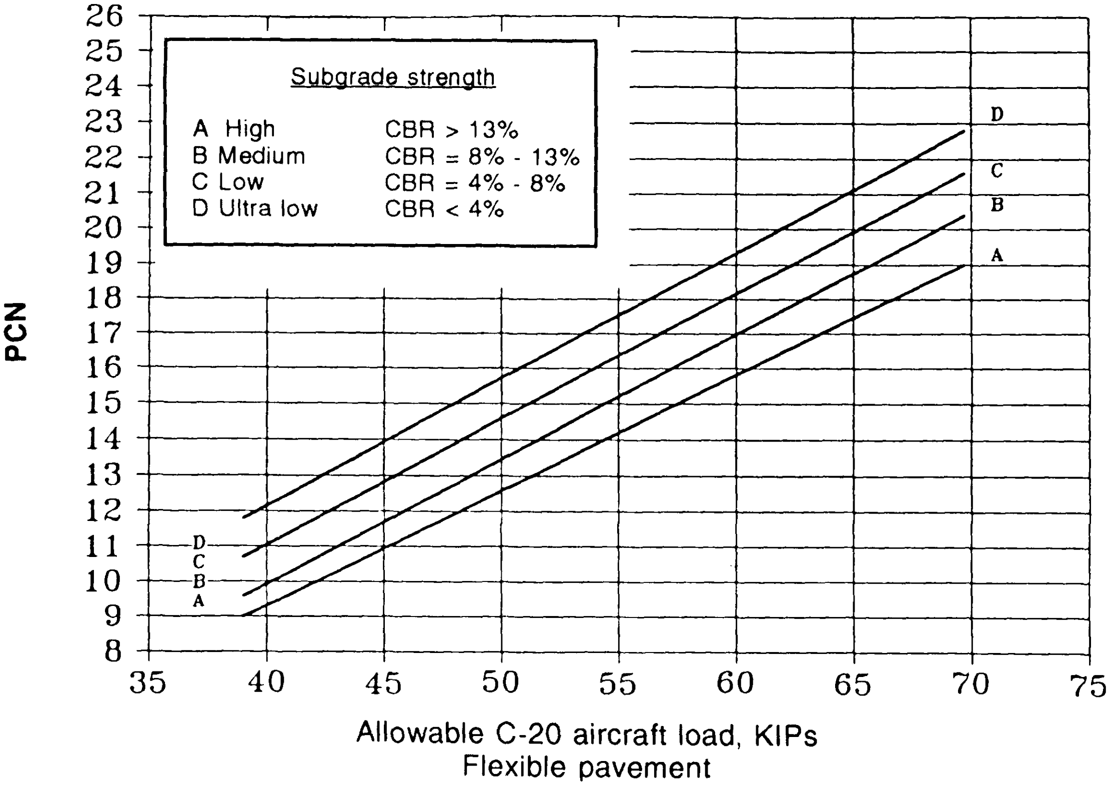


Figure O-22. PCH graphs for C-17A



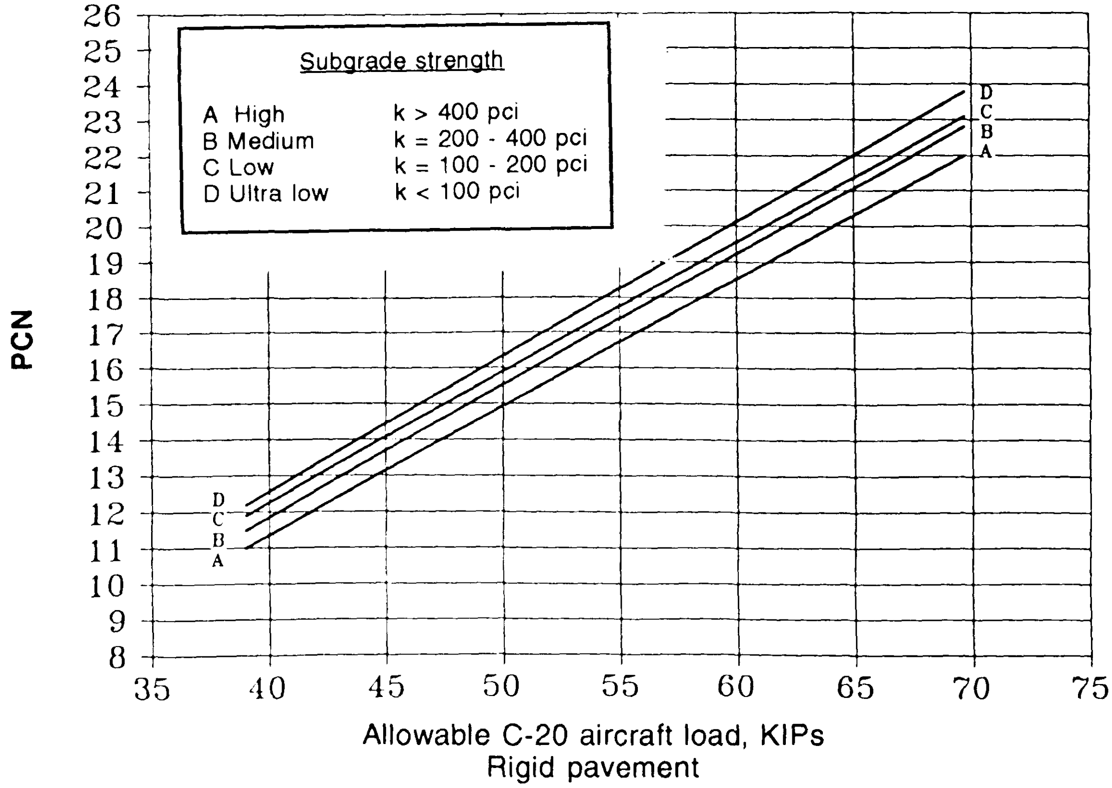
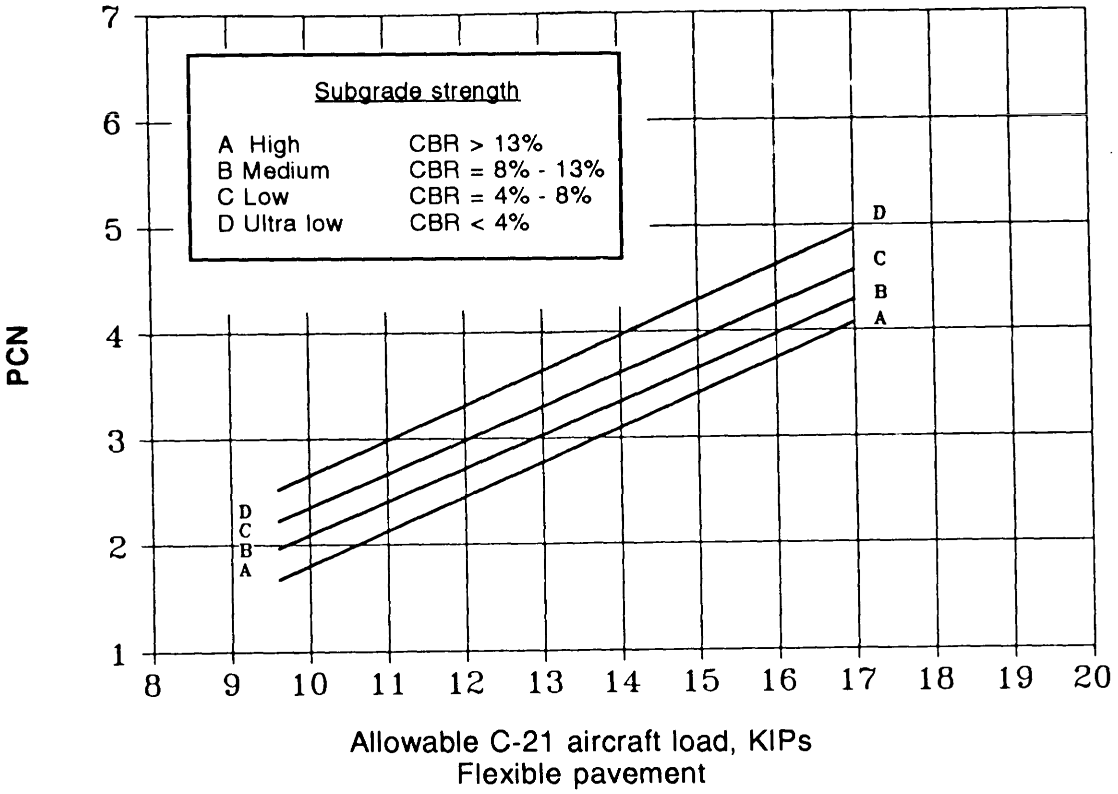


Figure O-23. PCN graphs for C-20



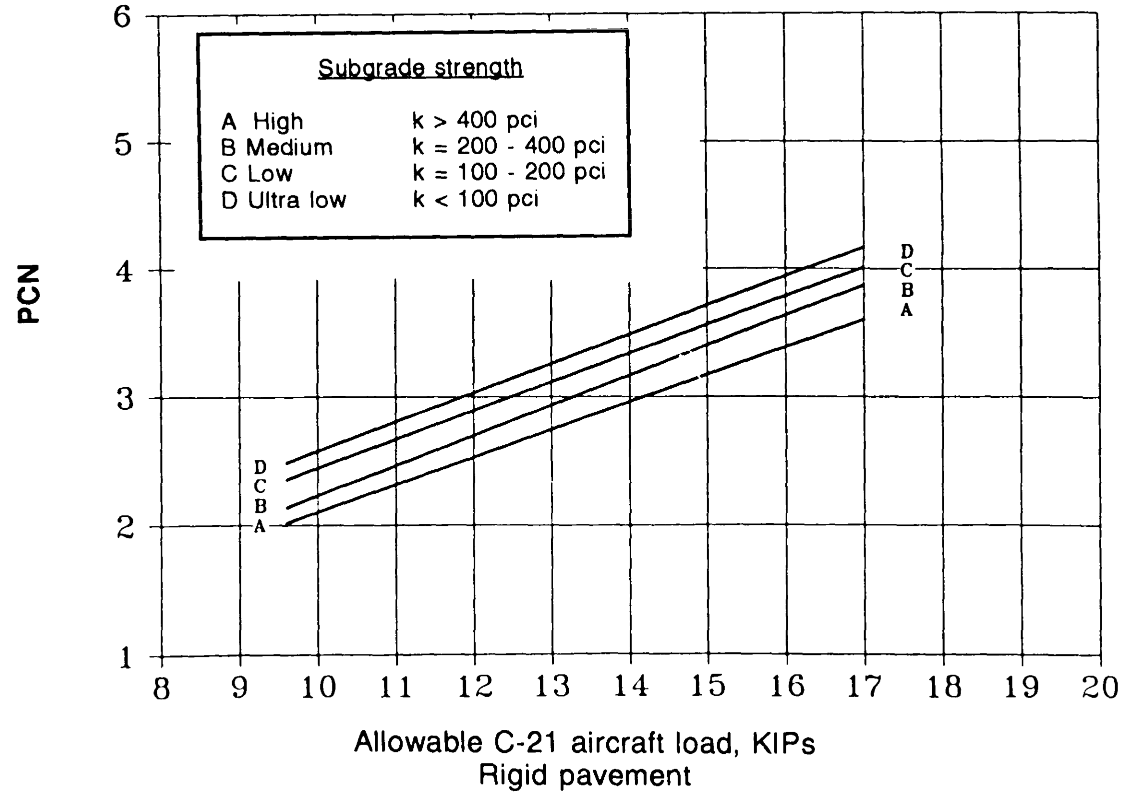
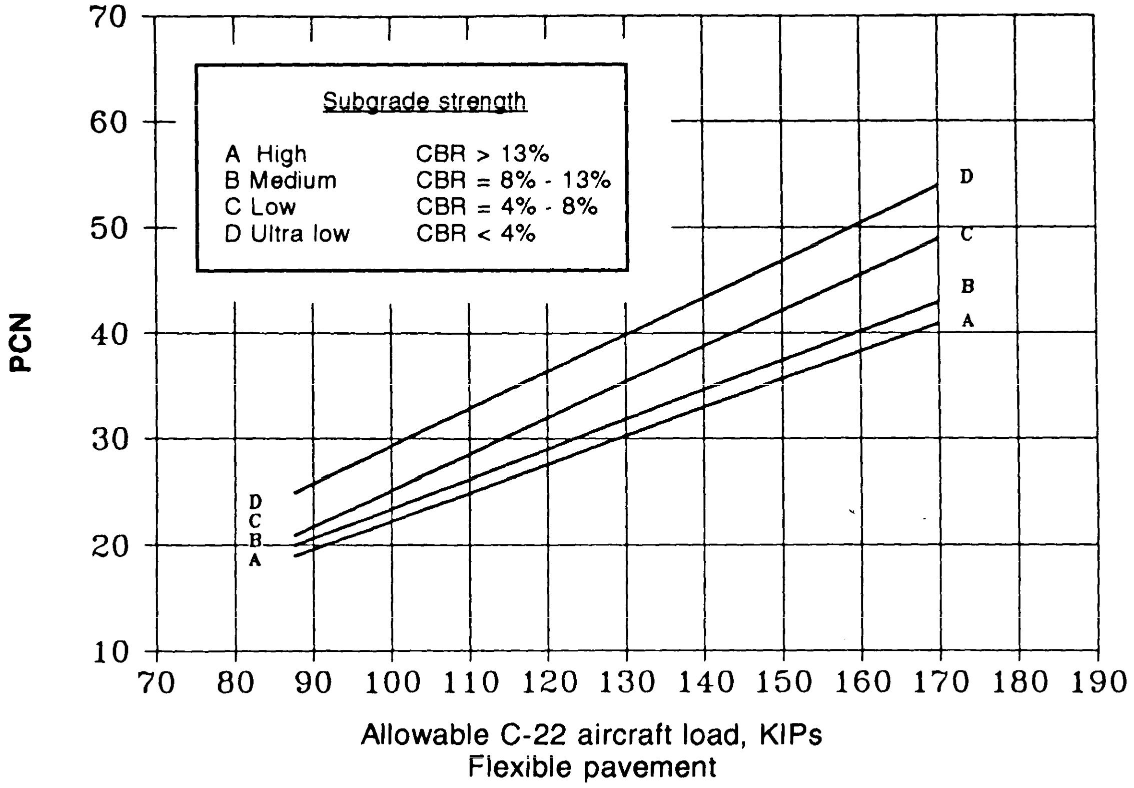


Figure O-24. PCN graphs for C-21



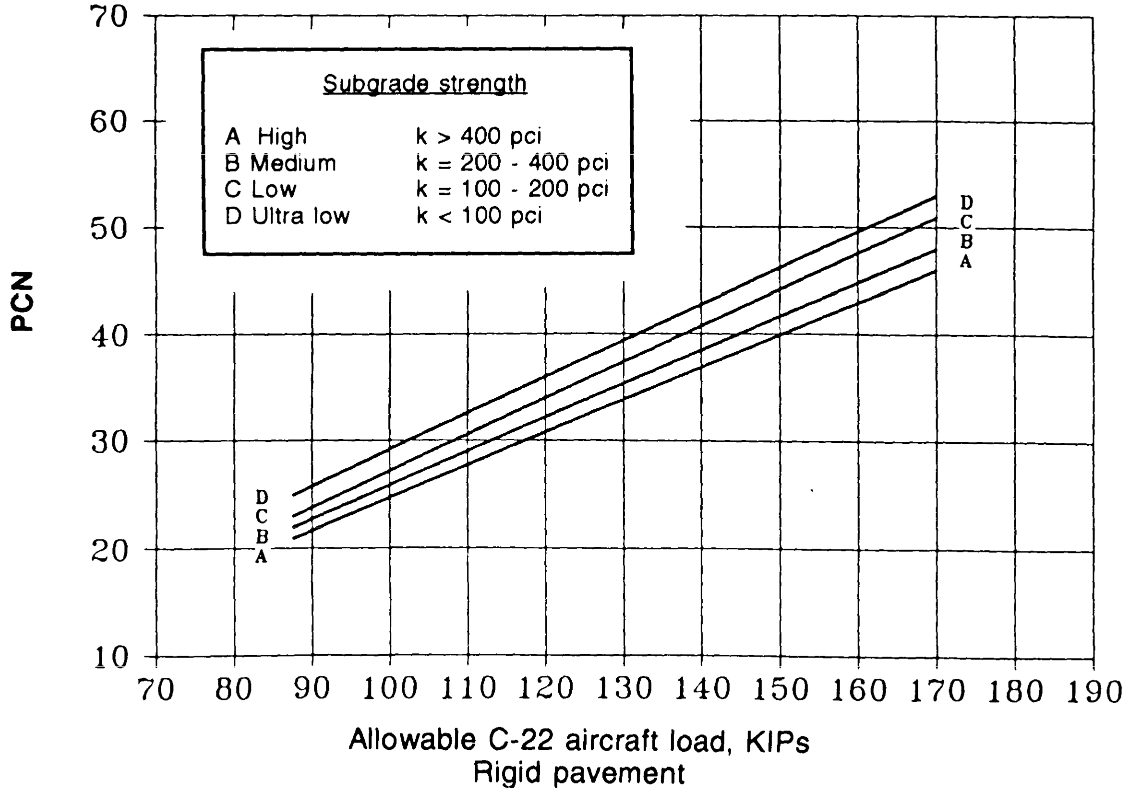
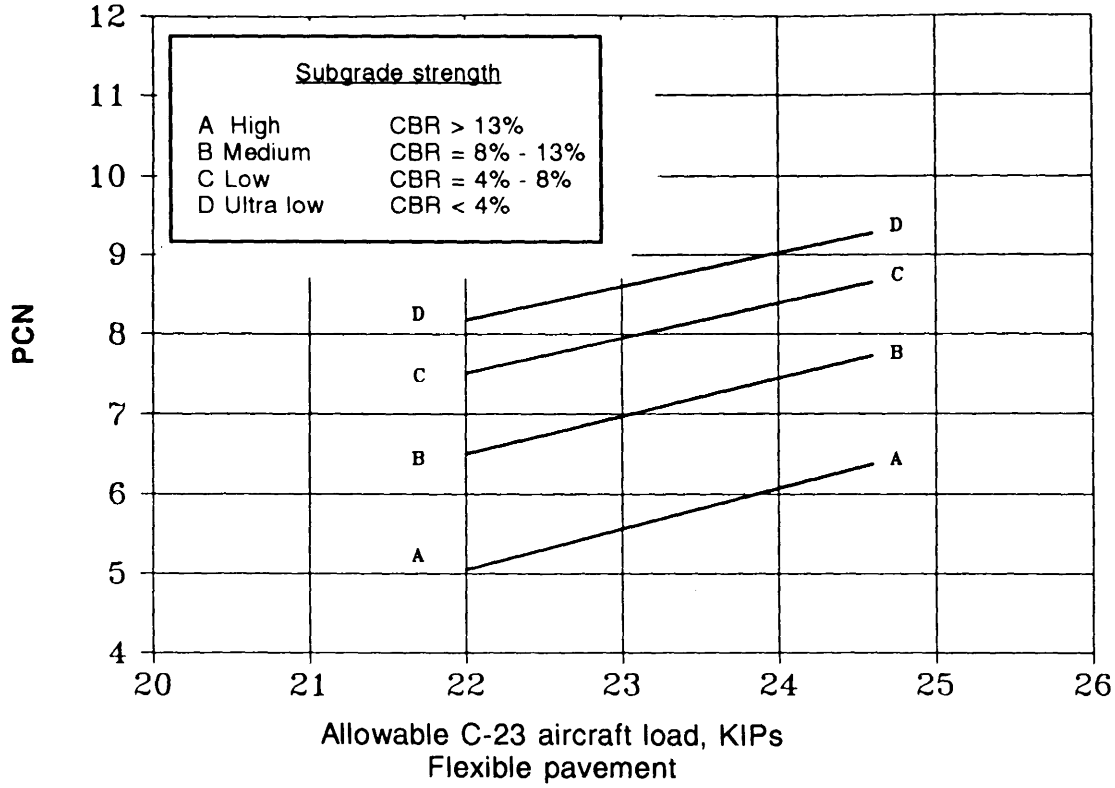


Figure O-25. PCN graphs for C-22



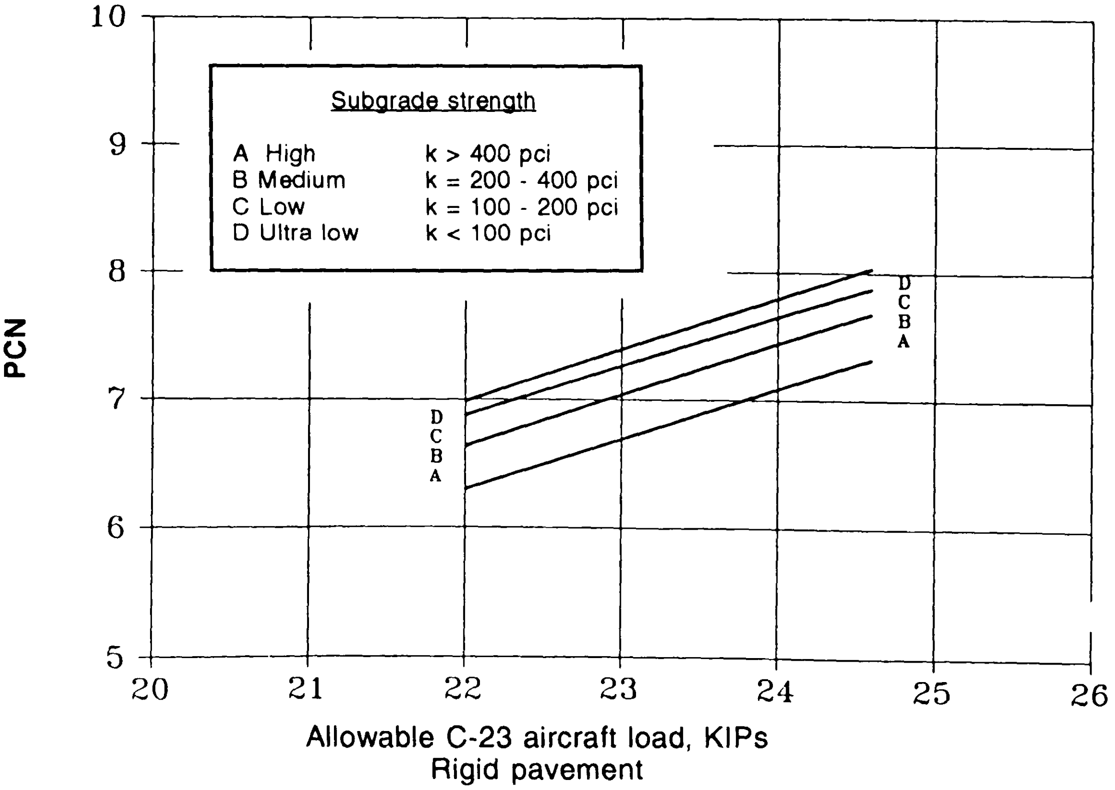
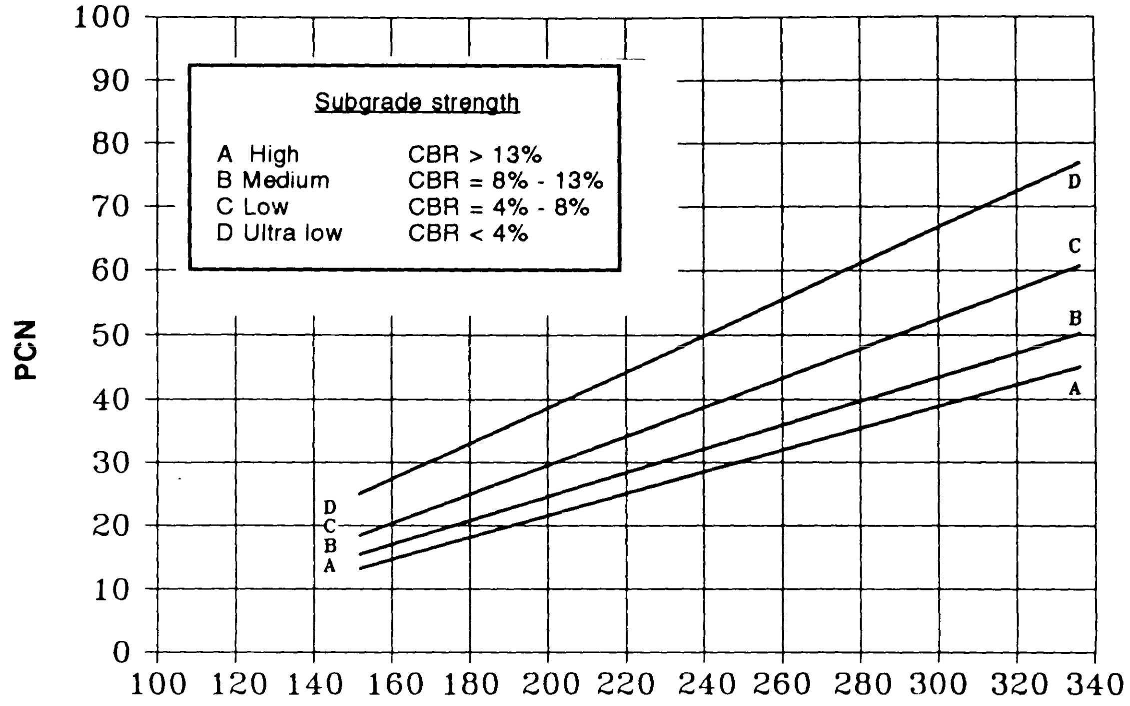
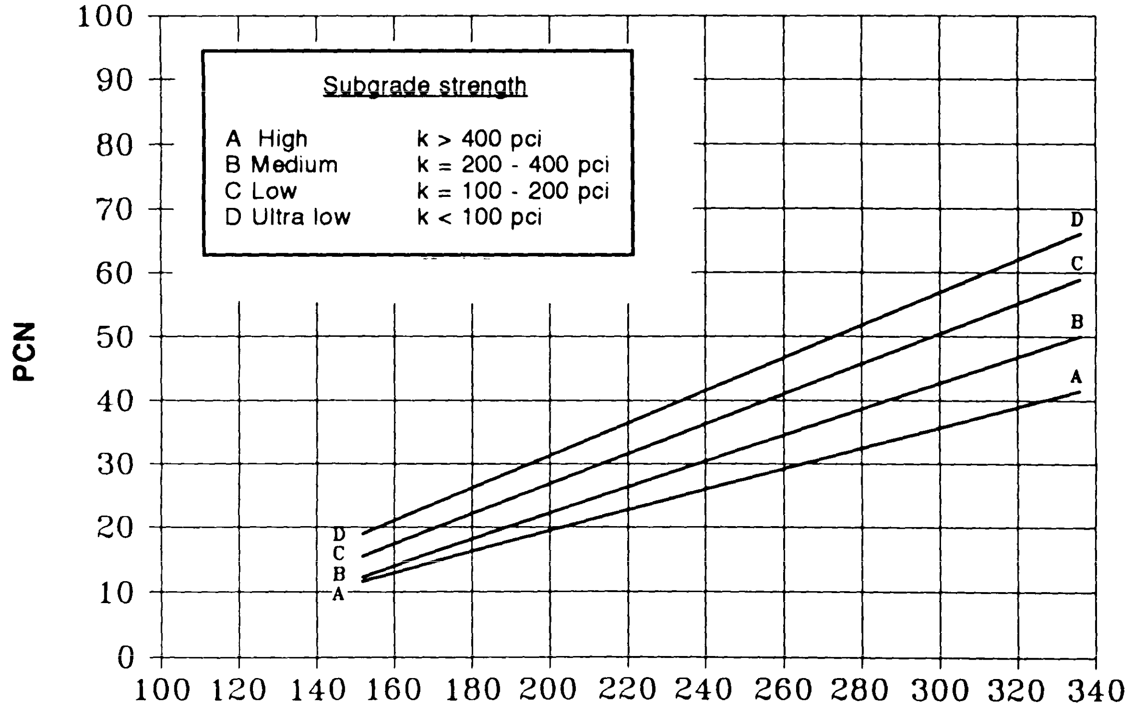


Figure O-26. PCN graphs for C-23

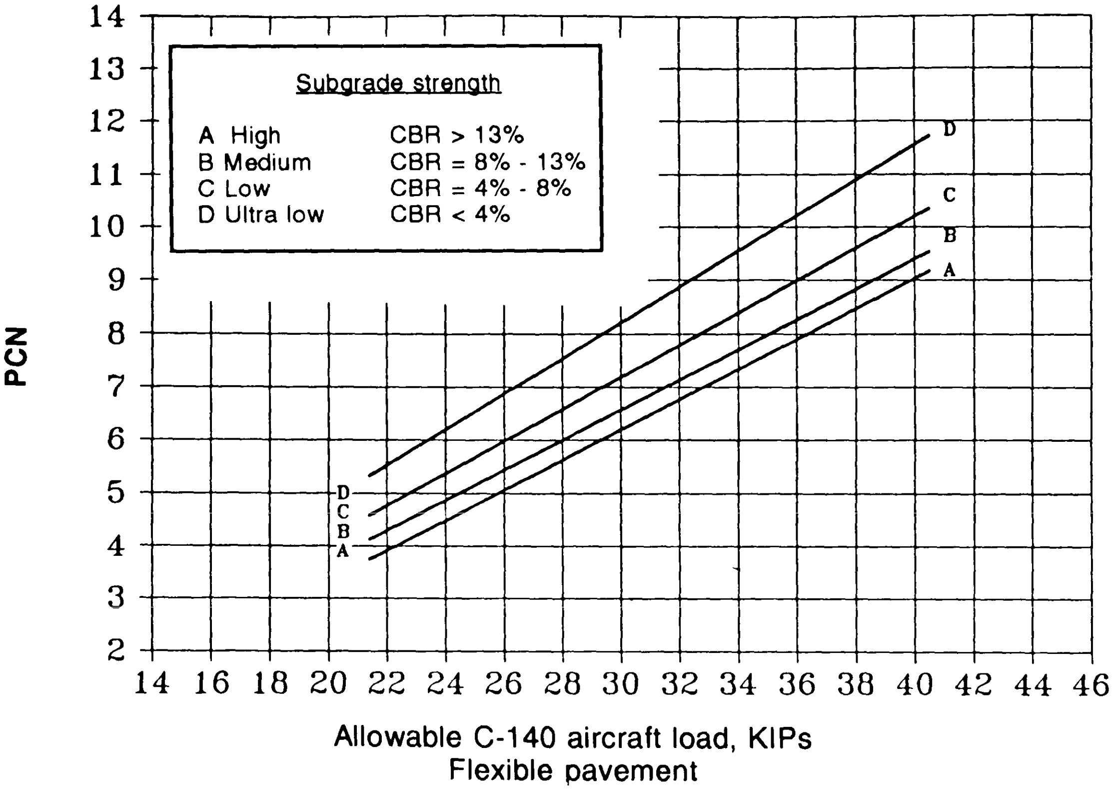


Allowable C-137 aircraft load, KIPs
Flexible pavement



Allowable C-137 aircraft load, KIPs
Rigid pavement

Figure O-27. PCN graphs for C-137



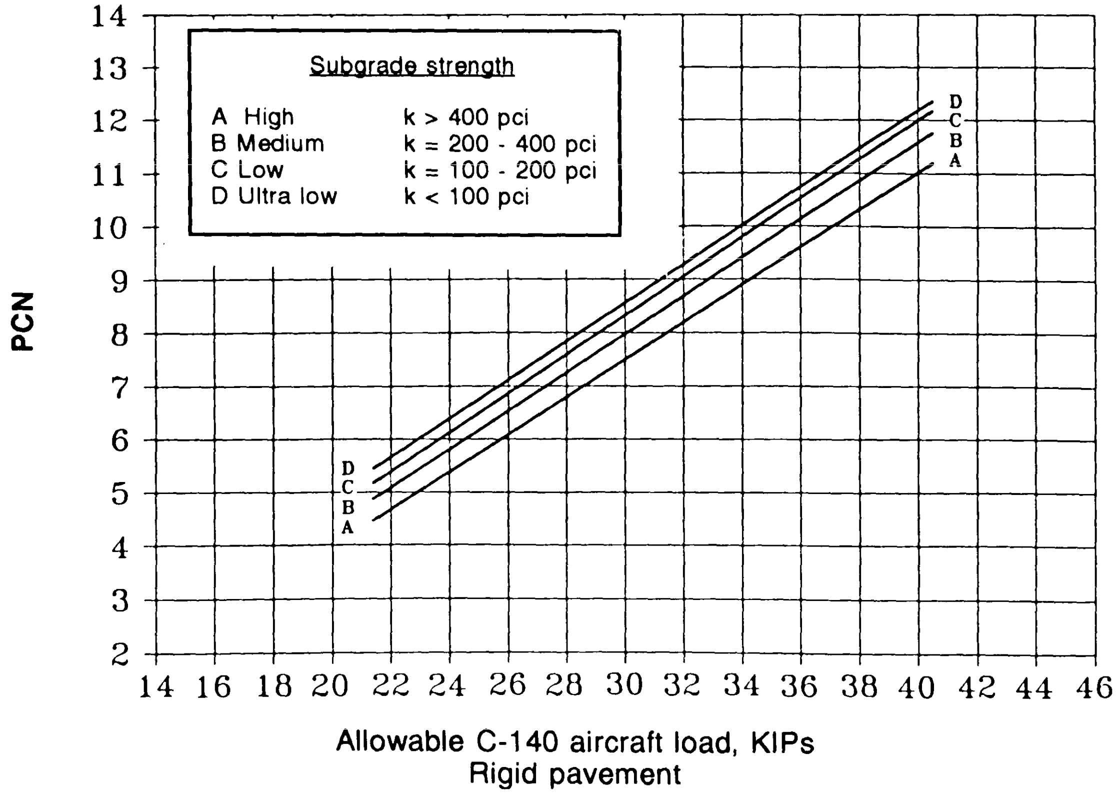
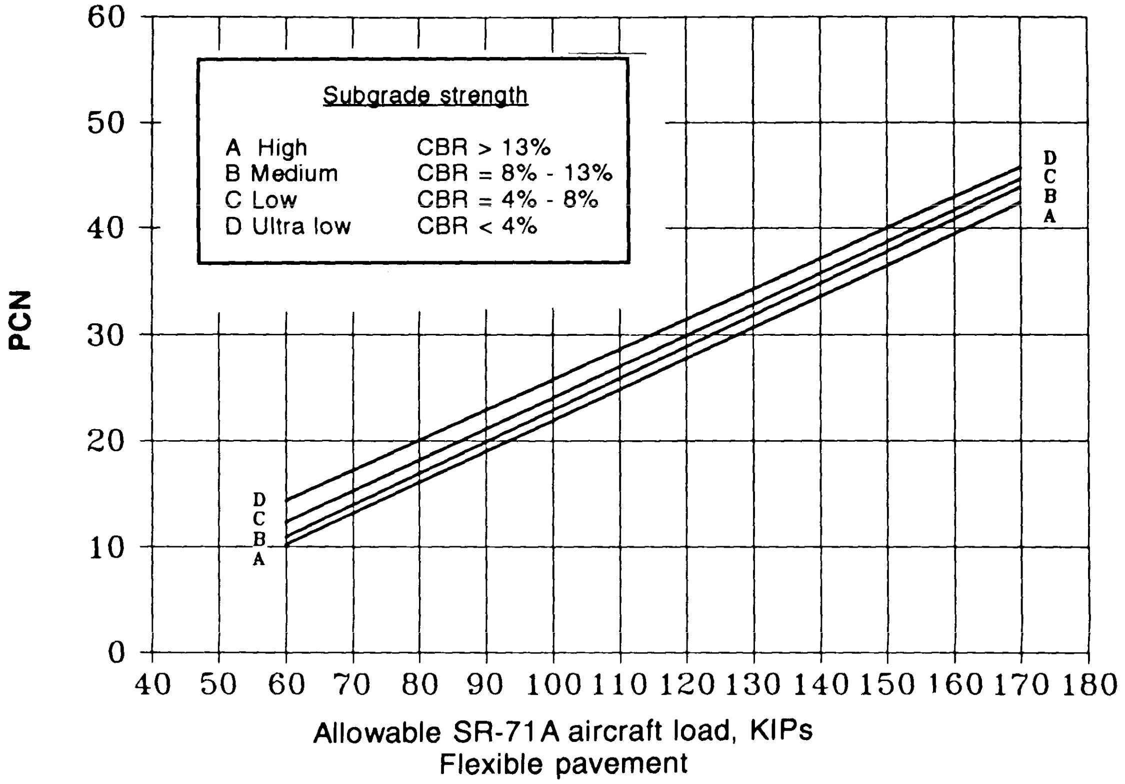


