TM 3-34.48-2

THEATER OF OPERATIONS: ROADS, AIRFIELDS, AND HELIPORTS—AIRFIELD AND HELIPORT DESIGN

FEBRUARY 2016

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Theater of Operations: Roads, Airfields, and Heliports—Airfield and Heliport Design

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Preface

TM 3-34.48-2 provides general guidance for the planning and design of roads, airfields, and heliports.

The principal audience for TM 3-34.48-2 is the United States Army, United States Marine Corps, United States Navy, and the United States Air Force.

Commanders, staffs, and subordinates ensure their decisions and actions comply with applicable United States, international, and, in some cases, host nation laws and regulations. Commanders at all levels ensure their Soldiers operate according to the law of war and the rules of engagement (see FM 27-10).

TM 3-34.48-2 implements standardization agreements (STANAGs) 3158, 3346, 3534, and 3619.

TM 3-34.48-2 uses joint terms where applicable. Selected joint and Army terms and definitions appear in both the glossary and the text. Terms for which TM 3-34.48-2 is the proponent (the authority) are marked with an asterisk (*) in the glossary. Definitions for which TM 3-34.48-2 is the proponent publication are boldfaced in the text. For other definitions shown in the text, the term is italicized and the number of the proponent publication follows the definition.

TM 3-34.48-2 applies to the Active Army, Army National Guard/Army National Guard of the United States, and United States Army Reserve unless otherwise stated. This manual is adopted for use by the United States Marine Corps, United States Navy, and United States Air Force personnel.

The proponent of TM 3-34.48-2 is the United States Army Engineer School. The preparing agency is the Maneuver Support Center of Excellence (MSCoE) Capabilities Development and Integration Directorate (CDID); Concepts, Organizations, and Doctrine Development Division (CODDD); Doctrine Branch. Send comments and recommendations on DA Form 2028 (*Recommended Changes to Publications and Blank Forms*) to Commander, MSCoE, ATTN: ATZT-CDC, 14000 MSCoE Loop, Suite 270, Fort Leonard Wood, MO 65473-8929; by e-mail to usarmy.leonardwood.mscoe.mbx.cdidcodddengdoc@mail.mil; or submit an electronic DA Form 2028.

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

Introduction

The United States. Army Engineer School developed this publication with the joint participation of the approving Service commands. The design of new structures and facilities is based on the results obtained from the methods and procedures in UFC 3-220-10N.

The test procedures and terminology used in this manual conform to the latest methods and specifications of the American Society for Testing and Materials (ASTM), the American Concrete Institute, and the Portland Cement Association. ASTM source publications are not required for the testing specified in this document as the procedure is fully explained for military personnel use.

Certain tests and procedures prescribed differ in principle or method and are more detailed than counterpart tests that are currently required by the United States Navy for new construction at Navy installations (including those in forward areas). The tests in this manual also apply to arctic construction. However, cold-weather effects present different problems and additional tests will be required for correct evaluation of the materials. These additional tests and considerations associated with arctic construction are in TM 5-349.

TM 3-34.48-1 and TM 3-34.48-2 should be used in conjunction with each other.

Appendix A contains a metric conversion chart for this manual. A complete listing of preferred metric units for general use is contained in Federal Standard 376B: <http://www.usaid.gov/policy/ads/300/fstd376b.pdf>.

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Chapter 1

Preliminary Planning

Successful construction of an airfield or heliport requires that careful planning be conducted as early as possible. Planning includes—

- Mission assignment.
- Data collection.
- Aircraft category designation.
- Airfield or heliport construction standard establishment.
- Required construction effort estimation.

MISSION ASSIGNMENT

1-1. Before actual airfield or heliport planning begins, a thorough analysis of the proposed mission must be conducted. The planner must determine what the primary mission will be and which organization and aircraft type (fighter, fighter-bomber, reconnaissance, tactical airlift, strategic airlift, rotary-wing aircraft, or combination) will be assigned. The planner must also know how long the using organization plans to stay, how many people will be deployed, which level of aircraft maintenance will be required, and whether an aerial port will be needed. The deploying command is sometimes unable to answer these questions with certainty, especially during the early stages of an operation; therefore, engineers are occasionally forced to make assumptions during the planning process.

1-2. Preliminary planning actions may address constructing a new airfield instead of occupying and upgrading an existing airfield. In the early stages of an operation, time requirements may dictate using existing airfields in-theater. Austere airfields will probably require upgrades and may be limited in their ability to expand its capacity. Large, commercial airfields may necessitate less initial work; however, as the mission evolves, military aircraft will probably be required to share facilities with humanitarian or commercial traffic. A detailed mission, enemy, terrain and weather, troops and support available, time available, and civil considerations (METT-TC) analysis should be conducted to determine the best course of action for constructing new, or repairing or upgrading existing airfield infrastructure.

PLANNING DATA

1-3. As with any theater of operations (TO) installation, the threat to the airfield is a primary concern and should be one of the first items of information that the planner obtains to determine required survivability and vulnerability reduction measures. Aircraft on the ground must be protected, airfield systems must be kept operational, and logistics support must be maintained to ensure continual aircraft operations. The threat will also help 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 (facility protection, camouflage, concealment) will be needed.

1-4. The threat will also influence airfield size. An airfield in a more forward area, employing dispersed measures, requires much more land area than an airfield that is located in the staging and logistics area, where the threat is minor or nonexistent. Topographic, climatologic, and hydrologic planning data is used to determine the prevailing wind direction and its expected velocity, temperature, humidity, annual rainfall, terrain conditions, soil characteristics, and site location (latitude and longitude). Personnel use the data to orient the runway, detect sewage lagoons, and locate facilities to make them blend in with the natural

surroundings. Available drawings, survey maps, and aerial photographs are essential to verify the presence of existing facilities and to determine the type and amount of vegetation and forested areas to enable the amount of grubbing and clearing to be established. These documents may also help determine available water sources (whether it is fresh, brine, or salt water; whether it comes from a well, river, lake, or ocean; what its temperature is; what its distance is from the site). These are representative questions that must be asked, not an inclusive list for every situation. An airfield is typically a component of a larger base camp or force projection base. It is important to link up with base camp or projection base master planners to ensure that airfield planning, construction, and enlargements are coordinated and synchronized. The more answers the planner obtains, the easier the planning job becomes.

AREA DETERMINATION FACTORS

1-5. An estimate of area requirements should involve space for immediate development and contemplated expansion. Area requirement considerations include the—

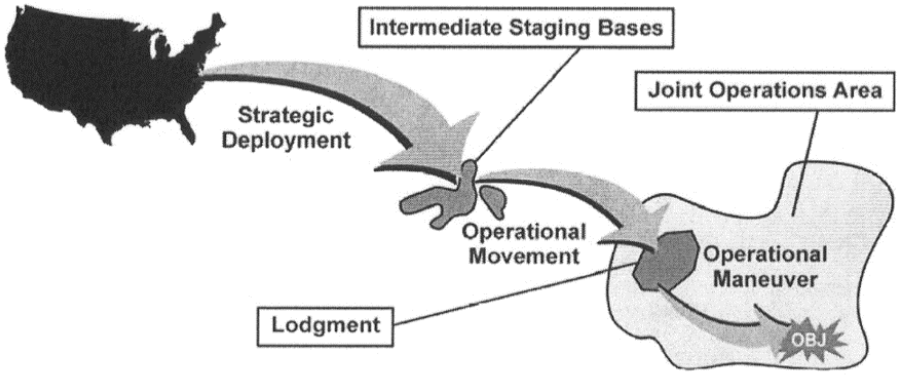
- Mission.
- Number of aircraft.
- Type of aircraft.
- Length of stay.
- Size of the airfield.
- Degree of passive defense measures, such as—
  - Operational procedures.
  - Maintenance procedures.
  - Servicing procedures.
  - Housing procedures.
  - Administrative procedures.
- Supply.
- Transportation.
- Security.

MILITARY AREAS

1-6. 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. Historically, airfields have been classified by their location on the battlefield and by whether they were in the decisive area, support area, or sustaining area. These terms no longer directly apply because unified land operations are now conducted on the noncontiguous battlefield, but the concept of different airfield categories designed to support specific air frames and missions still applies. Operational maneuvers from strategic distances may require multiple airfields and facilities that are capable of handling intra-theater, fixed-wing aircraft, and various rotary-wing aircraft. Figure 1-1 and figure 1-2 portray the operational maneuver from strategic distances and the noncontiguous battlefield geometry outlined in ADP 3-90 and ADRP 3-0.

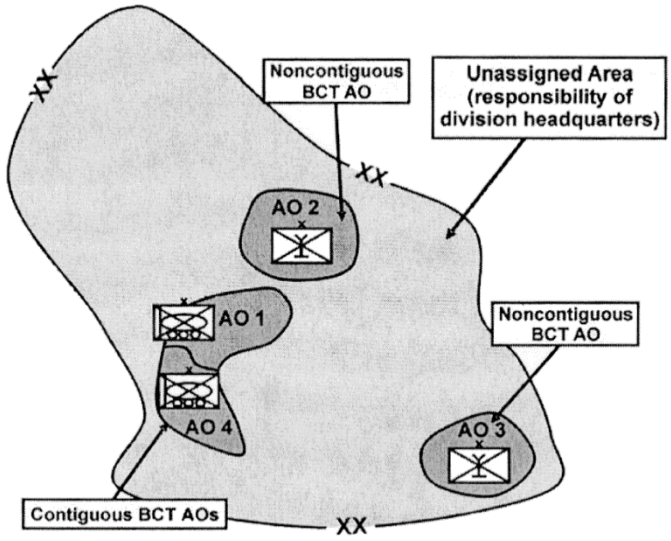
CLASSIFICATION

1-7. Basic Army and Air Force air frames have remained relatively constant; therefore, classifying runways according to their length is still a common reference method among military planners, logisticians, and engineers. Typical runway lengths are 2,000 feet, 2,500 feet, 3,000 feet, 3,500 feet, 6,000 feet, and 10,000 feet. Shorter runway lengths are usually associated with tactical support aircraft, are more austere in their support infrastructure, and are less permanent in nature. The heliport classification system developed in this manual is derived by combining selected helicopters with the appropriate military area.



Legend:
OBJ objective

Figure 1-1. Operational maneuver from strategic distances



Legend:
AO area of operations
BCT brigade combat team

Figure 1-2. Nonlinear battlefield geometry

FIXED-WING CONTROLLING AIRCRAFT

1-8. A controlling aircraft is designated for each airfield to establish limiting geometric and surface strength requirements. This ensures that the airfield is adequate for other possible using aircraft listed for that particular airfield. For example, for a 3,500-foot airfield, the controlling aircraft is the C-17. However, other possible using aircraft include C-130s, C-12As, and unmanned aerial vehicles like Gray Eagle. Designing the airfield for C-17s ensures that all three aircraft can use the same airfield.

ROTARY-WING AIRCRAFT

1-9. Based on different mission requirements, the following helicopters are the controlling aircraft that establish the limiting geometric and surface strength requirements for heliports:

- Observation (light) helicopters (OH) (OH-58 Kiowa).
- Utility helicopters (UH) (UH-60 Blackhawk).

- Cargo helicopters (CH) (CH-47 Chinook).
- Attack helicopters (AH) (AH-64 Apache).

AIRFIELDS

1-10. The airfield, as discussed in this manual, is the part of the air base that is devoted to aircraft operation. A typical airfield consists of runways, taxiways, hardstands, aprons, other airfield pavements, shoulders, overruns, navigation aids (NAVAIDs), aircraft arresting barriers, aircraft revetments or shelters, airfield lighting and markings, and approach and clear zones.

INITIAL AIRFIELDS

1-11. 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. For detailed planning and geometric data on DZs and EZs, refer to the Air Mobility Command regulations.

- **DZ.** The DZ area is used for delivering supplies by various methods of low-level parachute drops. The DZ should be rectangular, as level as possible, and clear of objects that could damage dropped material and personnel.
- **EZ.** The EZ is another area used for delivering supplies and equipment by aircraft without 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.** Expedient airfields are unsurfaced and surfaced airfields intended for short-term use. They are divided into several classes based on their location in the TO.
  - Assault airfields are normally unsurfaced airfields located in the most forward areas and are designed for C17s and smaller assault transports, such as C-130s. They are designed for up to four weeks of use. These airfields are built to the lowest construction standards and may not meet all the desired safety criteria. Therefore, operations on expedient airfields are hazardous, inefficient, and limited to good weather and visibility conditions. Operating gross weights may be limited by runway length, runway surface, and weather conditions.
  - Area of operations airfields are normally surfaced airfields located throughout the area of operations. They are designed for C-17s, smaller assault transports, and tactical aircraft (surfaced airfields only). They have a life expectancy of one to six months and are designed to permit full efficiency operations and support. They provide a greater margin of safety than assault airfields. Operations on area of operations airfields are practical under most weather conditions.

TEMPORARY AIRFIELDS

1-12. Temporary airfields are for more sustained use (6 to 24 months), include a higher standard of design and construction, and allow operations under most weather conditions. Temporary airfields are normally surfaced with various matting, bituminous asphalt, and concrete. They are designed for heavy lift and smaller transports (C-135s, C-17s, C-130s) and tactical aircraft.

SEMIPERMANENT AIRFIELDS

1-13. Semipermanent airfields are for sustained use and are the highest standard of design and construction for TO air bases. They are located at major air and staging bases and are used by mission aircraft. They are constructed of concrete (rigid pavement) or bituminous asphalt (flexible pavement).

HELIPORTS

1-14. The heliport is the part of the air base that is devoted to helicopter operations. 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

1-15. Initial heliport development 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 areas that sustain close combat. LZs of opportunity require little or no construction effort and may not meet all the desired safety criteria. Therefore, operations on this helipad are hazardous, inefficient, and limited to good weather and visibility conditions.
- Heliports with a life expectancy of one week to one month are usually unsurfaced and designed for observation, utility, and attack aircraft. Heliports that are designed with a life expectancy of one to six months are surfaced and unsurfaced (with expedient treatment for dust control) heliports designed for observation, utility, cargo, and attack aircraft. These heliports are designed to permit full efficiency of operations. They support and provide a greater safety margin than LZs of opportunity. Operations on this heliport are practical under most weather conditions.

Note. Various matting is available for surfaced heliports.

TEMPORARY HELIPORTS

1-16. Temporary heliports 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. Temporary heliports are usually surfaced with various matting, bituminous asphalt and concrete. They are designed for mission helicopter use.

SEMIPERMANENT HELIPORTS

1-17. Semipermanent heliports are for sustained use and are the highest standard of design and construction for TO heliports. They are only located at major facilities and are used by mission helicopters. Semipermanent heliports are constructed of concrete or bituminous asphalt.

BARE-BASE AIRFIELDS AND HELIPORTS

1-18. A bare base is a site with a usable runway, a taxiway, parking areas, and a water source 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 in a matter of hours or days.

1-19. The concept of the bare base is more important now than ever before. Even though many of them are limited and inadequate, there are many bare bases scattered around the world. Even underdeveloped countries may often have very austere runways that could support aircraft after they are analyzed and upgraded. The references listed in the TM 5-301 series, TM 5-302 series, TM 5-303, and TM 5-304 portion of this chapter provide valuable sites and databases that contain critical airfield data. These bare bases provide a clear advantage to those who can occupy them in the most rapid manner to conduct operations.

1-20. The current 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 facilities 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.

1-21. The nucleus to modern United States Air Force bare-base infrastructure centers is the enhanced version of earlier Harvest Eagle and Harvest Falcon equipment. This equipment has undergone several generations of modernization.

1-22. Conversely, the concept of employing this equipment remains unchanged. Harvest Eagle, for example, consists mainly of soft wall shelters and support equipment that is usually used to bed down individuals 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 based on 1,100-man increments of equipment divided into housekeeping sets, industrial operations sets, initial flight line support sets, and follow-on flight-line support sets. The Harvest Falcon package includes vehicular support, general aircraft maintenance, weapons system support facilities, and a broad base of logistics to support an operational squadron.

1-23. It is important in the preliminary planning stage to know the location of existing facilities and utilities. Known data can be referenced on classified and unclassified systems or can be queried through the United States Army Corps of Engineers (USACE) Field Force Engineering Reachback Systems. Layouts, drawings, and aerial photographs are vitally needed. Equally important are the lengths and widths of runways, taxiways, ramps, and aprons. The following questions should be asked:

- Does runway lighting exist? If so, is it adequate?
- Is there a requirement for aircraft arresting barriers?
- What 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?
- Does the site being developed use hard-wall or soft-wall shelters? (If the answer is soft-wall shelters, latrines will be field-expedient.)

1-24. Although this manual focuses on the initial construction of TO facilities, bare bases require the same geometric and construction standard requirements. Specific details regarding bare base operations are in AFH 10-222V1.

CONSTRUCTION

1-25. Under the appropriate Army command, engineer construction units are responsible for Air Force and 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 may also be assigned in direct support of that element for restoration of the Air Force air base or Army airfield.

ENGINEER RESPONSIBILITIES

1-26. When units are executing 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 Army or Air Force commander. As stated in Joint Army Regulation 415-30/AFR 93-10, normal maintenance of Air Force air bases is performed by the Air Force civil engineering squadron.

1-27. The engineer commander is concerned with site reconnaissance, location and alignment recommendations, airfield and support facility design, and airfield construction. The engineer is usually given standard designs for the type and capacity of the required airfield. However, these designs most often can be altered to meet time and material limitations or the limitations imposed by local topography, area, or obstructions. There are automated tools that can be used to evaluate various sites and airfield layouts. These can also be used to optimize the design that will require the least construction effort. The latest version of these tools can be requested through the USACE Engineer Research and Development Center. 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 constructions missions:

- Drainage system structure designs.
- Geometric runway, taxiway, and hardstand designs (overruns, blast areas, turnarounds).
- Soil selections found in cuts and soils used to improve subgrades.
- Compaction or stabilization subgrade requirements.
- Determinations of types and thicknesses of base and surface courses.
- Grade selections to minimize earthwork while meeting specifications.

- Designs 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

1-28. For planning purposes, the Air Force commander furnishes and defines aircraft characteristics, broad design layouts, and construction requirements. The Air Force commander may also furnish existing plans and specifications to the Army.

1-29. Engineer brigades and groups usually conduct site reconnaissance, make location recommendations, and complete detailed design efforts. Design work that exceeds the in-theater capacity can be worked through the USACE reachback process. Modular Army engineer construction elements, along with sister-Service engineers and contractors, usually construct the airfield and adapt the design to local conditions.

PLANNING CONSIDERATIONS

1-30. To ensure a proper design, the engineer planner must completely understand the purpose, scope, and estimated duration of the mission. (See TM 3-34.48-1 for site selection criteria.)

AIRFIELD LOCATION AND REQUIREMENTS

1-31. The first consideration of the engineer planner is directed toward selecting the site. The operational plan establishes tactical and logistical requirements that influence the type and number of required aircraft missions. The operational plan allows the planner to determine the number, type, service life, and construction time limitations for airfields in each military area. The planner then establishes reasonable site requirements for each airfield type.

1-32. Within the established site requirements, as dictated by the tactical situation, the geographic location of the airfields is based on topographic conditions (grading, drainage, hydrology), soil conditions, vegetation, and climatic conditions. Existing transport facilities (ports, rail lines, road networks, 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

1-33. 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 in the time available. All resources (Army, other Services, Logistics Civil Augmentation Program, local construction) should be included in the estimate.

1-34. The type and availability of local construction materials must be evaluated against the total needs of the proposed construction. The naturally occurring, in-place materials that are to be graded and the possible sources of select materials for subgrade strengthening should be examined. Requirements for importing special materials for surfacing, drainage, and dust control must be consistent with the available construction time and resources. Advanced stabilization and dust control techniques that save construction time and logistic burdens (weight and space) may be suitable for the terrain and soil in the TO. These should be investigated through the USACE reachback process when details of the in-place soils are determined.

TACTICAL SITUATIONS

1-35. Prepare a plan to keep construction troops, equipment, and materials safe from harassment and sabotage during airfield or heliport construction.

LOGISTIC RESPONSIBILITIES

1-36. 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

1-37. A completed air base is a major construction project. With proper planning and limited construction to essentials according to operational requirements, the base can support air operations soon after construction starts. Improvements are made later during use by incorporating 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.

1-38. Several development combinations may be selected for planning a new installation or for extending an existing installation. Within each development combination, construction will proceed according to the following priorities:

- Before the start of construction and continually during the construction mission, it is essential to ensure that the site provides adequate protection for personnel, equipment, and materials.
- The first priority of construction provides the most essential facilities for air operations at the earliest possible time. This construction consists of the minimal facilities required at the initial deployment of forces. Soft-wall tent structures; Harvest Eagle kits; innovative and expedient designs; locally available materials and equipment; and existing, usable airfield and support facilities are primarily 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 landing matting. This construction consists of airfield operational facilities (such as runways, taxiways, approaches, and aircraft parking areas of minimum dimensions, and 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 air base operations. 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

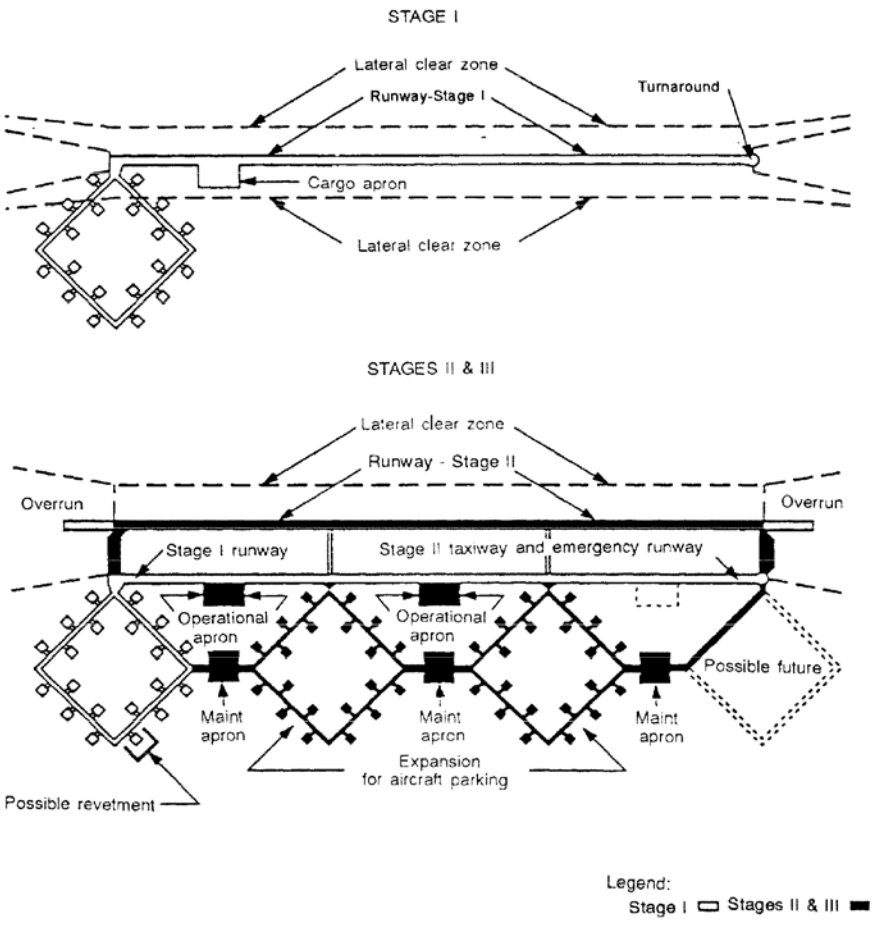
1-39. Airfields are generally constructed to final quality standards and are developed by adding increments of paved areas. However, support facilities may be constructed to varying standards, depending on the mission duration and available construction effort. Therefore, airfield and support facilities have separate construction standards. The TM 5-301 series includes standard design drawings for TO construction.

AIRFIELD CONSTRUCTION STANDARDS

1-40. Airfield standards are designated as Stages I, II, and III (see figure 1-3). The construction stages establish the sequence of constructing the airfield and provide for building the airfield in phases so that minimum operational facilities may be constructed in minimum time. The following describes each stage:

- **Stage I.** In Stage I, a loop that permits landing, takeoff, circulation, and limited apron parking is provided. Runway lengths and widths are the minimum lengths and widths 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.
- **Stage II.** In Stage II, a new runway is provided. Stage I runways become taxiways. Aprons, hardstands, and additional taxiways are also provided.
- **Stage III.** In Stage III, facilities are further expanded and provisions are made to accommodate additional aircraft if necessary. Expedient surfacing is normally used at airfields. When an existing surface in the staging antilogistics 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.



Legend:
maint maintenance

Figure 1-3. Airfield staged construction

1-41. The layout of each field is based on the assumption that the field is constructed on a previously unoccupied site. These layouts 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.

1-42. The use of preexisting airfields may be an operational necessity and will almost never be ideally suited for expansion and further development. Planners must balance immediate requirements against long-term requirements when deciding to use existing airfields or constructing new facilities.

FACILITY CONSTRUCTION STANDARDS

1-43. Regardless of priority or construction sequence, each facility may be constructed to one of two construction standards. These standards are based on life-cycle costs, the expected duration of facility use, and the time required to provide facilities according to their expected duration use. Detailed guidance regarding construction standards is found in the TM 5-301 series manuals.

Initial

1-44. 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

1-45. 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 throughout unit rotation. Shelters are simple, wooden-frame structures (or their equivalent) that are constructed by using local materials. Utilities and water are provided by using organic resources, with limited distribution to high-volume users. The nature of the 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.

FACILITY CLASSIFICATIONS

1-46. For classification and easier reference, air-base facilities are grouped in the following categories:

- **Category 1, Airfield.** Category 1 includes runways, taxiways, handstands, aprons, and other pavements; shoulders; overruns; approach zones; NAVAIDs; and airfield marking and lighting.
- **Category 2, Sanitary facilities.** Category 2 includes kitchens, dining areas, showers, and latrines.
- **Category 3, Direct operational support facilities.** Category 3 includes ammunition storage and the storage and distribution of aviation fuels and lubricants.
- **Category 4, Maintenance, operation, and supply facilities.** Category 4 includes aircraft maintenance, base shops, operations buildings, base communications, photograph laboratories, fire stations, weather facilities, general storage, and medical facilities.
- **Category 5, Indirect operational support facilities.** Category 5 includes roads and exterior utilities, such as water supply and electric power.
- **Category 6, Administration and special housing.** Category 6 includes headquarters, personnel services, and recreation and welfare facilities.
- **Category 7, General housing.** Category 7 includes general housing and troop quarters.

CONSTRUCTION COMBINATIONS

1-47. When constructing an airfield, the different categories of support facilities may be built according to varying standards. A construction combination refers to the support facilities selected and their associated design standards.

1-48. The theater commander usually establishes the construction combination followed in a construction program. It is desirable to construct an air base according 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 a facility. An example of a schedule of standards for construction for the entire air base, including the construction combinations, is shown in table 1-1.

Table 1-1. 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	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

1-49. 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 the TM 5-301 series, TM 5-303, and TM 5-304 for AFCS designs.

1-50. After plans and specifications are selected and modified for the specific site and mission, construction units are expected to conduct project management according to their standard operating policies. Many commercial project management applications are available that will help track overall project times, day-by-day resources, costs, critical paths, equipment, and manpower. At the theater level, engineers track the progress of multiple airfields and airbases to keep the commander updated on the status of airfield construction and repair.

AIRFIELD AND HELIPORT CONSTRUCTION

1-51. The estimation of the construction effort and the time required to complete specific airfields and heliports is based on—

- Security- and other combat-related tasks.
- Earthwork volumes.
- Grading and constructing difficulties.
- Adequate drainages.
- Site clearances.
- Previous construction experiences.
- Equipment maintenance rates.
- Assigned engineer unit experience and capabilities.

1-52. Each project must be considered on a case-by-case basis; therefore, developing an accurate estimate is difficult. There are often numerous 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 manpower and equipment. In addition, until the full modular Army is implemented, engineers will be employed in legacy formations and modular effects elements to accomplish the mission, so production comparisons between units can be difficult to quantify.

1-53. A reasonable estimate of the construction effort and time required is made only after thorough research and planning methods have been conducted. The following section outlines several information sources to help with the planning and estimating process.

INFORMATION SOURCES

1-54. A site visit and ground reconnaissance is typically the best information sources. They provide an ideal venue for developing a clear picture of what should be done. The opportunity to conduct an on-site technical reconnaissance and obtain soil samples can prove invaluable. In addition, there may be military units that have been operating in the area for extended periods of time. They should be able to comment on the weather, locations 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 sources listed in the following paragraphs.

INFRASTRUCTURE, INTELLIGENCE, IMAGERY, AND DESIGN INFORMATION

1-55. The USACE Field Force Engineering Program enables reachback support to deployed warfighters. Requests for information (RFIs) may be sent to USACE.

FLIGHT INFORMATION PUBLICATIONS AND EN ROUTE SUPPLEMENTS

1-56. These publications are carried by aircrews and give nominal runway lengths and load capacities. They are normally available at Air Force and Army base operations. Detailed information on and procedures for requisitioning National Geospatial Intelligence Agency (NGA) products are outlined in the Defense Logistics Agency (DLA) Customer Assistance Handbook. Various organizations serve as flight information publications account managers who are responsible for account start-ups, cancellations, and changes.

OPERATIONAL NAVIGATION CHARTS

1-57. Operational navigation charts provide detailed information for airfields (longer than 4,000 feet) for every country in the world. They are ordered through the DLA. Detailed information on and procedures for requisitioning NGA products are outlined in the DLA Customer Assistance Handbook.

GEOSPATIAL TOPOGRAPHIC DATA

1-58. Geospatial products can be requisitioned through the NGA with maps available through the DLA Web site.

CLIMATIC DATA

1-59. The United States Air Force Weather Service (AWS), Environmental Technical Applications Center (ETAC), United States Air Force/ETAC, Scott Air Force Base, IL furnishes the ETAC with a concise statement of requirements concerning the environmental factors involved or the climatological information desired.

1-60. The National Oceanic and Atmospheric Administration, United States Department of Commerce, Washington, DC 20330 is another source of information for climatic data.

AUTOMATED AIRFIELD INFORMATION FILES

1-61. Automated airfield information files are compiled in a classified and unclassified version and contains airfield information that is useful to the bare-base planner. The source of this document is the Mapping and Charting Program Branch, St. Louis, MO.

PAVEMENT EVALUATION REPORTS

1-62. Pavement evaluation reports are readily available through the Army Infrastructure Program and/ or AFCEC pavement evaluation teams. The Tri-Service Transportation Web site is the best resource.

FOREIGN MAPS

1-63. Nearly all foreign governments maintain mapping agencies. Although DLA maps cover all parts of the world, up-to-date maps may be available through local sources. Foreign maps may be ordered through the

Army Geospatial Center. The Army geospatial center maintains a wide variety of foreign maps that can be created for customers. NGA also provides foreign maps through their NGA support teams.

ARMY FACILITIES COMPONENTS SYSTEM

1-64. 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, and labor estimates for roughly 2,800 preengineered 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 the following four DA technical manuals:

- **TM 5-301 series.** These manuals are usually used by military planners and contain installation, facility, and prepackaged expendable contingency supply 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 that appear 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 the cost, weight, and volume of the prepackaged expendable contingency supply kits. Planners at all levels can use these manuals without referring to the details contained in TM 5-302 series and TM
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 TM 3-34.48-1 for definitions and applications of construction standards.)
- **TM 5-303.** This manual is typically used by planners, builders, and supply personnel to—
  - Identify and order the material items contained in the bill of materials.
  - Identify the cube and weight of the materials to determine the best transportation methods.
  - 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.

Note. Each item in a facility or prepackaged expendable contingency supply 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 system operation. It also gives the background and direction to use the following information in the AFCS:
  - Planning tables.
  - Design criteria.
  - Construction standards or use of construction.
  - Drawings.
  - Building structure types.
  - Material wattage and loss.
  - Climatic zones.
  - Construction efforts or the network analysis and critical path methods.
  - Engineer unit capabilities.
  - Logistical and cost information.
  - Operational conditions.
  - Storage and transit conditions.
  - Camouflage.

1-65. AFCS designs are categorized as vertical or horizontal construction. Vertical construction consists of buildings and facilities (usually everything aboveground). Horizontal construction consists of roads, runways, site development, and site utilities (usually everything at, below, or having to do with establishing grade). TM 5-302 series contains installation drawings and provides concepts and details for installations, such as—

- TO heliports (various sizes and usage), to include—
  - Site preparation.
  - Surface preparation.
  - Surface markings.
  - Lighting.
- TO airfields, to include—
  - Site preparation.
  - Surface preparation.
  - Surface markings.
  - Lighting.
  - Protective revetments.
  - Soil classification and identification.
  - 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 camps.
- Troop camp installations.
- POL installations.

1-66. The Office of the Chief of Engineers, United States Army, maintains the data for the manuals. The data in TM 5-301 series and TM 5-303 is available in printouts, magnetic tape, microfiche, or digitized 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. Correspondence and technical assistance requests, technical manual copies, drawings, and AFCS information should be forwarded to one of the following locations:

- Commander, United States Army Engineer Division, Huntsville, Huntsville, AL.
- Headquarters, Department of the Army (DAEN-2CM), Washington, DC.

Chapter 2

Airfield Characteristics and Airfield Design

This chapter provides information on the characteristics of common military aircraft, the design of military airfields and LZs, and the interrelation of the two. The design criteria for each military airfield, and LZ must be formulated individually to satisfy its specific set of operational requirements. The final airfield and LZ design must meet the requirements of the given aircraft and airfield and LZ type, allowing 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 practical judgment should be exercised 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

2-1. 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 mission is that aircraft establish the controlling aircraft. Less critical category types of aircraft may also use these facilities. More critical category types may use these facilities only under special limitations. Table 2-1, page 2-2, and table 2-2, page 2-3, show the important characteristics of selected Air Force, Army, Navy, and Marine Corps aircraft. For a complete listing and characteristics of military aircraft see Technical Report TSC 13-2.

2-2. LZs (formerly called short fields and training assault landing zones [ALZs]) are special-use airfields that consist of a runway, a runway and taxiway, or other aircraft operational surfaces, such as aprons and turnarounds. It is a prepared or semiprepared (unpaved) airfield used to conduct operation in an environment similar to forward operating locations. LZ runways are typically shorter and narrower than standard runways. This chapter specifically discusses the LZ requirements for the C-130 and C-17 aircraft based on ETL 09-6.

CORRELATION OF ARMY AND AIR FORCE TERMINOLOGY

2-3. The primary airfield complex has three specific airfield types. 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 ETL 09-6. Note that each airfield type 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.

2-4. Besides the three primary airfields, there are several special-use airfields (including DZs, EZs, blacked-out airfields, special operations forces [SOF] airfields, and Unmanned Aircraft System airfields) described in detail later in this chapter. ETL 09-6 details the requirement for the three primary airfields.

2-5. The Army airfield classification system for TO construction is the same as the Air Force airfield classification system. 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 decisive area and sustaining area airfields. Temporary construction airfields are for long-term use (6 to 24 months).

2-6. LZs can be classified into three groups: short-term (temporary) operation LZs, long-term (extended) operation LZs, or training LZs. Short-term LZs are usually defined as operations that last less than one year, while long-term LZs are generally defined as operations expected to be more than one year. Training LZs are typically constructed for extended or long-term periods. Permanent LZ construction is discussed in detail in the Unified Facilities Criteria (UFC) publications.