Figure O-28. PCN graphs for C-140



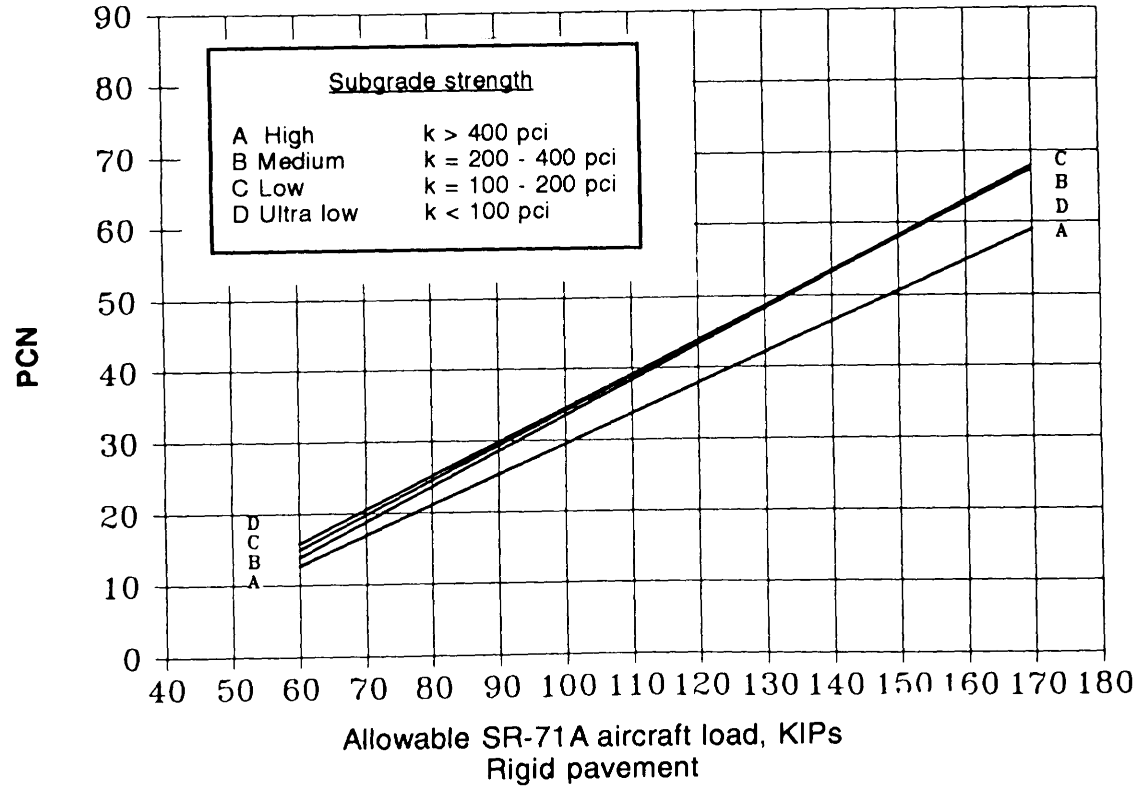
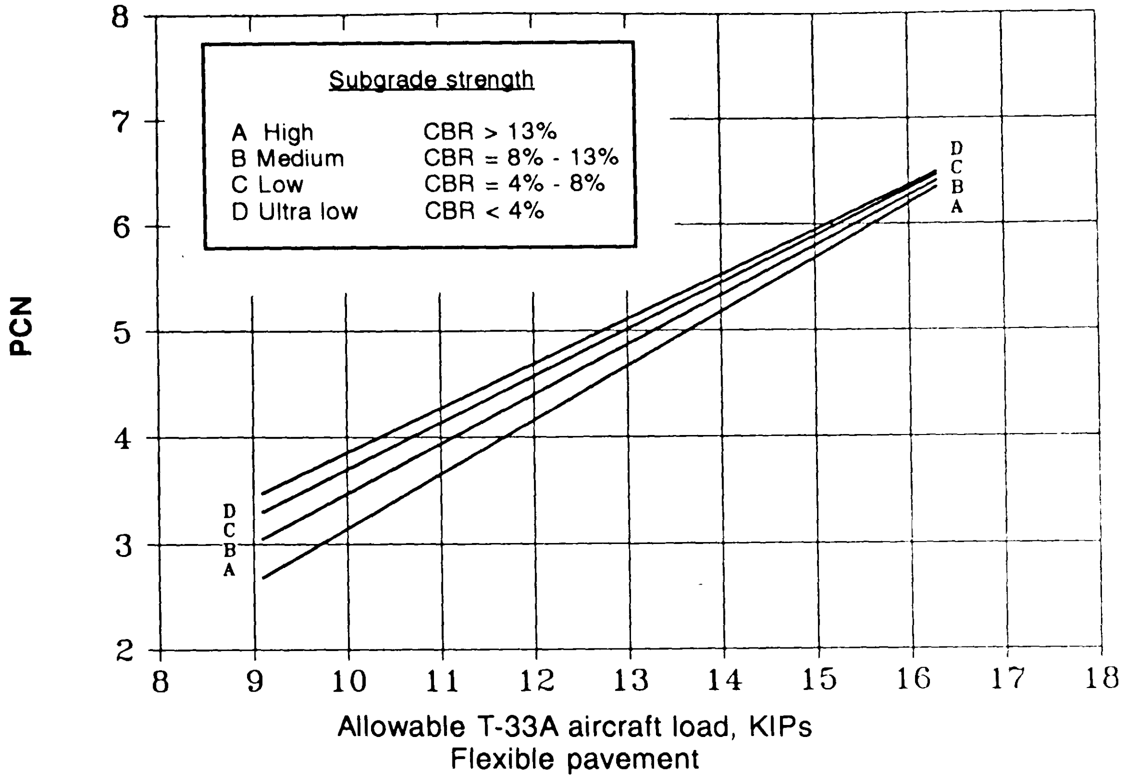


Figure O-29. PCN graphs for SR-71A



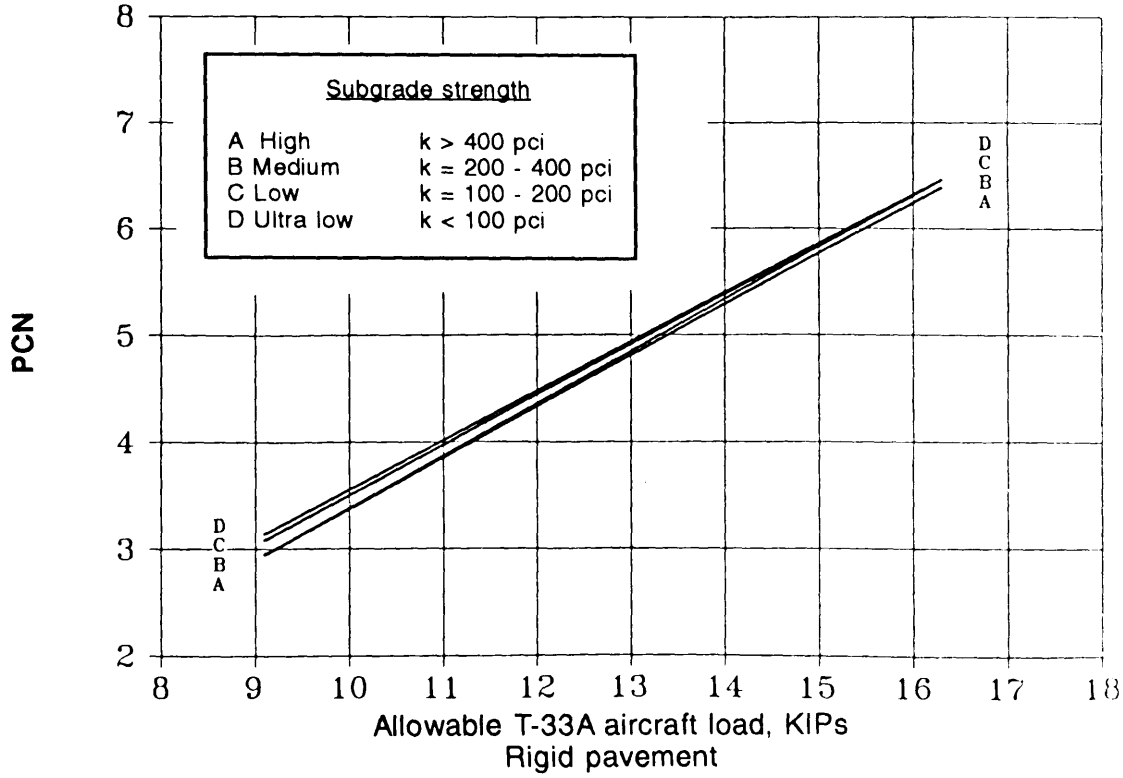
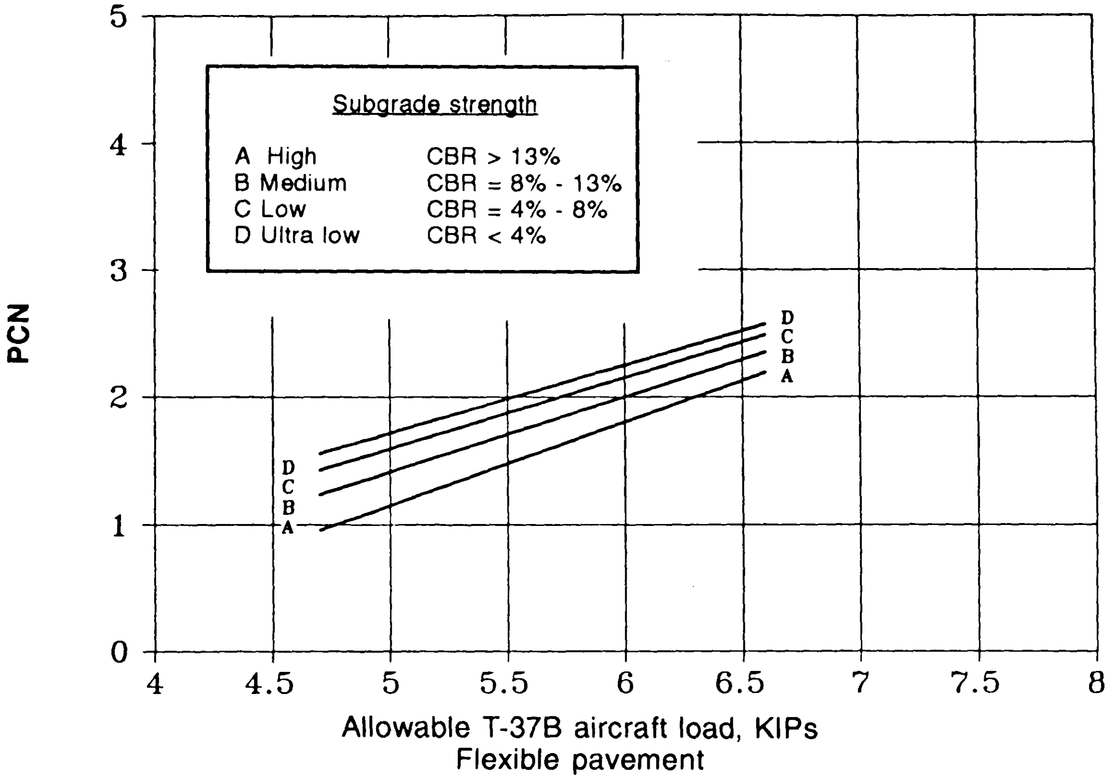


Figure O-30. PCN graphs for T-33A



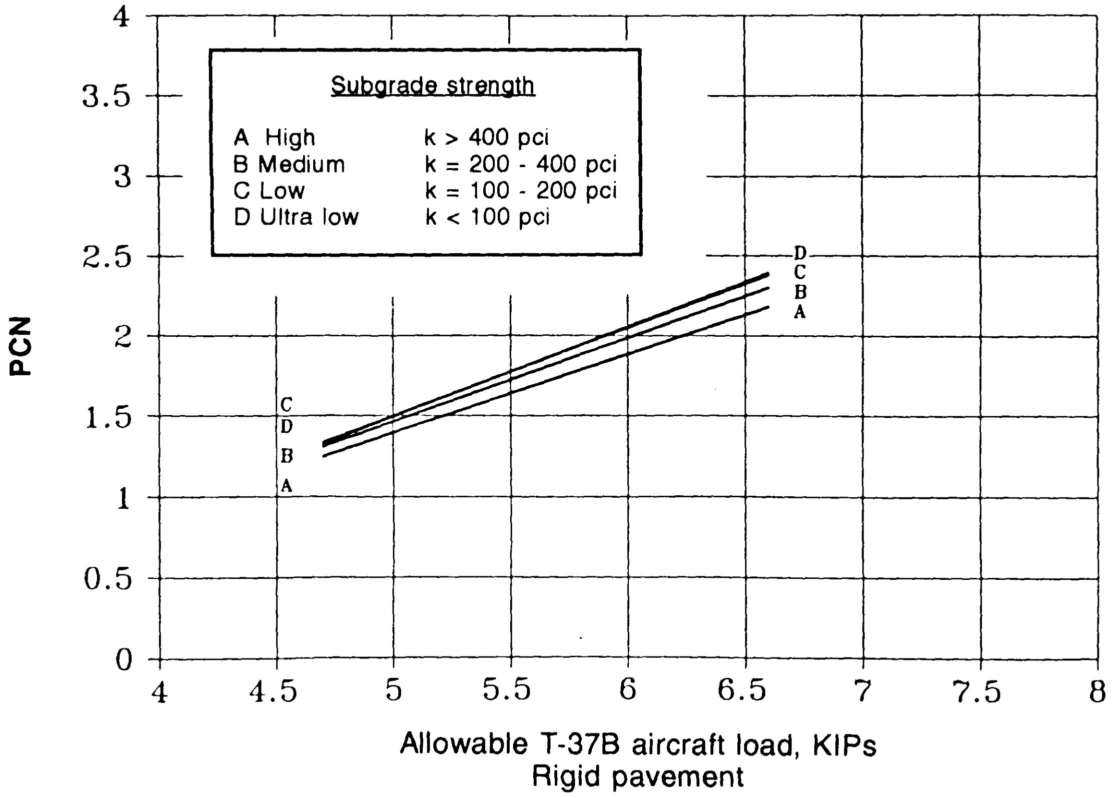
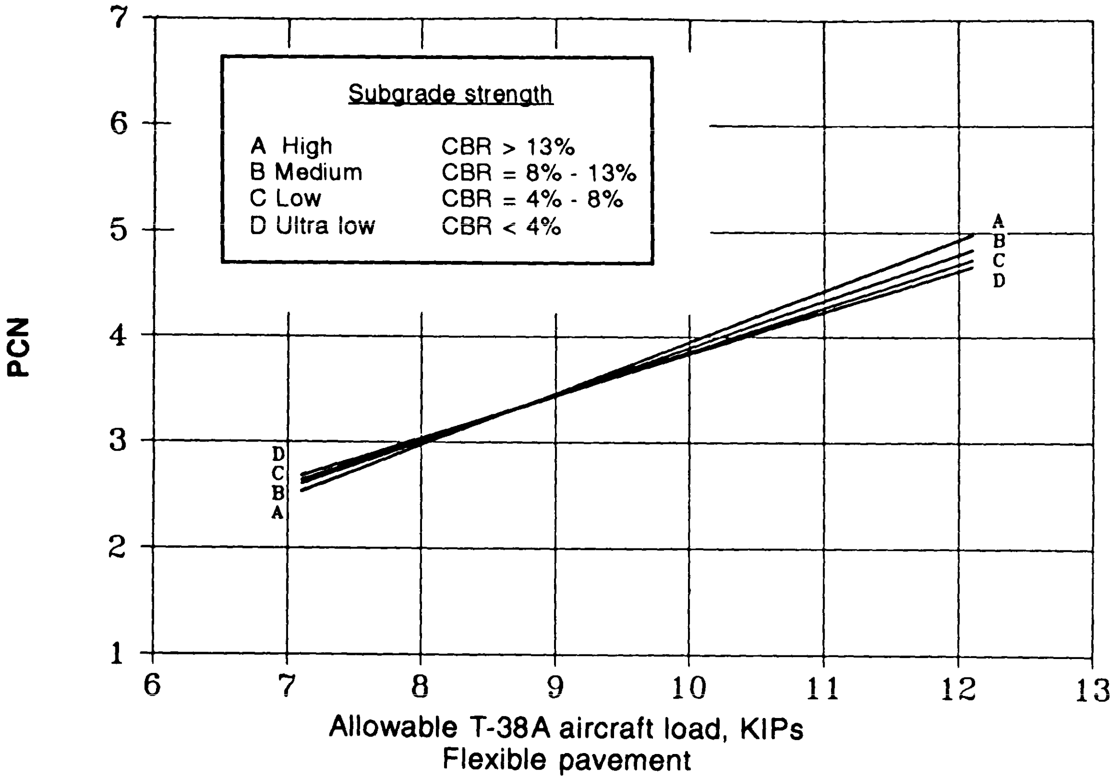


Figure O-31. PCN graphs for T-37B



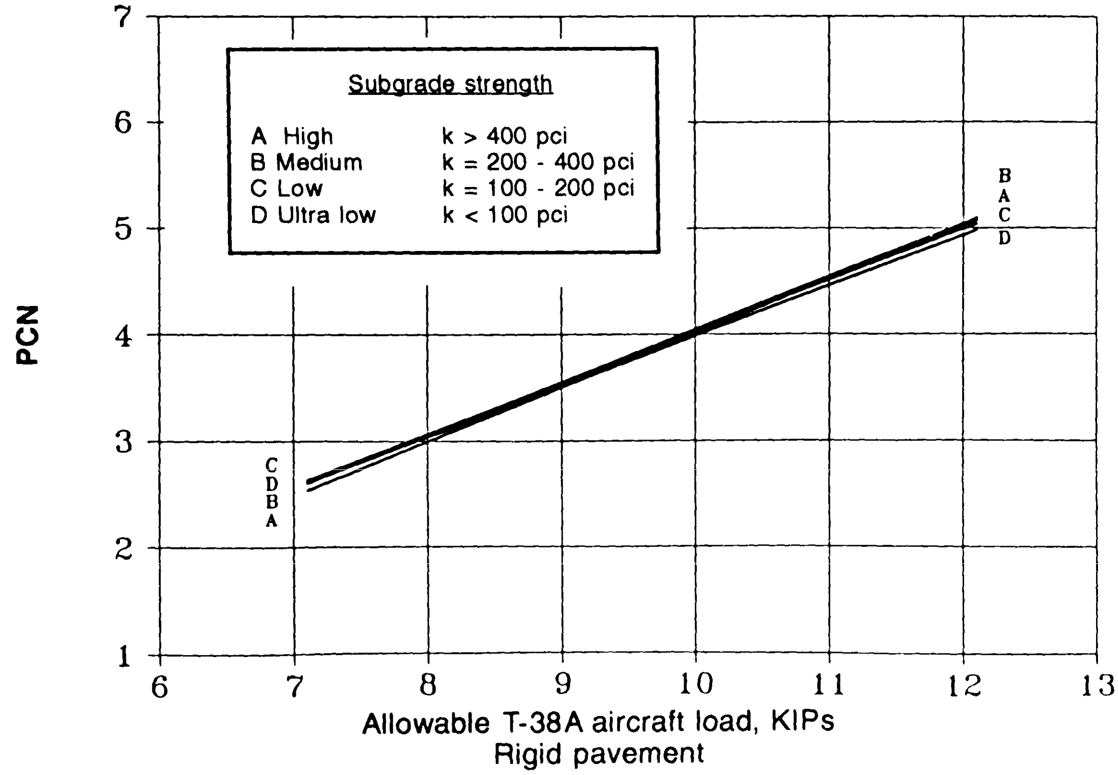
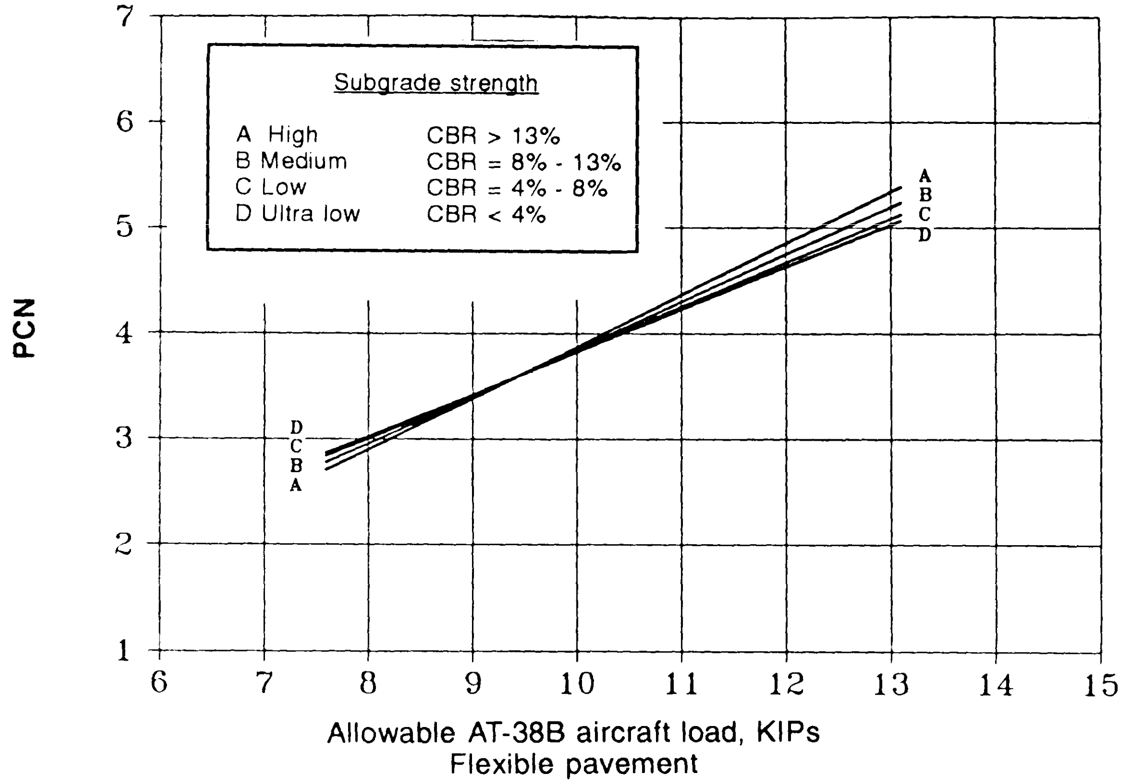


Figure O-32. PCN graphs for T-38A



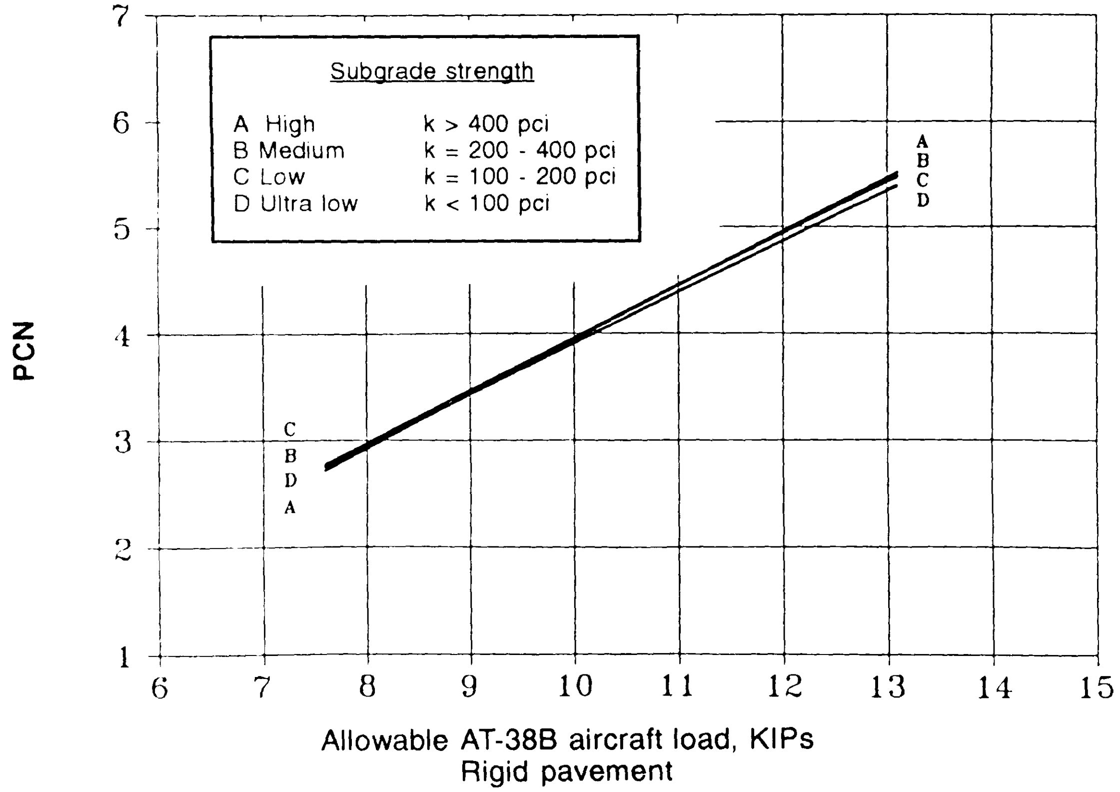
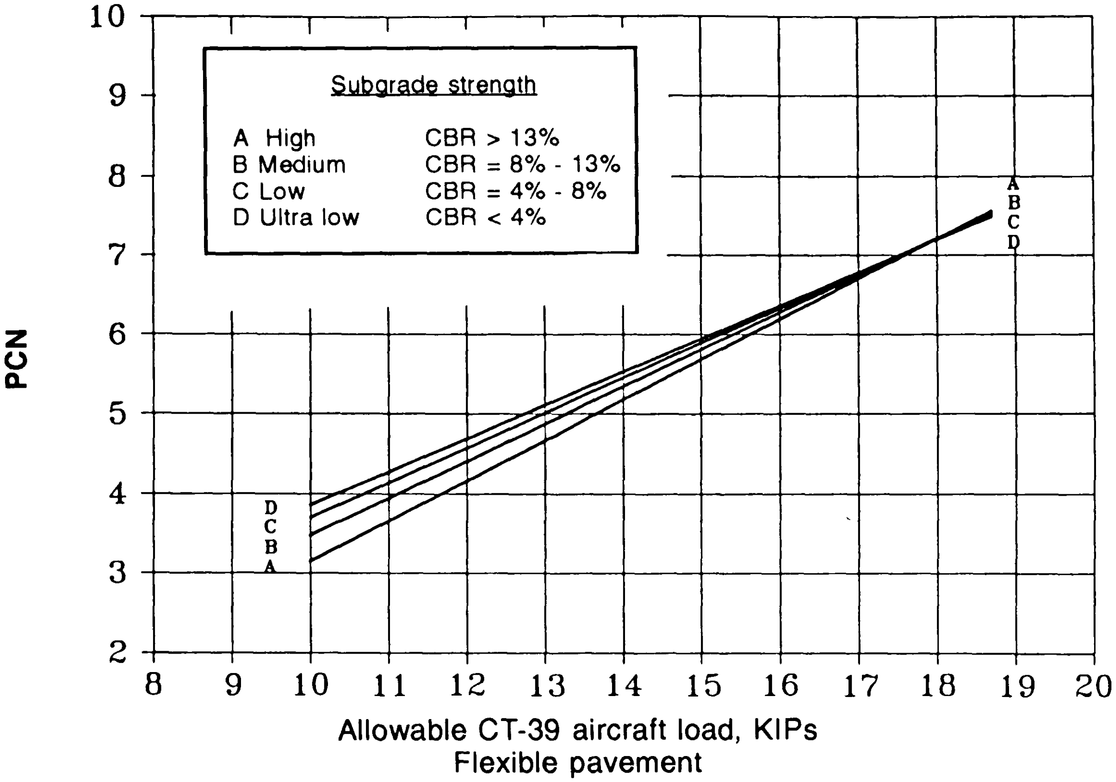


Figure O-33. PCN graphs for AT-38B



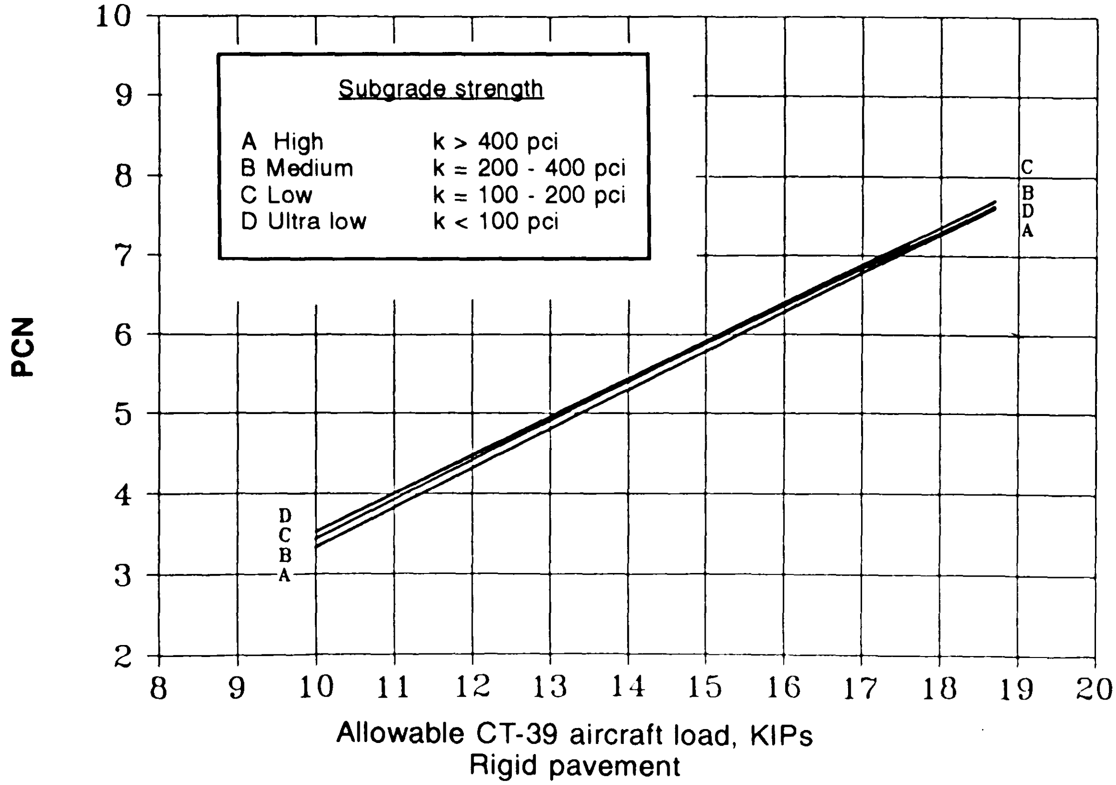
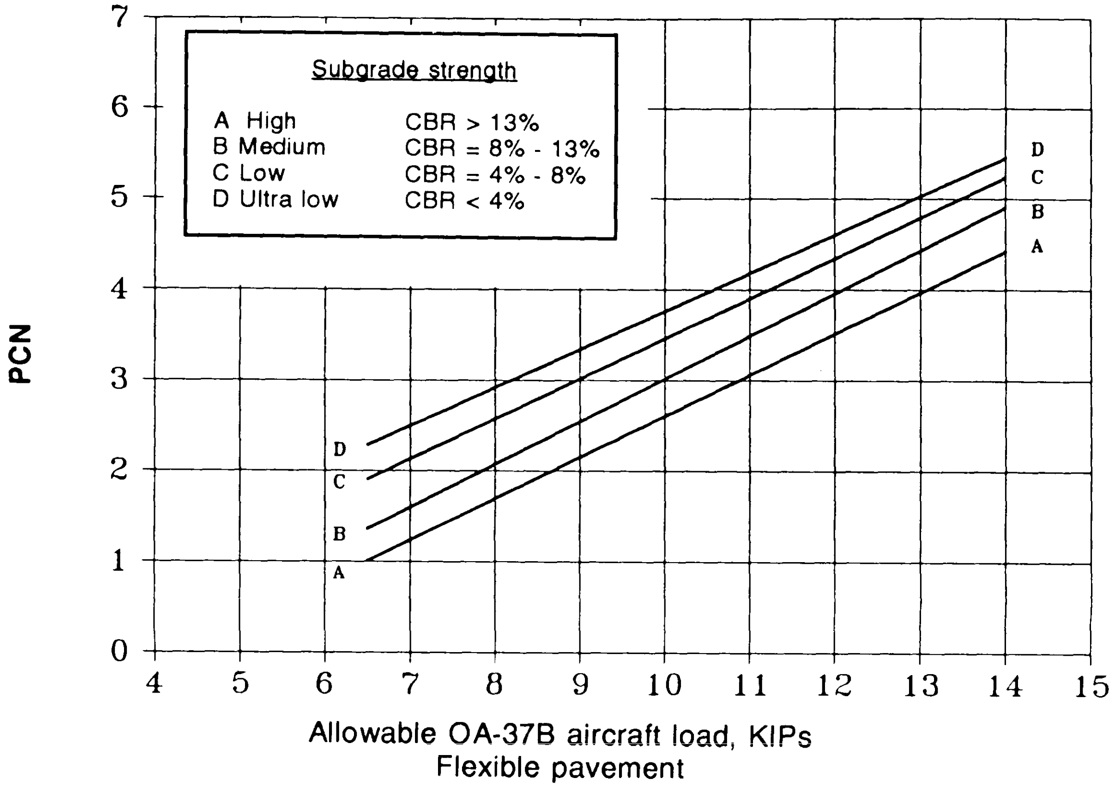


Figure O-35. PCN graphs for CT-39



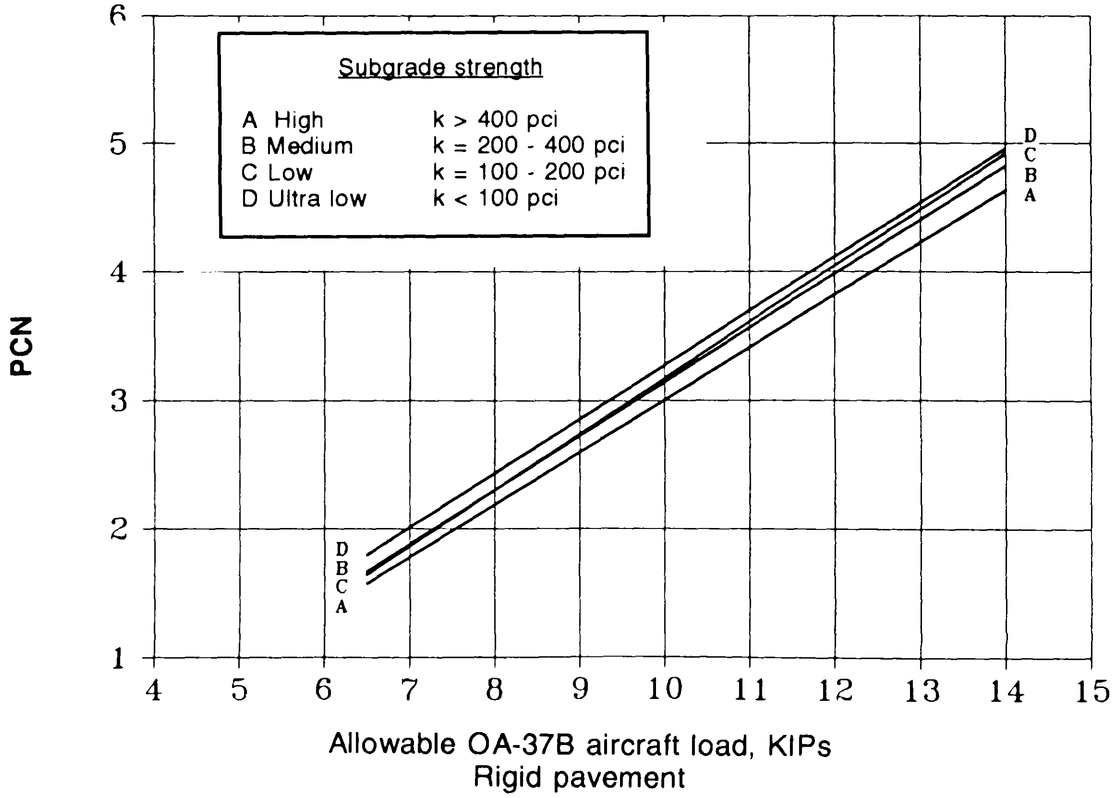
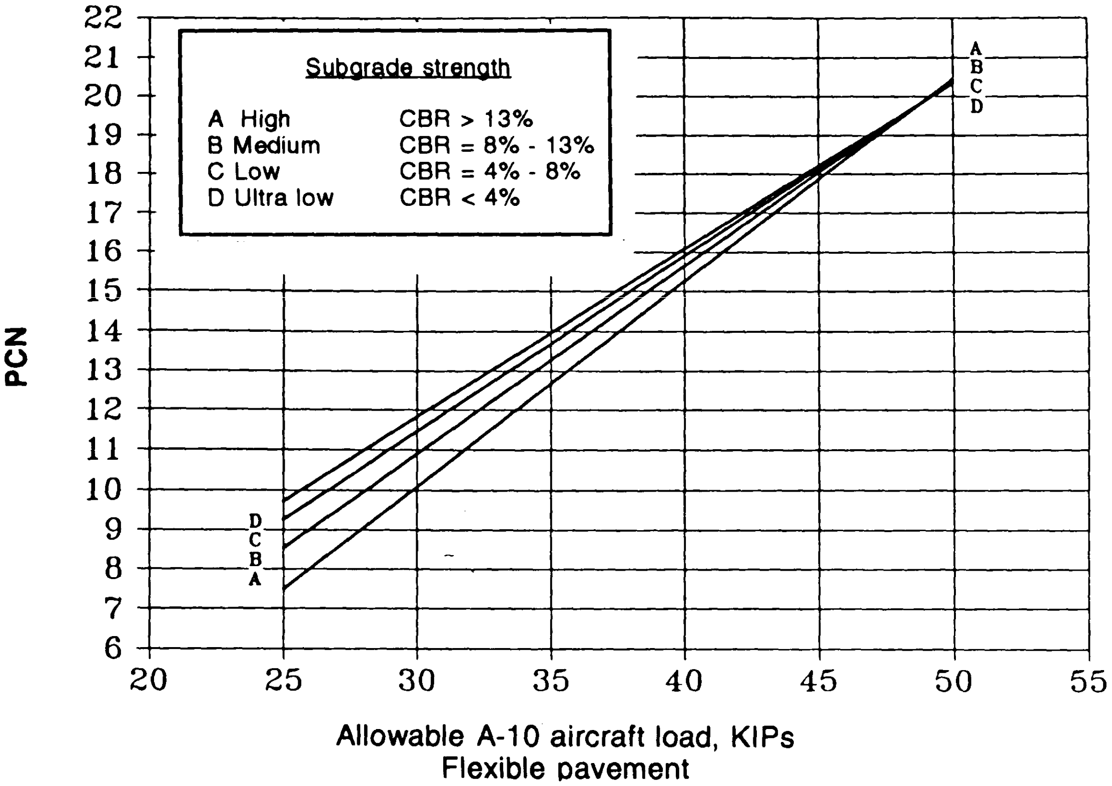


Figure O-35. PCN graphs for OA-37B



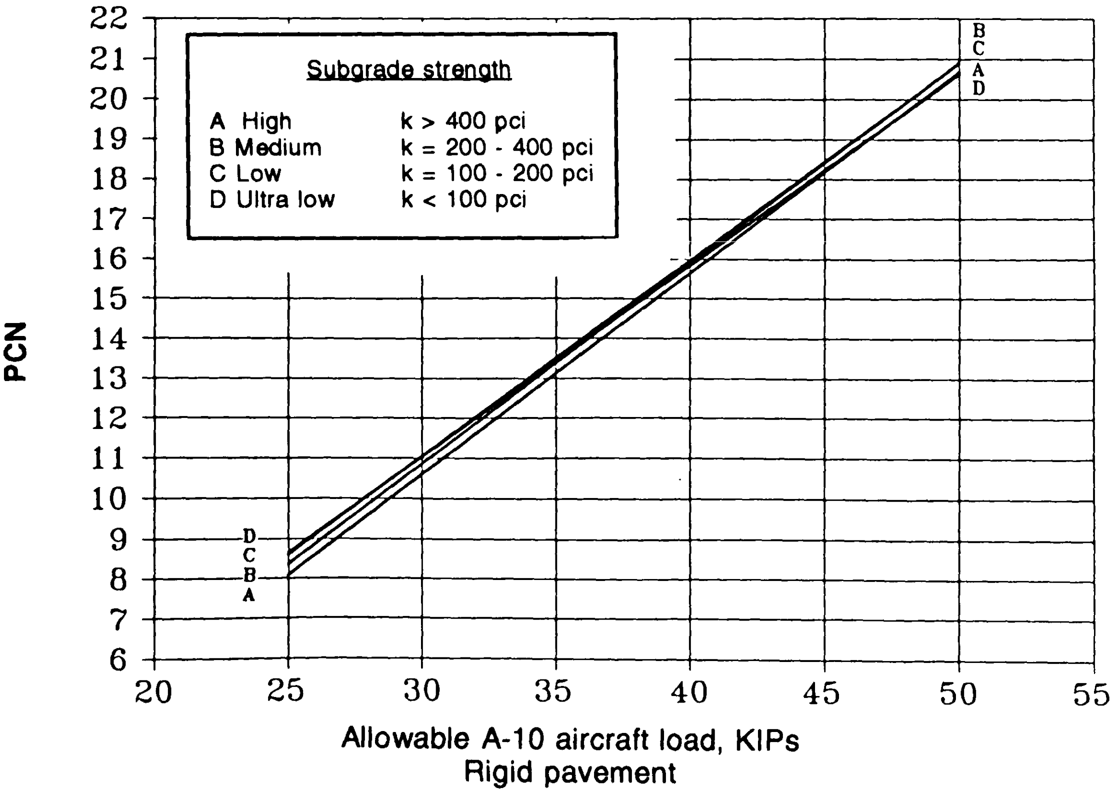
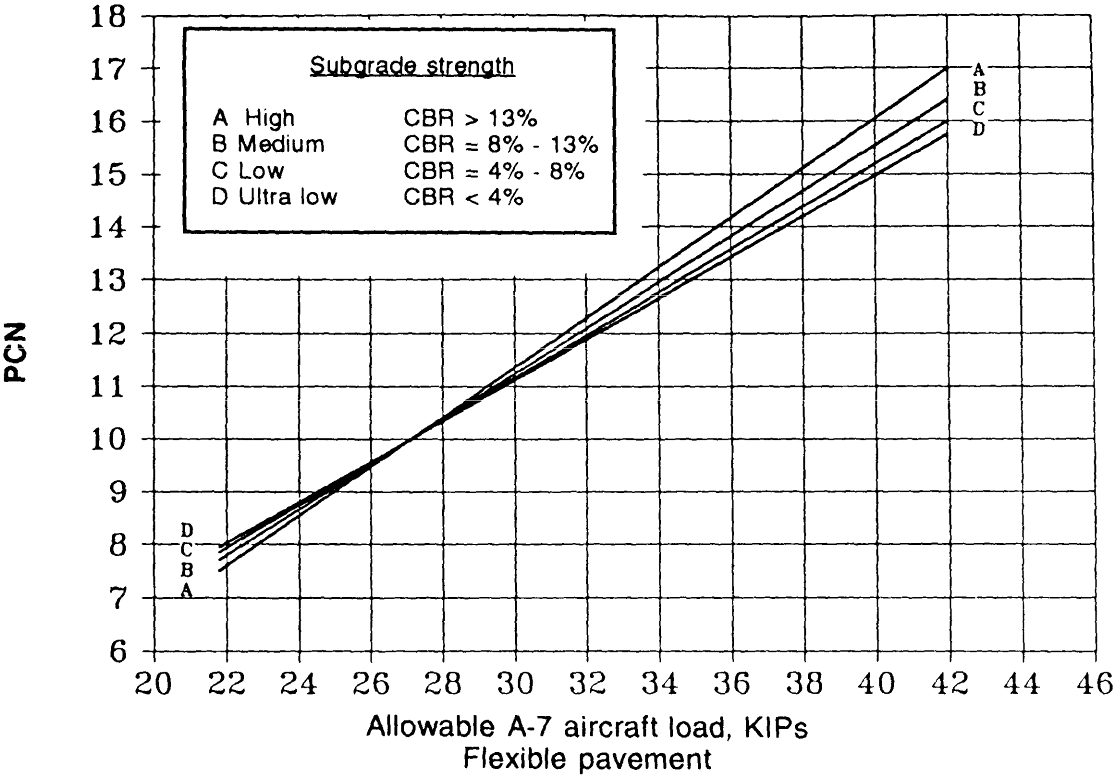


Figure O-36. PCN graphs for A-10



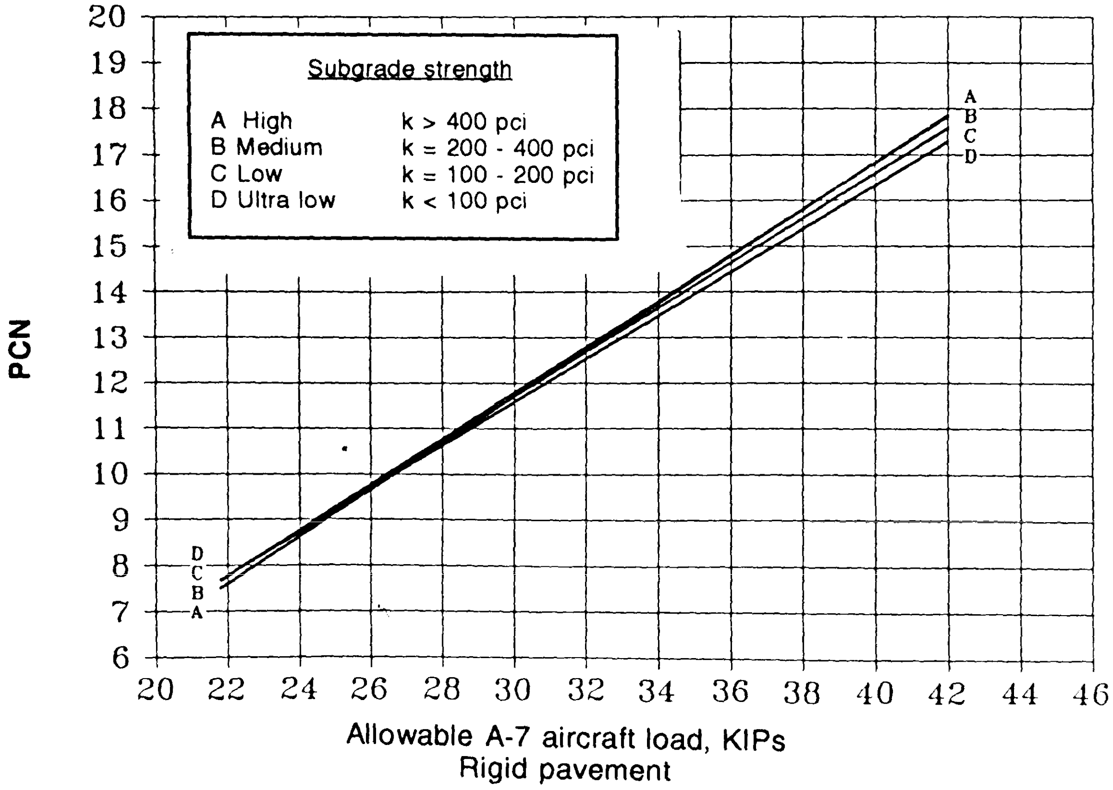
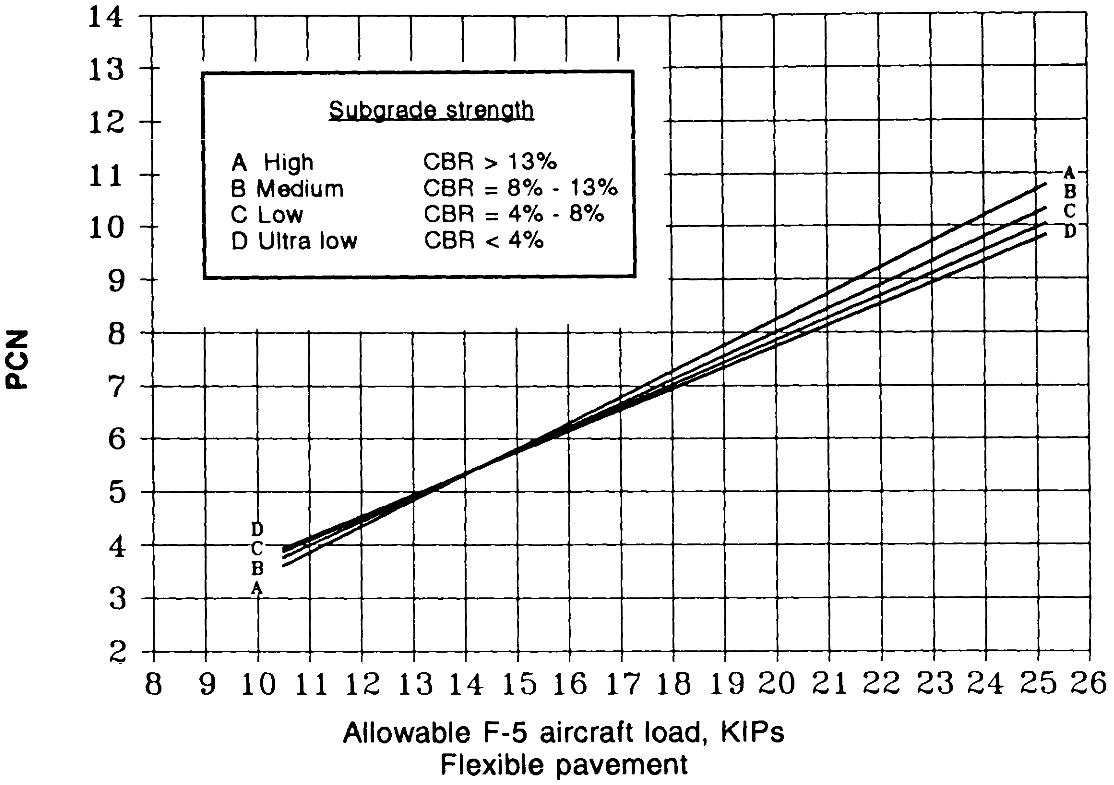


Figure O-37. PCN graphs for A-7



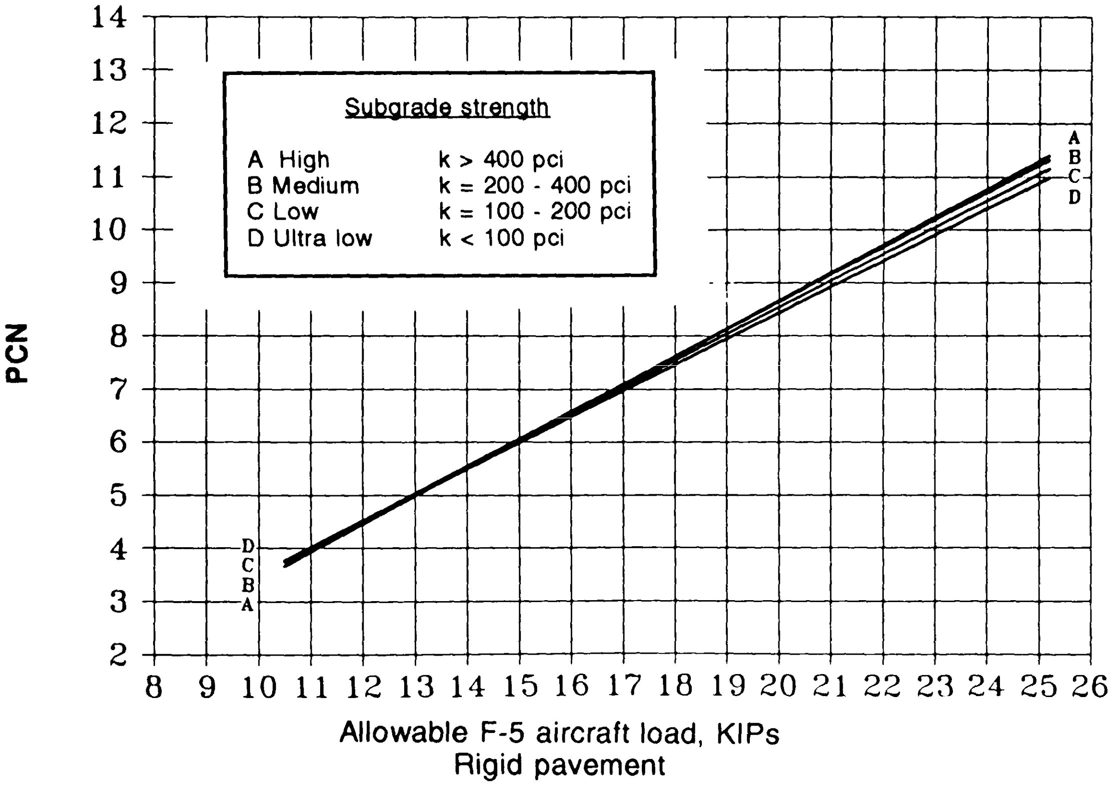
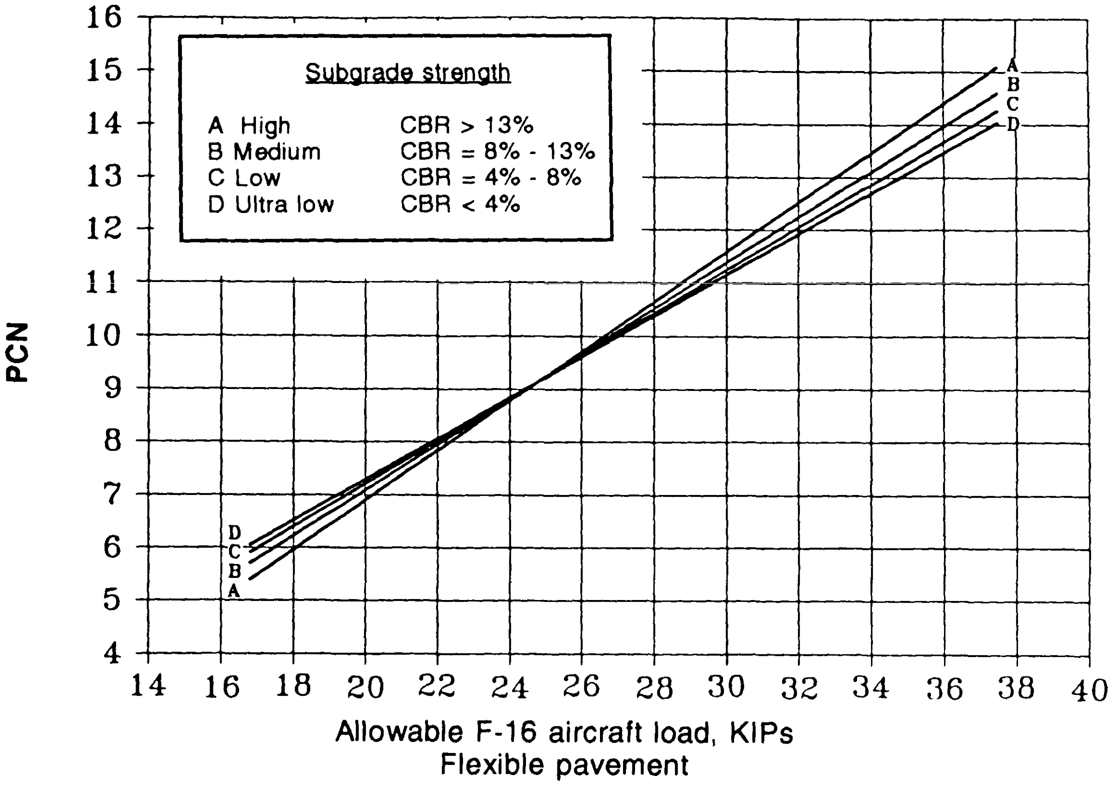


Figure O-38. PCN graphs for F-5



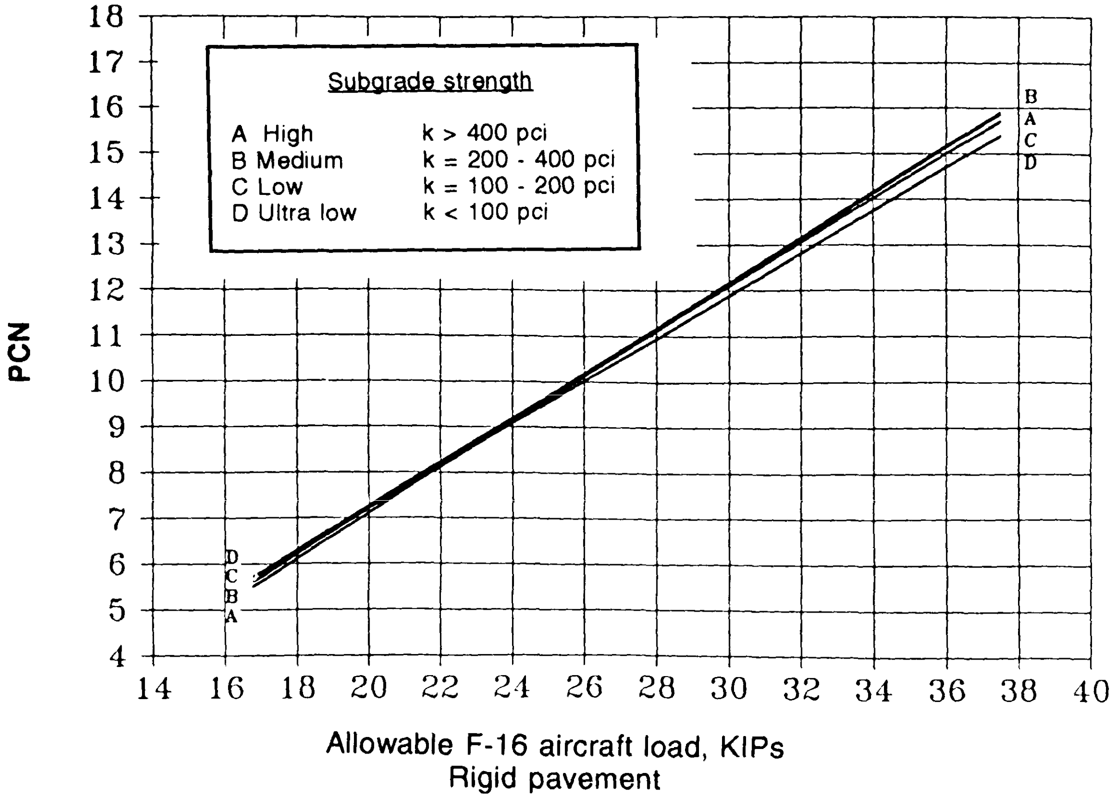
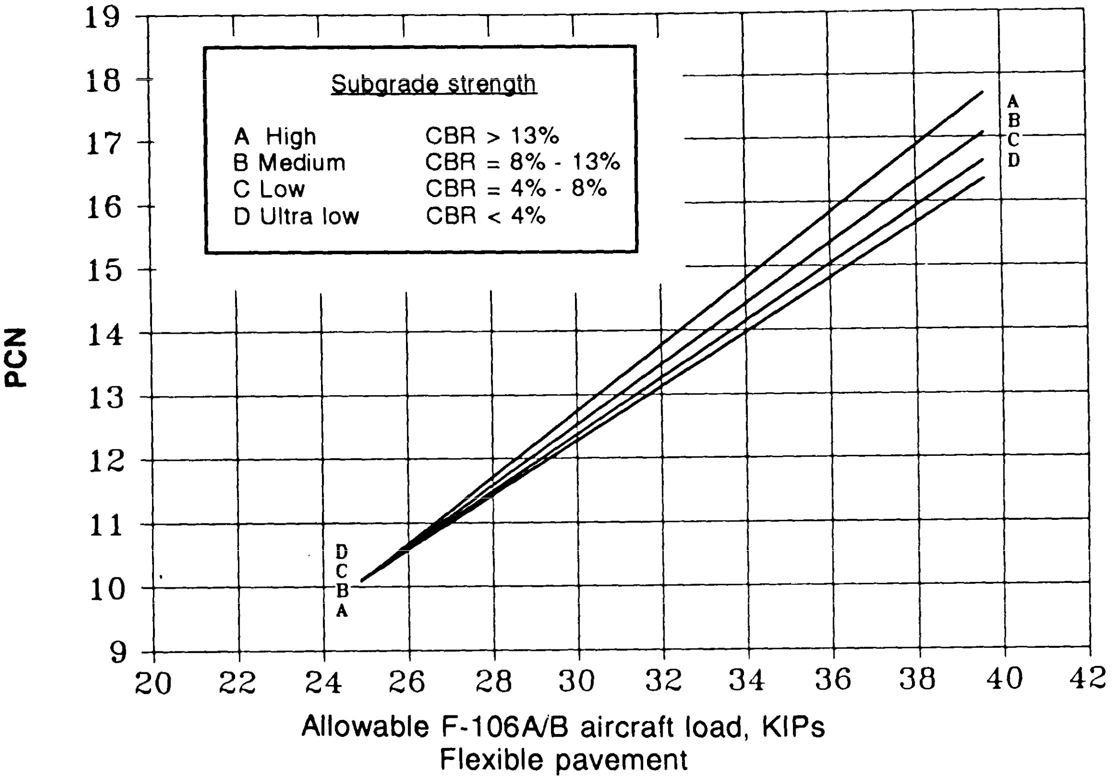


Figure O-39. PCN graphs for F-16



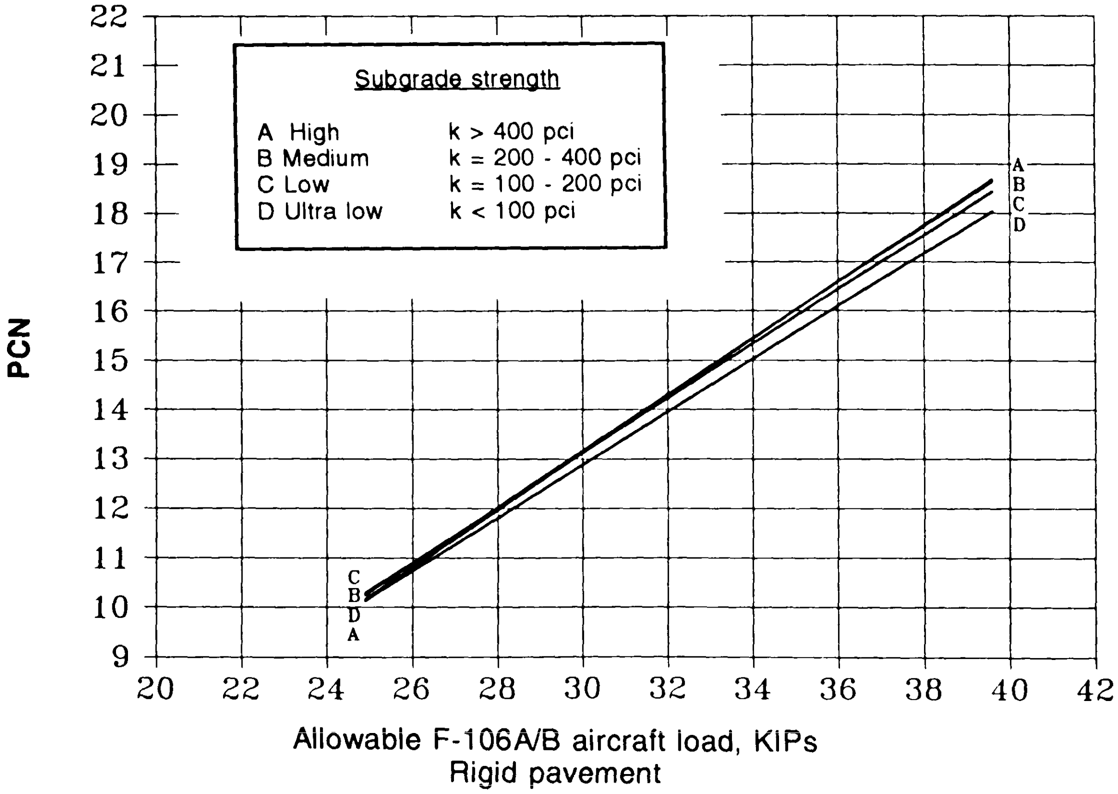
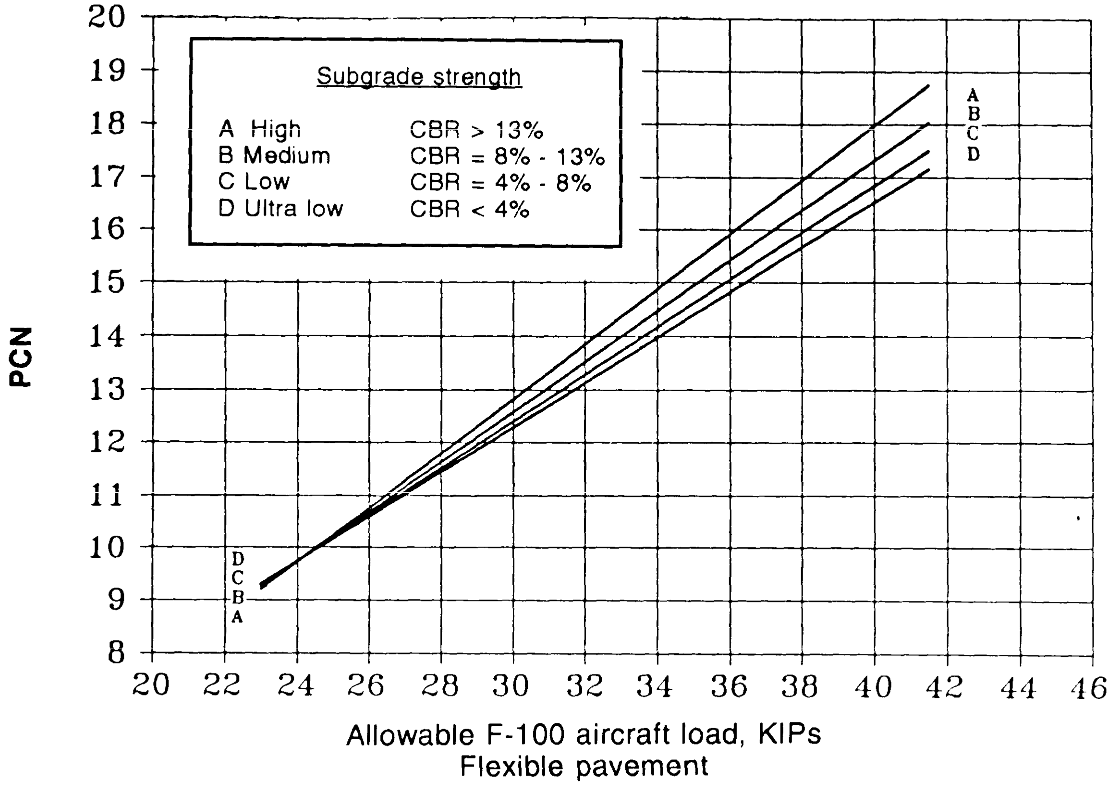