Table 2-1. Characteristics of certain United States military 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

Legend:

ft	feet
NA	not applicable
psi	pound per square inch
sq in	square inch

Table 2-2. Characteristics of additional certain Army and Air Force aircraft

Aircraft description		*Overall dimensions (ft)*			*Weight (kips)*		*Gear*	*Main gear tires*	*Takeoff (hard surface)*	
Designation	*Name*	*Length*	*Width*	*Height*	*Basic*	*Maximum takeoff*	*Type*	*psi*	*Sea level ground run*	*0 wind, ft clear 50 ft*
Army										
MQ-1C	Gray Eagle	29.0	56.3	9.8	3.2	3.6	Single tricycle	70-80	2,590	5,000
RQ-7B	Shadow 200	11.33	22	3.2	0.3	0.4	Single tricycle	35	NA	NA
MQ-5B	Hunter	23.0	34.3	6.1	1.5	2.0	Single tricycle	69-73	1275	TBD
Air Force										
RQ-4B	Global Hawk	47.6	130.9	15.3	15.3	32.2	Single tricycle	289-299	4,800	5,800
MQ-9A	Reaper	36.2	66.0	11.8	4.9	10.5	Single tricycle	170	3,450	3,600
MQ-1B	Predator	27	55.25	6.9	1.7	2.3	Single tricycle	48-52	1,800	2,500

Legend:
ft feet
NA not applicable
psi pounds per square inch
TBD to be determined

SITE PLANNING OF LANDING ZONES

2-7. When planning the layout of an LZ, safety of aircraft-related operations must be considered. When planning for extended operations, site conditions beyond the safety of aircraft-related operations must be considered. These include land use compatibility with clear zones, primary surfaces, exclusion areas, approach and departure surfaces, and existing and future use of the areas that surround the LZ. In planning an LZ, consider the use and zoning of the surrounding land for compatibility with aircraft operations. The purpose is to protect the operational capability of the LZ and prevent incompatible development, thus minimizing health and safety concerns in areas subject to high noise and accident potential resulting from frequent aircraft overflights.

2-8. For long-term-use LZs, restricting the use of available land beyond the minimum distances given is highly recommended to protect operational capability and enhance the potential for future mission expansion. (See AFH 32-7084 for land use and zoning restrictions.)

2-9. Adequate land for future aviation growth must be considered when planning a LZ. The LZ should be compatible with the existing installation plan. Potential instrument meteorological conditions (IMC)/instrument flight rules (IFR) capability will require additional criteria considerations. LZ criteria prohibit certain land uses within the exclusion area, clear zone, and accident potential zone.

2-10. Accident potential zones that are not on Department of Defense (DOD) property may require easements to control the development and removal of vegetation that could violate the approach or departure clearance surface. The need must be determined on a case-by-case basis.

2-11. Many considerations exist when siting an LZ. These considerations include topography, vegetative cover, existing construction, weather elements, wind direction, soil conditions, flood hazards, natural and man-made obstructions, adjacent land use, usable airspace availability, roads and utilities accessibility, and

expansion potential. Also consider the effects of ambient lighting for operations that require night vision goggles (NVG). The potential for encroachment and the effects of noise on the local community must also be considered. In addition to local permitting requirements, planners may need to file FAA Form 7480-1, *Notice for Construction, Alteration and Deactivation of Airports*, according to FAA JO 7400.2K.

2-12. For training LZs, it is preferred to site the runway within an airfield environment to take advantage of existing runway and taxiway clearance areas. To maximize the training environment, avoid aligning LZ runways parallel to existing runways.

2-13. If siting a training LZ within an existing built-up and occupied area, use a 1,000-foot-wide exclusion area. The exclusion zone runs from clear zone end to clear zone end and is centered on the runway centerline. In addition, the accident potential zone–LZs is widened to 1,000 feet in width. The goal is to provide an LZ environment that offers the greatest margin of safety and compatibility for personnel, equipment, and facilities.

2-14. Safety of aircraft-related operations is taken into consideration for all operations. For extended operations, site conditions beyond aircraft-related operations must be considered. These conditions include land use compatibility with clear zones, primary surfaces, exclusion zones, approach and departure surfaces, and existing and future use of the areas that surround the LZ. The purpose is to protect the operational capability of the LZ and prevent incompatible development, thus minimizing health and safety concerns in areas subject to high noise and accident potential resulting from frequent aircraft overflights.

AIRFIELD AND LANDING ZONE DESIGN

2-15. Army and Air Force staff engineers acting for the Joint Force Commander determine base airfield criteria for a specific TO. The engineers base criteria on local conditions.

2-16. ETL 09-6 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 AFPAM 10-219, Volume 5 for information on subgrade strength requirements.)

2-17. ETL 09-6 provides detailed information for LZ dimensional criteria for runway lengths, widths, gradients, shoulders, turnarounds, clear zones, and separation requirements. The surface type for runways, shoulders, turnarounds, taxiways, and aprons is also discussed.

TYPICAL AIRFIELD LAYOUTS

2-18. Figures 2-1 through 2-3, pages 2-5 through 2-7, show section views applicable to TO airfields. For example, to find the geometric requirements for a support area airfield, see ETL 09-6 at the applicable airfield type in column 1 and then read horizontally across the table under the various column headings to obtain the required dimensions (geometric requirements).

2-19. The circled numbers referring to the various airfield elements shown in figures 2-1 through 2-3 identify the column numbers in ETL 09-6, which give the geometric requirements for each element. Use of these figures with ETL 09-6 determines the specific airfield geometric requirements for each critical aircraft in each military area (decisive, support, and sustaining).

ELEMENTS OF THE AIRFIELD

2-20. The elements that make up the airfield include runways, taxiways, aprons, and hardstands. These elements usually consist of pavement placed on stabilized or compacted subgrades, shoulders and clear zones (normally composed of constructed in-place materials), and approach and lateral safety zones (which require clearing and removing obstructions that project above the prescribed glide and safety angles). The nomenclature for these elements is defined below and is shown in figures 2-1 through 2-3.

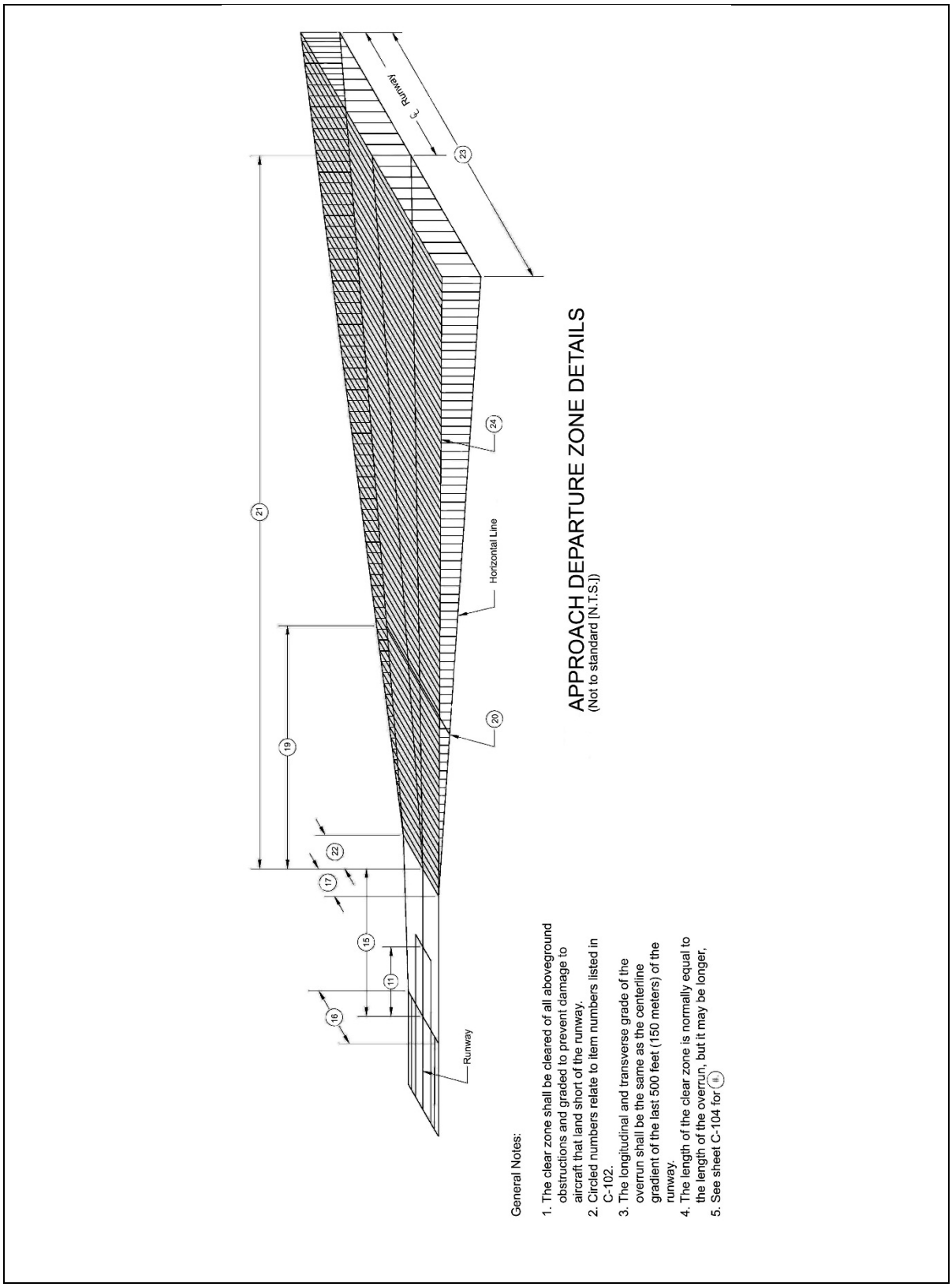


Figure 2-1. Approach zone details

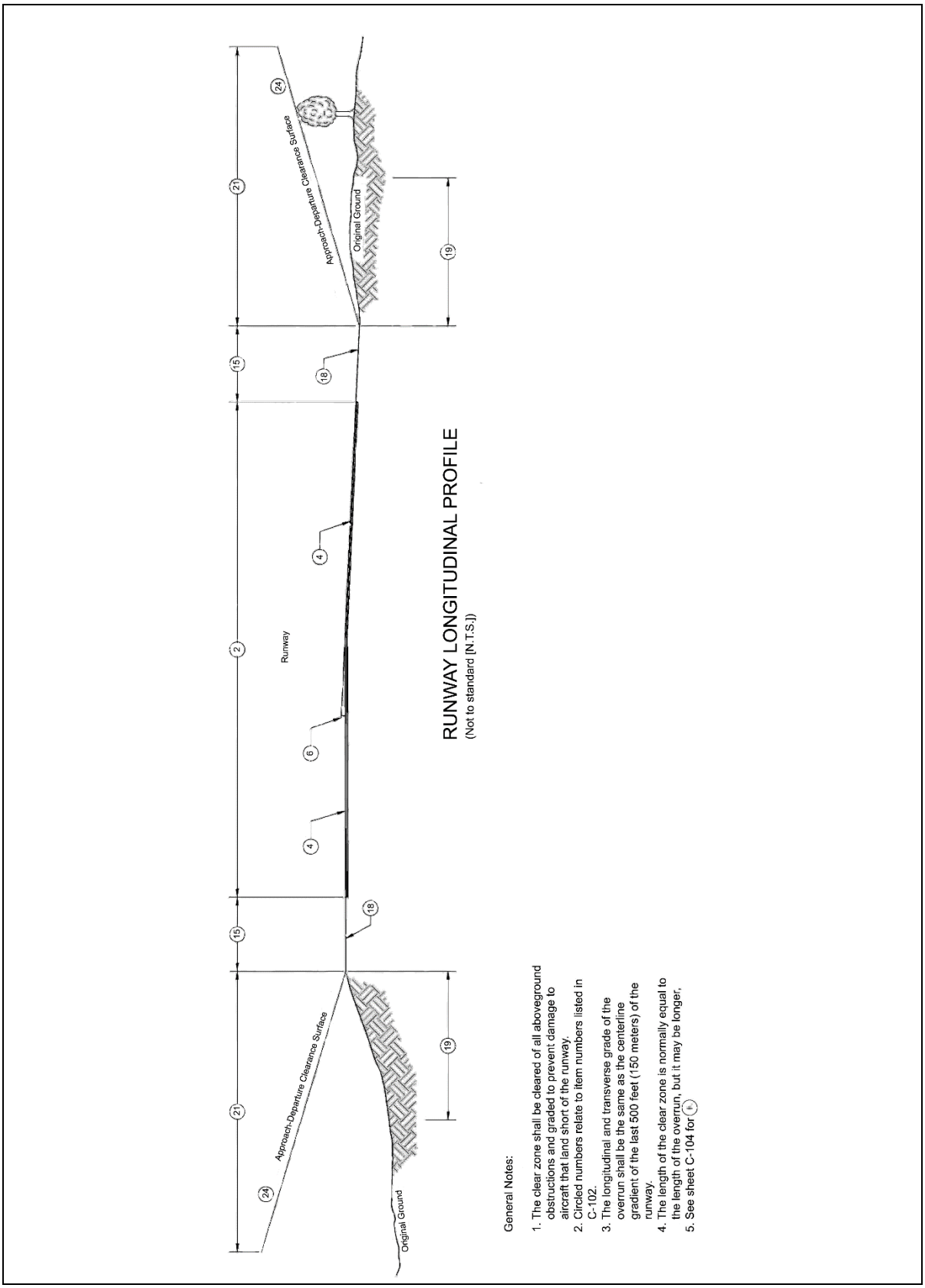
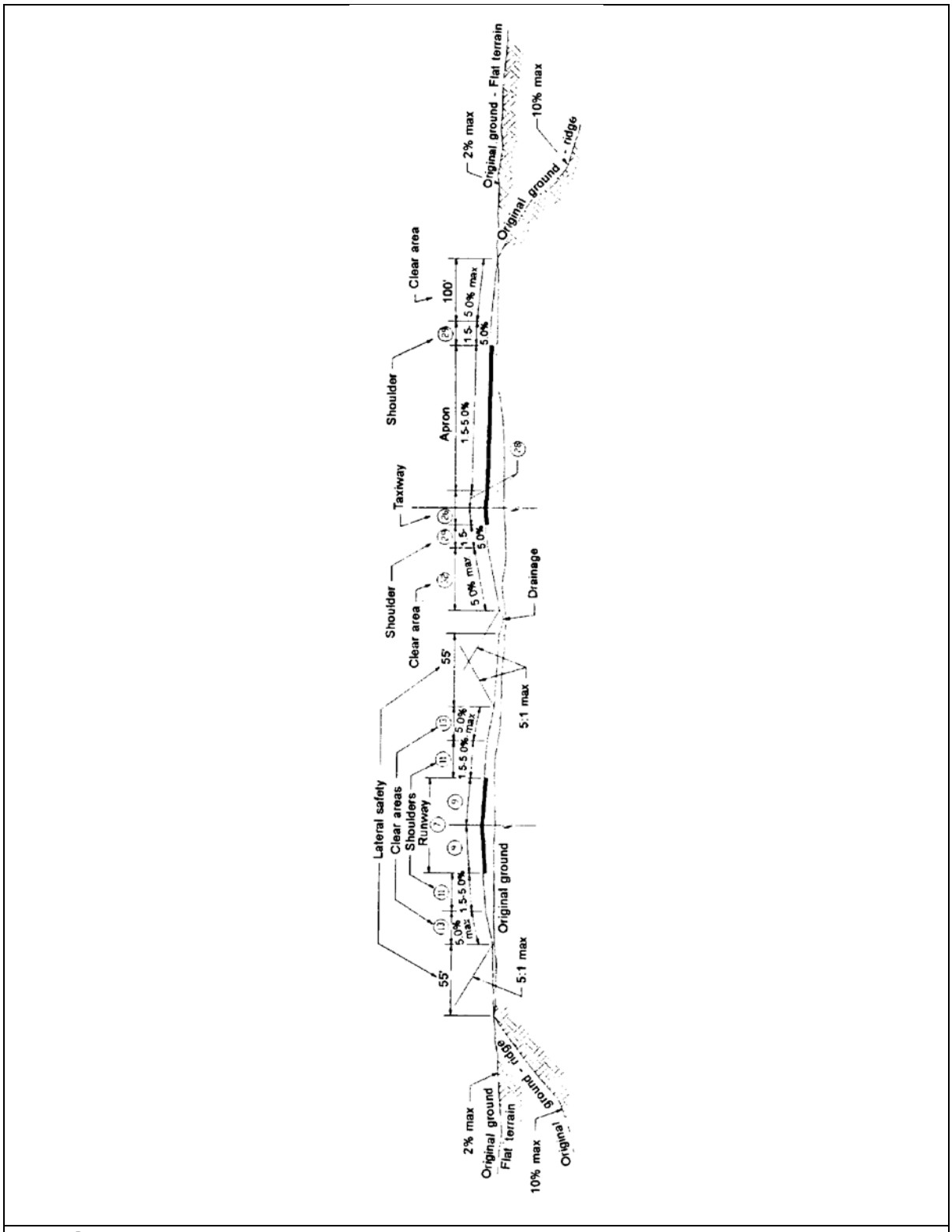


Figure 2-2. Runway longitudinal profile



Legend:

max	maximum

Figure 2-3. Typical runway, taxiway, and parking apron cross section

ELEMENTS OF THE LANDING ZONE

2-21. LZ elements include—

- **Clear zone LZs.** A clear zone LZ is a surface on the ground or water, beginning at the runway threshold and symmetrical about the extended runway centerline. It is graded to protect aircraft operations in which only properly sited NAVAIDs are allowed.
- **Primary surface LZs.** A primary surface LZ is an imaginary surface that is symmetrically centered on the runway. The elevation of a point on the primary surface is the same as the elevation of the nearest point on the runway centerline or extended runway centerline.
- **Exclusion areas.** Exclusion areas are required for paved and semiprepared (unpaved) LZs. The purpose of the exclusion area is to restrict facility development around the LZ. The exclusion area extends the length of the runway and the clear zone on each end. Only the features that are required to operate the LZ (operational surfaces, NAVAIDs, aircraft and support equipment, cargo loading and unloading areas, equipment) are permissible in the exclusion area. In addition, only properly sited facilities are allowed within this area (see UFC 3-260-01).
- **Approach–departure clearance surfaces.** An approach–departure clearance surface is an imaginary surface that is an inclined plane or combined inclined and horizontal planes arranged symmetrically about the extended runway centerline. Objects that penetrate this surface are considered obstructions to air navigation and should be removed if possible. If they are not removed, they must be mapped, marked, and lighted as obstructions. The first segment or the beginning of the inclined plane coincides with the ends and edges of the primary surface and the elevation of the centerline at the runway end. This surface flares outward and upward from these points.
- **Accident potential zone—LZs.** An accident potential zone—LZ is a land use control area beyond the clear zone of an LZ that possesses a significant potential for accidents; therefore, land use is a concern.
- **Aprons.** An apron is a defined area on an LZ. It is intended to accommodate aircraft for loading or unloading passengers or cargo, refueling, parking, or maintenance. LZ aprons are sized to accommodate the mission.
- **Graded areas.** A graded area is an area beyond the runway shoulder where grades are controlled to prevent damage to aircraft that may depart the runway surface. Culverts, headwalls, and elevated drainage structures are not allowed. Properly sited frangible NAVAIDs are allowed.
- **Maintained areas.** A maintained area is a land area that extends outward at right angles to the runway centerline and the extended runway centerline. It is outside the graded area but still within the exclusion area. This area must be free of obstructions. The maintained area is 70 feet wide for C-17 operations or 60 feet wide for C-130 operations. The grade may slope up or down to provide drainage, but may not exceed +10 percent or -20 percent slope.
- **Obstacles.** An obstacle is an existing object, natural growth, or terrain at a fixed geographical location or which may be expected at a fixed location within a prescribed area with reference to which vertical clearance is or must be provided during flight operations. Obstacles are not allowed if they violate grading criteria.
- **Overruns.** An overrun is an area that is the width of the runway, plus prepared shoulders, extending 300 feet from the end of the runway into the clear zone. This portion is a prolongation of the runway and is constructed to support aircraft traffic.
- **Primary surface LZs.** A primary surface LZ is an imaginary surface that is symmetrically centered on the runway. The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline or extended runway centerline.
- **Runway ends.** The runway end is where the normal threshold is located. When the runway has a displaced threshold, the using Service will evaluate each individual situation. Based on this evaluation, the point of beginning for the runway and airspace imaginary surfaces will be determined.
- **Shoulders.** A shoulder is a prepared (paved) or semiprepared (unpaved) area that is adjacent to the edge of operational surfaces (runways, taxiways, aprons, overruns, turnarounds).

- **Taxiways.** A taxiway is a specially prepared or designated path on an airfield or heliport, other than apron areas, on which aircraft move under their own power to and from landing, service, and parking areas.
- **Parallel taxiways.** A parallel taxiway is a path that runs parallel to the runway. The curved connections to the end of the runway or overrun permit aircraft ground movement to and from the runway and are considered part of the parallel taxiway when no other taxiway exits exist on the runway.
- **Visual landing zone marker panels (VLZMPs).** VLZMPs are vertical, colored panels that are installed along runway edges to indicate the threshold location and remaining distance. 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 that are usually composed of constructed in-place materials, and approach and lateral safety zones that require clearing and removing obstructions that project above prescribed glide and safety angles. The nomenclature for these elements is defined below and is shown in figures 2-1 through 2-3, pages 2-5 through 2-7.

RUNWAY DESIGN CRITERIA

2-22. Runway location, length, and alignment are the foremost design criteria in an airfield plan. Major influencing factors include—

- Using aircraft type.
- Local climate.
- Prevailing wind.
- Topography (drainage, earthwork, clearing).

AIRFIELD LOCATION

2-23. Use the runway as the primary consideration, and select the site. Also consider topography, prevailing wind, soil type, drainage, and the amount of clearing and earthwork required when selecting the site. (See TM 3-34.48-1 for airfield location criteria.)

AIRFIELD DESIGN PROCEDURES

2-24. The following is a procedural guide to completing a comprehensive airfield design:

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

Airfield Runway Length

2-25. When determining the runway length required for an aircraft, include the surface area required for landing rolls or takeoff runs. Provide a reasonable allowance for pilot technique variations; psychological factors; wind, snow, or other surface conditions; and unforeseen mechanical failures. Determine the runway length by applying several correction factors and a safety factor 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 an aircraft. Increases in temperature or altitude reduce the air density and increase the required ground run. Therefore, the length of runway required for a specific 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.

2-26. The pressure altitude is a measure of the atmospheric pressure at the site. The pressure altitude is zero under standard day conditions of 59 degrees Fahrenheit 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 atmosphere pressure and altitude (dH) value (height or elevation differential) shown in figure 2-4 to the geographic altitude of the site.

2-27. The average maximum temperature is the average of the highest daily values occurring during the hottest month of the year. Figure 2-5, page 2-12, shows worldwide temperature values to be used. In using these charts, obtain temperature and pressure altitude values for a specific site by interpolation.

Determining Airfield Runway Takeoff Ground Run

2-28. ETL 09-6 shows the TGR at mean sea level, 59 degrees Fahrenheit, with a runway effective gradient of 2 percent for most aircraft based on the location within the TO. Use data in figure 2-1, page 2-5, and figure 2-2, page 2-6, if aircraft is not found in ETL 09-6. The standard TGR must be increased for different local conditions. The following steps are used to determine the adjusted TGR:

- **Step 1.** Determine the standard TGR for an aircraft shown in ETL 09-6.
- **Step 2.** Correct for pressure altitude. Add the dH value of the site (from figure 2-5) 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.
- **Step 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 degrees Fahrenheit increase in temperature above 59 degrees Fahrenheit (from figure 2-5). If the pressure-corrected TGR is less than 5,000 feet, increase the pressure-corrected TGR by 4 percent for each 10 degrees Fahrenheit increase above 59 degrees Fahrenheit. Never decrease the runway length if the temperature is less than 59 degrees Fahrenheit.
- **Step 4.** Adjust for safety. Multiply the temperature-corrected TGR by 1.5 for sustaining area airfields and by 1.25 for support and decisive area airfields.
- **Step 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.
- **Step 6.** Round off the gradient-corrected TGR to the next higher 100 feet.
- **Step 7.** Compare the computed value of the TGR with the minimum required runway length. Use the higher of the two values.

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. The maximum allowable longitudinal gradient is the steepest slope into which an aircraft can safely land.

2-29. The final runway length is the TGR as corrected (if required) for pressure altitude, temperature, safety factor, and effective gradient conditions 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 degrees Fahrenheit. Also, the final runway length is never less than the minimum length shown in ETL 09-6.

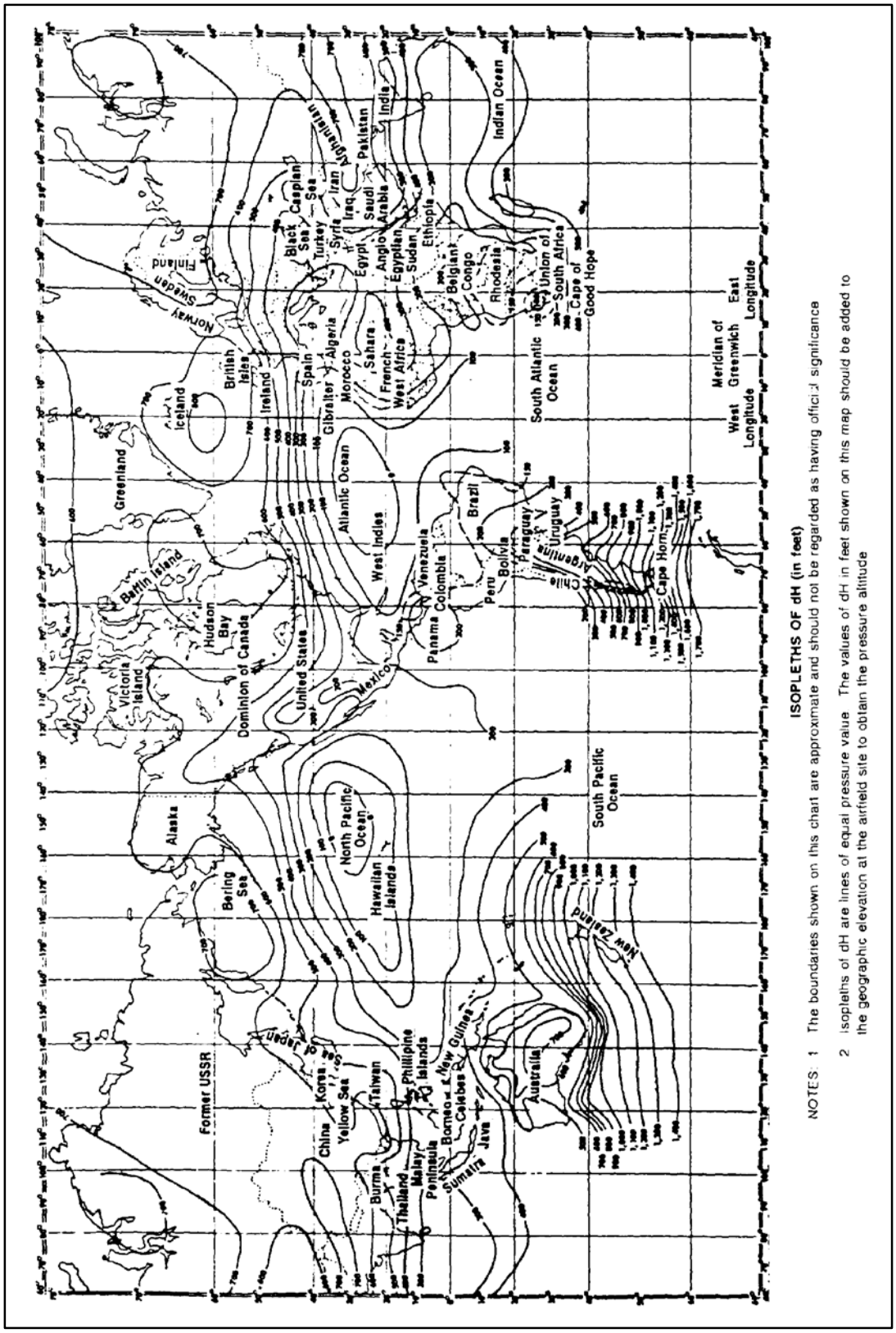


Figure 2-4. Isopleths of dH, worldwide

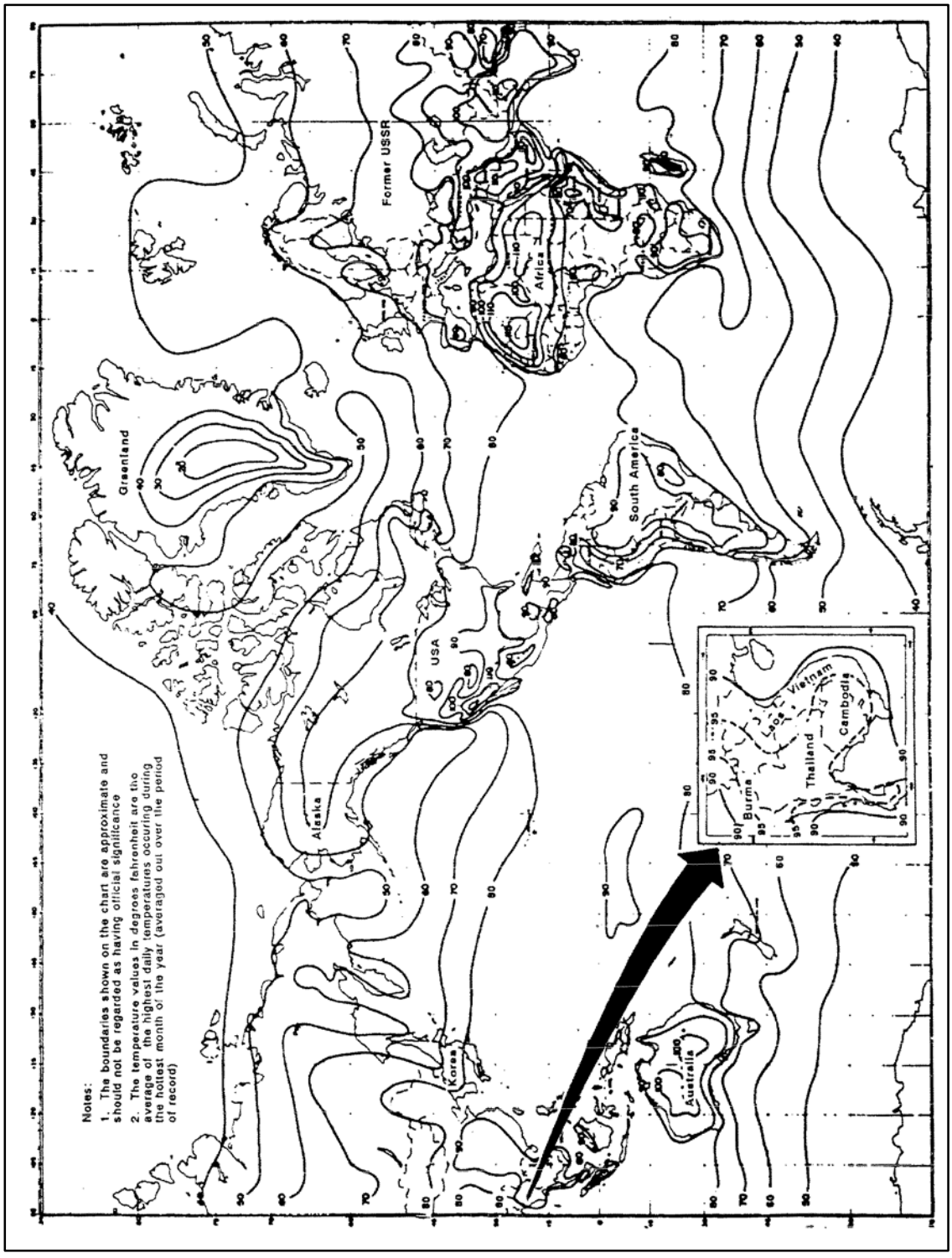


Figure 2-5. Worldwide average maximum temperature map

Airfield Runway Width

2-30. The primary factors that determine runway width are the safety of operation under reduced visibility conditions and 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. ETL 09-6 shows the required widths of clear areas and dimensional criteria of clear zones.

Airfield Approach Zones

2-31. 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 ETL 09-6 for widths to be used for each airfield type and construction stage.) ETL 09-6 shows the required length of the approach zone. The following dimensions are necessary 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.

Airfield Glide Angle

2-32. No obstruction should extend above the glide angle within an approach zone. The upper limit of the glide angle is a sloping plane that extends from the ground surface at the end of the approach zone nearest the runway to a higher elevation at the outer edge. The slope of this plane depends on the glide-angle characteristics of the using aircraft.

2-33. 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 (rotation point for ascent) or at its point of touchdown (descent). Glide-angle ratios, as they are given for various aircraft, include a safety adjustment.

2-34. 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 20:1 to 50:1, depending on airfield location, aircraft characteristics, and mission requirements.

Airfield Gradients

2-35. ETL 09-6 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 decisive area airfields is 3 percent.

2-36. Use ditches at the shoulder edges, parallel to the centerline (longitudinally), to provide adequate drainage. Also, lateral ditches might be required to provide water flow away from the longitudinal ditches that parallel the runway. Neither longitudinal nor lateral ditches can have side slopes greater than 7:1. This ensures that the ditches meet the design drainage requirement but do not present a safety hazard to aircraft running off the runway.

2-37. 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 TO airfields. These figures pertain to centerline measurements, but higher rates of grade change to permit transverse sloping of the runway and may be allowed along the runway edges. Using the vertical curve design procedure will satisfy these requirements.

2-38. When jet aircraft are involved, hold longitudinal grade changes to an absolute minimum. Make necessary grade transitions as long as possible to keep grade change rates very low.

2-39. 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.

2-40. Grade shoulders to a transverse slope of 1.5 to 5 percent. Permissible transverse overrun grades are the same as those for the runway.

Airfield Surface and Pavement Thickness

2-41. Design-criteria tables contain recommendations on the surface types and pavement thicknesses used for each airfield type.

Airfield Shoulders

2-42. Shoulders are required for runways. Shoulders range in width from 10 feet to 50 feet, depending on the airfield location and the using aircraft. Normally, airfield pavement shoulders are thoroughly compacted and constructed with soils that have 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.

Airfield Signal Cables

2-43. 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.

Landing Zone Surface

2-44. Semiprepared (unpaved) LZ surfaces may be composed of stabilized soils, aggregate surfaces, compacted native soils, or matting materials. Specific design guidance for semiprepared surfaces can be found in UFC 3-270-07.

2-45. Paved LZs may be surfaced with asphalt concrete (AC) or portland cement concrete (PCC) pavement. On runways, taxiways, turnarounds, and aprons used by C-17 aircraft, asphalt pavement distress has been observed in areas where 90^0 to 180^0 turns are made; for this reason, PCC is preferred in areas where turning movements occur. Designers should consider durability and maintenance of the pavement and economics when selecting a surface type for an area associated with an LZ intended for long-term use. AC and PCC pavement structures shall be designed to support the traffic level defined in UFC 3-260-02.

Landing Zone Runways and Overruns

2-46. Unpaved LZ runway and overrun surfaces shall be designed to support the anticipated aircraft type, weight, and number of planned operations. Overruns will be designed to the same standard as the runway. Paved runways and overruns may be surfaced with AC or PCC pavement. Saw cut grooving may be used to improve drainage characteristics on runways. Special design consideration is needed if the overrun is used as a taxiway or turnaround area. For semiprepared runways, the shoulder structure will be designed to the same standard as the runway. For paved runways, shoulders may be surfaced with AC or PCC pavement.

Landing Zone Turnarounds

2-47. Unpaved turnarounds will be designed to support the anticipated aircraft type, weight, and number of operations. Designers should give special consideration to stabilization for turnarounds used by C-17 aircraft because the surface can be easily damaged by the turning action of the main landing gear. Paved turnarounds may be surfaced with AC, PCC, or resin modified pavement. Special consideration should be given to surface durability for turnarounds used by C-17 aircraft; for this reason, PCC pavement is preferred.

Landing Zone Taxiways

2-48. Unpaved taxiways will be designed to support the anticipated aircraft type, weight, and number of operations. Designers should give special consideration to stabilization at taxiway turns used by C-17 aircraft because the surface can be easily damaged by the turning action of the main landing gear. Paved taxiways may be surfaced with AC, PCC, or resin modified pavement. Special consideration should be given to surface durability for taxiways used by C-17 aircraft; for this reason, PCC pavement is preferred.