Figure O-40. PCN graphs for F-I06A/B



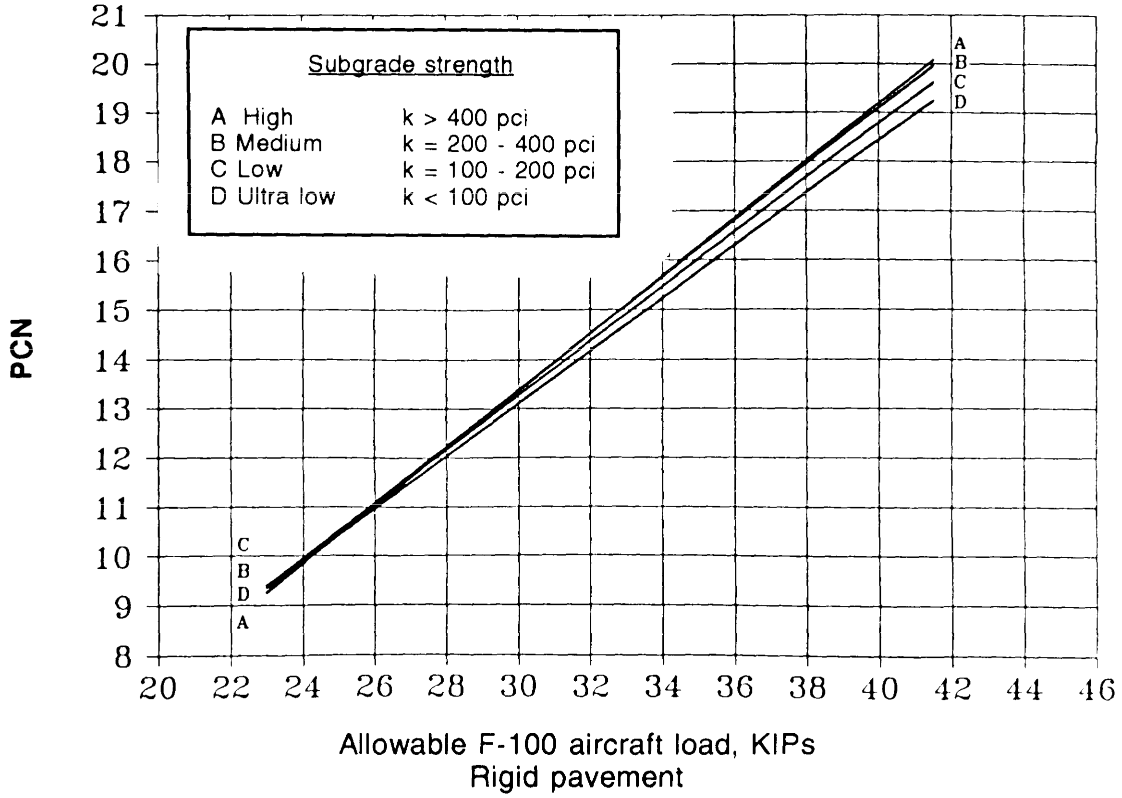
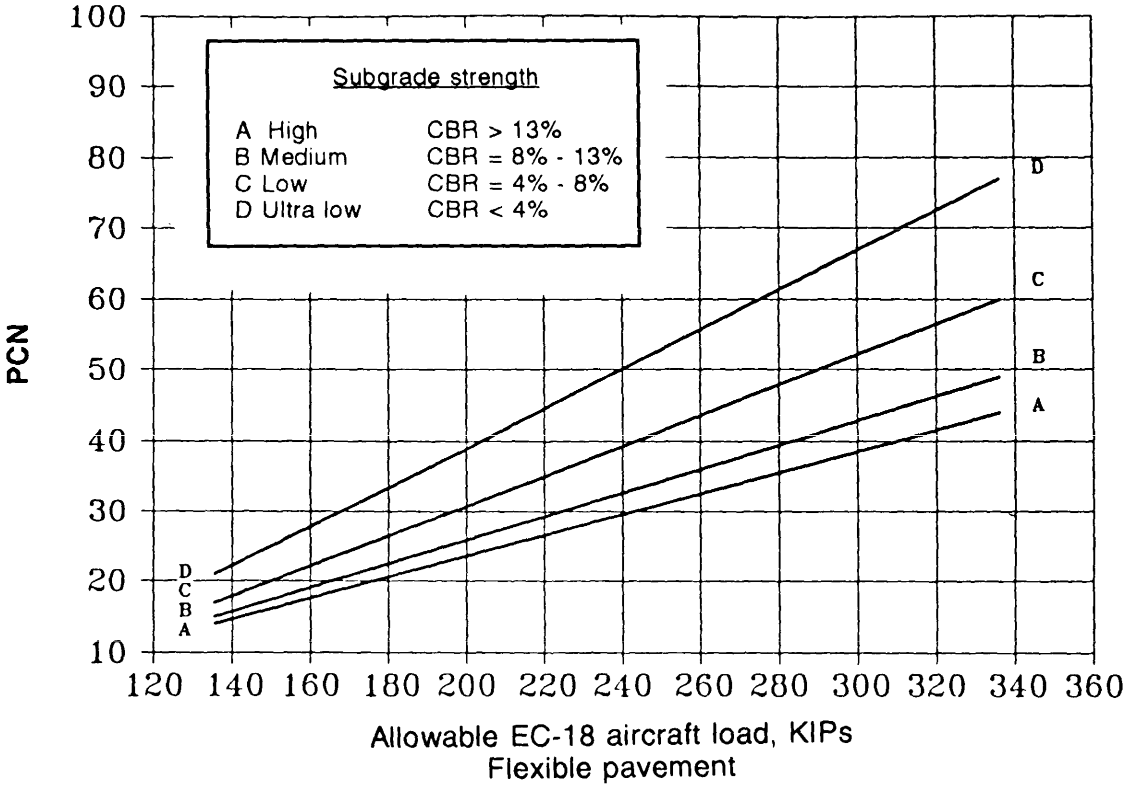


Figure O-41. PCN graphs for F-100



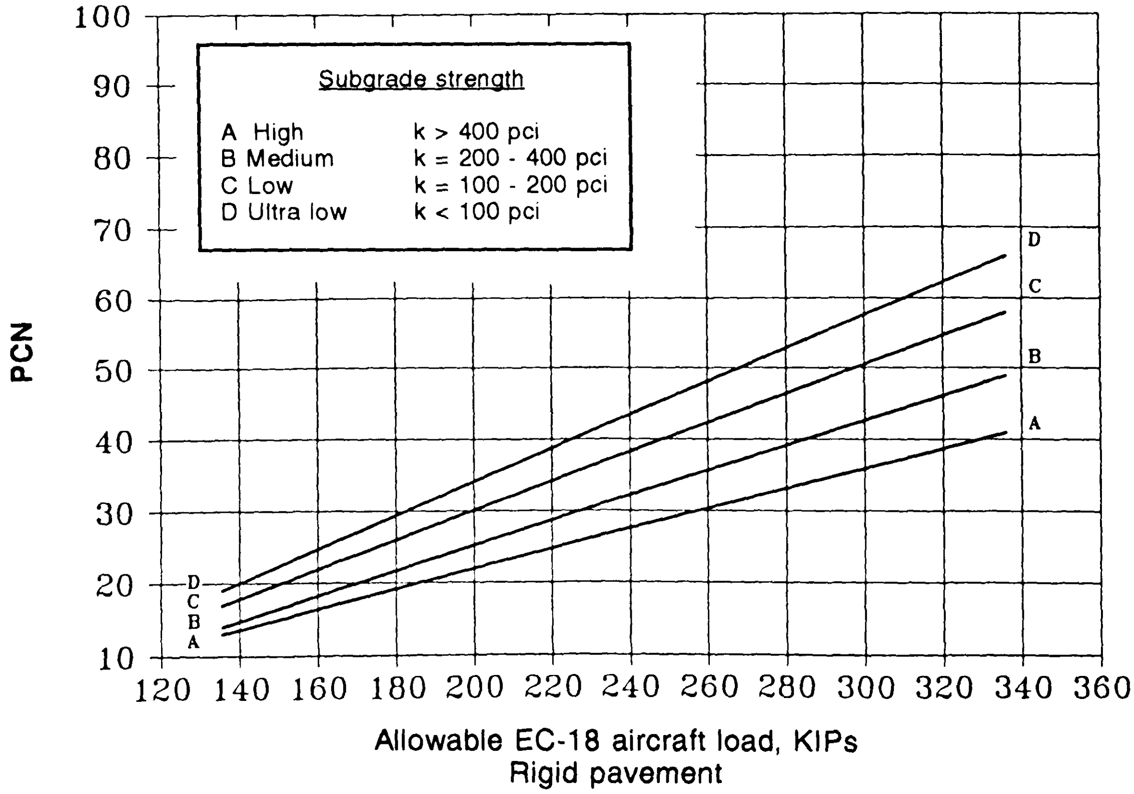
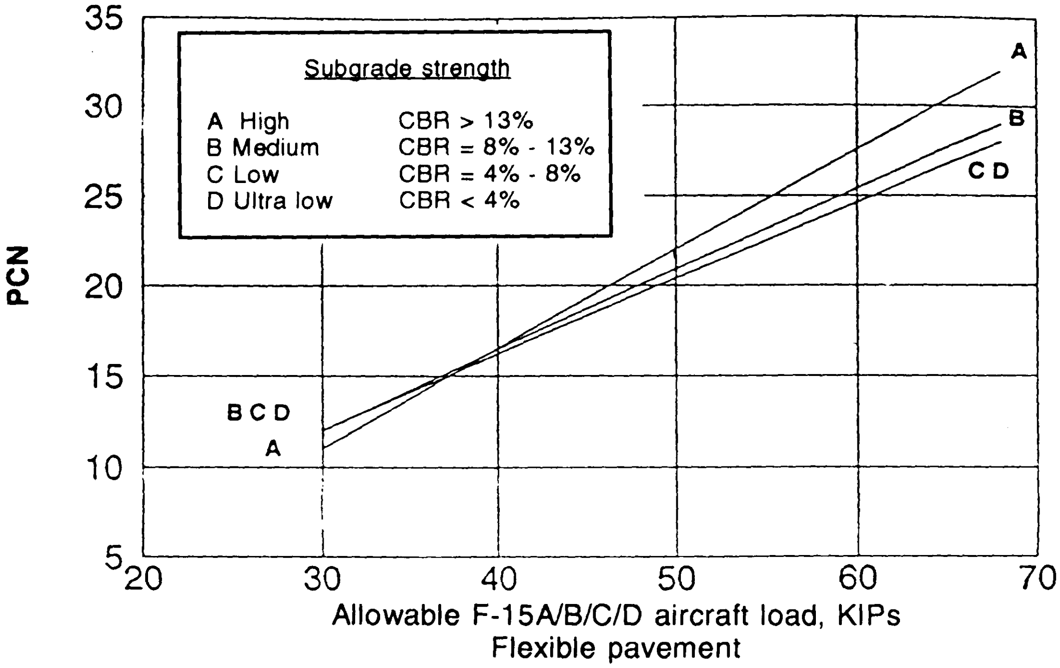


Figure O-42. PCN graphs for EC-18



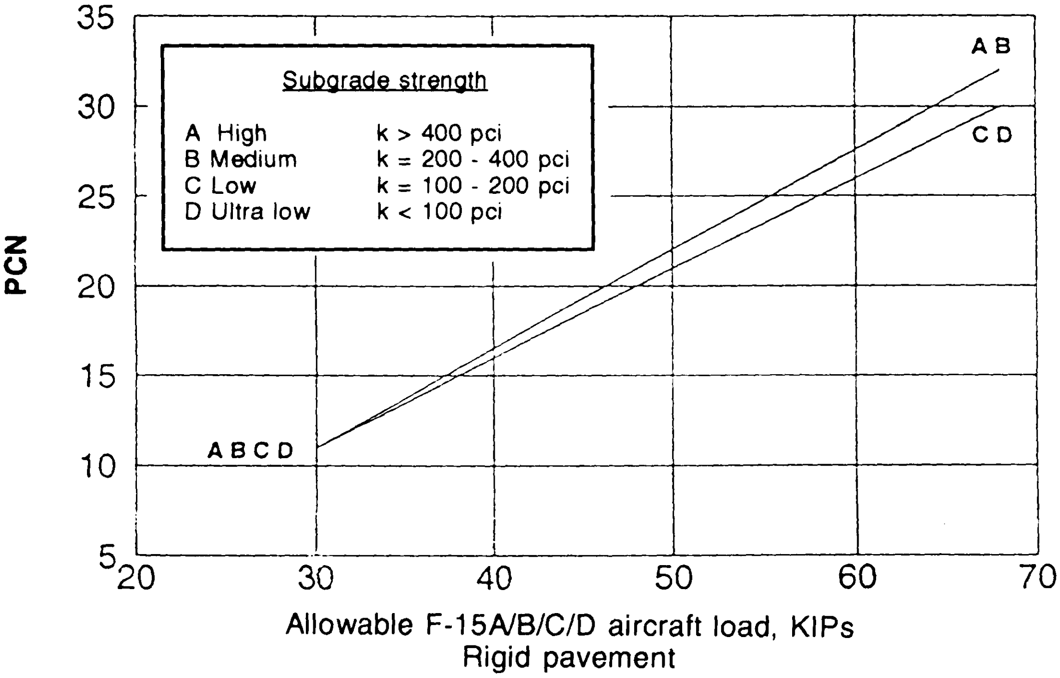


Figure O-43. PCN graphs for F-15

APPENDIX P

BALLISTIC DATA

Condition I

Figures P-1 through P-11, pages P-2 through P-12, provide detailed ballistic data for different types of ammunition under Condition I, when no standoff is used. Each graph pertains to one of the 11 types of the protective material discussed.

Condition II

Figures P-12 through P-22, pages P-13 through P-23, provide penetration data under Condition II, when a steel standoff is used.

Condition III

Figures P-23 through P-33, pages P-24 through P-34, provide penetration data under Condition III, when a wooden standoff is used.

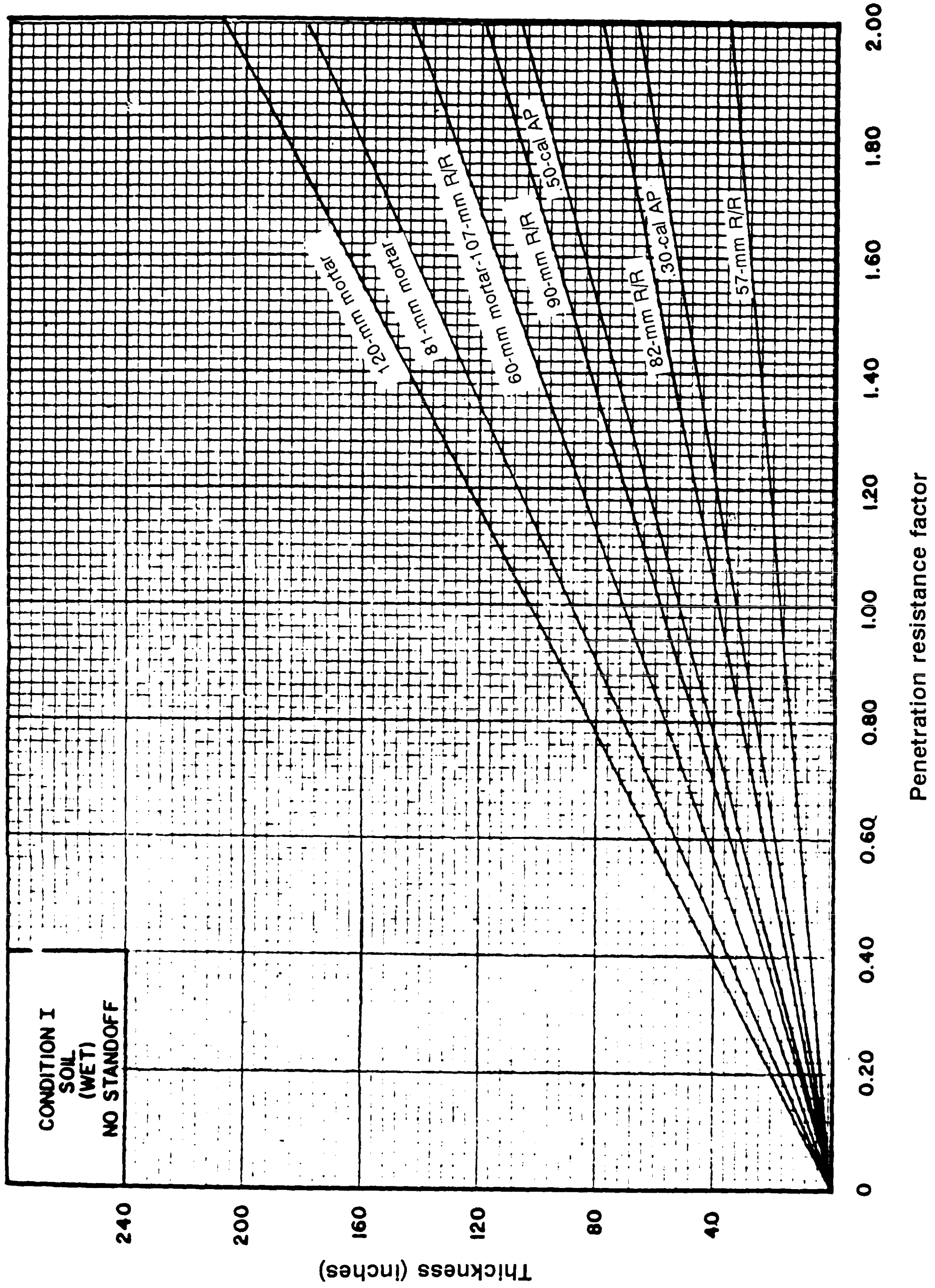


Figure P-1. Ballistic graphs for Condition I for wet soils

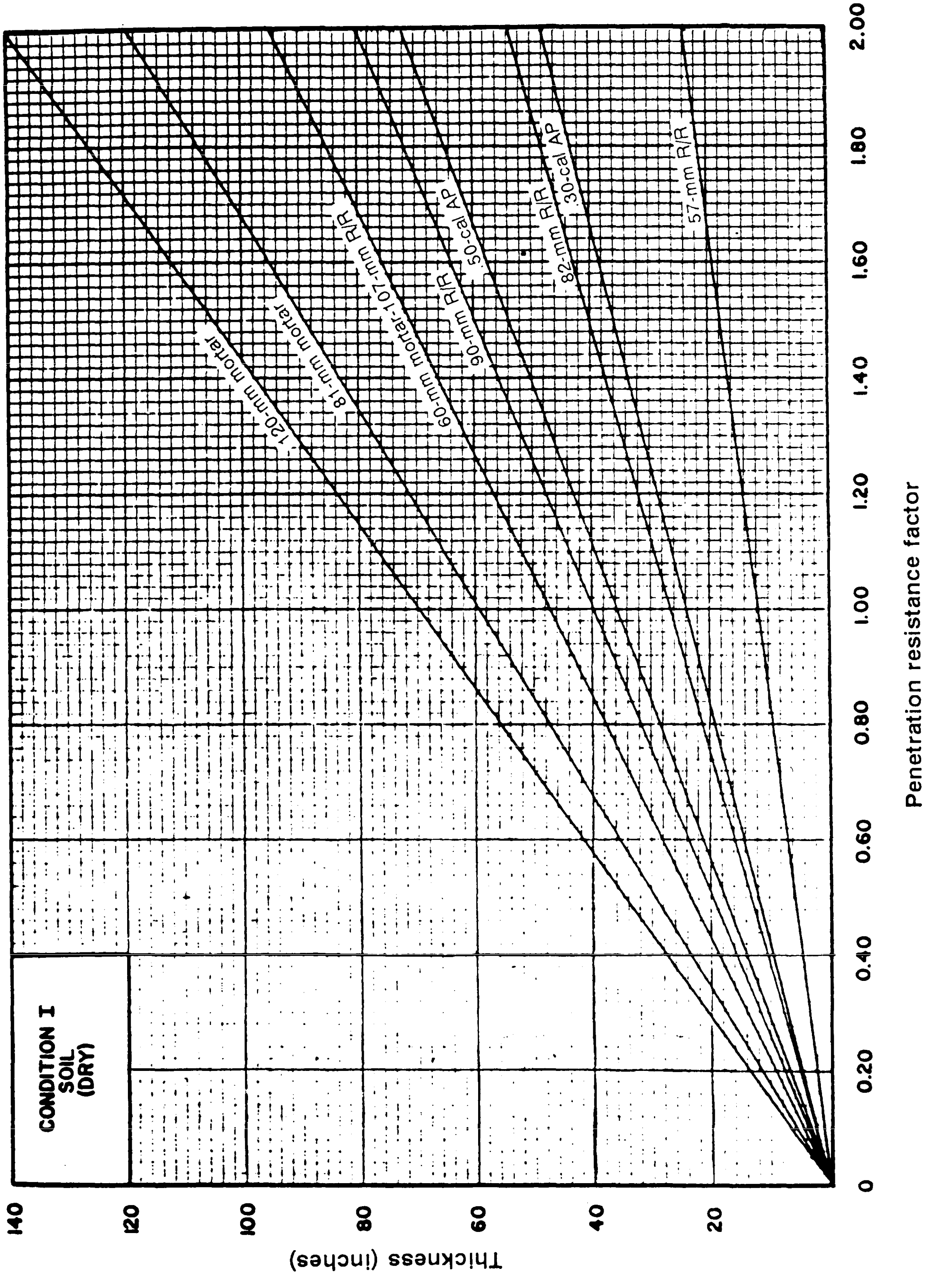


Figure P-2. Ballistic graphs for Condition I for dry soils

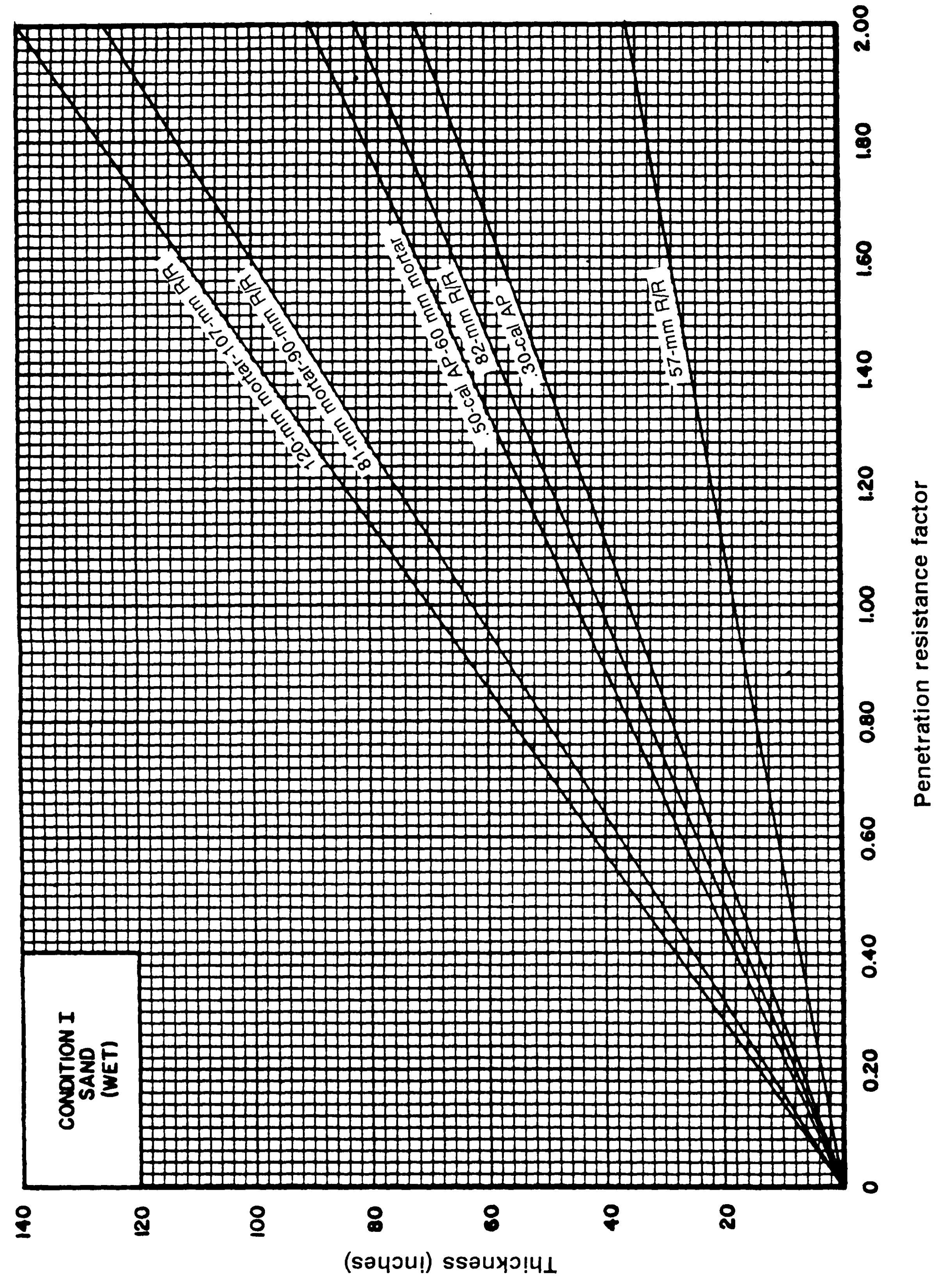


Figure P-3. Ballistic graphs for Condition I for wet sand

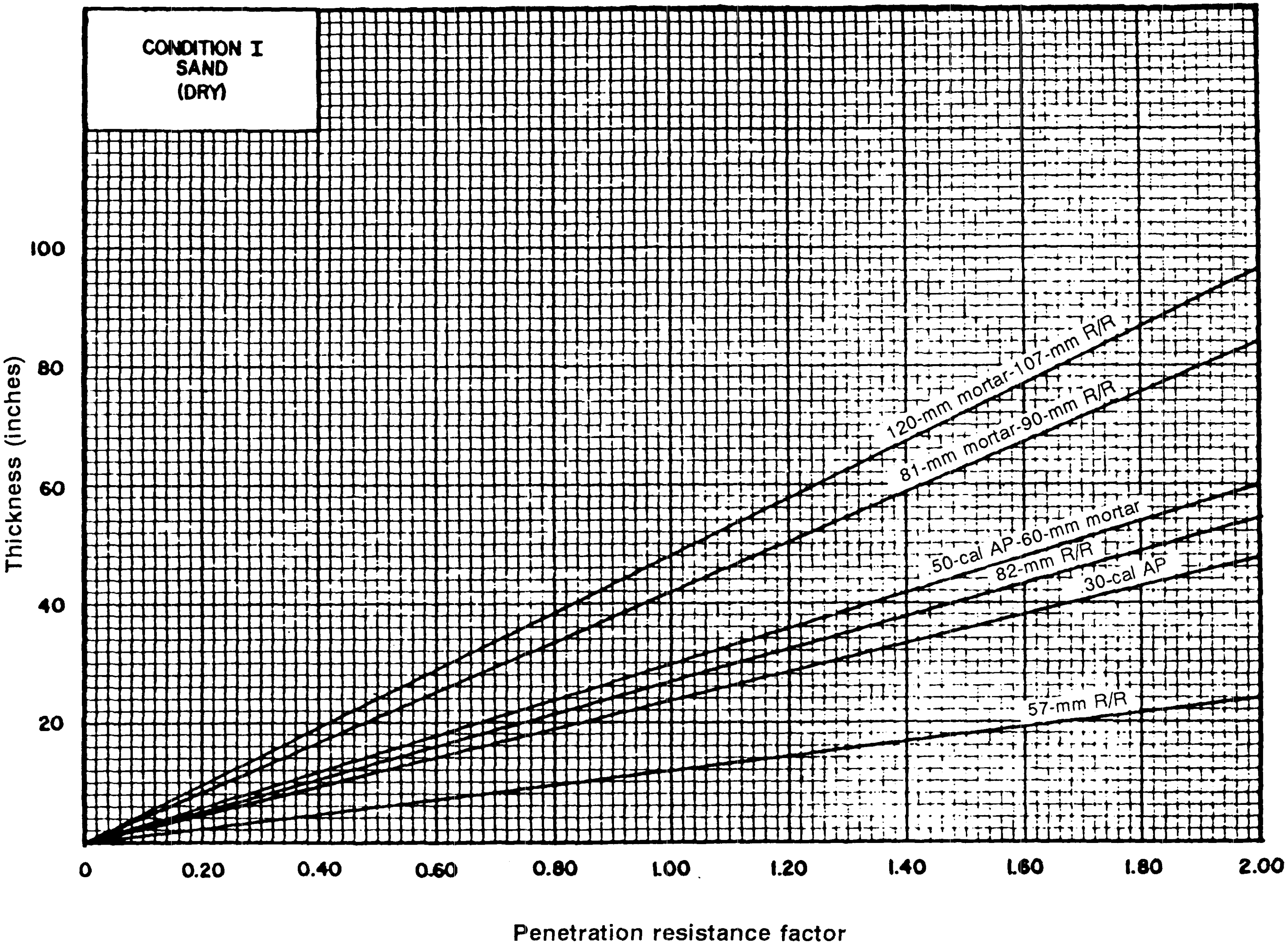


Figure P-4. Ballistic graphs for Condition I for dry sand

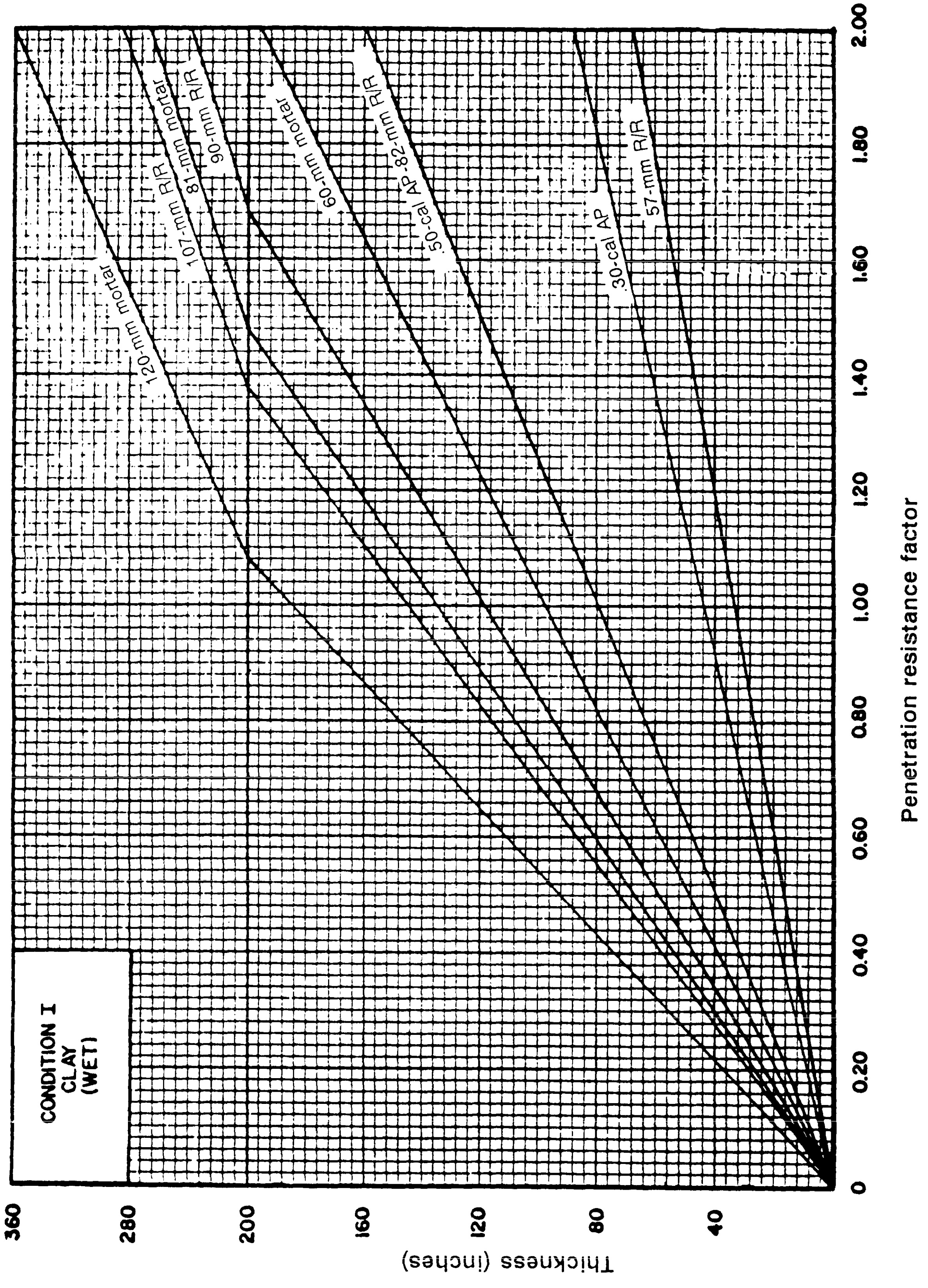


Figure P-5. Ballistic graphs for Condition I for wet clay

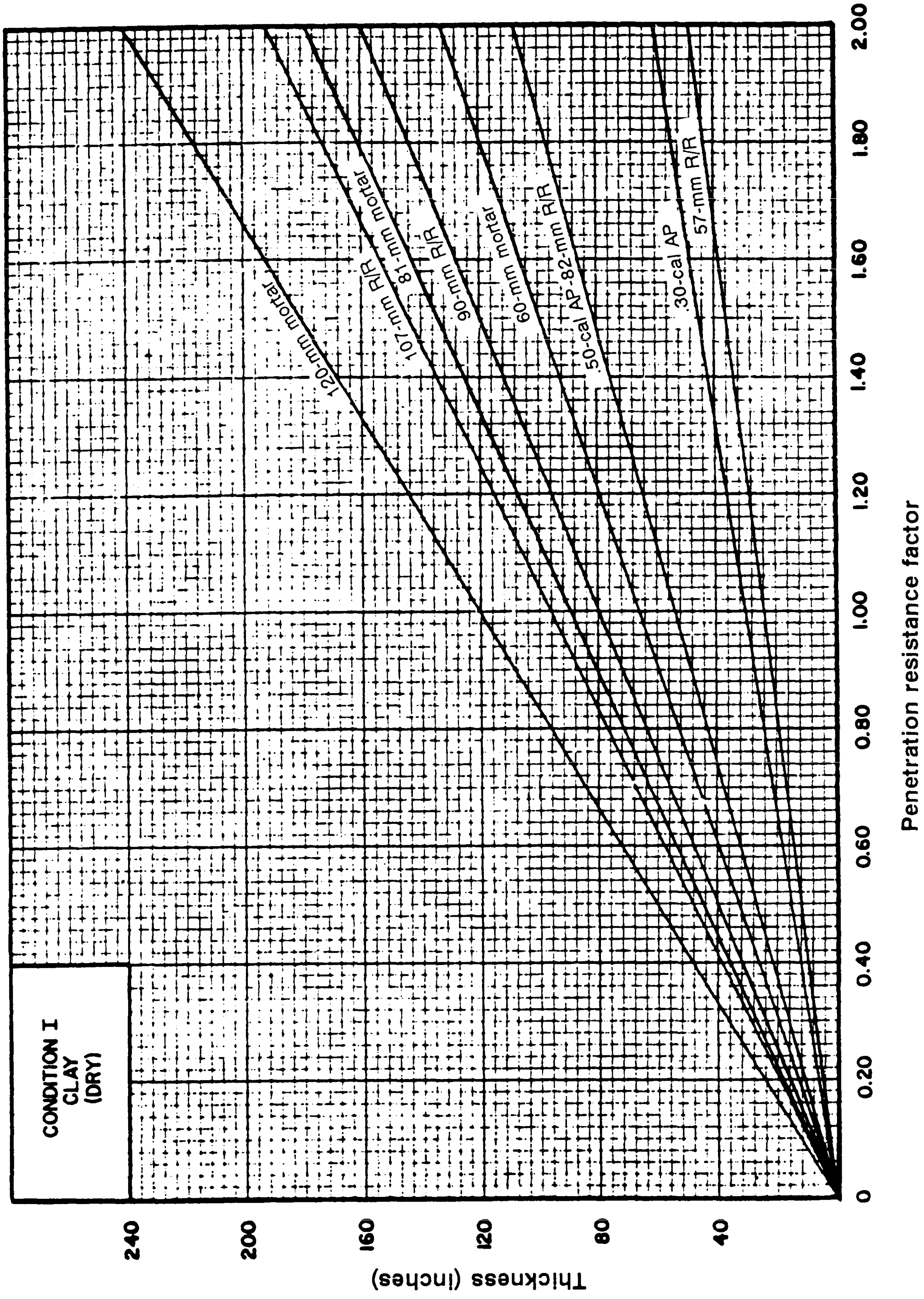


Figure P-6. Ballistic graphs for Condition I for dry clay

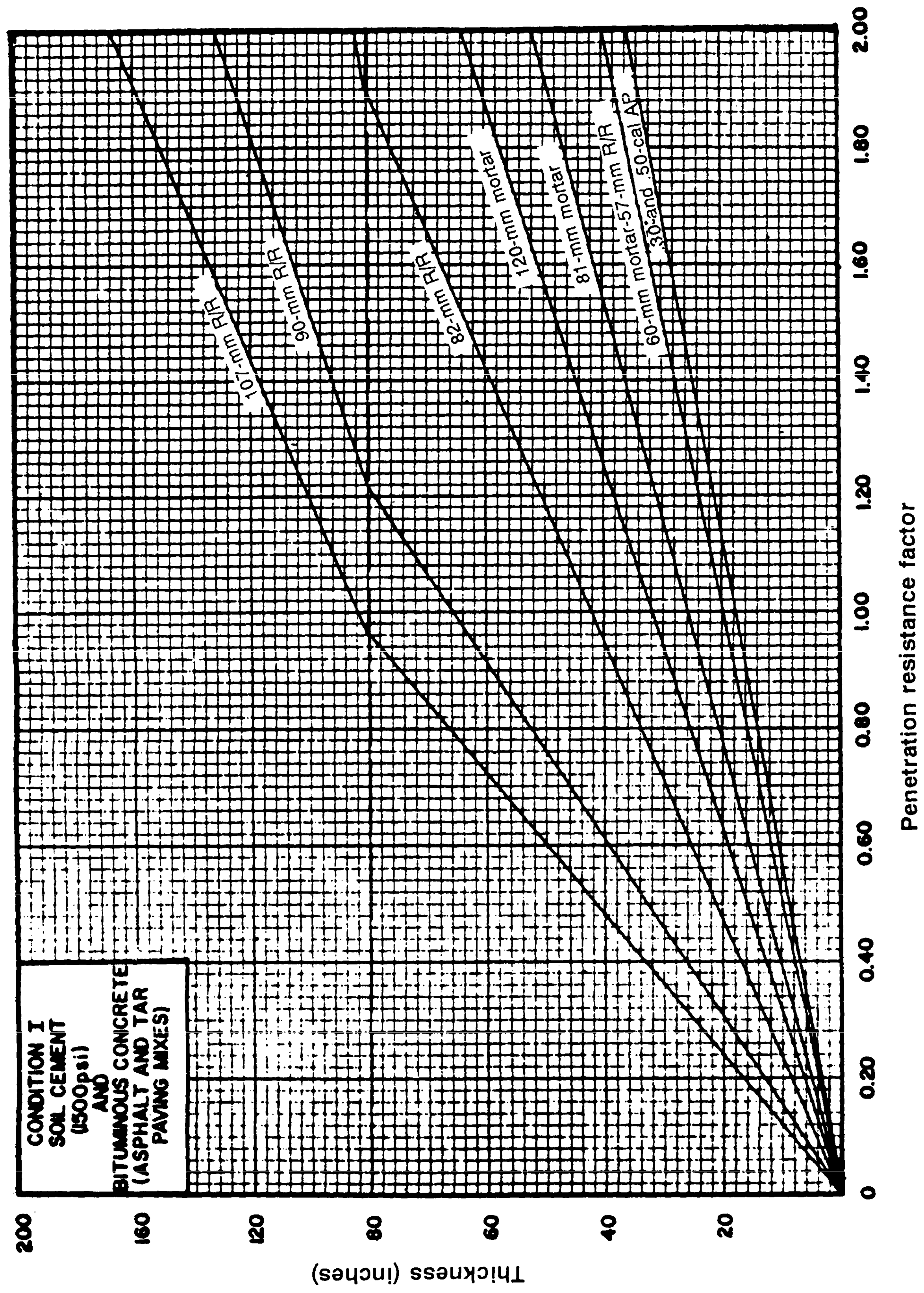


Figure P-7. Ballistic graphs for Condition I for soil cement and bituminous concrete

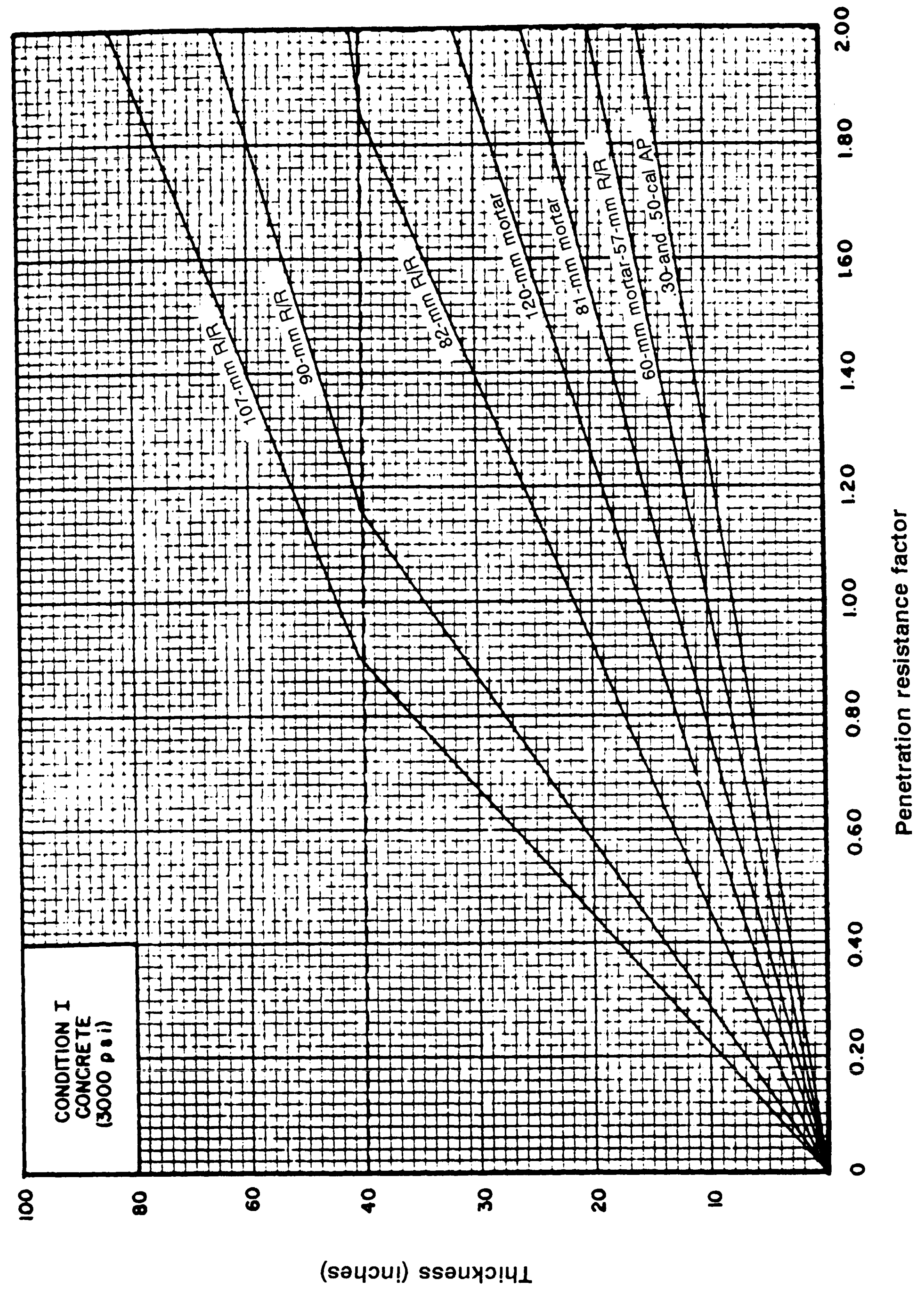


Figure P-8. Ballistic graphs for Condition I for concrete

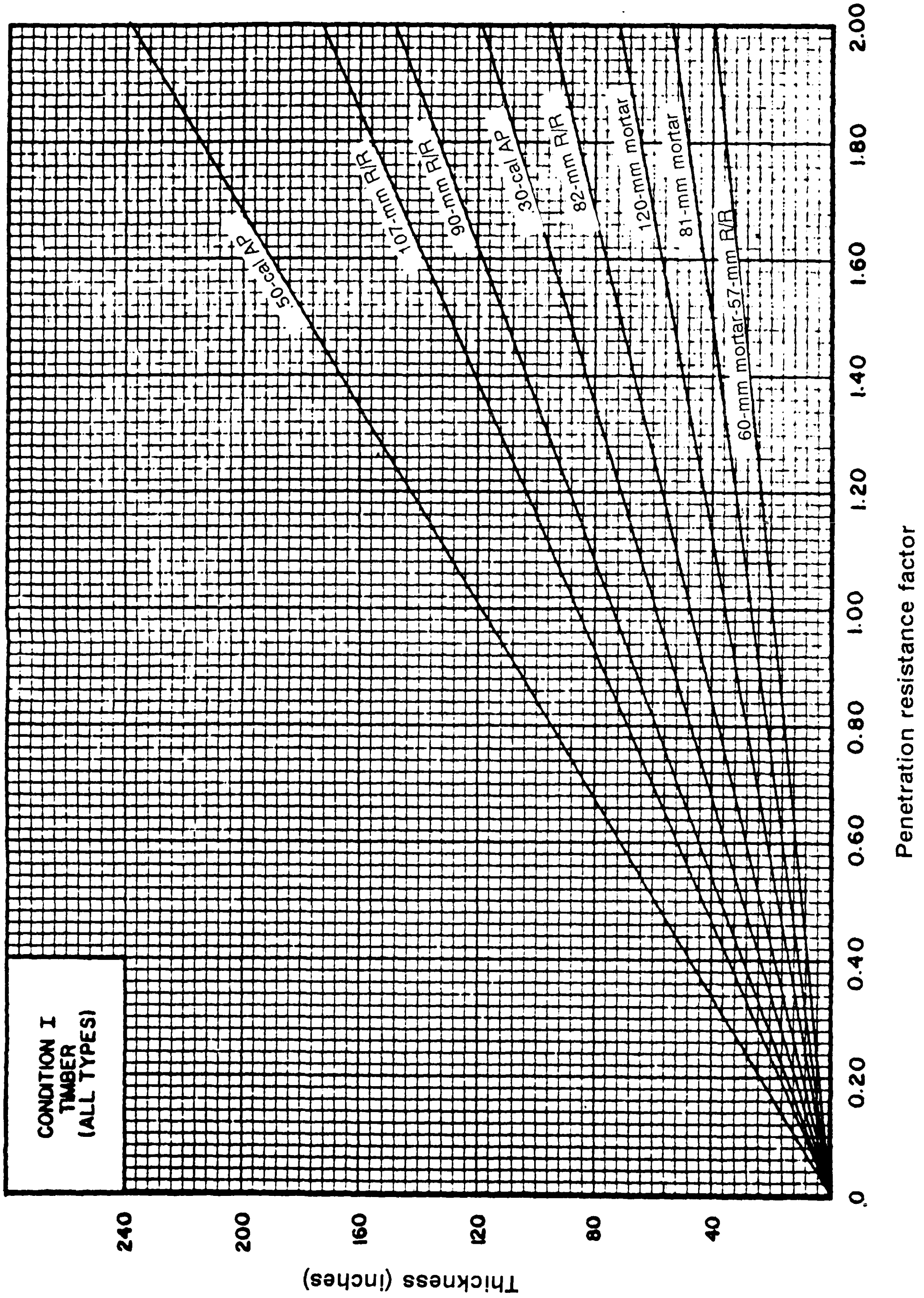
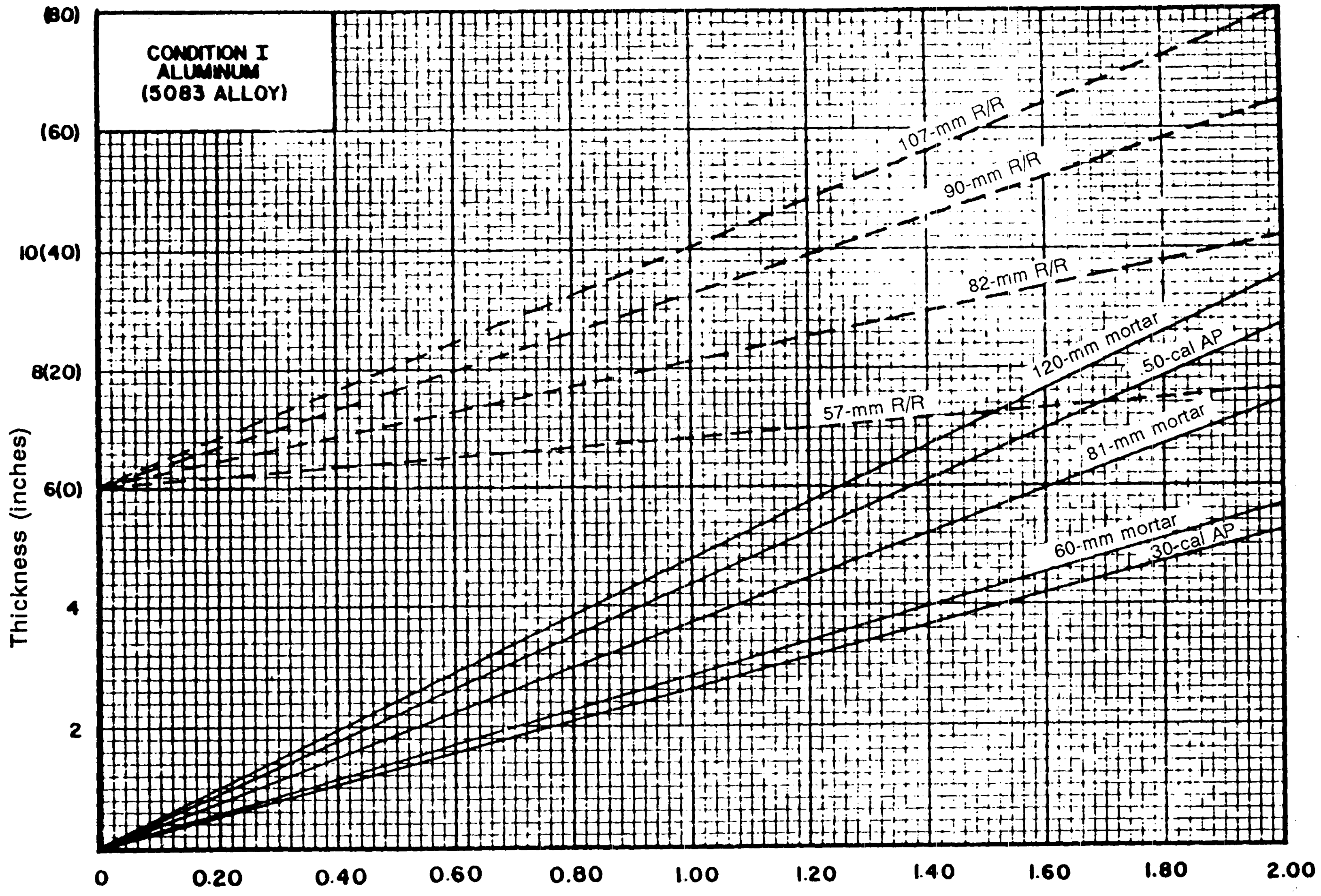
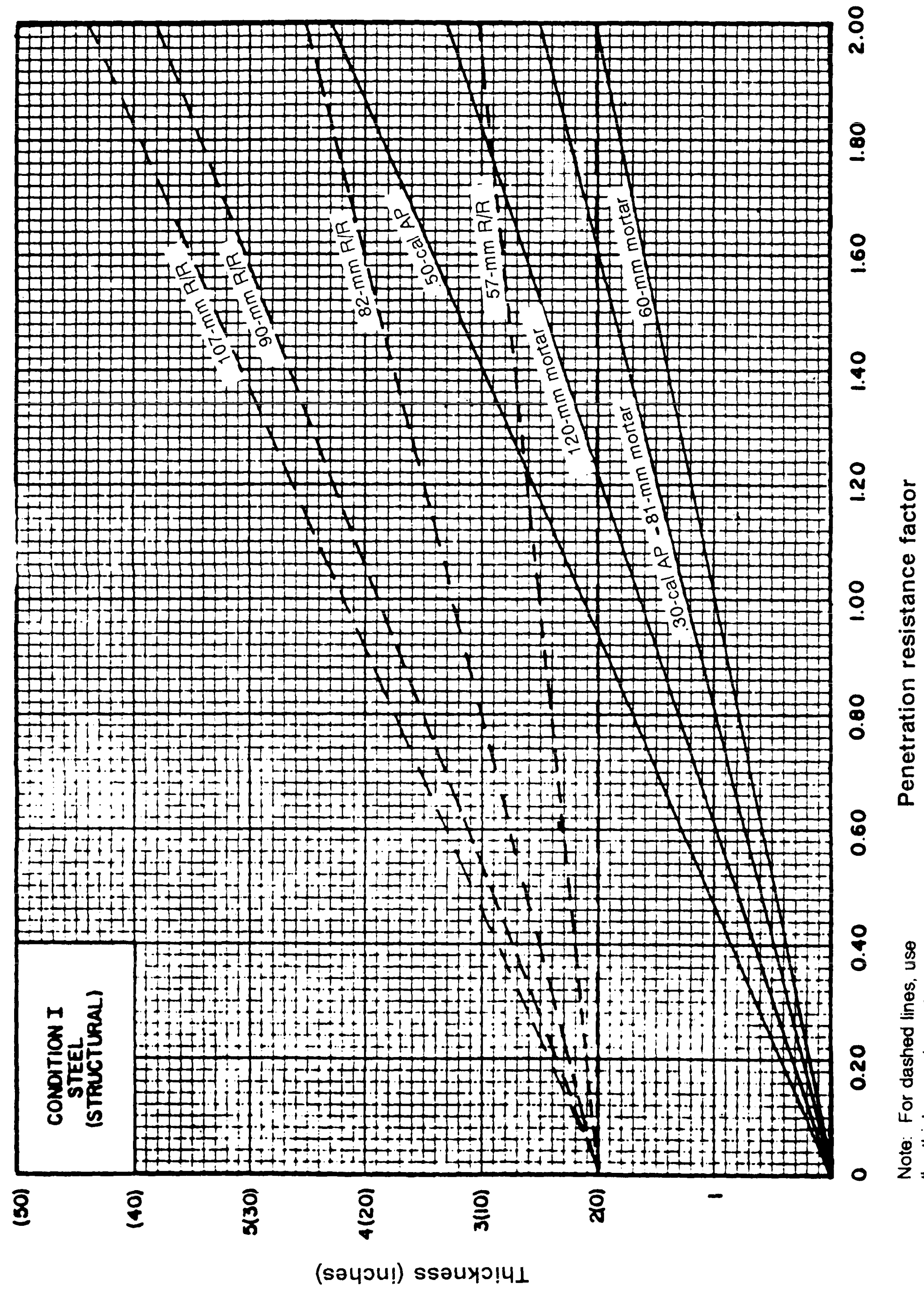


Figure P-9. Ballistic graphs for Condition I for timber



Note: For dashed lines, use the thickness shown in parentheses.

Figure P-10. Ballistic graphs for Condition I for aluminum



Note: For dashed lines, use the thickness shown in parentheses.