Landing Zone Aprons

2-49. Unpaved aprons will be designed to support the anticipated aircraft type, weight, and number of operations. Designers should give special consideration to stabilization on aprons used by C-17 aircraft because the surface can be easily damaged by the turning action of the main landing gear. Paved aprons may be surfaced with AC, PCC, or resin modified pavement. Special consideration should be given to surface durability and fuel resistance for aprons used by C-17 aircraft; for this reason, PCC pavement is preferred.

Runway Orientation

2-50. Runways are usually oriented according to prevailing area winds. When determining the runway location, pay particular attention to gusty winds of high velocity.

2-51. 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. 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 10^0 to the prevailing wind so that dust clouds produced by takeoffs will blow diagonally off the runway.

Gathering Wind Data

2-52. Wind data is usually based on the longest period for which information is available. At least 10 years of data depicting wind directions, velocity, and frequency of occurrence is necessary for conclusive analysis. Military and civilian maps for 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 2-3 shows the form for which wind data may be obtained from AWS.

Table 2-3. Annual percentage of all surface winds, categorized by velocity (miles per hour) and directions

Direction	*Wind velocity group (miles per hour)*						*Total*
	1-4	4-13	13-25	25-32	32-47	Over 47	
	(a)	(b)	(c)	(d)	(e)	(f)	
	Percent						
North	0.3	3.3	1.4	0.1	0	0	5.1
North-northeast	0.3	3.0	0.9	0	0	0	4.2
Northeast	0.5	3.3	0.9	0	0	0	4.7
East-northeast	0.2	1.4	0.4	0	0	0	2.0
East	0.5	2.5	0.6	0	0	0	3.6
East-southeast	0.3	2.4	0.8	0	0	0	3.5
Southeast	0.6	5.9	2.9	0.2	0	0	9.6
South-southeast	0.5	6.7	7.9	0.6	0.1	0	15.8
South	0.8	7.4	6.0	0.4	0	0	14.6
South-southwest	0.6	5.2	5.0	0.4	0	0	11.2
Southwest	0.5	2.9	1.3	0.1	0	0	4.8
West- southwest	0.3	1.7	1.1	0.1	0	0	3.2
West	0.4	2.3	0.6	0.1	0	0	3.4
West-northwest	0.4	2.3	0.8	0.1	0	0	3.6
Northwest	0.5	2.6	0.8	0	0	0	3.9
North-northwest	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.			

Wind Rose

2-53. A wind rose graphically depicts wind velocities, directions, and probability of occurrence in a format that resembles a compass. (See figure 2-6.) The radii of the concentric circles are scaled to represent wind velocities of 4, 13, 25, 32, and 47 miles per hour. 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, east-northeast, and east). Each direction subtends an angle of 22.5°.

2-54. The probabilities of occurrence for the wind velocities and directions are recorded in the appropriate spaces on the diagram. Figure 2-6 uses the wind data from table 2-4.

Table 2-4. Example of wind-rose evaluation (percentage covered)

Direction	***Wind velocity group (miles per hour)***						***Total***
	1-4	4-13	13-25	25-32	32-47	Over 47	
	(a)	(b)	(c)	(d)	(e)	(f)	
	Percent						
North	0.3	3.3	1.4	0.1	0	0	5.1
North-northeast	0.3	3.0	0.9	0	0	0	4.2
Northeast	0.5	3.3	0.4	0	0	0	4.2
East-northeast	0.2	1.4	0	0	0	0	1.6
East	0.5	2.5	0	0	0	0	3.0
East-southeast	0.3	2.4	0.1	0	0	0	2.8
Southeast	0.6	5.9	0.9	0	0	0	7.4
South-southeast	0.5	6.7	7.9	0.4	0	0	15.5
South	0.8	7.4	6.0	0.4	0	0	14.6
South-southwest	0.6	5.2	5.0	0.3	0	0	11.1
Southwest	0.5	2.9	0.5	0	0	0	3.9
West-southwest	0.3	1.7	0.1	0	0	0	2.1
West	0.4	2.3	0	0	0	0	2.7
West-northwest	0.4	2.3	0.1	0	0	0	2.7
Northwest	0.5	2.6	0.4	0	0	0	3.5
North-northwest	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 2-3, page 2-15, the resultant wind rose, and the rectangular indicator positioned as shown in figure 2-9, page 2-23.							

Example

Record 9 percent (the sum of 2 percent calms plus 7 percent winds under 4 miles per hour) within the innermost concentric circle, the radius of which represents 4 miles per hour. Record the percentages of 3.3, 1.4, 0.1, 0.0, and 0.0 (shown for the north direction in columns [b], [c], [d], [e], and [f] of table 2-4) on the diagram (figure 2-7, page 2-18) 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 miles per hour, respectively. Record the remainder of the data in table 2-4 on the diagram in the same manner.

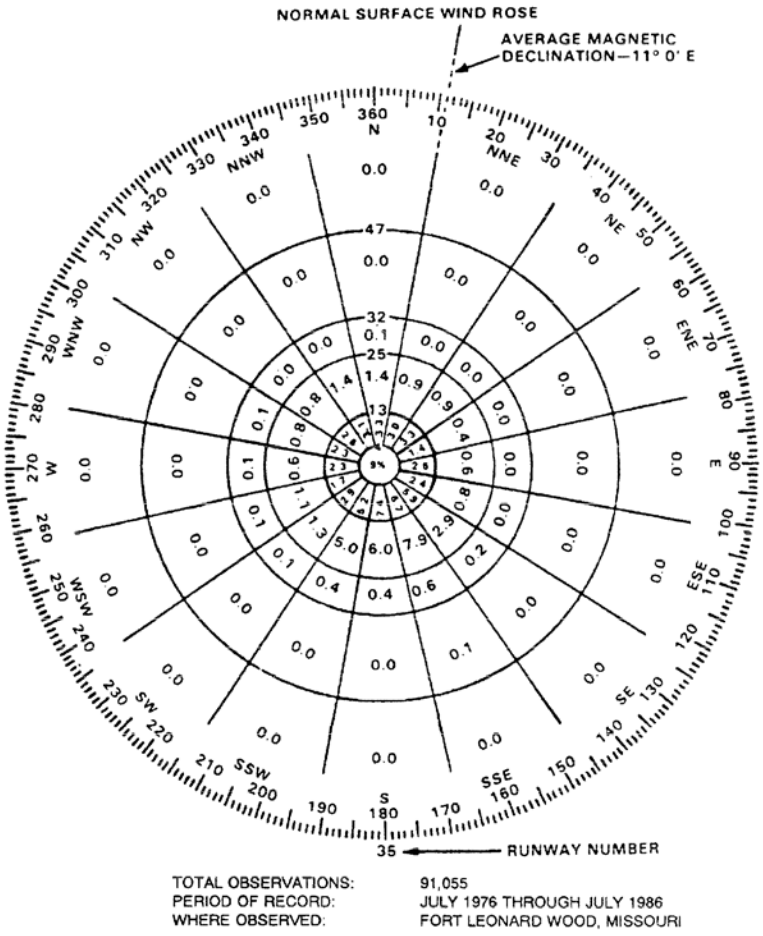
Wind Vectors

2-55. Figure 2-7 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 mile

per hour (the scale generally used) and the prevailing wind has a velocity of 18 miles per hour, 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 miles per hour, the crosswind velocity. Line b-o measures 1.56 inches and represents 15.6 miles per hour, 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 Pythagorean Theorem.

Example

$(9 \text{ miles per hour})^2 + (15.6 \text{ miles per hour})^2 = (18 \text{ miles per hour})^2$



Legend:

E	east	SW	southwest
ENE	east-northeast	W	west
ESE	east-southeast	WNW	west-northwest
N	north	WSW	west-southwest
NE	northeast		
NNE	north-northeast		
NNW	north-northwest		
NW	northwest		
S	south		
SE	southeast		
SSE	south-southeast		
SSW	south-southwest		

Figure 2-6. Typical wind rose

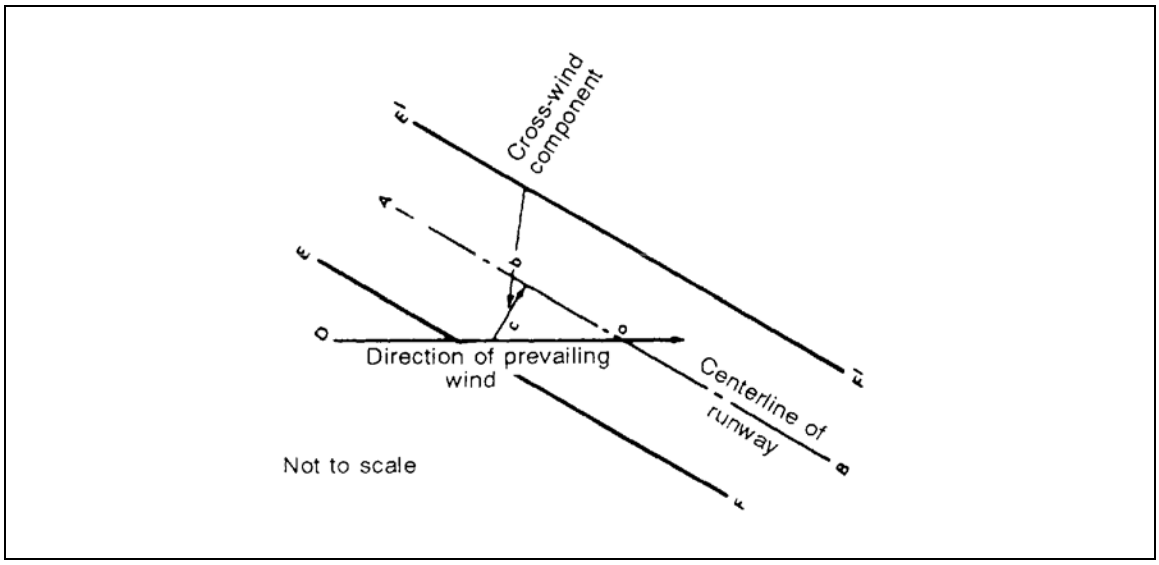


Figure 2-7. Wind vector

Graphic Analysis of Wind Rose

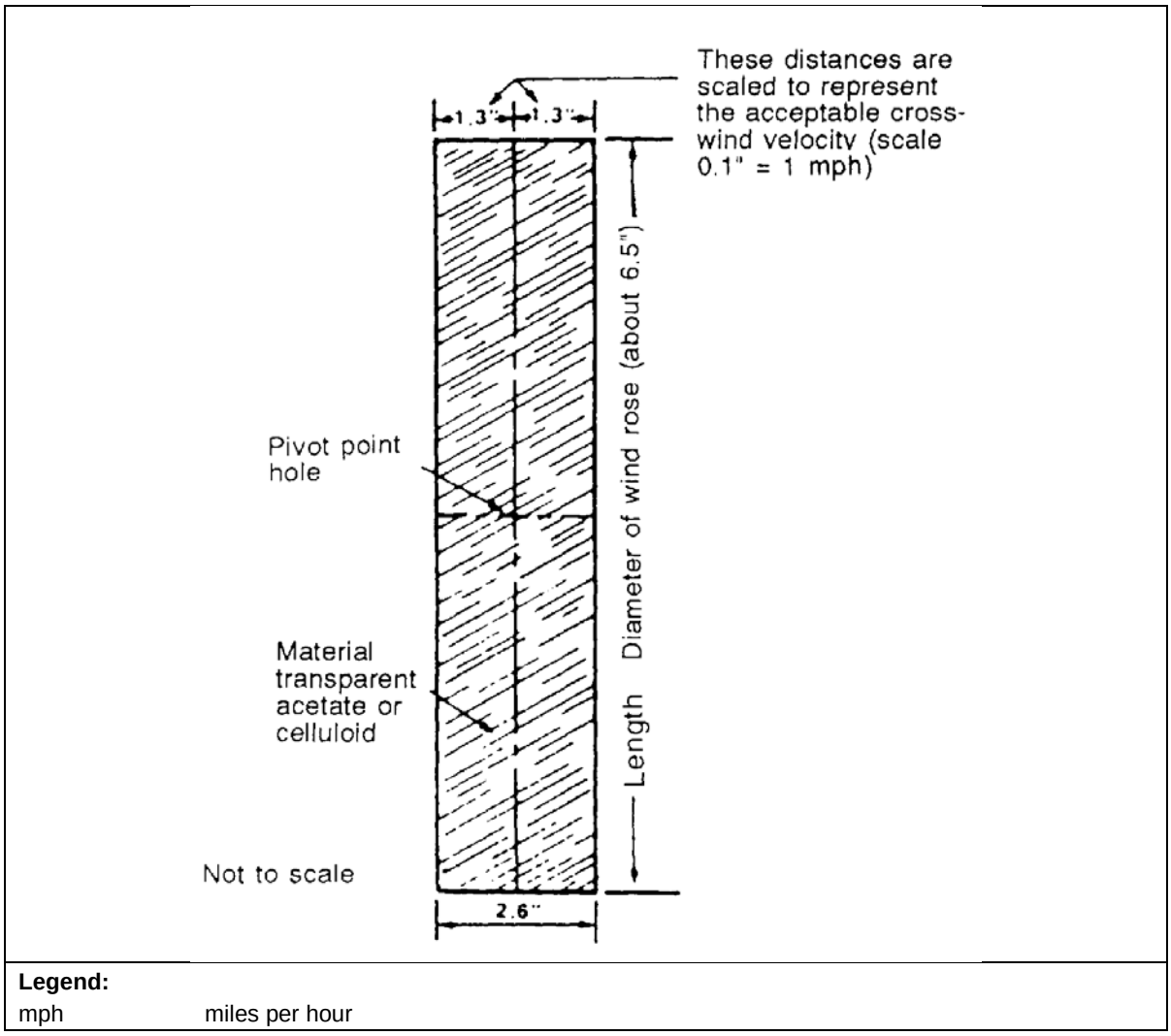
2-56. Use a thin, transparent, rectangular indicator to analyze a wind rose (see figure 2-8). This indicator is constructed to the same scale as the wind rose on which it is used. The width of the indicator is based on the acceptable crosswind velocity. With an acceptable crosswind velocity of 13 miles per hour and a wind rose scale of 0.1 inch equals 1 mile per hour, 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.

2-57. The indicator is securely pivoted at the center of the wind rose (see figure 2-9, page 2-20). Because the edges of the indicator define the limits of the acceptable crosswind velocity 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) are maximized. Total the percentages under the indicator. The total is the percentage of time that crosswind velocities will be within the specified limit for a runway that is oriented in the direction shown by the rectangular indicator.

2-58. Determine the percentage coverage totals with the indicator oriented in several directions. Compare the totals to determine the best runway orientation, based solely on 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

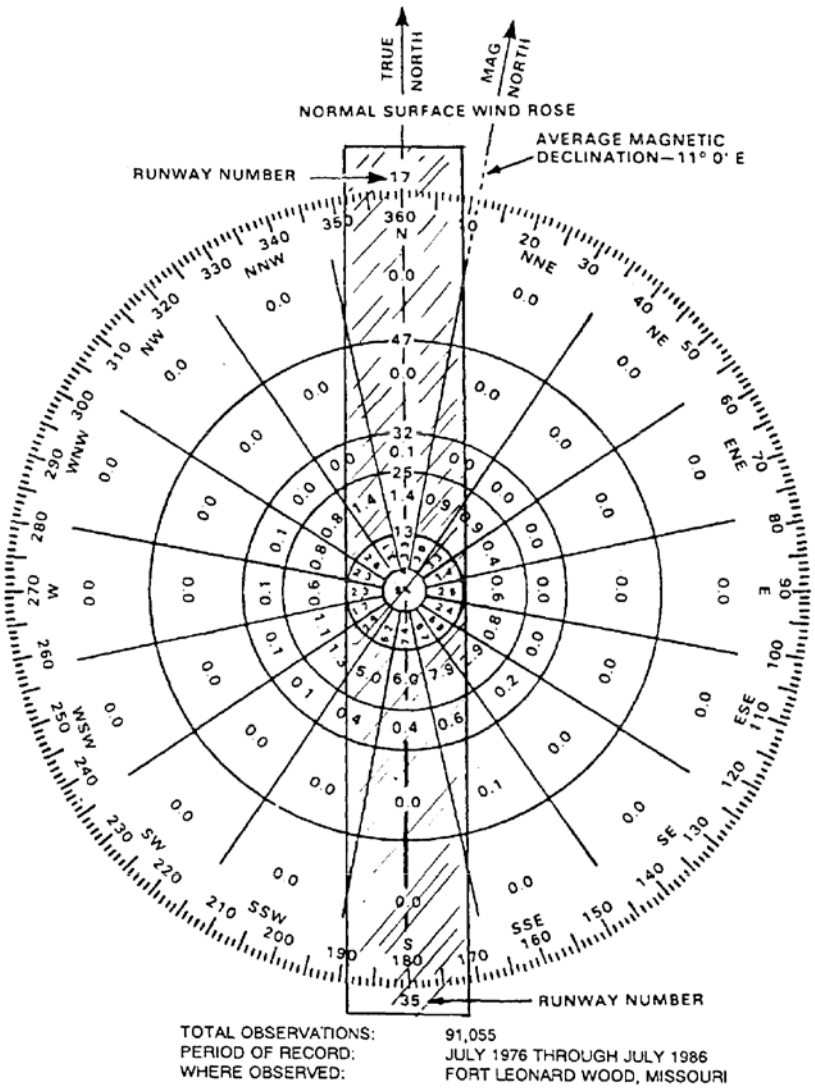
2-59. One of two procedures may be followed to evaluate the total percentage covered by the rectangular indicator on a wind rose. One procedure is to calculate the total of the representative percentages covered by the indicator. The other procedure is to calculate the total of the representative percentages not covered by the indicator and subtract this total from 100 (see table 2-5, page 2-21). Table 2-4, page 2-16, and table 2-6, page 2-21, show examples of each procedure. The wind data in table 2-6 the resultant wind rose, and the indicator in the position shown in figure 2-9, page 2-20, are used to compile the examples.