Figure P-11. Ballistic graphs for Condition I for steel

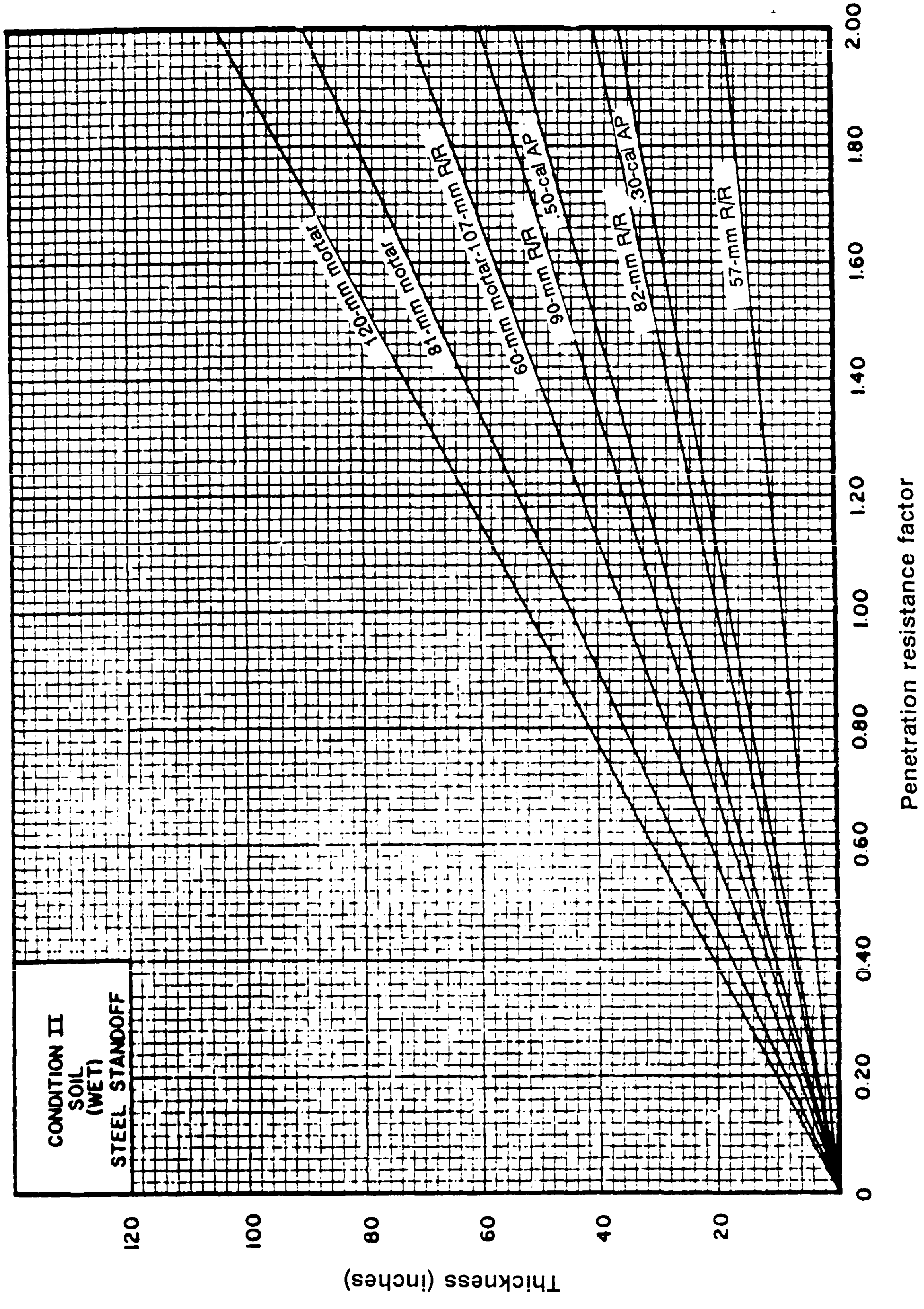


Figure P-12. Ballistic graphs for Condition II for wet soil

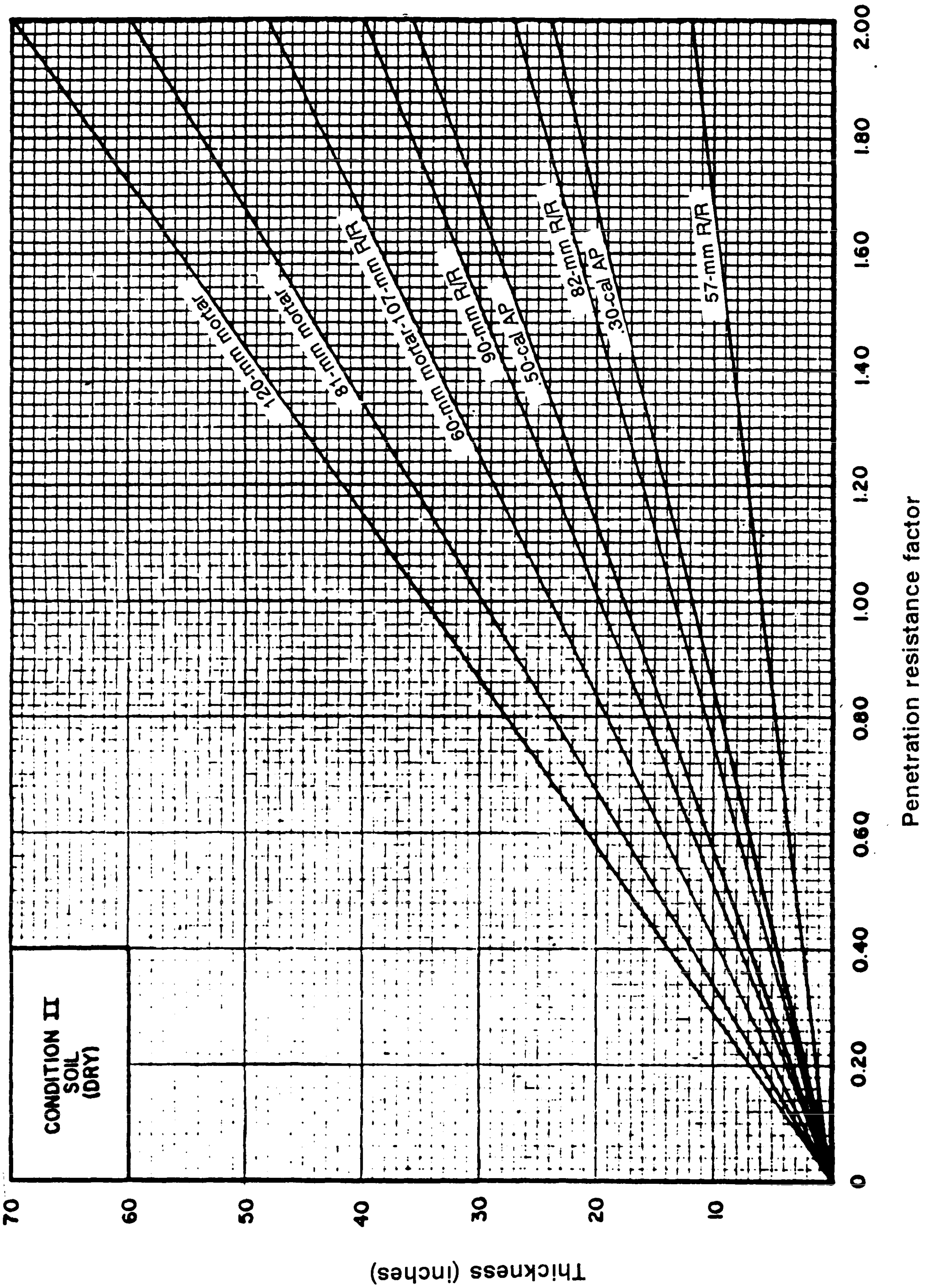


Figure P-13 Ballistic graphs for Condition II for dry soil

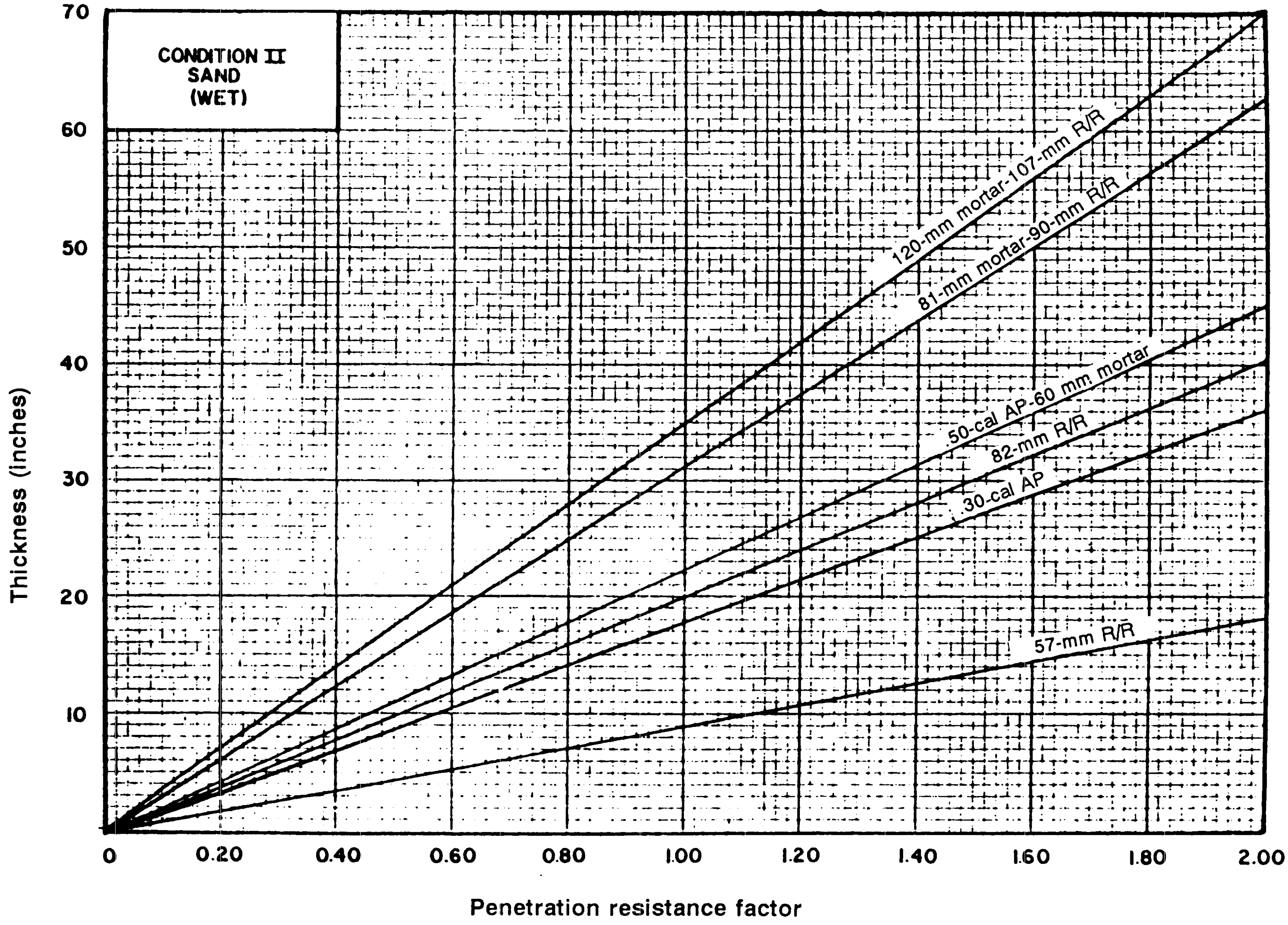


Figure P-14. Ballistic graphs for Condition II for wet sand

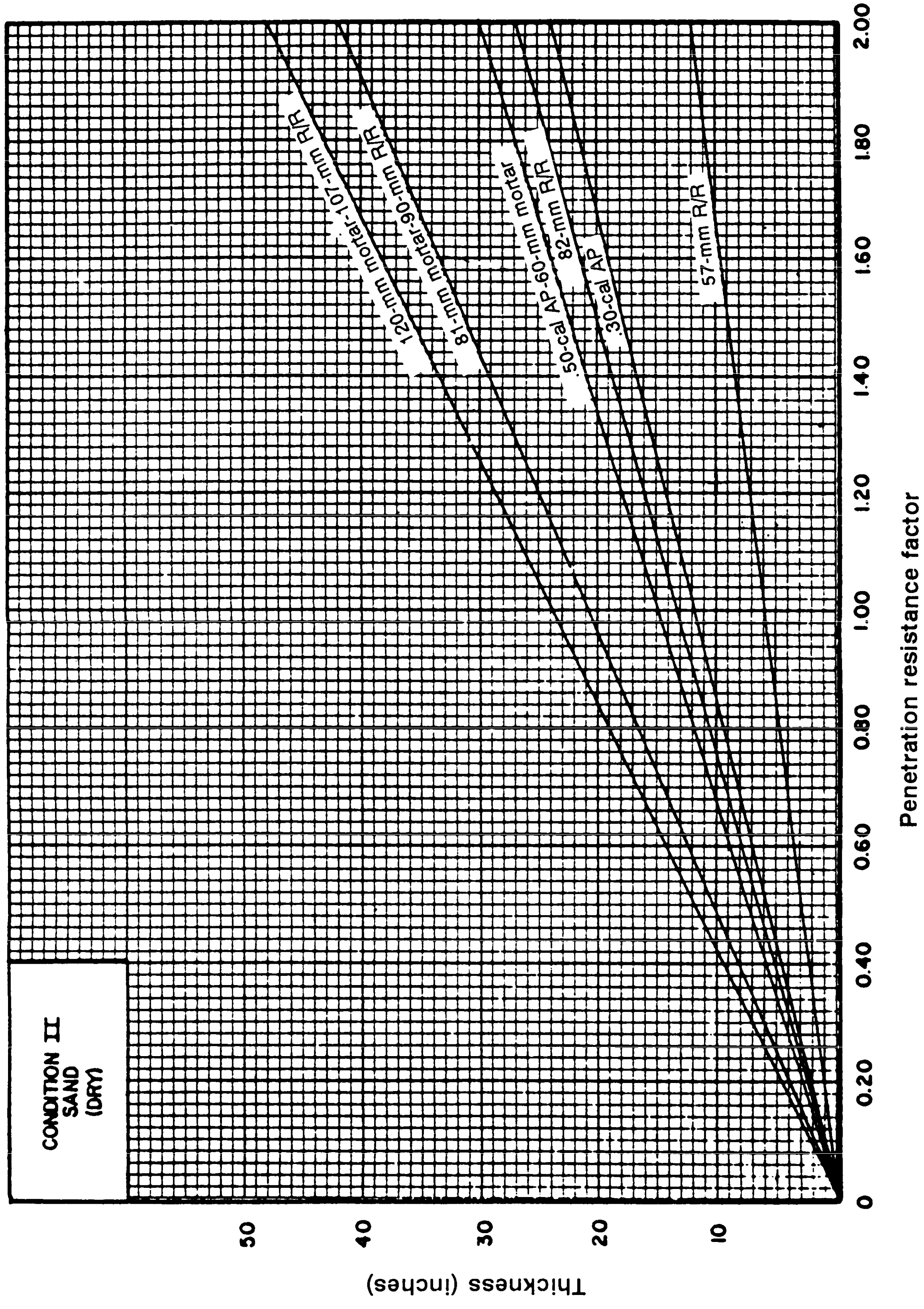


Figure P-15. Ballistic graphs for Condition II for dry sand

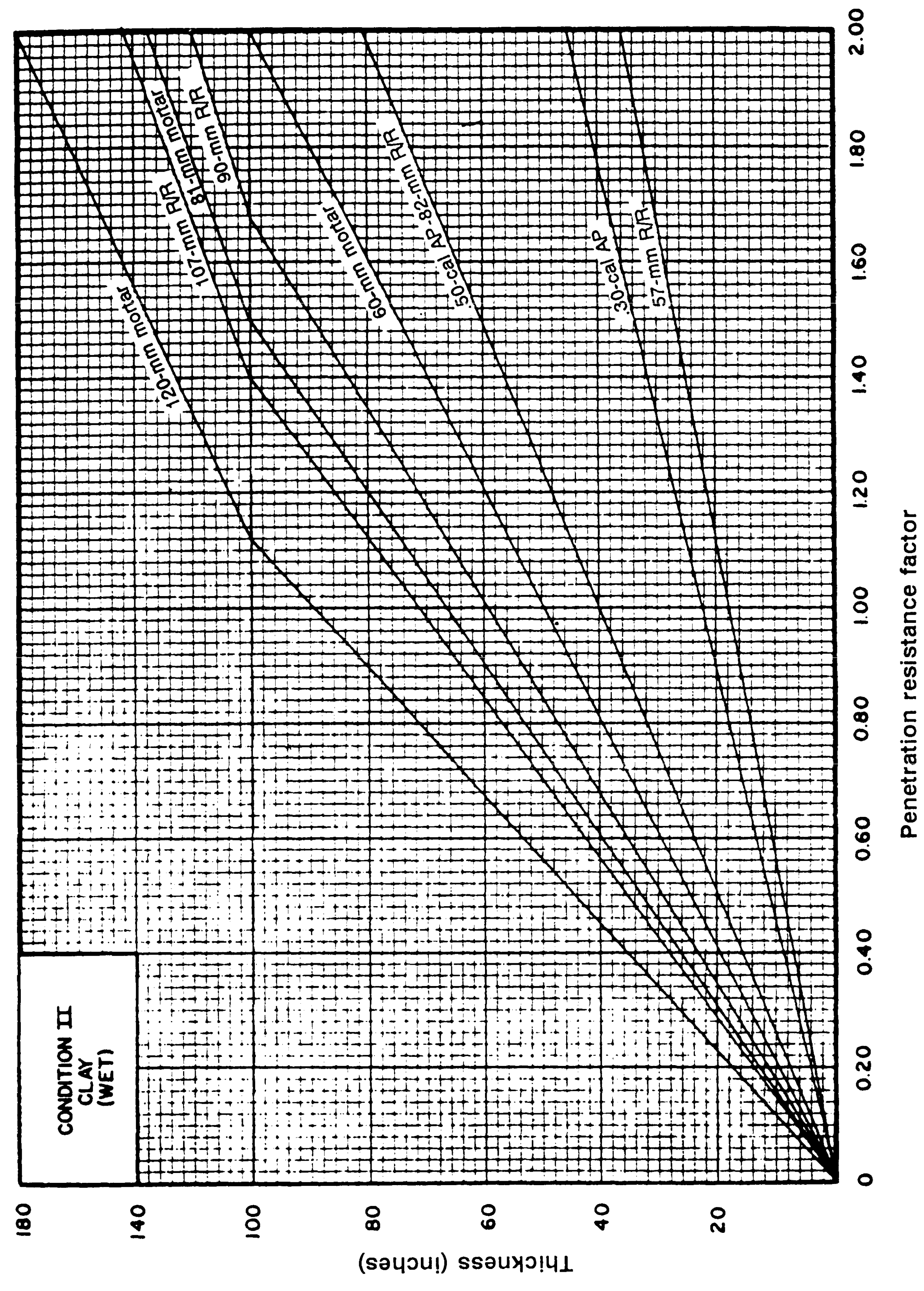


Figure P-16. Ballistic graphs for Condition II for wet clay

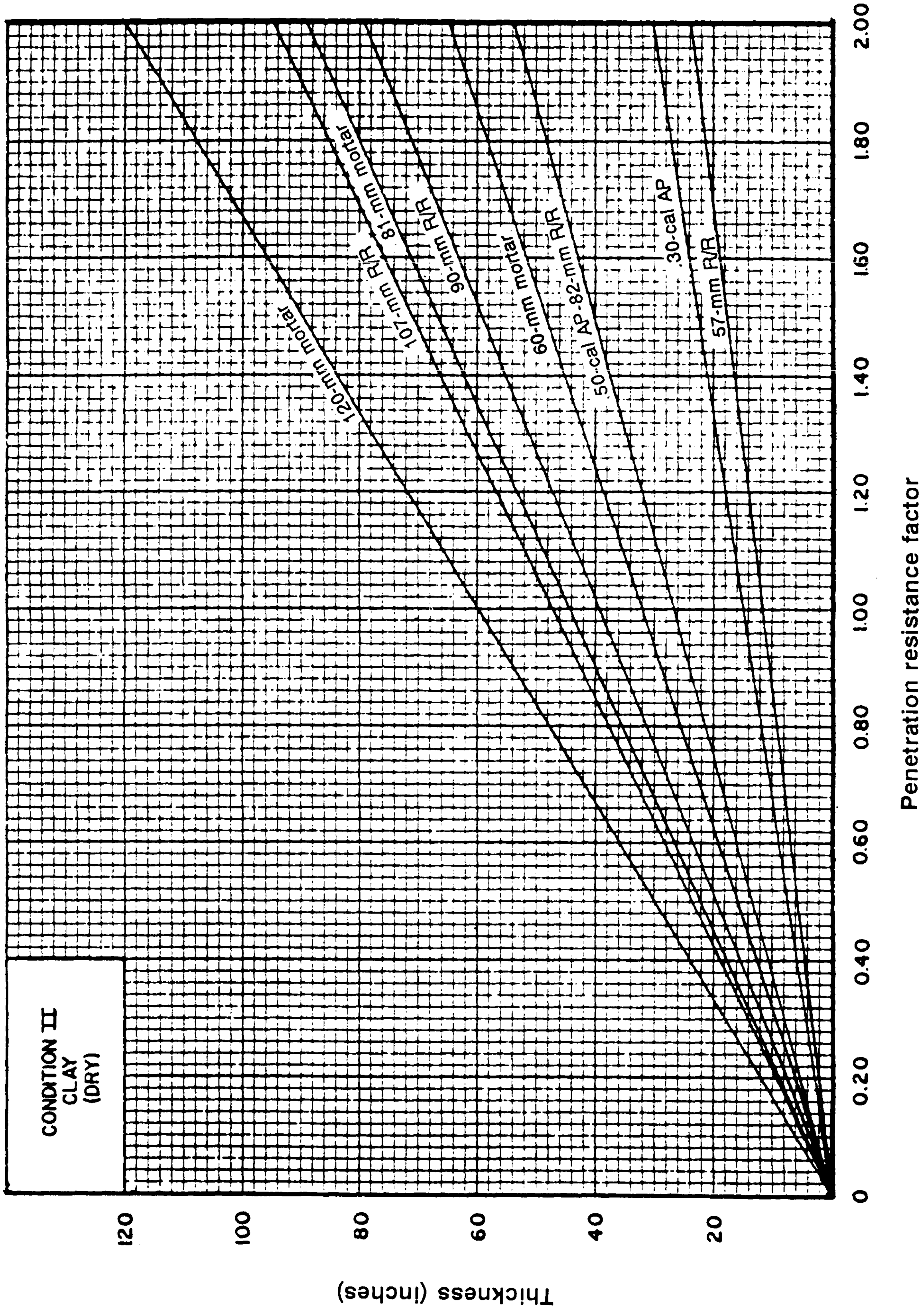


Figure P-17. Ballistic graphs for Condition II for dry clay

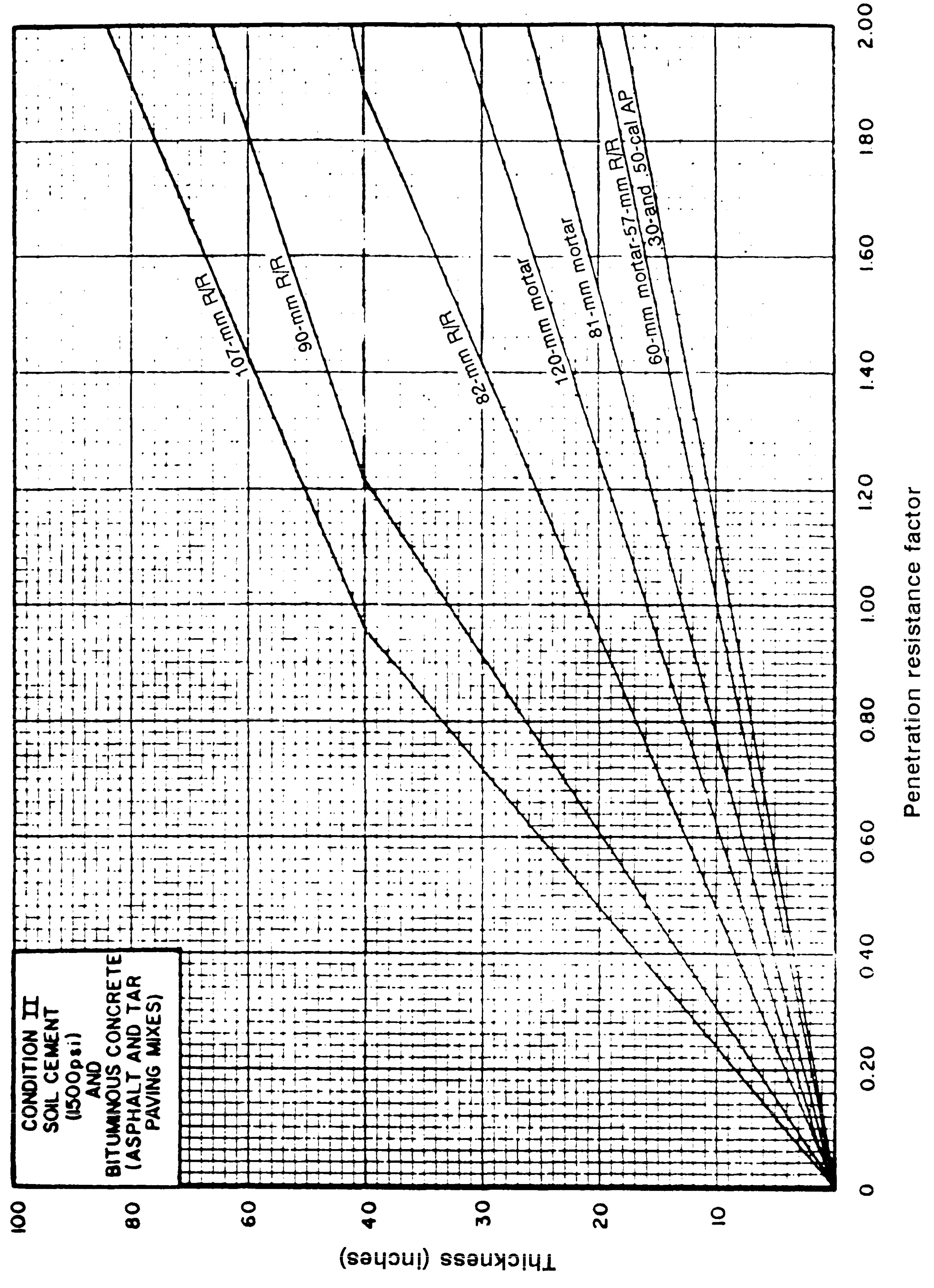


Figure P-18. Ballistic graphs for Condition II for soil cement and bituminous concrete

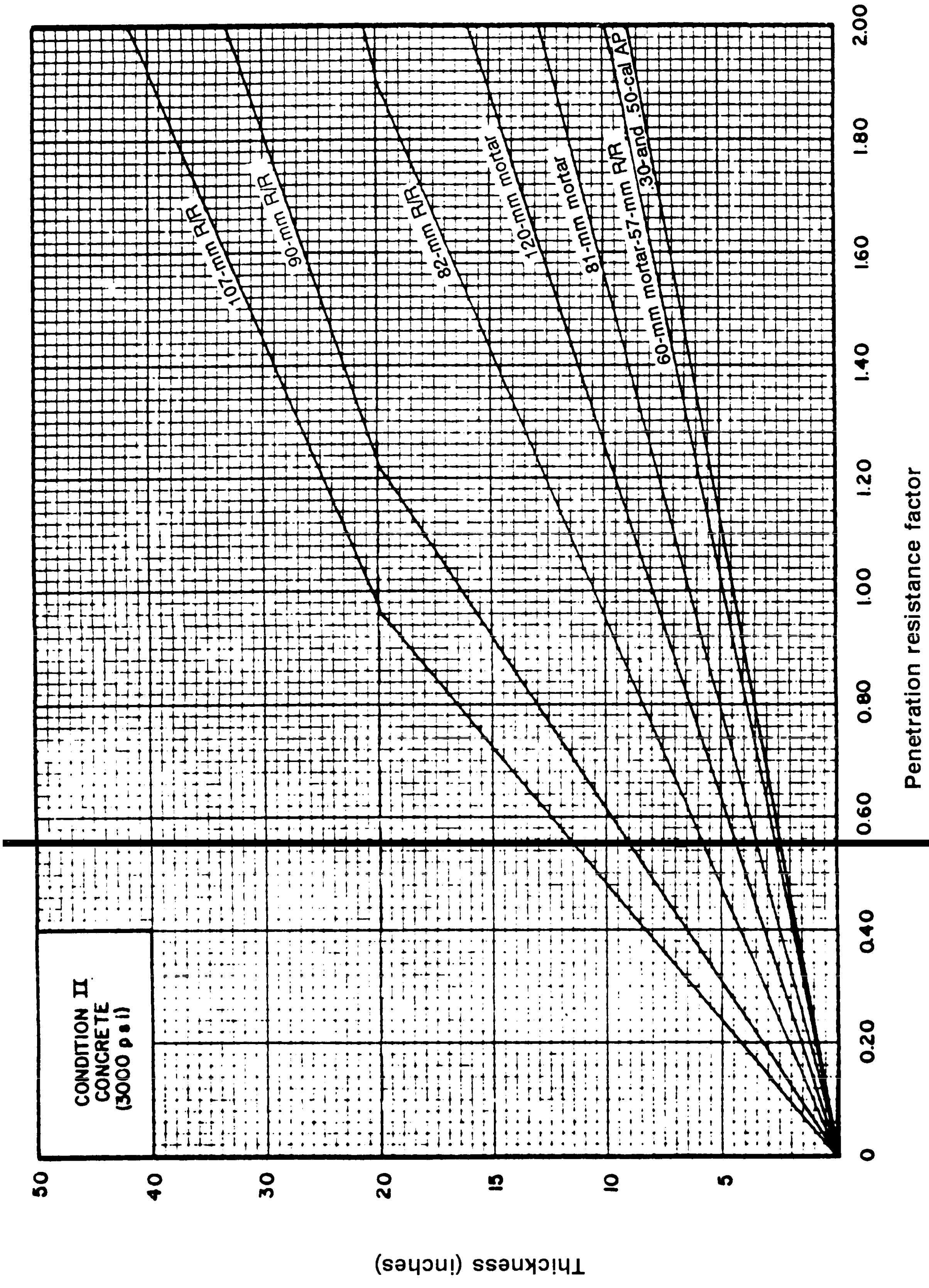


Figure P-19 *Ballistic graphs for Condition II for concrete*

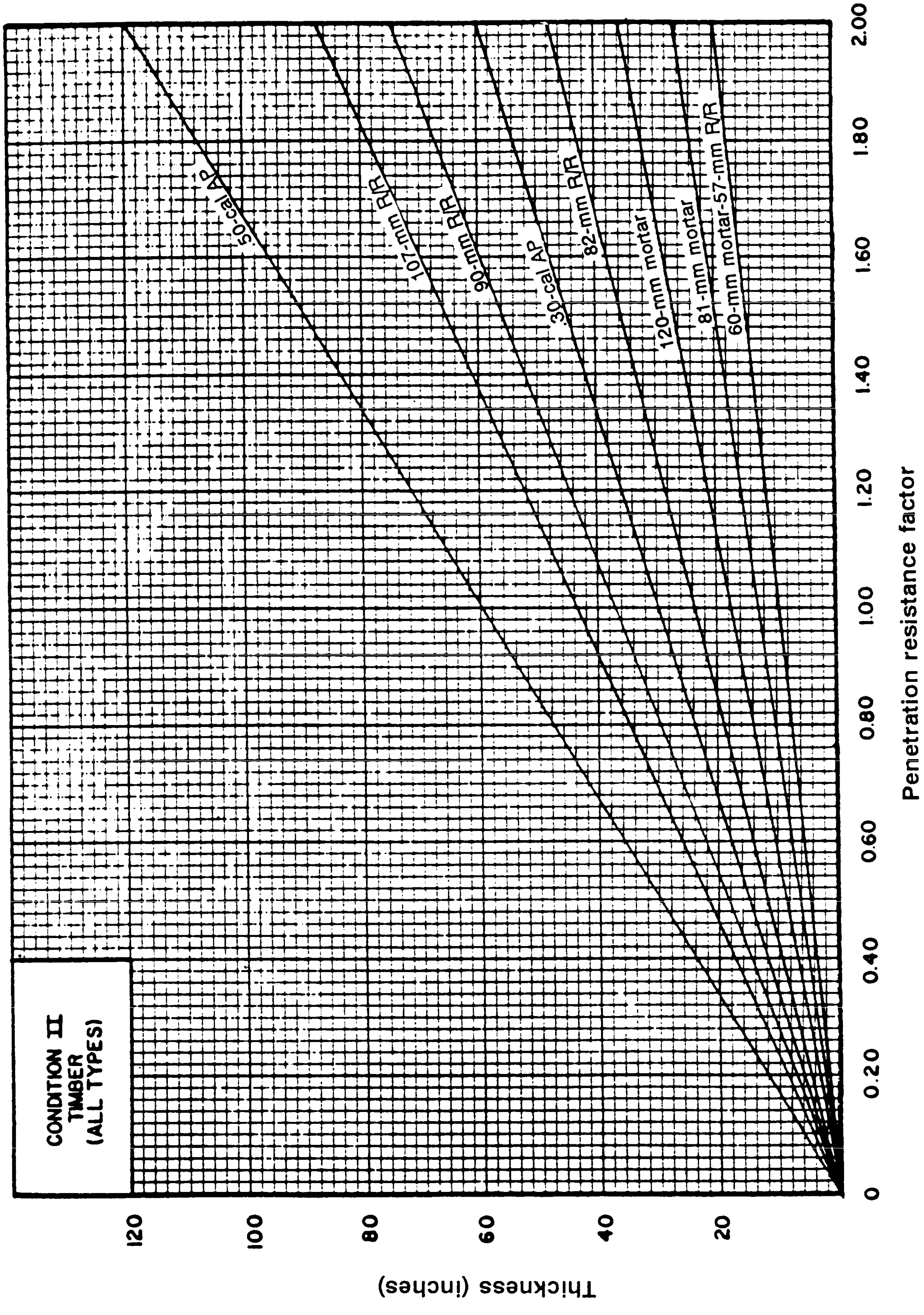
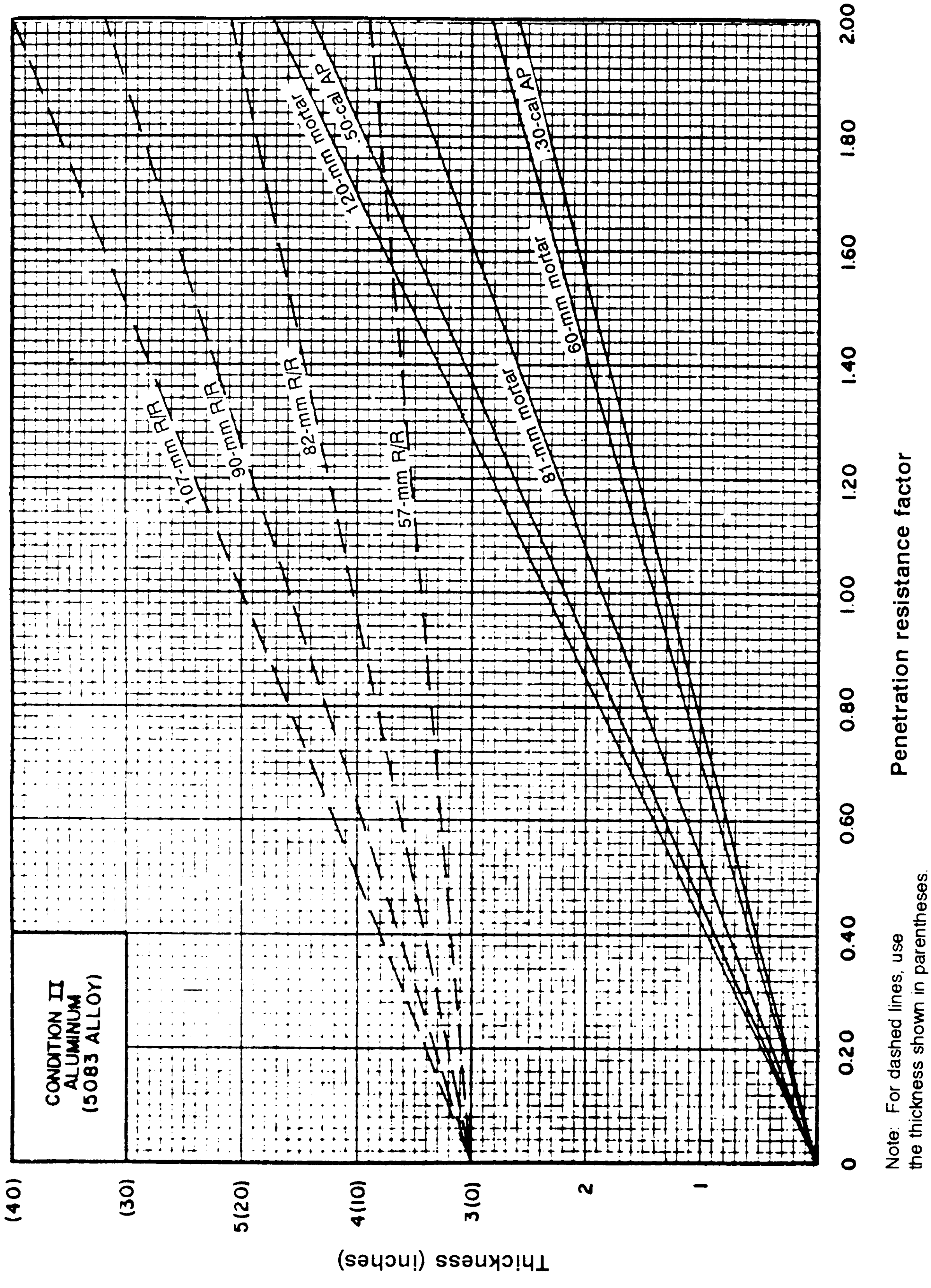


Figure P-20. Ballistic graphs for Condition II for timber



Note: For dashed lines, use the thickness shown in parentheses.

Figure P-21. Ballistic graphs for Condition II for aluminum

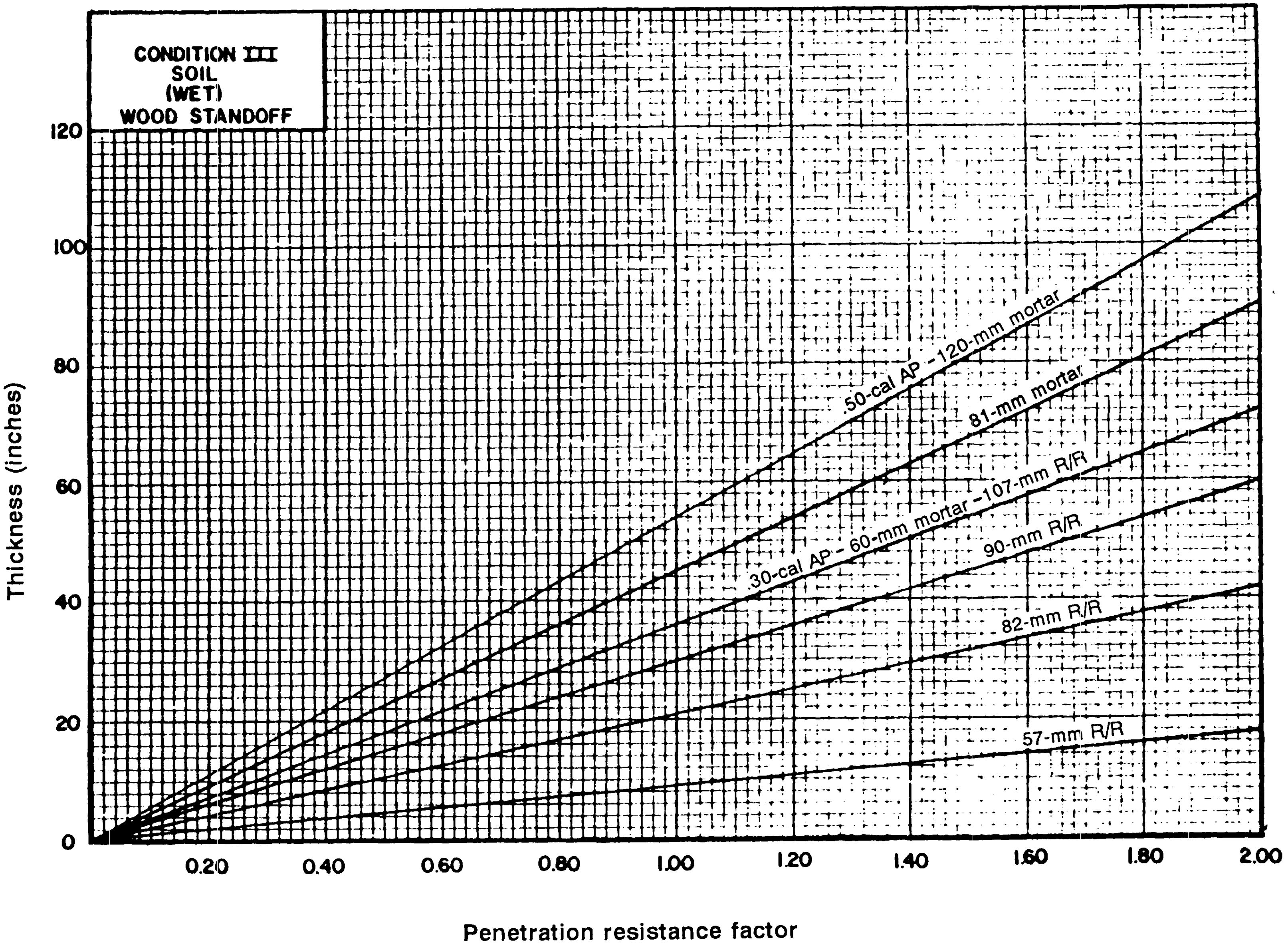
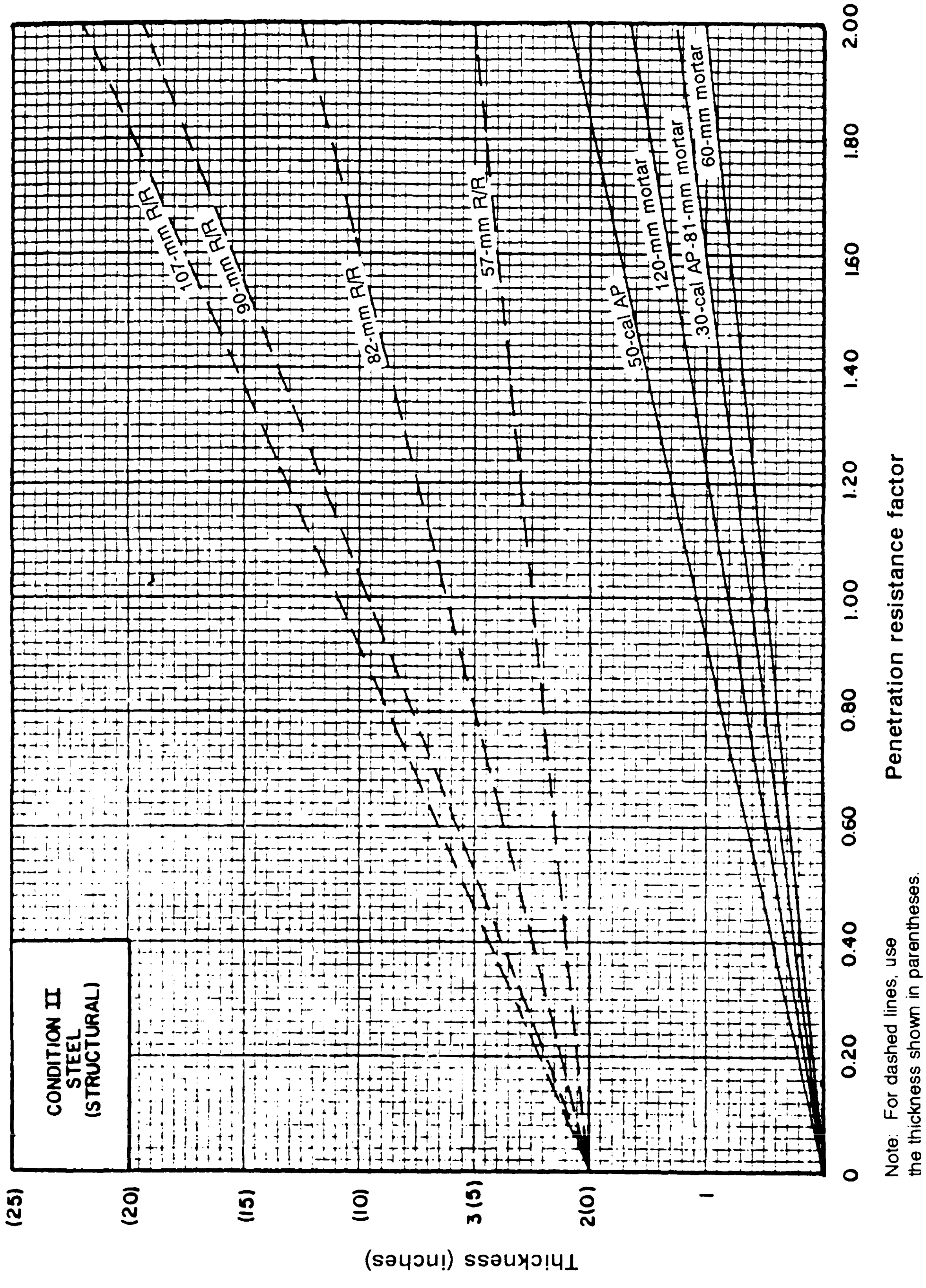


Figure P-22. Ballistic graphs for Condition II for steel



Note: For dashed lines, use the thickness shown in parentheses.

Figure P-23. Ballistic graphs for Condition III for wet soil

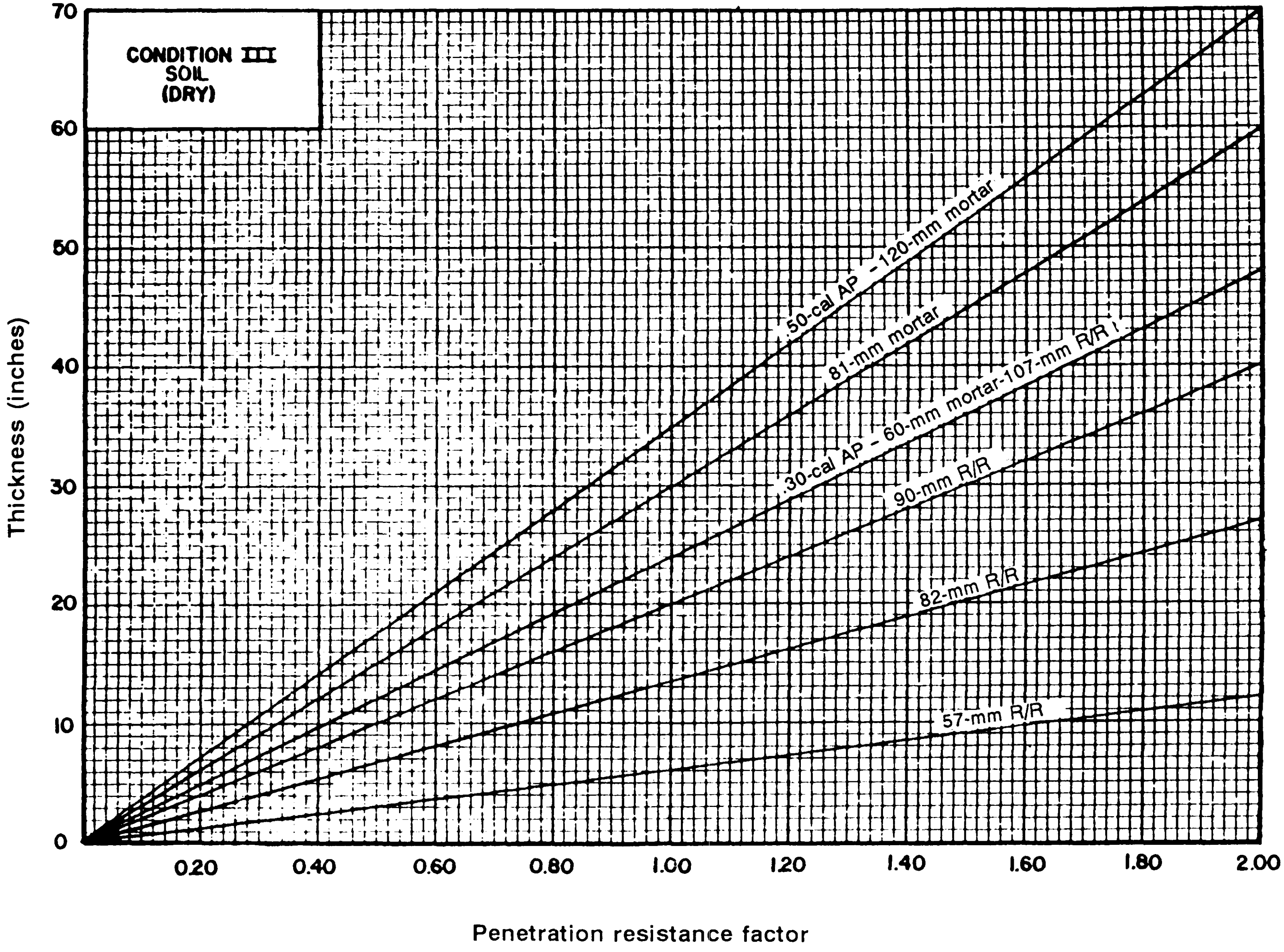


Figure P-24 Ballistic graphs for Condition III for dry soil

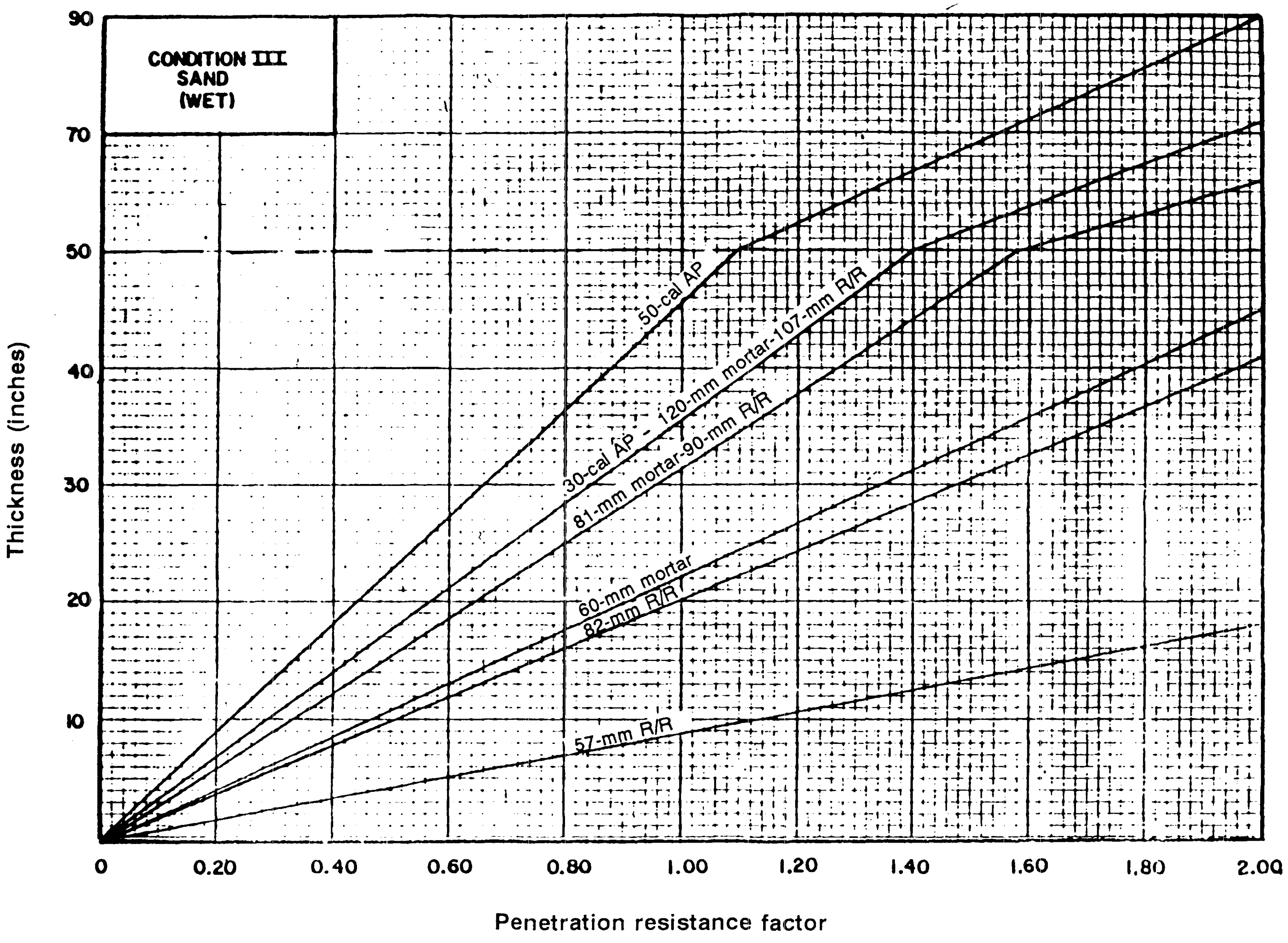


Figure P-25. Ballistic graphs for Condition III for wet sand

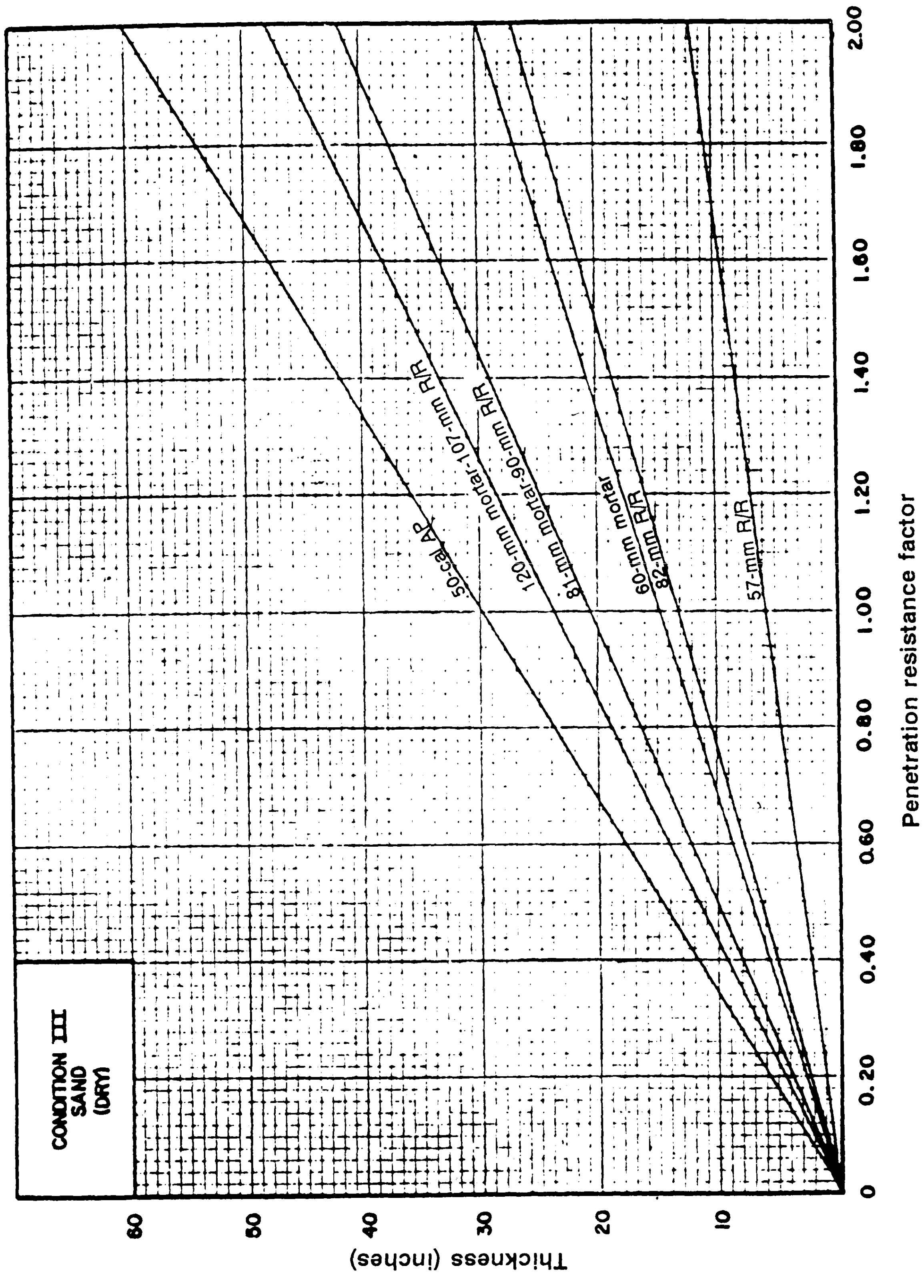


Figure P-26. Ballistic graphs for Condition III for dry sand

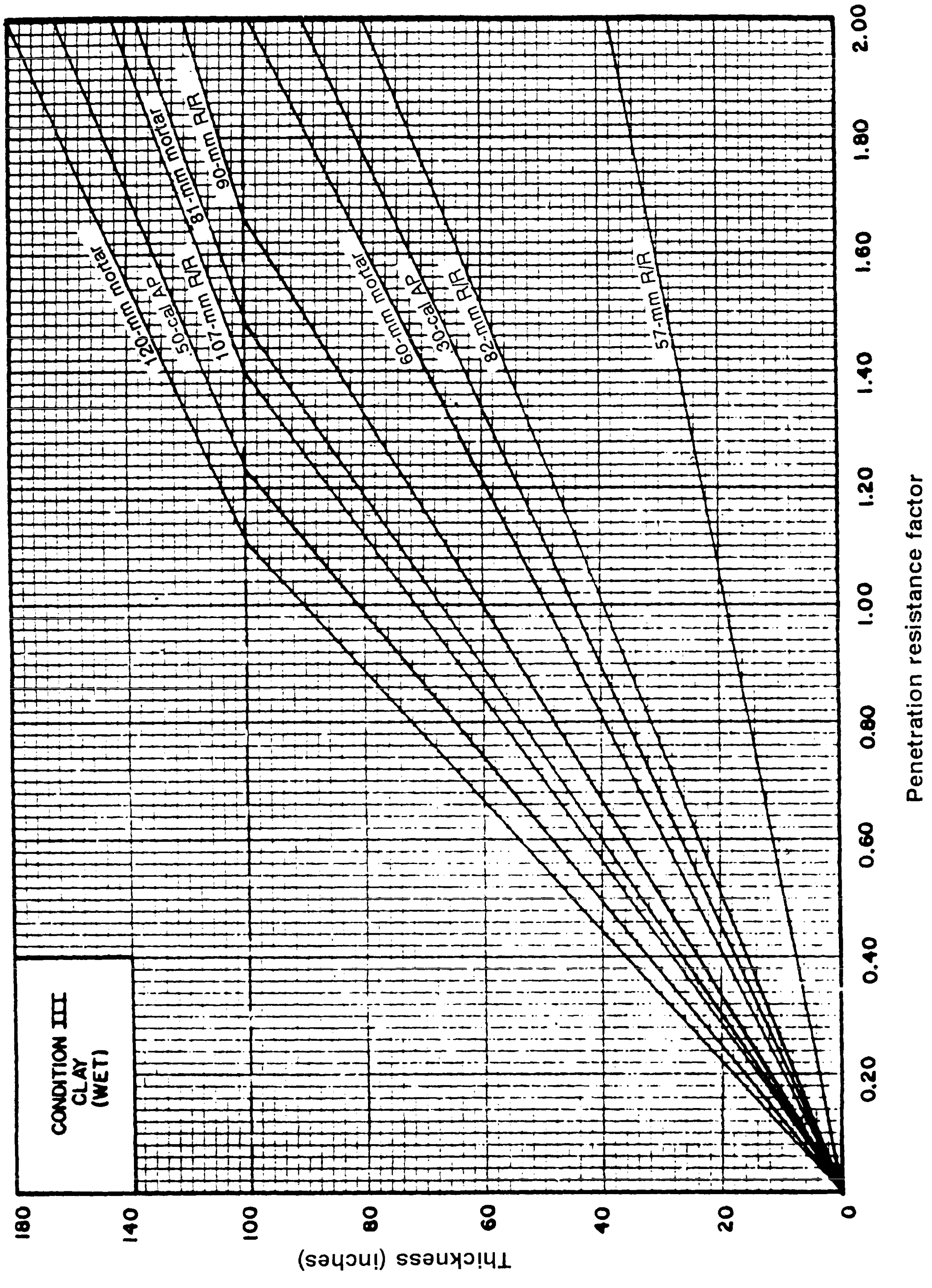


Figure P-27 Ballistic graphs for Condition III for wet clay

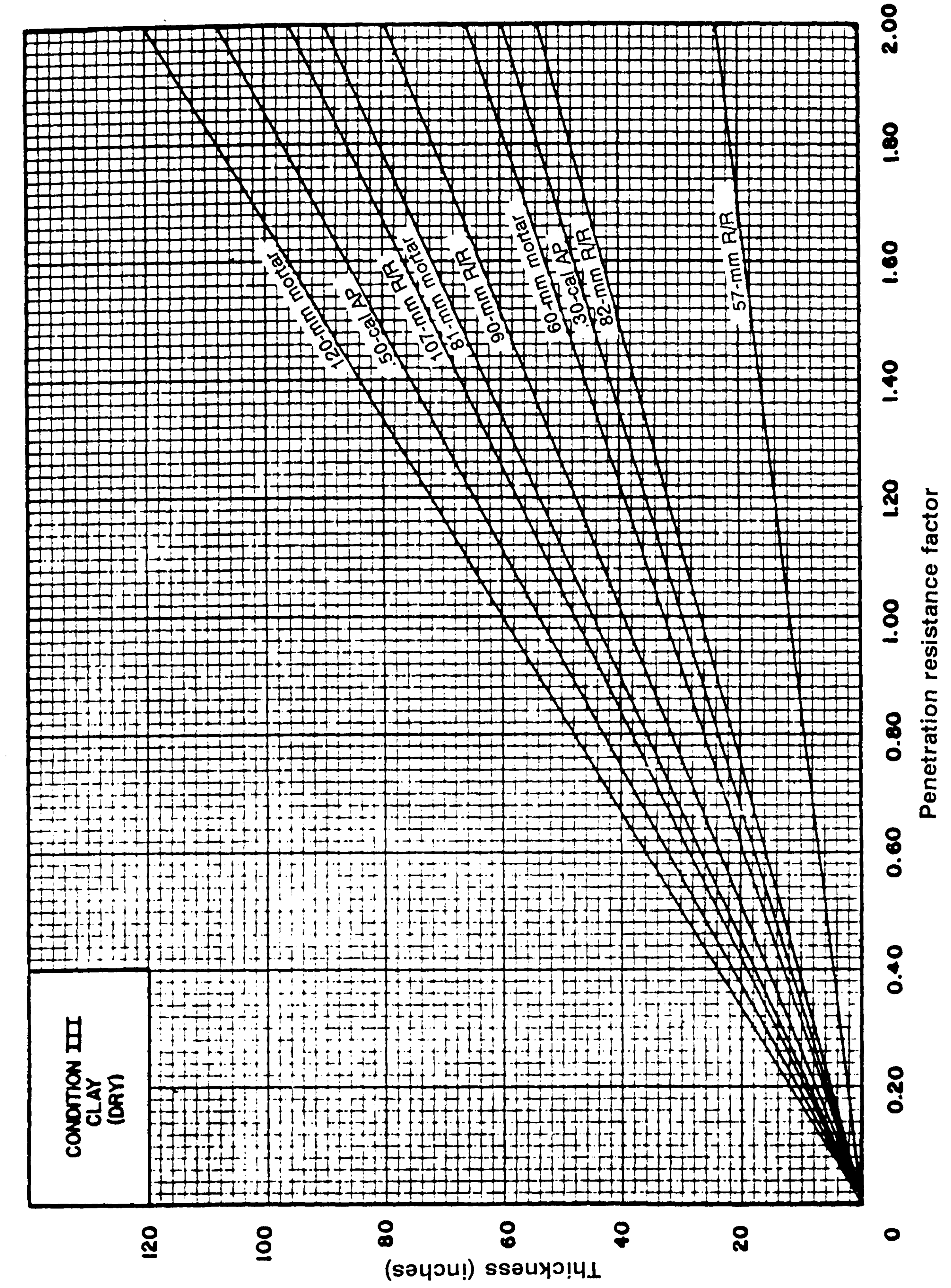


Figure P-28. Ballistic graphs for Condition III for dry clay

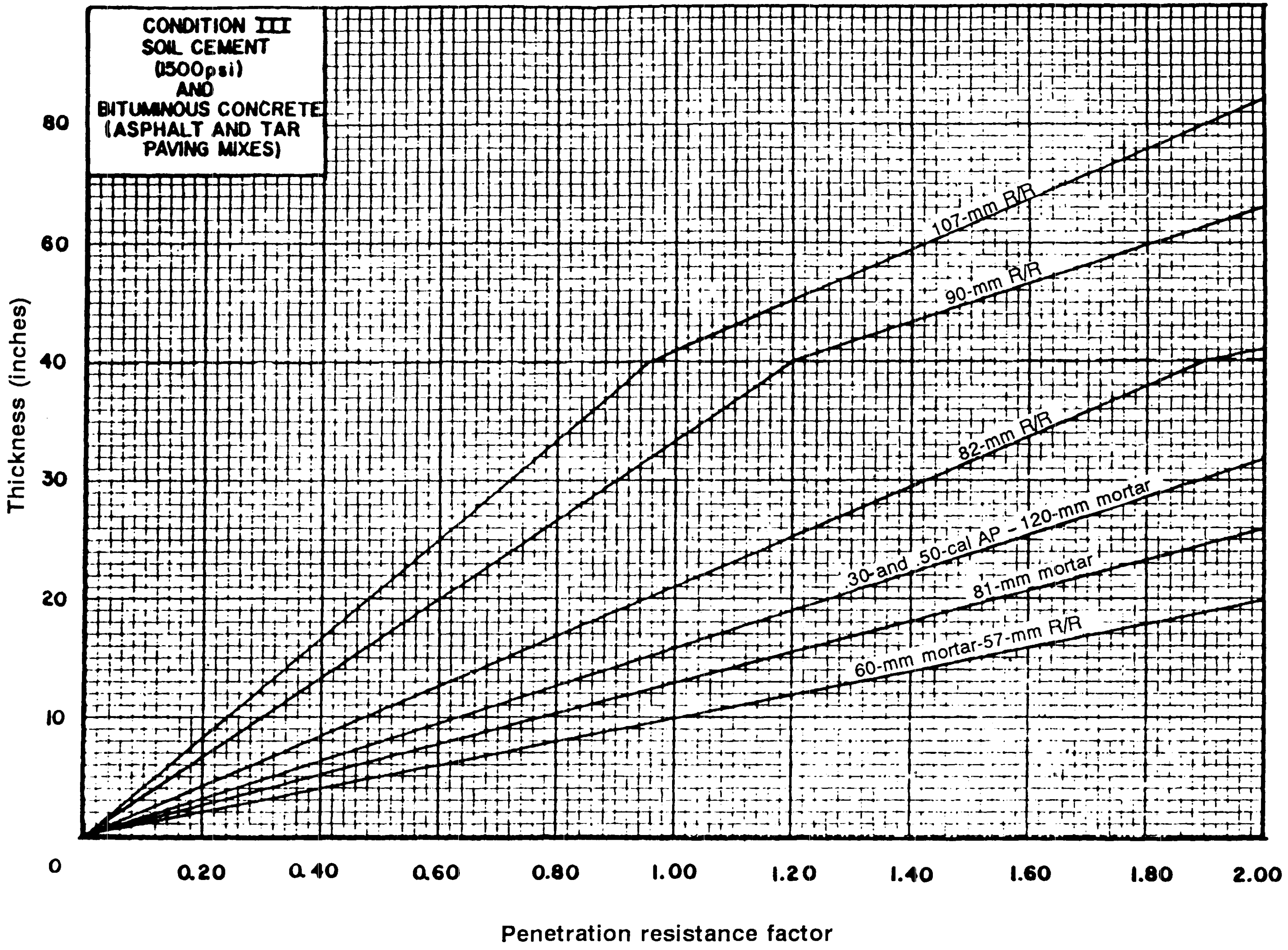


Figure P-29. Ballistic graphs for Condition III for soil cement and bituminous concrete

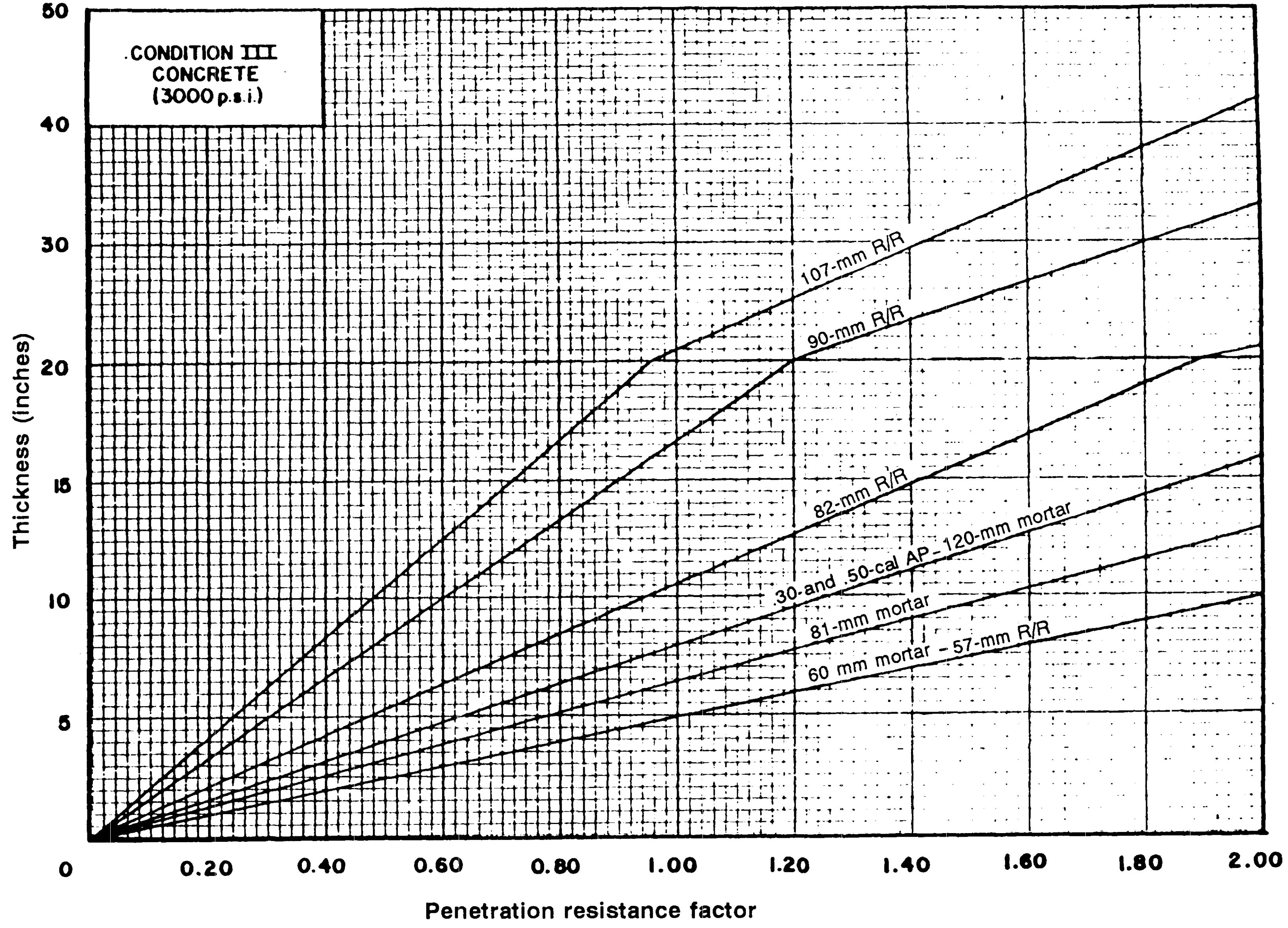


Figure P-30. Ballistic graphs for Condition III for concrete

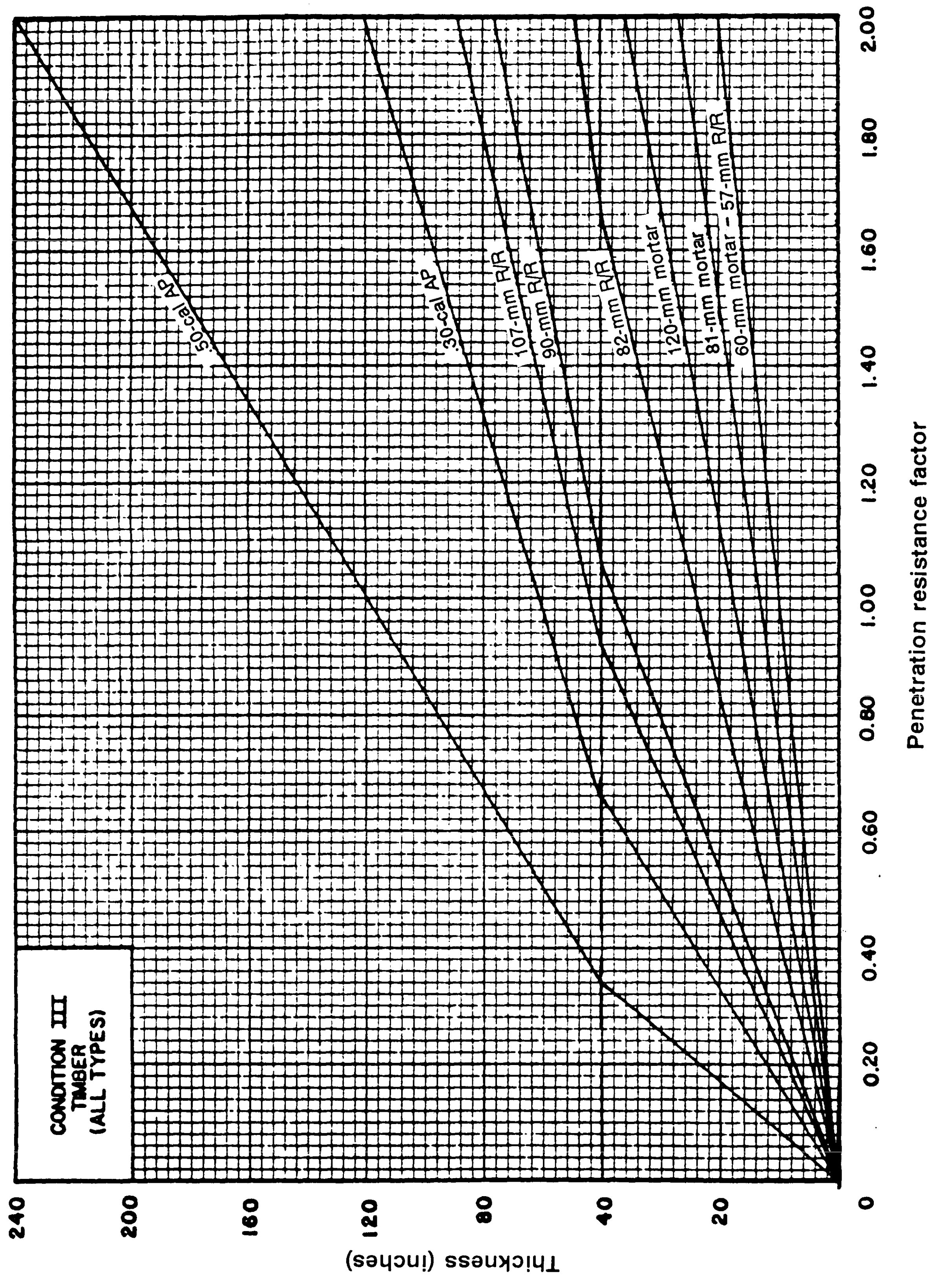
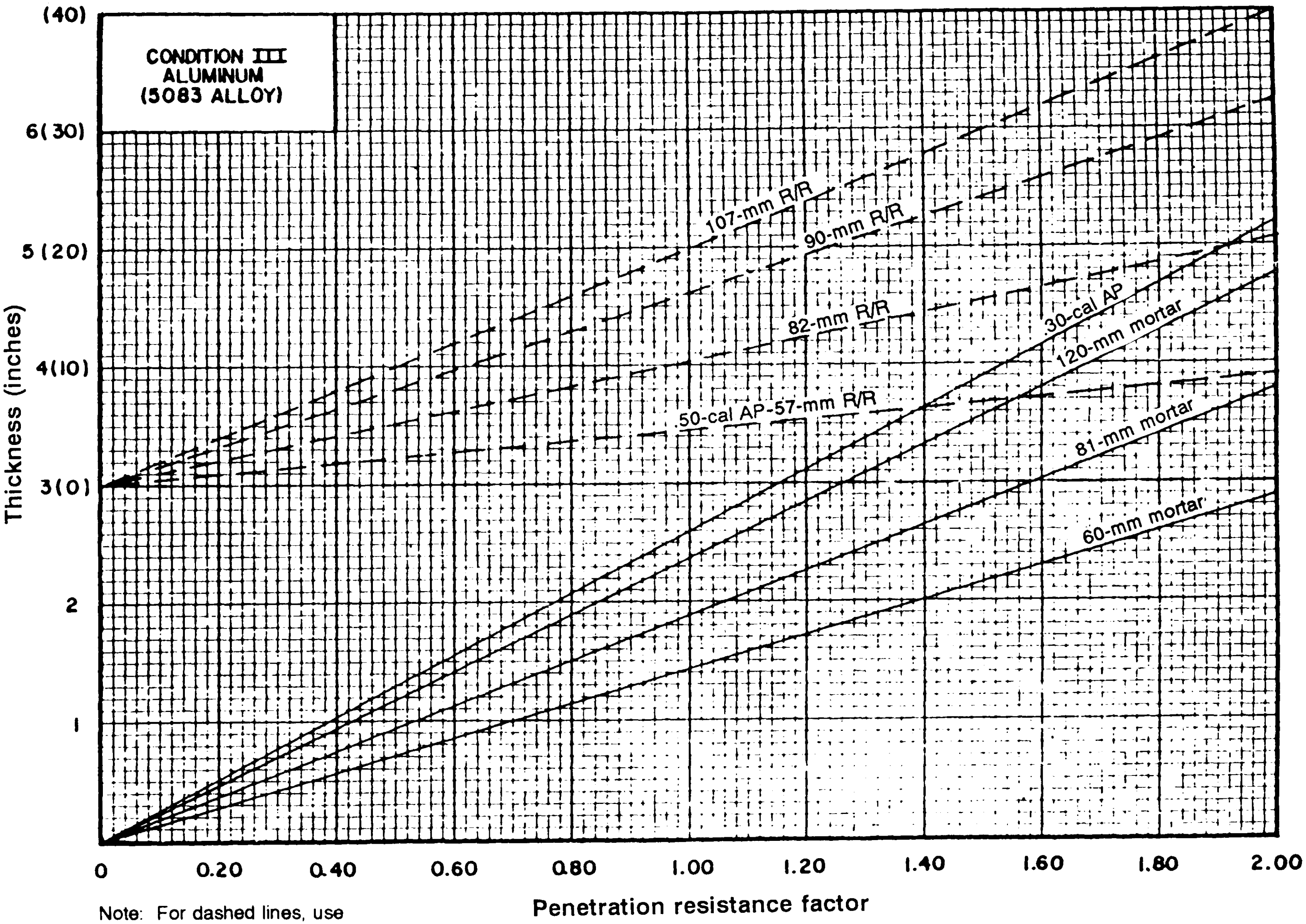
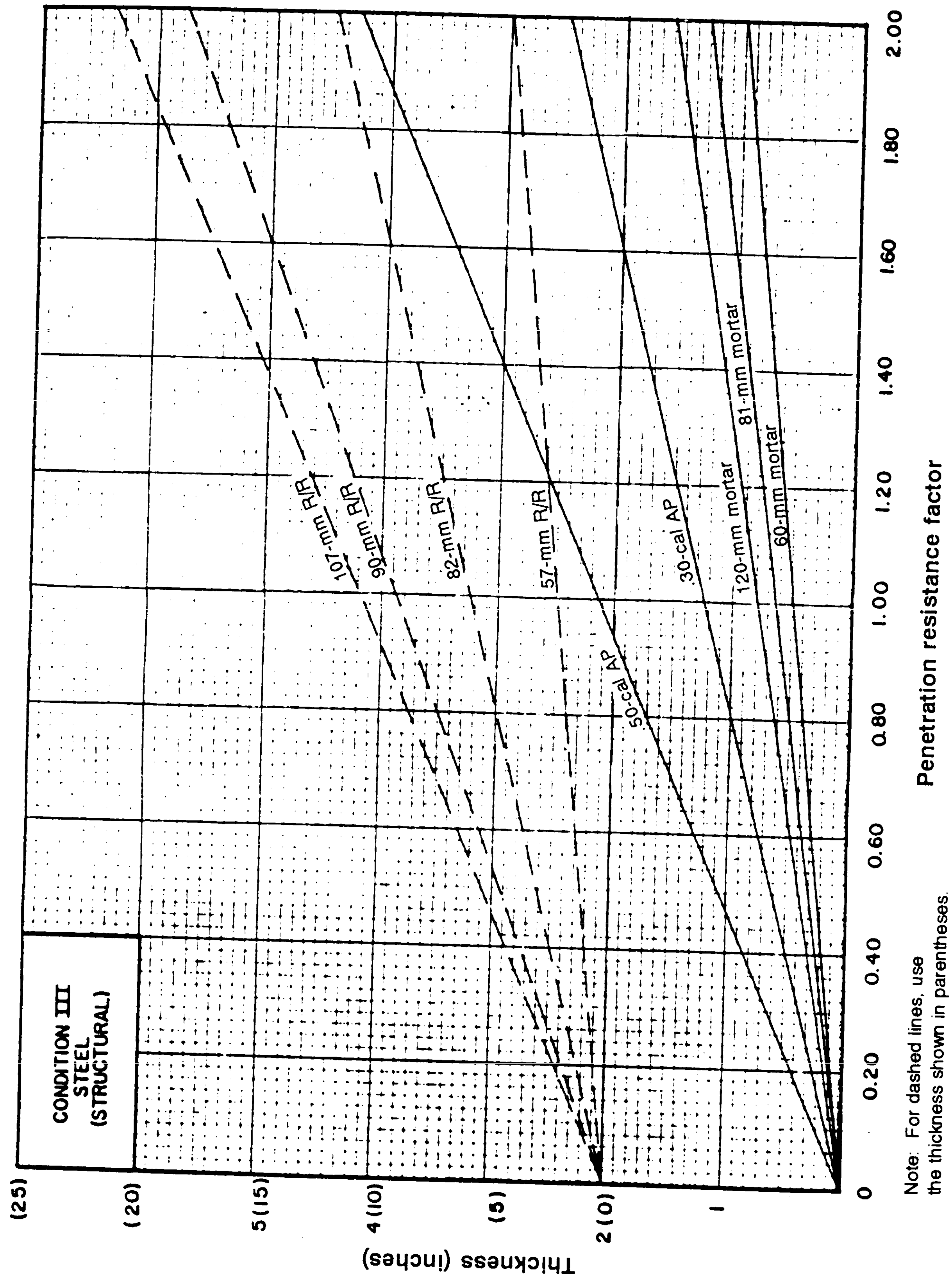


Figure P-31. Ballistic graphs for Condition III for timber



Note: For dashed lines, use the thickness shown in parentheses.

Figure P-32. Ballistic graphs for Condition III for aluminum



Note: For dashed lines, use the thickness shown in parentheses.