Legend:

mph	miles per hour

Figure 2-8. Transparent rectangular indicator used in wind-rose analysis



Legend:

E	east	S	south
ENE	east-northeast	SE	southeast
ESE	east-southeast	SSE	south-southeast
mag	magnetic	SSW	south-southwest
N	north	SW	southwest
NE	northeast	W	west
NNE	north-northeast	WNW	west-northwest
NNW	north-northwest	WSW	west-southwest
NW	northwest		

Figure 2-9. Determination of runway alignment by wind-rose analysis

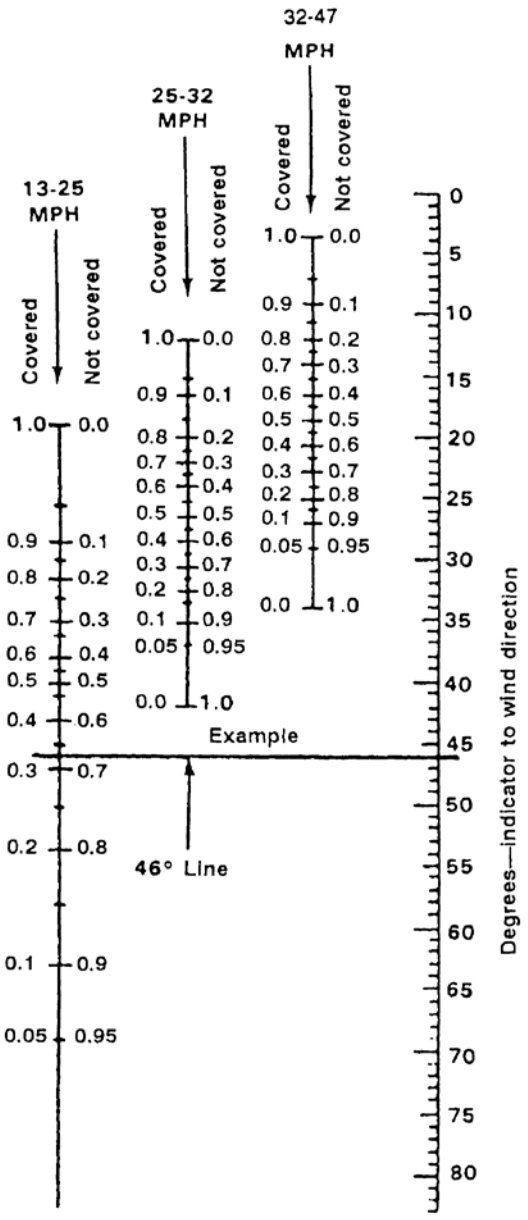
Table 2-5. Example of wind-rose evaluation (percentage not covered)

Direction	*Wind velocity group (miles per hour)*						*Total*
	1-4	4-13	13-25	25-32	32-47	Over 47	
	(a)	(b)	(c)	(d)	(e)	(f)	
	Percent						
North	0	0	0	0	0	0	0
North-northeast	0	0	0	0	0	0	0
Northeast	0	0	0.5	0	0	0	0.5
East-northeast	0	0	0.4	0	0	0	0.4
East	0	0	0.6	0	0	0	0.6
East-southeast	0	0	0.7	0	0	0	0.7
Southeast	0	0	2.0	0.2	0	0	2.2
South-southeast	0	0	0	0.2	0.1	0	0.3
South	0	0	0	0	0	0	0
South-southwest	0	0	0	0.1	0	0	0.1
Southwest	0	0	0.8	0.1	0	0	0.9
West-southwest	0	0	1.0	0.1	0	0	0.2
West	0	0	0.6	0.1	0	0	0.7
West-northwest	0	0	0.8	0.1	0	0	1.8
Northwest	0	0	0.4	0	0	0	0.4
North-northwest	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 2-3, page 2-16, the resultant wind rose, and the rectangular indicator positioned as shown in figure 2-10.							

Table 2-6. 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*
$L = \frac{G}{r^a}$	$L = \frac{G}{r^a}$	$L = 2S - \frac{40}{G}$ Where $S^b = \frac{RW^b}{2} + 5$	Raise to next higher even station
Notes. 1. The symbol r varies, and the rates of change are listed in ETL 09-6. 2. Enter an equation with RW and S in stations to obtain a value for L in stations.			
LEGEND: L length of vertical curve G change in grade r allowable rate of change of grade RW runway length S sight distance			

2-60. 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 (see figure 2-10).



Legend:
mph miles per hour

Figure 2-10. Nomograph for estimating wind coverages

2-61. As an example of how the nomograph is used, assume that figure 2-9, page 20, 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 miles per hour. 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.

2-62. In this example, the azimuth of the wind direction (southeast) is 135°. The azimuth of the centerline of the indicator is roughly 181°. Their angular difference is roughly 46°. Figure 2-10, page 2-22, shows that for this angular difference, the rectangular indicator covers approximately 0.3 percent of the space representing winds from 13 to 25 miles per hour. Because the entire space represents 2.9 percent of the time, the 0.3 portion of the space represents 0.9 percent (derived from multiplying 2.9 by 0.3 and rounding up to the nearest tenth) of the time. Accuracy to the closest 0.1 percent is the same as that of the basic wind data.

2-63. 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 2-4, page 2-16. The total of 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 2-9, page 2-20, are recorded in table 2-5, page 2-21.

True and Magnetic North Directions

2-64. 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

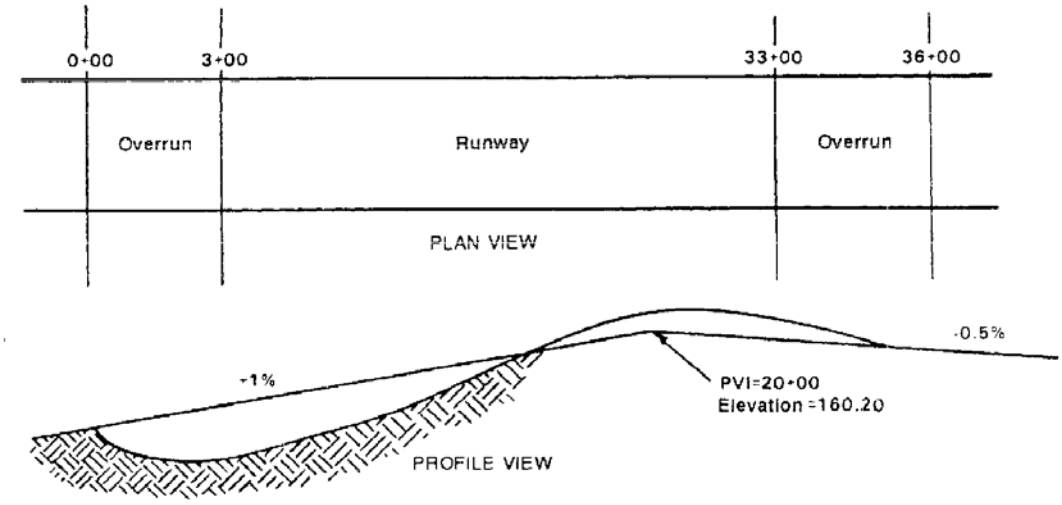
2-65. Airfield construction specifies a minimum length of each grade line or a minimum distance between the grade line intersection points. Although this specification is based on the type of aircraft involved and the standard of construction desired, a minimum of 400 feet between points of vertical intersection is used.

VERTICAL CURVES

2-66. The same vertical-curve design procedures used for roads in TM 3-34.48-1 are used for airfields. However, the curve length may be longer. In many cases, the runway is a segment of a curve, and the point of vertical curvature and point of vertical tangency (PVT) are off the airfield. Confusion of stationing must be avoided. Table 2-6, page 2-21, shows equations to determine airfield vertical curve lengths. For overt curves, use sight distance or maximum change of grade to determine the curve length. Use the longest length.

Example

A decisive area airfield is built to accommodate C-17 and C-130 aircraft. The runway length is determined to be 3,000 feet (after adjustments are made to the TGR). Figure 2-11, page 2-24, 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 point of vertical curvature and point of vertical tangency, calculate the offsets every 100 feet, and prepare the equation in tabular form.



Legend:
PVI point of vertical intercept

Figure 2-11. Profile of proposed runway

SOLUTION

2-67. The cross section of a runway may be a crowned cross section or a transverse slope cross section (see figure 2-12). 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.

2-68. 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.

2-69. Shape and grade changes of a properly sloped runway are small compared to 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 are usually located to conform to the existing ground surface.

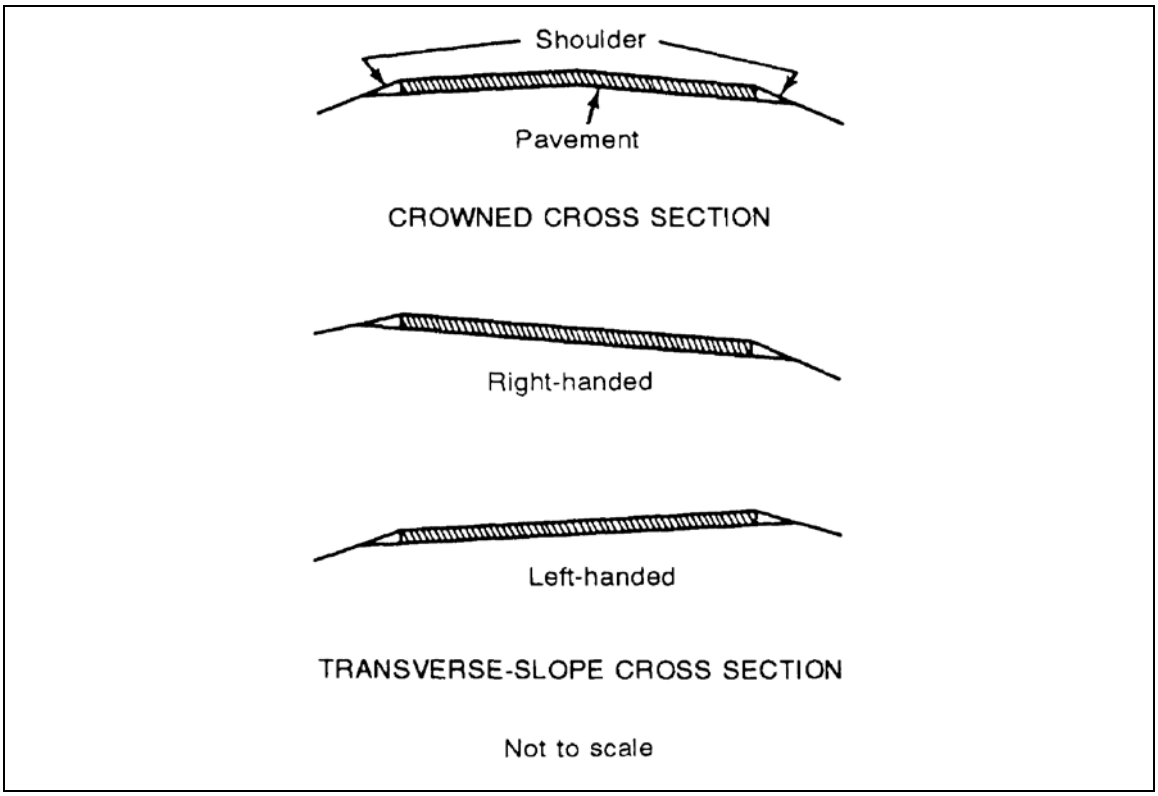


Figure 2-12. Crowned cross section and traverse-slope cross sections of runways

Limitations

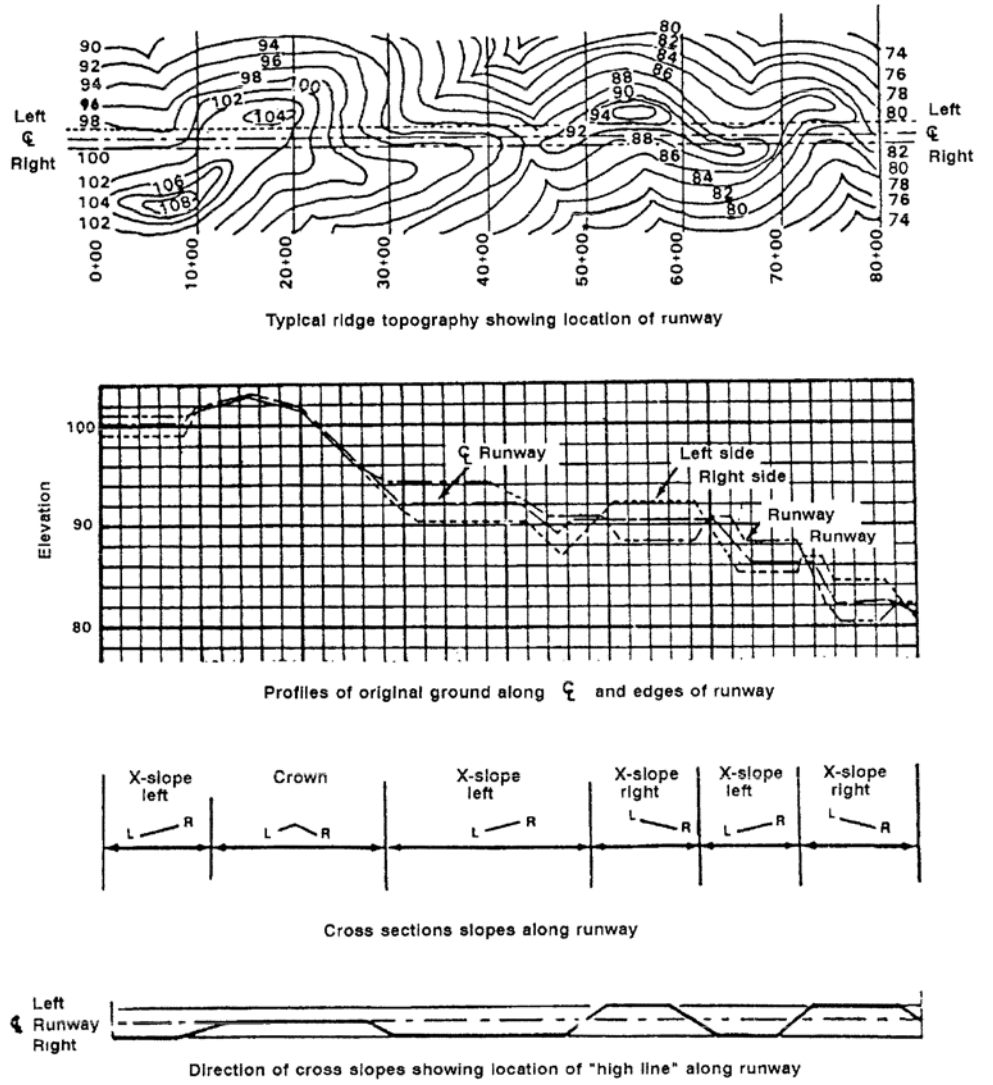
2-70. In applying transverse slopes to a runway, it may be economical to change from a left-hand to a right-hand transverse-slope cross section or to change from a transverse-slope cross section to a crowned cross section. These changes may occur often, provided the following limitations are observed:

- 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 ETL 09-6 are not exceeded.

Designing Transverse Slope Cross Sections

2-71. Transverse sloping of a runway is primarily a computing and drafting job. The two main tasks in a sloping problem are—

- Selecting proper cross sections for various runway lengths (see figure 2-13, page 2-26).
- Designing proper transitions to connect different cross-sectional shape lengths (see figure 2-14, page 2-27).



Legend:

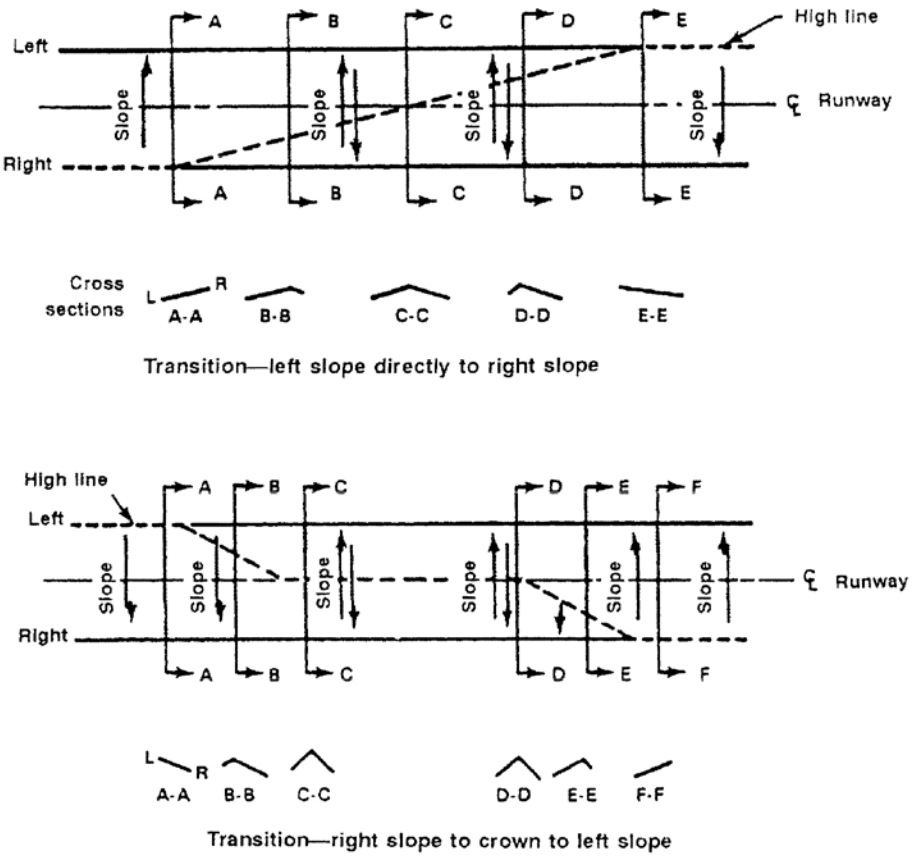
℄	centerline
L	left of runway centerline
R	right of runway centerline

Figure 2-13. Determination of runway cross sections

Selecting Cross Sections

2-72. Use the following steps to select proper runway cross sections:

- **Step 1.** Plot the ground profiles at the centerline, left edge, and right edge of the runway as shown in figure 2-13. Plot each profile with a different colored pencil.
- **Step 2.** Determine the relative positions of three profiles at each cross section. When both edges are 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.
- **Step 3.** Design proper cross-sectional shapes for each distinct runway length. 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.