Figure P-33. Ballistic graphs for Condition III for steel

GLOSSARY

AA	assembly area
AABNCP	advanced airborne control platform
AAFIF	Automated Airfield Information File
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ABC	all-bituminous pavement
ABS	acrylonitrile-butadiene-styrene (plastic)
A/C	aircraft
AC	asphalt cement or asphaltic cement
ACC	asphalt-cement concrete
ACE	armored combat earthmover
ACN	aircraft classification number
ADEPT	alternating door exit procedures for training
adj	adjusted
ADR	air base damage repair
AF	Air Force
AFB	Air Force Base
AFCESA	Air Force Civil Engineering Support Agency
AFCS	Army Facilities Components System
AFESC	Air Force Engineering and Services Center
AFI	Air Force Instruction
AFM or AFMAN	Air Force manual
AFP or AFPAM	Air Force pamphlet
AFR	Air Force regulation

AFWL-TR	Air Force Weapons Laboratory Technical Report
agg	aggregate
AGL	above ground level
AH	attack helicopter
AHD	average haul distance
AI	airfield index
air base	An airfield having, in addition to operational facilities, shelter for personnel and facilities for supply and repair of aircraft.
airfield	An area prepared for the accommodation (including any buildings, installations, and equipment), landing, and takeoff of aircraft.
AM-2	aluminum matting
AMC	Air Mobility Command
AML	airfield marking and lighting
ammo	ammunition
ammunition and explosives storage area	An accessible and defiladed area having good cover; located at a safe distance from troops, aircraft, and other facilities; and used for storing explosives and ammunition.
ancillary items	Components of the mat system for use with the basic mat to construct the runway and taxiway complex, to replace damaged mat, or to remove mat for repair of the subgrade. The ancillary items are type-classified into a mat set to simplify requisitioning.
ANG	Air National Guard
angle, glide	A small vertical angle measured outward and upward from the end of the flight strip, above which no obstruction should extend within the area of the approach zone. It also indicates the safe descent angle for various types of aircraft and is expressed as a ratio such as 35:1.
antiskid coating	A compound applied to the top surface of a landing mat during fabrication to provide a skid-resistant surface, especially during inclement weather.
AP	antipersonnel
APC	armored personnel carrier

approach zone	A trapezoidal area extending outward from each end of a flight strip, within which no natural or man-made object may project above the glide angle.
apron, cargo	A prepared area for loading and unloading personnel and cargo.
apron, maintenance	A prepared area for parking aircraft while being serviced or repaired.
apron, parking	A prepared area used in place of hardstands for the parking of aircraft. It is also referred to as a conventional apron.
apron, warm-up	A stabilized or surfaced area used for the assembly or warming up of aircraft, usually located at both ends of the runway adjacent to and with the long axis parallel to the connecting taxiway.
approx	approximately
Apr	April
APSB	asphalt penetrative soil binder
AR	Army regulation
ARIA	advanced range instrumentation aircraft
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
ATC	air traffic control
atk	attack
Atterberg Limits	Soil plasticity test used to measure soil cohesiveness; that is, cohesive or cohesionless.
ATTN	attention
Aug	August
AUTOCAD	automated computer-aided drafting and design
av	absolute volume
average daily traffic (ADT)	The anticipated average number of vehicles per day that will use a completed facility.
average running speed	The speed expected to be maintained by most vehicles. It is equal to the total traveled distance divided by total time consumed.
avg	average
AVIM	aviation intermediate maintenance
avn	aviation

AWACS	Airborne Warning and Control System
AWADS	Adverse Weather Aerial Delivery System
AWS	Air Weather Service
banked cubic yardage (BCY)	Soil measured in its natural state.
base course or base	Base course consists of well-graded, granular materials that have a liquid limit less than 25 percent and a plastic limit less than 5 percent. The base course is the most important element in a road structure. It functions as the primary load-bearing component of the road, ultimately providing the pavement (or surface) strength. Therefore, it is made of higher quality material than subbase material.
bbl	barrel
bde	brigade
bearing capacity	The ability of a soil to support a vehicle without undue sinkage of the vehicle.
benching	Terracing on a slope.
berm	A raised lip, usually of earth, placed at the top edge of a channel to prevent flow into the channel at places not protected against erosion.
bitumen or bituminous	The most common type of asphalt surface placed in the theater of operations.
bn	battalion
BOM	bill of materials
borrow pit	An excavated area where material has been dug for use as fill at another location.
BTU	British thermal unit
BVM	Bays Village of Maryland
C, CL, or C/L	centerline
C	Celsius
C	cut
C	confidential
CAD	computer-aided design
cal	caliber

California Bearing Ratio (CBR)	A measure of the bearing capacity of a soil based upon its shearing resistance. CBR is expressed as a percentage of the unit load required to force a piston into the soil divided by the unit load required to force the same piston the same depth into a standard sample of crushed stone. See Chapter 5, FM 5-430-00-1/ AFPAM 32-8013, Vol 1, or FM 5-541.
CAMMS	Condensed Army Mobility Modeling System
CAPES	Controlled Alternate Parachute Exit System
CARP	computed air release point
cav	cavalry
CBA	close battle area
cbt	combat
C/C	center to center
CCT	combat control team
cdr	commander
CDS	container delivery system
CE 55	Laboratory compactive effort (CE) accomplished by the impact of 55 hammer blows per layer.
CES	civil engineering squadron
CEV	combat engineer vehicle
cf	cubic feet
cfs	cubic feet per second
CG	center of gravity
CH	inorganic clays of high plasticity, fat clays
CH	cargo helicopter
CI	cone index
CL	clays, low compressibility (LL<50)
clear area	A rectangular area located adjacent to and outside of the runway shoulders, in which tree stumps are cut close to the ground, boulders removed, and the general area roughly graded to the extent necessary to reduce damage to aircraft in the event of erratic performance in which the aircraft runs off the runway.

cm	centimeter
cmd	command
CMP	corrugated metal pipe
cm/sec	centimeters per second
co	company
coarse-grained soil	A free-draining soil of which more than 50 percent by weight of the grains will be retained on a No. 200 sieve. For trafficability purposes, these are dry beach and desert soils usually containing less than 7 percent of material passing the No. 200 sieve. Gravels are not considered to pose a trafficability problem.
comm	communications
COMMZ	communications zone
comp	compacted
compacted cubic yards (CCY)	A measurement of compacted soil.
compaction	Process of mechanically densifying a soil, normally by the application of a moving (or dynamic) load.
compactive effort (CE)	Method used to compact the soil.
cone index [CI)	An index of the shearing resistance of soil. The CI is obtained with a cone penetrometer. The number represents resistance to penetration into the soil of the 30-degree cone with a 1/2-square-inch base area (actual load in pounds on cone base area in square inches), using a dial calibrated to produce an index of 300 when 150 lb of pressure are exerted on the handle. The CI reading is normally taken at the 0-inch (base of the cone) and at every 3-inch interval down to 18 inches or until the dial reaches the maximum of 300. A number of tests will be taken and each specified interval reading will be averaged. That average becomes the CI for the inch level.
const	construction
cont	continue
control tower	Usually a covered and enclosed platform for the direction and control of traffic. Depending upon the type of construction authorized, the control tower may be a mobile unit or a self-supported structure, no higher than necessary to afford an unobstructed view of the entire flight path and taxiways.
CONUS	continental United States
CPM	critical path method

CPT	captain
critical layer	The soil layer that determines the rating cone index (for fine-grained soil) or cone index (for coarse-grained soil) of the area considered. Its depth varies with the soil profile and the weight and type of vehicle. Generally, the critical layer for fine-grained soils is 6 to 12 inches below the surface when subjected to passes of a vehicle. For coarse-grained soils, the critical layer is usually from the surface to a 6-inch depth for all vehicular passes.
crown	(1) The difference in elevation between the centerline and the surface edge. The crown expedites surface-water runoff on the road. The amount of crown depends on the surface used. Surfaces such as concrete or bituminous materials require little crown because of their impermeability, but permeable surfaces such as earth or gravel require a large crown. (2) The outside top of the culvert.
CRS	Central Radar System
CSS	cationic slow setting
cu cm	cubic centimeter
CUCV	commercial utility cargo vehicle
cu ft	cubic foot/feet
culvert	An enclosed waterway used to pass water through a structure consisting of an embankment or fill.
cut or cutting	That portion of through construction produced by the removal of the natural formation of earth or rock, whether sloped or level. The terms *sidehill cut* and *through-hill* cut describe the resulting cross sections commonly encountered.
cut slope	The slope from the top of a cut to the ditch line (bottom of ditch). Sometimes it is called the back slope.
cu yd or cy	cubic yard(s)
D	depth
DA	Department of the Army
DBH	diameter at breast height
DCA	dust-control agent
DCP	dynamic cone penetrometer
DD	Department of Defense
Dec	December

deg	degree(s)
dept	department
design hourly volume (DHV)	The number of vehicles that a road may typically be expected to accommodate in an hour. The DHV is 15 percent of the ADT.
design speed	The speed for which a facility is designed. Pertinent geometric features, such as horizontal curves and grades, may be based on design speed.
design storm	The storm of greatest intensity for a given period. For example, a *2-year design storm* is a storm expected to be equalled once in 2 years.
detention	The storage of water in depressions in the earth's surface.
DF	direction finder
dH	pressure altitude
dia	diameter
dip	A paved ford used for crossing dry, wide, shallow arroyos or washes in semi-arid regions subject to flash floods.
ditch slope	The slope of the ditch extending from the outside edge of the shoulder to the bottom of the ditch. This slope should be relatively flat to avoid damage to vehicles driven into the ditch and to permit easy recovery.
diversion ditch	A ditch used to transport water away from roadways or airfields.
DMA	Defense Mapping Agency
DMZ	demilitarized zone
DOD	Department of Defense
drop	A structure that absorbs the impact energy of water as it falls vertically to a lower level waterway.
DSA	division support area
DSN	Defense Switched Network
DT	ditch time
DZ	drop zone
DZC	drop zone control
E	east

ea	each
earth anchors	A device used along the sides and ends of the matting to hold the mat in position. Power equipment can be used in driving the anchors. The pneumatic wood-boring drill and posthole digger have both proven effective in this. The average pull required to remove anchors after emplacement is 2,040 pounds.
EL or elev	elevation
EM	engineer manual
EM	enlisted member
ENE	east northeast
engr	engineer
EOD	explosive ordnance disposal
EPW	enemy prisoner of war
erosion	The transportation of weathered materials by wind or water.
ESE	east southeast
ETAC	Environmental Technical Applications Center
EW	east-west
EZ	extraction zone
EZC	extraction zone control
F	fill
F	Fahrenheit
FAA	Federal Aviation Authority
FC	field circular
Feb	February
fill or filling	Material used to fill a receptacle, cavity, passage, or low place. Using material to fill a cavity or low place.
fill slope	The incline extending from the outside edge of the shoulder to the toe (bottom) of a fill.
fine-grained soil	A silt or clay soil of which more than 50 percent by weight of the grains will pass a No. 200 sieve (smaller than 0.074 millimeter in diameter).

firing-in-butt	A U-shaped revetment, normally of earth, and hardstand for boresiting aircraft armament and test firing.
fld	field
flight path	The line connecting successive positions occupied by an aircraft, missile, or space vehicle as it moves through air or space.
flight strip	Includes area of the runway, shoulders, clear area, overruns, and clear zones.
FM	field manual
ford	A shallow place in a waterway where the bottom permits the passage of personnel and vehicles.
fpm	foot (feet) per minute
fps	foot (feet) per second
frost action	Processes which affect the ability of soil to support a structure when accumulated water in the form of ice lenses in the soil is subjected to natural freezing conditions.
frost-susceptible soil	Soil in which significant ice segregation will occur when the necessary moisture and freezing conditions are present.
FSN	federal stock number
ft	foot/feet
FT	Fort
ft/ft	feet per foot
ft/in	feet per inch
FTR	fighter
ft^2/yd^2	square feet per square yard
fuel storage area	An accessible area, having good cover, located a safe distance from troops, aircraft, and other facilities, and used for the storage and dispensing of aviation fuels.
G	gravel
G-1	Assistant Chief of Staff, G-1 (Personnel)
gabion	Large, steel wire-mesh baskets filled with stones, usually rectangular in shape and variable in size. They are designed to solve the problem of erosion.

gal	gallon(s)
gal/lb	gallon(s) per pound
gal/yd^2	gallon(s) per square yard
GC	clayey gravels, gravel-sand-clay mixture
GCA	ground-controlled approach
geometric design (geometry or geometric features)	Refers to all visible features of the road such as lane width, shoulder width, and alignment.
GLE	grade-line elevation
gm	gram(s)
GM	silty gravels, gravel-sand-silt mixture
GMRS	Ground Mark Release System
GP	poorly graded gravels or gravel-sand mixture, little or no fines
grade	To level off to a smooth horizontal or sloping surface.
ground icing	An icing whose source of water is from groundwater flow above permafrost.
groundwater table	The upper limit of the saturated zone of free water.
Gunite	A mixture of cement, sand, and water sprayed from a high-pressure nozzle onto a surface to protect it.
GW	well-graded gravels, gravel-sand mixture, little or no fines
H	height
HAARS	High-Altitude Airdrop Resupply System
hardstand	A paved or stabilized area where vehicles are parked. Open ground area having a prepared surface and used for the storage of material.
hel	helicopter
HM	heavy mat
HMMWV	high mobility, multipurpose wheeled vehicle
HP	high point
HQ	headquarters

HQDA	Headquarters, Department of the Army
HSLLADS	High-Speed, Low-Level Airdrop System
HVCDS	High-Velocity Container Delivery System
HW	high water
hydraulic gradient	The slope in feet per foot of a drainage structure.
hydrologic cycle	The continuous process in which water is transported from the oceans to the atmosphere to the land and back to the sea.
Hz	hertz
I	initial
LAW	in accordance with
icing	An irregular sheet or field of ice.
IFR	instrument flight rules
ILAS	Instrument Landing Approach System
IL	Illinois
IMC	instrument meteorological conditions
in	inch(es)
infiltration	The absorption of rainwater by the ground on which it falls.
in/hr	inches per hour
INS	Inertial Navigation System
in situ	Soil in its natural (undisturbed) state.
interception	The holding of rainfall in the leaf canopy of trees and plants.
IR	infrared
Jan	January
JCS PUB or Joint Pub	Joint Chiefs of Staff publication
Jul	July
Jun	June
kg	kilogram(s)

kip	kilopound (1,000 pounds)
km	kilometer(s)
kph	kilometers per hour
kv	kilovolt(s)
KVA	kilo-volt-amp(s)
kw	kilowatt(s)
L	length
laminar flow	The type of flow that occurs when viscosity forces predominate and the particles of the fluid move in smooth, parallel paths.
landing field	A very general term designating an area of land prepared for the takeoff and landing of aircraft.
landing mat	A prefabricated, portable mat so designed that any number of planks (sections) may be rapidly fastened together to form surfacing for emergency runways, landing beaches, and so forth.
LAPES	Low-Altitude Parachute Extraction System
lat	latitude
lateral safety zone	An area (transitional surface) located between the runway clear area or runway edge when no clear area is provided and the clearance lines limiting the placement of building construction and other obstacles with respect to the runway centerline. The slope of the transitional surface is 7:1 outward and upward at right angles to the runway centerline.
lb	pound(s)
ldg	loading
lin ft	linear foot/feet
LIP	length in place
liq	liquid
LL	liquid limit
LM	light mat
LOC	lines of communication
LP	low point

LZ	landing zone
m	meter(s)
M	silt
MAC	Military Airlift Command
MACOM	major Army command
maint	maintenance
MAJCOM	major command
Mar	March
mass diagram	Earthwork volume plotted on graph paper, showing cut and fill operations.
mat'l	material
max	maximum
maximum towing force (T1)	The maximum continuous towing force in pounds a vehicle can exert. It is expressed as a ratio or percentage of vehicle weight.
MCPB	Mapping and Charting Program Branch
MD	Maryland
mental hazard	An object, real or imaginary, not within the specified glide angles and clearance lines, but in the vicinity of the airfield, which constitutes in the mind of the pilot a hazard to the safe operation of aircraft in landing or taking off.
met	meteorological
MH	inorganic silts, micaceous or diatomaceous fine sandy or wilty soils, elastic silts
mi	mile(s)
mil	military
MIL-STD	military standard
min	minimum
min	minute
ML	inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity

mm	millimeter(s)
MM	medium mat
mo	month
MO	maximum offset
MO	Missouri
mobility index (MI)	A number that results from a consideration of certain vehicle characteristics.
MOPP	mission-oriented protective posture
MOS	military occupational specialty
mph	mile(s) per hour
MS	medium setting
MSR	main supply route
MTOE	modified table of organization and equipment
N	Slipperiness symbol meaning not slippery under any conditions.
N	north
NA or N/A	not applicable
NATO	North Atlantic Treaty Organization
NAVAID	navigational aid
NBC	nuclear, biological, chemical
NCO	noncommissioned officer
NCOIC	noncommissioned officer in charge
NE	northeast
NEACP	National Emergency Airborne Command Post
NFS	nonfrost-susceptible
NGR	National Guard regulation
NM	nautical mile(s)
NNE	north northeast

NNW	north northwest
no.	number
NOAA	National Oceanic and Atmospheric Administration
Nov	November
NP	number of pipes
NRMM	NATO Reference Mobility Model
NRS	naval radio station
NS	north-south
NSN	national stock number
NVG	night-vision goggles
NW	northwest
O	offset
Oct	October
OD	outside diameter
OH	observation helicopter
OL	order length
ONC	operational navigation chart
opns	operations
overrun	A graded and compacted portion of the clear zone, located at the extension of each end of the runway, to minimize risk of accident to aircraft due to overrun on takeoff or undershooting on landing. Its length is normally equal to that of the clear zone and its width is equal to that of the runway and shoulders.
P	Slipperiness symbol meaning slippery when wet.
PAPI	precision approach path indicator
para	paragraph
PBS	prefabricated bituminous surfacing
PC	Portland cement
PC	point of curvature

pcf	pounds per cubic foot
pci	pounds per cubic inch
PCN	pavement classification number
PECS	prepackaged expendable contingency supply
perm	permanent
permafrost	Constantly frozen ground.
PFS	partially frost-susceptible
PI	plasticity index
PI	point of intersection
pkg	parking
PL	plastic limit
PO	post office
POI	point of impact
POL	petroleum, oils, and lubricants
ponding	The accumulation of water at the upstream end of a culvert.
pop	population
Pr	probability
PRF	penetration resistance factor
Prime BEEF	prime base engineer emergency forces
psf	pounds)per square foot
psi	pounds per square inch
PSP	pierced steel plank
PT	point of tangency
PVC	point of vertical curvature
PVC	polyvinyl chloride
PVI	point of vertical intersection
PVT	point of vertical tangency

QSTAG	Quadripartite Standardization Agreement
qtrs	quarters
RACON	radar beacon
RAM	raised angle marker
rating cone index [RCI)	The measured cone index multiplied by the remolding index (RCI = CI x RI). The RCI expresses the soil-strength rating of a soil area subjected to sustained traffic.
RC	rapid curing
RCL	recognition control light
REDCOM	Readiness Command
RED HORSE	rapid engineering deployable heavy operational repair squadrons, engineering
reg	regulation
remoldable sand	A poorly drained, coarse-grained soil, usually containing 7 percent or more material passing a No. 200 sieve. Poor internal drainage increases the water content greatly influencing the trafficability characteristics and permitting the remolding test to be performed. When wet, these soils react to traffic in a manner similar to fine-grained soils and are more sensitive to remolding.
remolding	The changing or working of a soil by traffic or a remolding test. The beneficial, neutral, or detrimental effects of remolding may change soil strength.
remolding index (RI)	The ratio of remolded soil strength to original strength. Soil conditions that permit the remolding test to be performed with ease will usually result in a loss of strength.
req’d or reqd	required
required towing force (T2)	The force in pounds required to tow an operable, powered vehicle on level terrain.
revetment	Usually a mound or wall of earth, masonry, timber, sandbags, or other suitable material erected as a protection for aircraft against small arms or artillery fire, bomb splinters, or blast.
RI	remolding index
riprap	Rocks or rubble placed in the bottom and on the sides of a ditch to prevent soil erosions.

river icing	An icing formed along rivers or streams and adjacent areas having a source of water above or below the riverbed.
RL	real length
road, access	A two-way road, normally improved, connecting the air base or airfield with the existing road system of the vicinity.
roadbed	The entire width of surface on which a vehicle may stand or move. The roadbed consists of both the traveled way and the shoulders.
road classification system	An organized list of four road types based on the number of vehicles each is designed to accommodate in a 24-hour period. Road characteristics are based on average daily traffic.
road, service	A road connecting the access road and the bomb and fuel storage areas with all hardstands and aprons for the purpose of refueling, rearming, and servicing aircraft.
roadway	The entire width within the limits of earthwork construction and is measured between the outside edges of cut or fill slopes. Roadway width does not include interceptor ditches if they fall outside the slopes. The roadway width varies from section to section depending on the height of cut or fill, depth of ditches, and slope ratios.
row	A strip of landing mat equal to one panel length and extending longitudinally (parallel to the direction of traffic) for the entire length of the runway or taxiway.
R/R	recoilless rifle
RR	railroad
RRR	rapid runway repair
RS	rapid setting
RT	road tar
RT	right
RTCB	road-tar cutback
RTO	radiotelephone operator
run	A strip of mat equal to one panel width and extending transversely (perpendicular to the direction if traffic) across the entire width of the runway, taxiway, or roadway.
runway	A defined rectangular area of an airfield, prepared for the landing and takeoff run of aircraft along its length.

RW	real width
R/W	runway
S	south
S	Slipperiness symbol meaning slippery at all times.
S	sand
S2	Intelligence Officer (US Army)
S3	Operations and Training Officer (US Army)
SAAF	small austere airfield
sand grid	A honeycomb shaped geotextile measuring 20 feet by 8 feet by 8 inches deep when fully expanded. It is used to develop a beachhead for logistics-over-the-shore operations. It is also useful in expedient revetment construction.
SC	clayey sands, sand-clay mixture
SC	supply catalog
SC	slow curing
SCIP	scarify and compact in place
SE	southeast
SEATO	Southeast Asia Treaty Organization
sec	second
Sept	September
SF	standard form
SFC	sergeant first class
shoulder	(1) That part of the top surface of an approach embankment, causeway, or cut immediately adjoining the roadway that accommodates stopped vehicles in emergencies and laterally supports base and surface courses. (2) A graded and compacted area on either side of the runway to minimize the risk of accident to aircraft running off or landing off the runway.
shoulder slopes	These may be the same as the traveled way, but usually they are greater because shoulders are more pervious than the surface course.

sight distance restriction factor	The percent of the total length of the road on which the sight distance is less than 1,500 feet.
SKE	station keeping equipment
slipperiness	The low traction capacity of a thin soil surface owing to its lubrication by water or mud without the occurrence of significant vehicle sinkage.
slope	The inclined surface of an excavated cut or an embankment.
slope ratio	The relative steepness of the slope expressed as a ratio of horizontal distance to vertical distance. Thus, a 2:1 slope ratio signifies that for every 2 feet horizontally there is a rise or fall of 1 foot. The value of the slope ratio used in construction depends on the properties of the soil and the vertical height of the slope. Ditch slopes may also be governed by the amount of water to be drained and the possibility of erosion.
SM	silty sands and poorly graded sand-silt mixture
SOCOM	special operations command
SOF	special operations forces
SOLL	special operations low-level
SOP	standing operating procedure
SP	poorly graded sands or gravelly sands, little or no fines
spring icing	An icing whose source of water is from subpermanent levels.
sq	square
sqdn	squadron
sq ft	square foot/ feet
sq in	square inch(es)
sq yd	square yard(s)
Sr	senior
SS	slow setting
SSE	south southeast
SSG	staff sergeant
SSW	south southwest

sta	station
STANAG	Standardization Agreement
stickiness	The ability of a soil to adhere to the vehicle undercarriage or running gear.
stilling basin	A structure used to protect the culvert outlet against erosion.
STOL	short takeoff and landing
subbase or subgrade	Describes the in situ soil on which a road, airfield, or heliport is built. The subgrade includes soil to the depth that may affect the structural design of the project or the depth at which climate affects the soil.
subsurface water	Water beneath the surface of the land.
sum	summation
superelevation	The transverse downward slope from the outside to the inside of the traveled way on a curve. It is usually expressed in inches of drop per horizontal foot or foot-drop per horizontal foot.
surface course	The surface course provides a smooth, hard surface on which the traffic moves. It may be constructed from asphalt or tar products, concrete, gravel, or compacted earth with certain types of binders. The surface course should be all-weather and should provide for the rapid urnoff of water. The use of treated surfaces is limited to roads that have a long design life. A divisional road with a life expectancy of 6 months or less will receive only an earth or gravel surface.
surveil	surveillance
SUSV	small-unit support vehicle
SW	well-graded sands, gravelly sands, little or no fines
SW	southwest
T	thickness
T	temporary
T1	maximum towing force
T2	required towing force
TA	Theater Army
TACAN	tactical air navigation

takeoff ground run (TGR)	The distance traveled by an aircraft along the runway before becoming airborne.
taxiway (txy)	A specially prepared or designated path on an airfield for the use of taxiway aircraft.
TBM	temporary bench mark
TC	training circular
TDF	total depth of fill
temp	temperature
TH	thickness x height
thd	thread
time of concentration (TOC)	The time it takes for an entire drainage basin to begin contributing runoff to a drainage structure.
TM	technical manual
TN	air transport
TNT	trinitrotoluene
TO	theater of operations
TOE	table(s) of organization and equipment
touchdown area	That portion of the beginning of the runway normally used by aircraft for primary contact of wheels on landing.
TP	transition point
traction capacity	The ability of soil to resist the vehicle tread thrust required for steering and propulsion.
traffic lane	The traffic lane consists of the road surface over which a single lane of traffic will pass.
trans	transportation
transpiration	The process by which water that has traveled from the ground through the plant’s system is returned to the air through the leaf system.
traveled way	The road surface upon which all vehicles move or travel. For a single-lane road, the traveled way is the same as one traffic lane. For a multilane road, the traveled way is the sum of the traffic lanes. If a surface course is provided, it normally extends only across the traveled way.

trk	truck
turbulent flow	The type of flow that occurs when viscosity forces are relatively weak and the individual water particles move in random patterns within the aggregate forward-flow pattern.
TYP	typical
U	unsurfaced soil with or without mat
UAV	unmanned aerial vehicle
UH	utility helicopter
UHF	ultrahigh frequency
UHFDF	ultrahigh frequency direction finder
US	United States
USAASO	United States Army Aeronautical Services Office
USAE	United States Army Engineer
USAES	United States Army Engineer School
USAF	United States Air Force
USCS	Unified Soil Classification System
util	utility
UXO	unexploded ordnance
V	volt
VA	Virginia
VASI	visual approach slope indicator
VC	vitrified clay
vehicle cone index (VCI)	The index assigned to a given vehicle that indicates the minimum soil strength in terms of rating cone index (or cone index for coarse-grained soil) required for one pass (VCI_1) or other passes (VCI_n) of the vehicle. Usually one and fifty passes are used as extremes.
VFR	visual flight rules
VGSI	Visual Glide Scope Indicating System
vis	visibility

VMC	visual meteorological conditions
vol	volume
VTOL	vertical takeoff/landing
W	west
W	width
W1	weight of a towing vehicle
W2	weight of a towed vehicle
w/	with
w/o	without
WES	Waterways Experiment Station
WF	waste factor
wg	wing
wind sock	A long fabric cone open at both ends, used to indicate the wind direction to an airborne pilot.
wind tee	A T-shaped device for indicating landing direction to pilots.
WNW	west northwest
wp	wetted perimeter
W.R.C.	wire rope cable
WSW	west southwest
wt	weight
WT	weight type
yd	yard(s)
yr	year
ZM	zone marker
<	less than
≤	less than or equal to
>	greater than

$\geq$	greater than or equal to
°	degrees
ΔG	change of grade

REFERENCES

SOURCES USED

These are the sources quoted or paraphrased in this publication.

Standardization Agreements (STANAGs and QSTAGs)

QSTAG 306. *Fortification for Parked Aircraft.* 14 June 1978.
STANAG 2929. *Airfield Damage Repair.* 11 January 1989.
STANAG 3158 AML (Edition 4). *Day Marking of Airfield Runways and Taxiways.* 3 March 1989.
STANAG 3346 AML (Edition 4). *Marking and Lighting of Airfield Obstructions.* 17 October 1988.
STANAG 3601 TN (Edition 3). *Criteria for Selection and Marking of Landing Zones for Fixed Wing Transport Aircraft.* 2 July 1985.
STANAG 3619 AML (Edition 2, Amendment 2). *Helipad Marking.* 7 October 1980.
STANAG 3652 AML (Amendment 3). *Helipad Lighting, Visual Meteorological Conditions.* 1 March 1979.
STANAG 3684. *Helipad Lighting (IMC).* 29 November 1983.
STANAG 3685 AML. *Airfield Portable Marking.* 26 April 1988.

Department of Defense [DOD] Publications

DOD Directive 1315.6. *Responsibilities for Military Troop Construction Support of the Department of the Air Force Overseas.* 26 August 1978.
JCS Pub 3-01.1. *Joint Doctrine for the Defense of the United States Against Air Attack.* 1 February 1982.

Joint and Multiservice Publications

AR 415-30/AFR 93-10. *Troop Construction and Engineering Support of the Air Force Overseas.* 15 May 1979.
FM 5-430-00-1/AFPAM 32-8013, Vol 1. *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations: Volume I, Road Design.* To be published within 6 months.
FM 5-530/NAVFAC MO-330/AFM 89-3. *Materials Testing.* 17 August 1987.
TM 5-818-4. *Backfill for Subsurface Structures (AFM 88-5, Chap 5).* 1 June 1983.
TM 5-818-5. *Dewatering and Groundwatering Control (NAVFAC P-418; AFM 88-5, Chap 6).* 15 November 1983.
TM 5-820-1, *Surface Drainage Facilities for Airfields and Heliports (AFM 88-5, Chap 1).* 20 August 1987.
TM 5-820-2. *Drainage and Erosion Control: Subsurface Drainage Facilities for Airfields (AFM 88-5, Chap 2).* 30 March 1979.
TM 5-820-3. *Drainage and Erosion Control Structures for Airfields and Heliports (AFM 88-5, Chap 3).* 3 June 1991.
TM 5-820-4. *Drainage for Areas Other Than Airfields (AFM 88-5, Chap 4).* 14 October 1983.
TM 5-822-7. *Standard Practice for Concrete Pavements (AFM 88-6, Chap 8).* 16 August 1987.
TM 5-822-8. *Bituminous Pavements—Standard Practice (AFM 88-6, Chap 9).* 30 July 1987.
TM 5-822-9. *Repair of Rigid Pavements Using Epoxy Resin Grouts, Mortars, and Concretes (AFM 88-6, Chap 10).* 20 January 1989.

TM 5-822-10. *Standard Practice for Pavement Recycling (AFM 88-6, Chap 6).* 26 August 1988.
TM 5-824-1. *General Provisions for Airfield Pavement Design (AFM 88-6, Chap 1).* 12 June 1987.
TM 5-825-2. *Flexible Pavement Designs for Airfields (NAVFAC DM-21.3; AFM 88-6, Chap 2).* 1 August 1978.
TM 5-825-2-1. *Flexible Pavement Design for Airfields (Elastic Layered Method) (AFM 88-6, Chap 2, Section A).* 27 November 1989.
TM 5-825-3. *Rigid Pavements for Airfields (AFM 88-6, Chap 3).* 11 August 1988.
TM 5-825-3-1. *Rigid Pavement Design for Airfields, Elastic Layered Method (AFM 88-6, Chap 3, Section A).* 12 September 1988.
TM 5-826-1. *Airfield Pavement—Evaluation Concepts Table of Contents (AFM 88-24, Chap 1).* 12 August 1988.
TM 5-826-2. *Engineering and Design: Airfield Flexible Pavement Evaluation (AFM 88-24, Chap 2).* 12 December 1990.
TM 5-826-3. *Airfield Rigid Pavement Evaluation (AFM 88-24, Chap 3).* 5 December 1990.
TM 5-830-3. *Dust Control for Roads, Airfields, and Adjacent Areas* (AFM 88-7, *Chap 3).* 30 September 1987.

Miscellaneous Publications

AFI 32-1044. *Visual Air Navigation Systems.* March 1994.
AFM 127-100. *Explosive Safety Standards.* August 1990.
AFP 93-12. *Bare Base Conceptual Planning.* To be published within 6 months.
AFR 88-19, Vol 1. *Arctic and Subarctic Construction, General Provisions.* September 1987.
AFR 93-2. *Contingence Response Planning.* January 1990.
AFR 93-13. *Air Force Airfield Pavement Evaluation Program.* February 1990.
AMC Reg 55-60. *Assault Zone Procedures.* October 1992.

Army Publications

FM 5-103. *Survivability.* 10 June 1985,
FM 5-410. *Military Soils Engineering.* 23 December 1992.
FM 5-482. *Military Petroleum Pipeline Systems.* To be published within 6 months.
FM 5-742. *Concrete and Masonry.* 14 March 1985.
FM 10-69. *Petroleum Supply Point Equipment and Operations.* 22 October 1986.
FM 34-25. *Corps Intelligence and Electronic Warfare Operations.* 30 September 1987.
FM 90-4. *Air Assault Operators.* 16 March 1987.
FM 101-10-1/1. *Staff Officers Field Manual—Organizational, Technical, and Logistical Data (Volume I).* 7 October 1987.
FM 101-10-1 /2. *Staff Officers Field Manual—Organizational, Technical, and Logistical Data (Volume 2).* 7 October 1987.
MIL-STD 621. *Subgrade, Subbase, and Test Method for Pavements.* 12 December 1968.
SC 5680-97-CL-E05. *Membrane Surfacing Outfit, Airfield Roads: Section I, Heavy Duty Runway/Heliport (NSN 5680-00-173-6828) (LIN M33061); Section II, Heavy Duty Taxiway (5680-00-173-6829) (LIN M33097); Section III, Heavy Duty Parking Apron (5680-00-173-6831) (LIN M33025); Section IV, (LIN M33133) Heavy Duty Warm-Up Apron (5680-00-164-3372); Section V, (LIN M32953) Heavy Duty Helipad/Replacement (5680-00-173-6832) and Section VI, Heavy Duty Maintenance (5680-00-201-8296) (LIN M32989) (24X Microfiche).* 14 November 1974.
TC 1-204. *Night Flight Techniques and Procedures.* 27 December 1988.
TC 5-340. *Air Base Damage Repair (Pavement Repair).* 27 December 1988.
TM 5-301-1. *Army Facilities Components System—Planning (Temperate).* 27 June 1986.
TM 5-301-2. *Army Facilities Components System—Planning (Tropical).* 27 June 1986.

TM 5-301-3. *Army Facilities Components System—Planning (Frigid).* 27 June 1986.
TM 5-301-4. *Army Facilities Components System-Planning (Desert).* 27 June 1986.
TM 5-302 Series. *Army Facilities Components System: Design.* 28 September 1983
TM 5-303. *Army Facilities Components System—Logistic Data and Bills of Material.* 1 June 1986.
TM 5-304. *Army Facilities Components System—User Guide.* 1 October 1991.
TM 5-337. *Paving and Surfacing Operations.* 21 February 1966.
TM 5-822-12. *Design of Aggregate Surfaced Roads and Airfields.* 28 September 1990.
TM 5-823-4. *Marking of Army Airfield-Heliport Operational and Maintenance Facilities.* 7 July 1987.
TM 5-826-3. *Airfield Rigid Pavement Evaluation.* 5 December 1990.
TM 9-1300-206. *Ammunition and Explosives Standards.* 30 August 1973.

Nonmilitary Publications

ASTM D- 1557. *Soil and Soil Aggregate Mixture Using 10 Pounds 4.54KJ Rammer and 18-inch 457 mm Drop, Moisture Density Relation of 27* Apr 78. 1989.
ASTM D- 1633. *Compression Strength of Molded Soils Cementing Cylinders.* 1990.
ASTM D-43 18. *Liquid Limit, Plastic Limit, and Plasticity Index.* 1984.
ASTM D-5034. *Breaking Force and Elongation of Textile Fabrics.* 26 June 1990.
ASTM D-5035. *Breaking Force and Elongation of Textile Fabrics, Strip Force.* May 1990.
EM 1110-3-138. *Engineering and Design Pavement Criteria for Seasonal Frost Conditions, Mobilization Construction.* 9 April 1984.
MIL-C-43006D. *Cloth and Strip Laminated or Coated Vinyl, Nylon, or Polyester High Strength and Flexible.* 10 April 1989.

DOCUMENTS NEEDED

These documents must be available to the intended users of this publication.

DA Form 2028. *Recommended Changes to Publications and Blank Forms.* February 1974.
SF 344. *Multiuse Standard Requisitioning/Issue System Document.* January 1972.

INDEX

FM 5-430-00-2/AFJPAM 32-8013, VOL II
29 SEPTEMBER 1994

By Order of the Secretary of the Army:

GORDON R. SULLIVAN
General, United States Army
Chief of Staff

Official:

Milton H. Hamilton
MILTON H. HAMILTON
Administrative Assistant to the
Secretary of the Army
06458

By Order of the Secretary Air Force:

MERRILL A. McPEAK
General United States Air Force
Chief of Staff

Official:

JAMES E. McCARTHY, Maj General, USAF
The Civil Engineers

DISTRIBUTION:

Active Army, USAR, and ARNG: To be distributed in accordance with DA Form 12-11 E, requirements for FM 5-430-00-2, Vol II, *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations - Airfield and Heliport Designs* (Qty rqr. block no. 5342).

★**U.S. GOVERMENT PRINTING OFFICE:** *1995-628-027/20075*

PIN: 073049-000