Legend:

℄ centerline

L left of runway centerline

R right of runway centerline

Figure 2-14. Transitions between cross sections

2-73. Figure 2-13, page 2-26, 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

2-74. The upper area of figure 2-14 shows a transition that is suitable for changing from a left-hand, transverse-slope cross section to a right-hand, transverse-slope cross section. In figure 2-14, the dotted line on the plan connects the high points of successive cross sections. A similar situation occurs when the change involves a crowned section. The lower part of figure 2-15, page 2-28, shows a crowned section, high points, and typical cross sections in a similar fashion. Note that the cross sections, between and including C-C and D-D, are alike.

2-75. 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 runway edges. These are enough stakes for construction, but additional stakes may be required for close grade control.

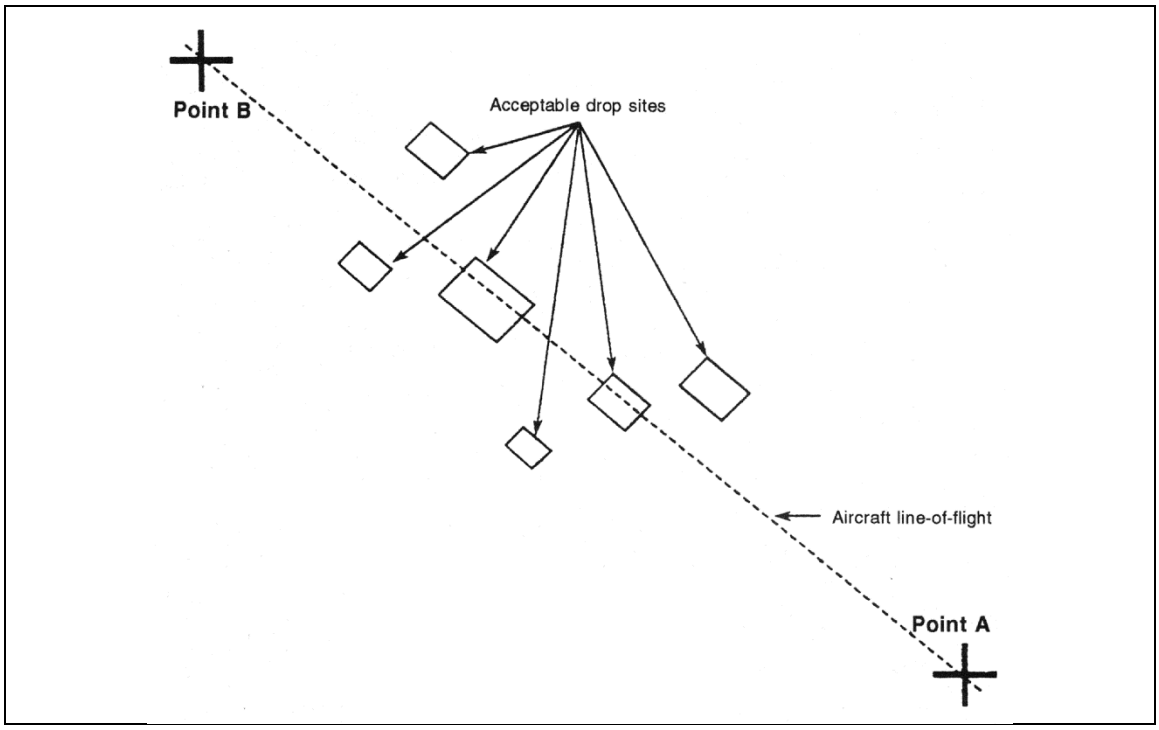


Figure 2-15. Area DZ

TAXIWAYS

2-76. Taxiways are pavements provided for the ground movement of aircraft. They connect parking and maintenance airfield areas to the runway. The location of these facilities determines the location of taxiways.

2-77. Locate taxiways to provide direct access to the ends of takeoff runways. 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.

2-78. Provide cutoff taxiways or exit paths that permit landing aircraft to promptly clear the runway. Excessive cutoffs can complicate the traffic control problem.

2-79. Construct taxiways on a loop system. This provides an alternate route in case maintenance operations or a disabled airplane blocks the taxiway. Make the taxiway parallel with the runway, and form a closed loop by tying onto it at both ends.

2-80. 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

2-81. Three aprons are used in TO airfields—warm-up, operational, and cargo. The following paragraphs contain descriptions of each apron.

Warm-Up Apron

2-82. The warm-up apron, sometimes called a holding-pad apron, is a paved area that is adjacent to the taxiway near the runway end. The warm-up apron permits—

- The final portion of warm-up, engine, and instrument checks to be performed 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.

2-83. A satisfactory warm-up apron should—

- Provide a paved area at each end of the operational runways.
- Be large enough to simultaneously accommodate two of the largest aircraft assigned to the air base.
- 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 that 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 the runway end and the taxiway while headed into the wind.

Operational Apron

2-84. 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.

2-85. 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.

2-86. The minimum wingtip clearance for aircraft taxiing or operational apron parking is 10 or 20 feet, depending on aircraft use categories.

2-87. 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.

2-88. Jet aircraft must operate within a designated parking area so that 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 the area in which the blast velocity does not exceed 35 miles per hour and the temperature does not exceed 100 degrees Fahrenheit. The apron configuration at each base depends on the number and type of aircraft to be parked and the local apron and terrain features.

2-89. The operational apron is usually designed to accommodate 100 percent of the 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

2-90. 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 the frequency of operation, total number of cargo aircraft involved, air-traffic-control rate, runway saturation rate, and station workload capabilities.

2-91. Experience from within the TO or a specific assessment by the troop transport commander should determine apron requirements. Use a 10-percent estimate of the total number of cargo aircraft in the

operation, or estimate required additional apron areas by multiplying the number of aircraft to be accommodated by the factors shown in table 2-7.

Table 2-7. Factors for determining cargo apron areas

Aircraft type	*Area per aircraft (square yards)*
C-130	4,280
C-5A	12,450
C-17	11,250

CALIBRATION HARDSTAND

2-92. 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 periodically perform this calibration reduces the ability of the aircraft to complete its assigned mission.

2-93. A calibration facility normally consists of a calibration hardstand and a firing-in butt. The facility provides a suitable means for aligning an aircraft and offers the precise calibration of aircraft navigation, bombing, and gunnery equipment. A calibration facility normally consists of a calibration hardstand (formerly called a compass wiring base) and a firing-in butt.

2-94. The hardstand is a level, surfaced area marked with precision alignment indications accurate to within 0.25 of 1^0. Because of the calibration operation involved, locate the paved hardstand in an area with minimum local magnetic influence.

CORROSION CONTROL HARDSTAND

2-95. Aircraft must always be kept clean. Dirt, grime, oil, and grease on aircraft increases airflow drag, promotes corrosion, changes balance, slows the dissipation of heat from engines, and prevents effective aircraft inspection for airframe and mechanical failures.

2-96. 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

2-97. Aircraft revetments may be needed for protection against small arms fire, mortars, strafing attacks, and near misses with conventional bombs and to prevent sympathetic detonation of explosives on nearby aircraft. Any open revetments or soft shelters may be used.

AIRCRAFT MAINTENANCE FACILITIES

2-98. 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 guidelines below may be used.

Airfield Initial Construction

2-99. 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 conditions. 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 sustaining area maintenance facilities if possible.

Airfield Temporary Construction

2-100. An air base provided with temporary facilities usually has a maintenance site that has facilities for proper and efficient aircraft maintenance and repair. Keep the area free of 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 tents, prefabricated, or portable structures; fixed frame structures; or converted existing structures. The choice of facilities depends on the locale, tactical situation, weather conditions, duration of operational usage, and related factors.

2-101. In a fluid tactical situation or under temporary static conditions, tentage or converted existing structures are normally used. Fixed structures are used under more stable conditions. For information on portable frame and structures, see TM 3-34.48-1 and TM 5-302 series. An important factor in the relative locations of maintenance facilities, particularly hangars, is the functioning of the control tower.

SPECIAL CONSIDERATION

2-102. As previously stated, special airfields include DZs, EZs, and special operations forces (SOF) airfields; blacked-out airfields; and Unmanned Aircraft System airfields. Example considerations for these airfields are listed below.

DROP ZONES

2-103. DZs are used for delivering supplies by various methods of low-level parachute drops. The DZ should be as level as possible and clear of objects that could damage materials and personnel being dropped. The following paragraphs prescribe the normal minimum DZ sizes; however, other than for Air Force unilateral airdrops, the ground commander may waiver these minimums on a by-exception basis. Specific DZ operation details are contained in AFI 13-217.

Tactical Airlift Drop Zone

2-104. 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. The DZ size should be determined by delivery modes, load dispersal statistics, receiving unit discussions, and professional judgments.

2-105. Air item recoverability and load survivability or recoverability 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 2-8, page 2-32, shows the minimum DZ sizes.

High-Altitude Airdrop Resupply System

2-106. Table 2-9, page 2-33, shows the minimum DZ sizes for the High-Altitude Airdrop Resupply System and the High-Velocity Container Delivery System.

Special Operations Airdrops

2-107. During special operations airdrops, the minimum DZ sizes shown in table 2-10, page 2-34, normally apply unless they are precluded by mission requirements.

Area Drop Zones

2-108. An area DZ consists of a start point (point A), an end point (point B), and a prearranged flight path (line of flight) over a series of acceptable drop sites between these points (see figure 2-15, page 2-28). The distance between point A and point B should not exceed 15 nautical miles, and changes in ground elevation along the line of flight should not exceed 300 feet. Drop sites along the line of flight should not be located more than 1/2 nautical miles 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 when 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 that they are displayed or turned on 2 minutes before the aircraft is scheduled to arrive over that segment of the DZ.

Table 2-8. Tactical airlift DZ size criteria

Altitude (AGL)	*Width (see note 1)*	*Number of containers*		*Length (See note 2)*
		Single	*Double*	
Container delivery system C-130				
To 600 feet	400 yards	1	1-2	400 yards
		2	3-4	450 yards
		3	5-6	500 yards
		4	7-8	550 yards
		5-8	9 or more	700 yards
Above 600 feet	Add 40 yards/35 meters to DZ width and length for each 100 feet above 600 feet (20 yards/18 meters 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 feet	600 yards	1,000 yards	Add 400 yards (C-130) or 500 yards (C-5) to trailing edge for each additional platform.	
Above 1,100 feet	Add 30 yards to width and length for each 100 feet above 1,100 feet (add 15 yards 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 feet	600 yards	600 yards	Add 75 yards for each additional parachutist to trailing edge (100 yards when using CAPES).	
Above 1,000 feet	Add 30 yards to width and length for each 100 feet above 1,000 feet (add 15 yards to each side of the DZ).			

Notes.

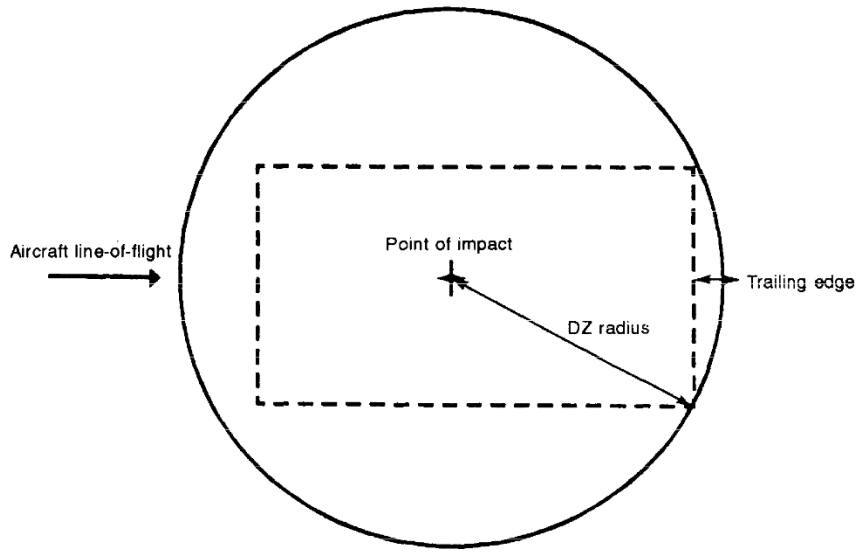
1. For day visual formations, increase width by 100 yards (50 yards each side). For SKE formation, increase width by 400 yards (200 yards each side). Official sunset to sunrise, increase width by 100 yards for single-ship visual drops (50 yards each side) or 200 yards for visual formations (100 yards each side).
2. Official sunset to sunrise, increase length by 100 yards for visual drops (50 yards each end).
3. For CCT/pararescue unilateral operations. Controlled exit (CAPES) and alternating door (ADEPT) procedures do not apply to CCT/pararescue operations.

Legend:

ADEPT	adaptive diagnostic electronic portable test-set
AGL	above gravel level
CAPES	controlled alternate parachute exit system
CCT	combat control team
DZ	drop zone
SKE	station keeping equipment

Circular Drop Zones

2-109. 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 2-16). The entire DZ box must fit inside the circle. The POI of a circular DZ is normally at the DZ center.



Legend:
DZ drop zone

Figure 2-16. Circular DZ dimensions

Table 2-9. Size criteria for delayed opening (High-Altitude Airdrop Resupply System and High-Velocity Container Delivery System) DZ

HAARS CONTAINER DELIVERY SYSTEM			
Altitude (feet AGL)	***Width***	***Length (yards)***	
		1-8 containers	***9 or more containers***
Up to 3,000	500 yards	1,200 yards	1,900 yards
Above 3,000	Add 25 yards to each side and 50 yards to each end for every 1,000-foot increase in drop altitude.		
HIGH VELOCITY CONTAINER DELIVERY SYSTEM *			
Altitude (feet AGL)	***Width***	***Length (yards)***	
		1 or 2 containers single or double	***Additional containers***
Up to 3,000	580 yards	660 yards	Add 50 yards to trailing edge for each additional container.
Above 3,000	Add 25 yards to each side and 100 yards to each end for every 1,000-foot increase in drop altitude.		
* Using 12-, 22-, or 26-foot ring slot parachutes.			
Legend: AGL aboveground level HAARS High-Altitude Airdrop Resupply System			

Drop-Zone Markings

2-110. DZs are normally marked with a raised angle marker or VS-17 marker panels, omnidirectional visible lighting systems, and if required, rotating light beacons. Virtually any overt lighting or visual marking system is acceptable if participating units are briefed and concur in its use. Other day markings or visual acquisition devices include colored smoke, mirrors, railroad fusses, or reflective or contrasting marker panels (space blankets). In some cases, geographical points may be used. Night markings or acquisition aids may include a B-2 light gun, flares, fire or fire pots, railroad fusses, flashlights, or chemical lights. Combat control

units may use specialized clandestine infrared lighting systems. Electronic markings may be used for day or night operations.

Table 2-10. Size criteria for special operations DZs

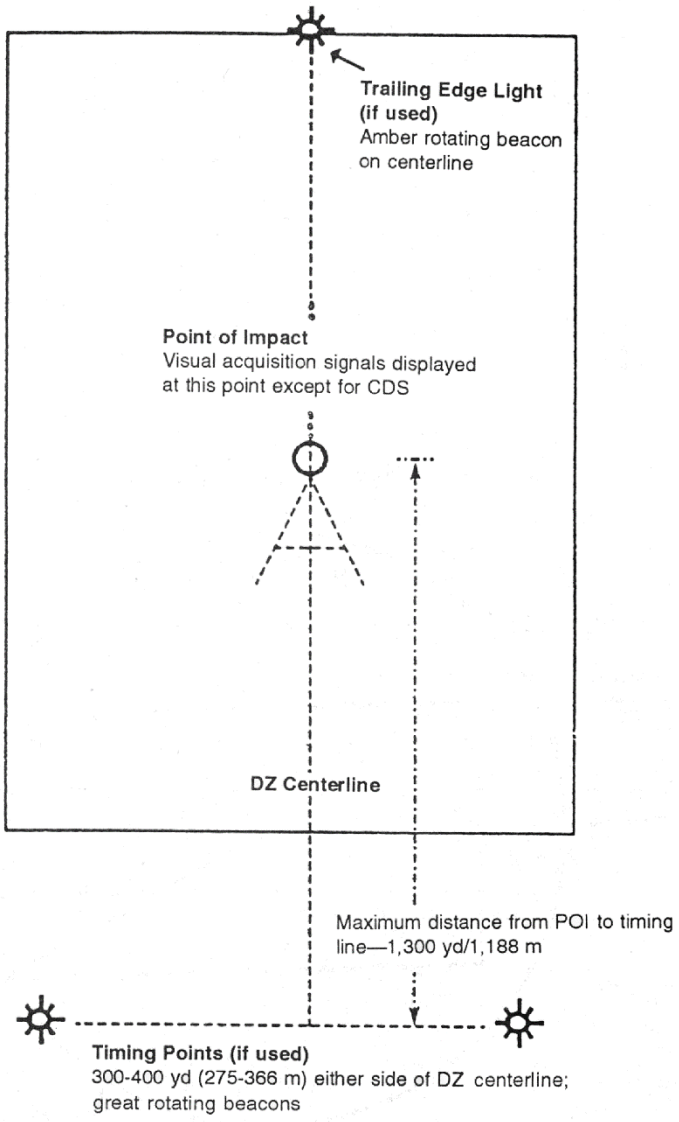
Type drop	*MC-130 (WxL)*	*AWADS (WxL)*	*C-130 (WxL)*
Marked drop zones			
Personnel (CARP) (GMRS)	300 x 300 yards 300 x 300 yards	600 x 600 yards 300 x 300 yards	600 x 600 yards 300 x 300 yards
Add 75 yd (69 m) to the length for each additional parachutist.			
CDS/CRS (CARP & GMRS)	400 x 400 yards	400 x 400 yards	400 x 400 yards
For all, add 50 yards (45 meters) to the DZ length for each additional.			
HSLLADS (CARP and GMRS)	300 x 600 yards	Not applicable	Not applicable
Recovery kit (CARP and GMRS)	200 x 200 yards	400 x 400 yards	400 x 400 yards
Heavy equipment (CARP and GMRS)	600 x 1,000 yards	600 x 1,000 yards	600 x 1,000 yards
For all, add 400 yards (366 meters) to DZ length for each additional platform.			
Blind drop zones (Natural radar targets only or radar beacon/zone marker on the DZ.)			
Personnel	600 x 600 yards	600 x 600 yards	600 x 600 yards
Add 75 yd (69 m) to the length for each additional parachutist.			
CDS/CRS	400 x 400 yards	400 x 400 yards	400 x 400 yards
Type drop	***MC-130*** (WxL)	***AWADS*** (WxL)	***C-130*** (WxL)
Add 50 yards (45 meters) to the DZ length for each additional container.			
HSLLADS	400 x 600 yards	Not applicable	Not applicable
Recovery kit	400 x 400 yards	400 x 400 yards	400 x 400 yards
Heavy equipment	600 x 1,000 yards	600 x 1,000 yards	600 x 1,000 yards
For all, add 400 yards to DZ length for each additional platform.			
Note. For all blind drops, add 30 yards to each side and 30 yards to each end of the DZ for each 100-foot increase in altitude above the minimum drop altitude for the load being dropped.			
Legend: AWADS Adverse Weather Aerial Delivery System CARP computed air release point CDS container delivery system CRS Central Radar System DZ drop zone GMRS Ground Mark Release System HSLLADS High-Speed, Low-Level Airdrop System SKE station keeping equipment SOCOM Special Operations Command WxL width times length			

Tactical Airlift Drop-Zone Markings

2-111. Darkness, fog, haze, rain, brush, trees, and terrain affect DZ visibility on the ground and impact on assembly. Assembly during darkness is complicated by poor visibility and difficulty in identifying or recognizing avenues of approach, control posts, personnel, and equipment. The darkness contributes to confusion, to stragglers, and to the loss of equipment. An assembly during darkness takes longer and requires more elaborate assembly aids and larger control posts than a daylight assembly.

Timing Points

2-112. Timing points are not usually 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) before the POI and 300 yards to 400 yards on either side of the centerline (see figure 2-17).



Legend:

CDS	container delivery system
DZ	drop zone
m	meter
yd	yard

Figure 2-17. DZ markings

Point of Impact

2-113. See table 2-11 for a normal POI location. When mission requirements dictate, the random POI placement option may be used. In this option, the mission commander will notify the DZ control unit that

random POI placement is to be used at least 24 hours in advance. When the DZ is set up, the DZ control randomly selects a point on the DZ and establishes that point as the POI for the drop. The DZ control ensures that DZ minimum 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 may also request that 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 ensures that the minimum DZ size requirements remain on the surveyed DZ or accepts responsibility for the drop if they do not. These procedures are used only during visual flight rules (VFR). Aircrew schedulers ensure that requests for these operations are consolidated to prevent more than two POI location changes on one DZ during a mission or operation.

Table 2-11. DZ POI placement minimums

Drop type	*Aircraft type*	*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
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	Not applicable	Not applicable	Not applicable	Not applicable
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. The POI location may be adjusted for special operations or to meet specific mission requirements. All participants will be briefed.
3. The 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.

Legend:

AWADS	Adverse Weather Aerial Delivery System
CDS	container delivery system
DZ	drop zone
INS	Inertial Navigation System
POI	point of impact
SKE	station keeping equipment
ZM	zone marker

2-114. Unless otherwise coordinated with the aircrew, the POI is normally marked with a raised angle marker (day operations) or a block letter (night operations), as described below

- **Raised angle marker.** The raised angle marker 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.** Block letters are at least 35 feet by 35 feet. They consist of at least nine white/infrared, 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 DZs. If used for day operations, the letter will consist of at least nine marker panels.

2-115. If used, smoke is displayed next to and downwind of the POI for other than container delivery system drops. For a container delivery system, visual acquisition signals are normally displayed on the DZ centerline, 200 yards short of the intended POI.

2-116. On a small container delivery system (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 DZ control must ensure that participating aircrews have been thoroughly briefed on the change in location.

Trailing Edge

2-117. 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 airdrop type being done) on the DZ centerline.

No-Drop Signals

2-118. 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

2-119. 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

2-120. 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.

- **Marked special operations DZ.** This is an authenticated DZ, which has the POI or release point marked with a precoordinated signal. This marking may be either overt (block letter, flares, smoke, mirror, or a raised angle marker) or covert (infrared 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. MC130 aircraft can use a single I-band beacon or other radar beacon type. Tactical air navigation is not normally placed on a DZ as an airdrop aid.

EXTRACTION ZONES

2-121. 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 2-18, page 2-38, shows a typical LAPES deployment from a C-130 aircraft.

2-122. 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.

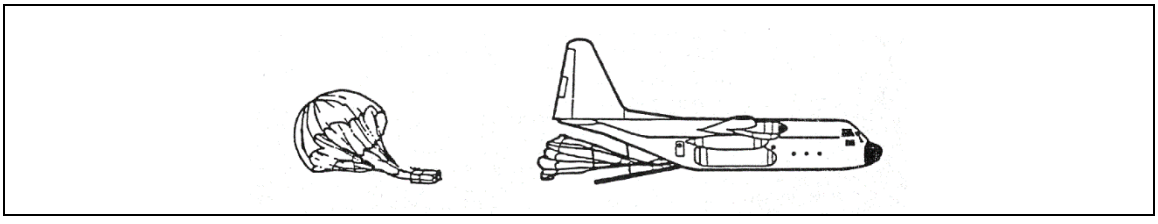


Figure 2-18. LAPES

General Extraction Zone Criteria

2-123. 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. EZ criteria are shown in figure 2-19.

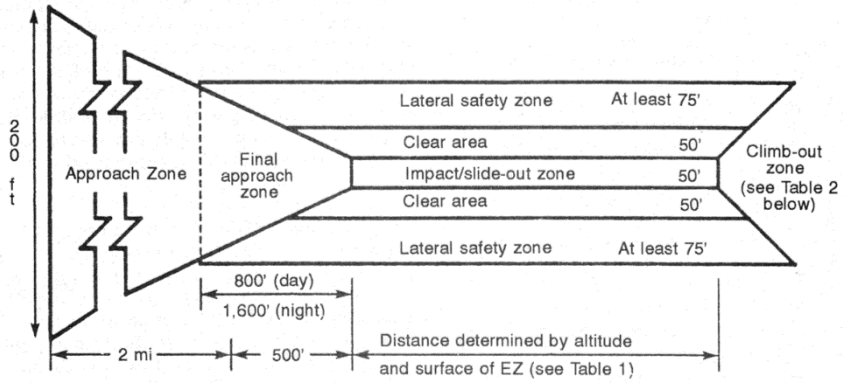


Table 1. Impact/slide-out Zone length

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'

Legend:

EZ	extraction zone	mi	mile
ft	feet	PSP	prefabricated steel plank

Figure 2-19. EZ criteria

Approach Zones

2-124. 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.

2-125. 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.

2-126. 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).

2-127. 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, snow, or short, light brush.
- 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.

2-128. 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 Low-Altitude Parachute Extraction System

2-129. Extraction lanes are designated in numerical sequence from left to right. The left lane in the direction of flight 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 2-20, page 2-40. 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. See figure 2-18, page 2-38, for multiple LAPES zones. Minimum aircraft spacing is 10 seconds.

Extraction Zone Marking Equipment

2-130. EZs are normally marked with VS-17 marker panels, omnidirectional visible lighting systems, and if required, strobe lights. Virtually any overt lighting type or marking system is acceptable if participating units are briefed.

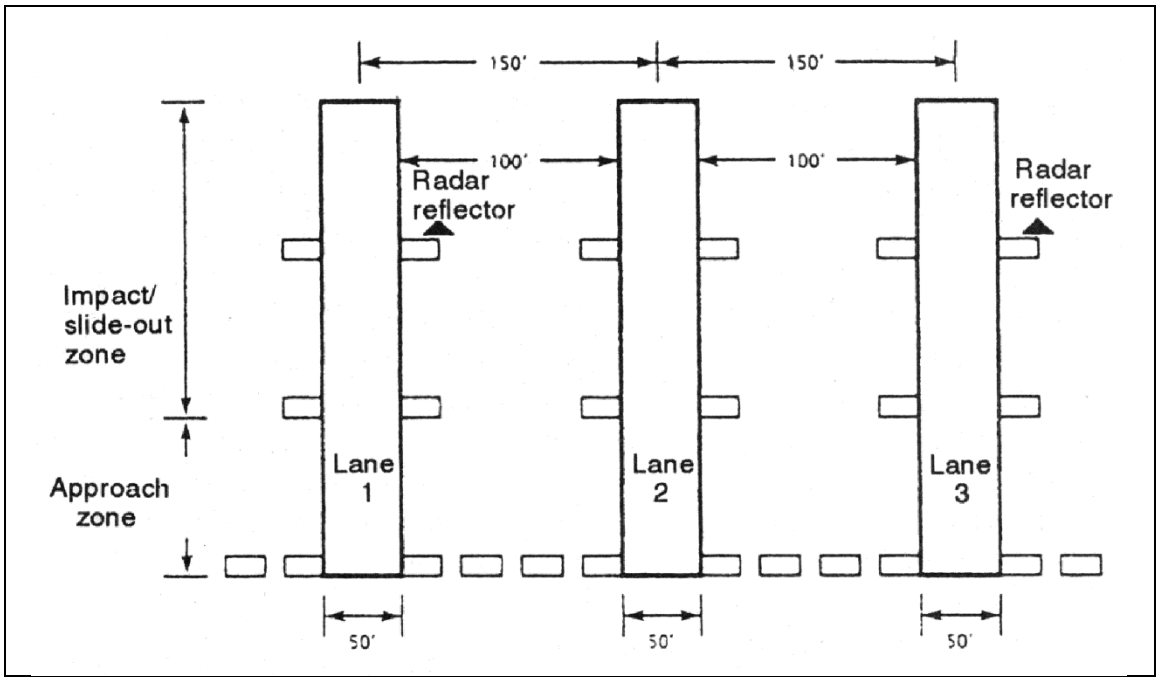
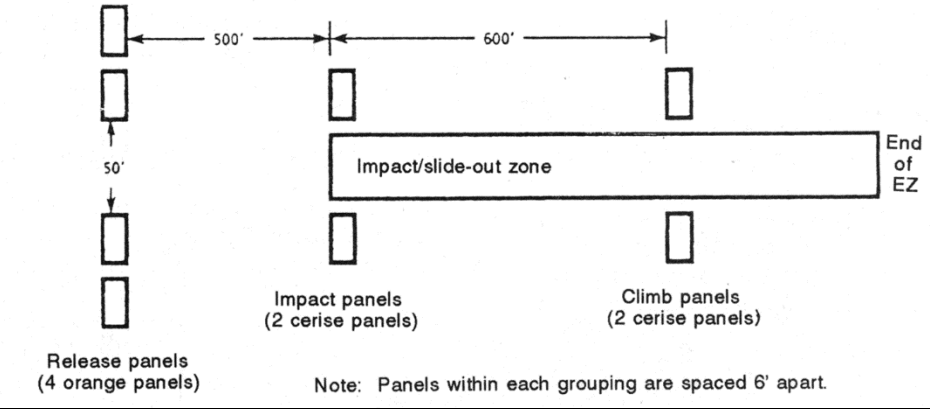


Figure 2-20. Multiple LAPES zones configuration and marking

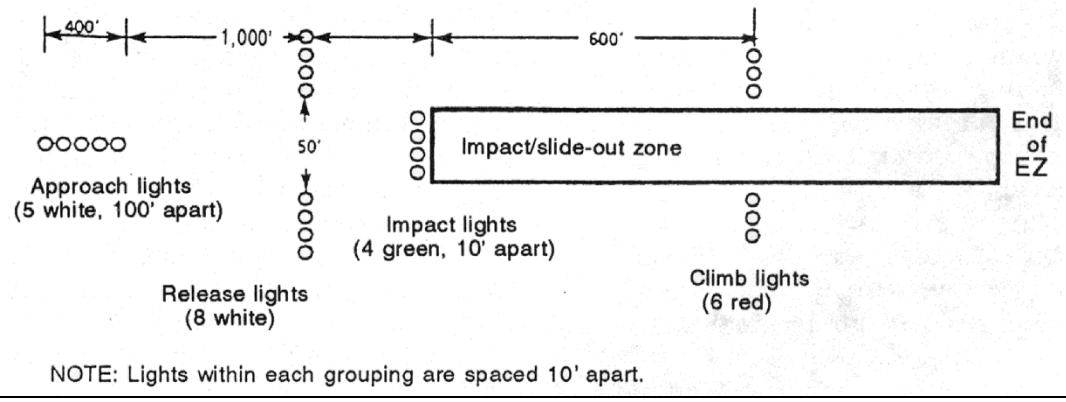
Extraction Zone Markings and Identification

2-131. This information will be a special subject at the final briefing to ensure that required ground and aircrew members thoroughly understand the EZ recognition and identification procedures. EZ markings for day operations will be according to figure 2-21. EZ markings for night operations will be according to figure 2-22.



Legend:
EZ extraction zone

Figure 2-21. Day EZ markings



Legend:
EZ extraction zone

Figure 2-22. Night EZ markings

Control Point

2-132. The control point for the EZ will be established at the direction of the EZ control. The EZ control 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 should be in full view of the EZ control. It should, whenever possible, be upwind of the extraction area so that the dust and debris that rise from the EZ will not obscure the vision of the EZ control.

Marking Considerations

2-133. 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 approach of the aircraft. 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° angle from the surface toward the aircraft approach to increase the ability of the pilot to see them.

SPECIAL OPERATIONS FORCES

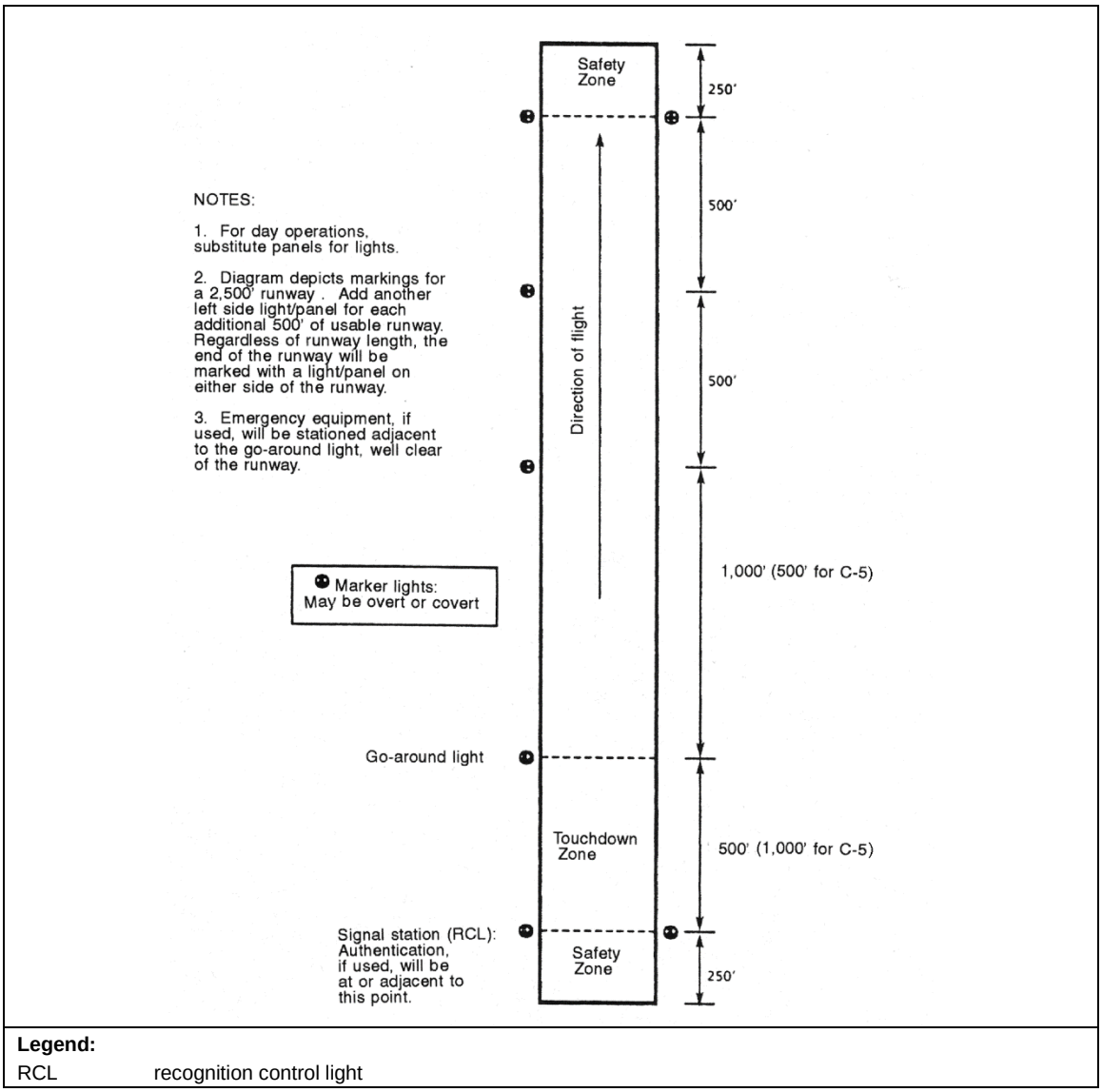
2-134. Minimum airfield criteria for SOF are noted in table 2-12, page 2-42. Runway marking patterns for SOF airfields are shown in figure 2-23, page 2-42, and figure 2-24, page 2-43.

Table 2-12. Minimum airfield criteria (SOF)

Landing zone type	*Length[1] (feet)*	*Width[1] (feet)*		
		Qualified crews	*Unqualified crews*	*180° turn (on runway)*
C-130 SOLL I	3,000[2]	60	60	60
C-130 SOLL II	4,000	60	75	75
Blacked out (MC-130)	4,000	60	75	75

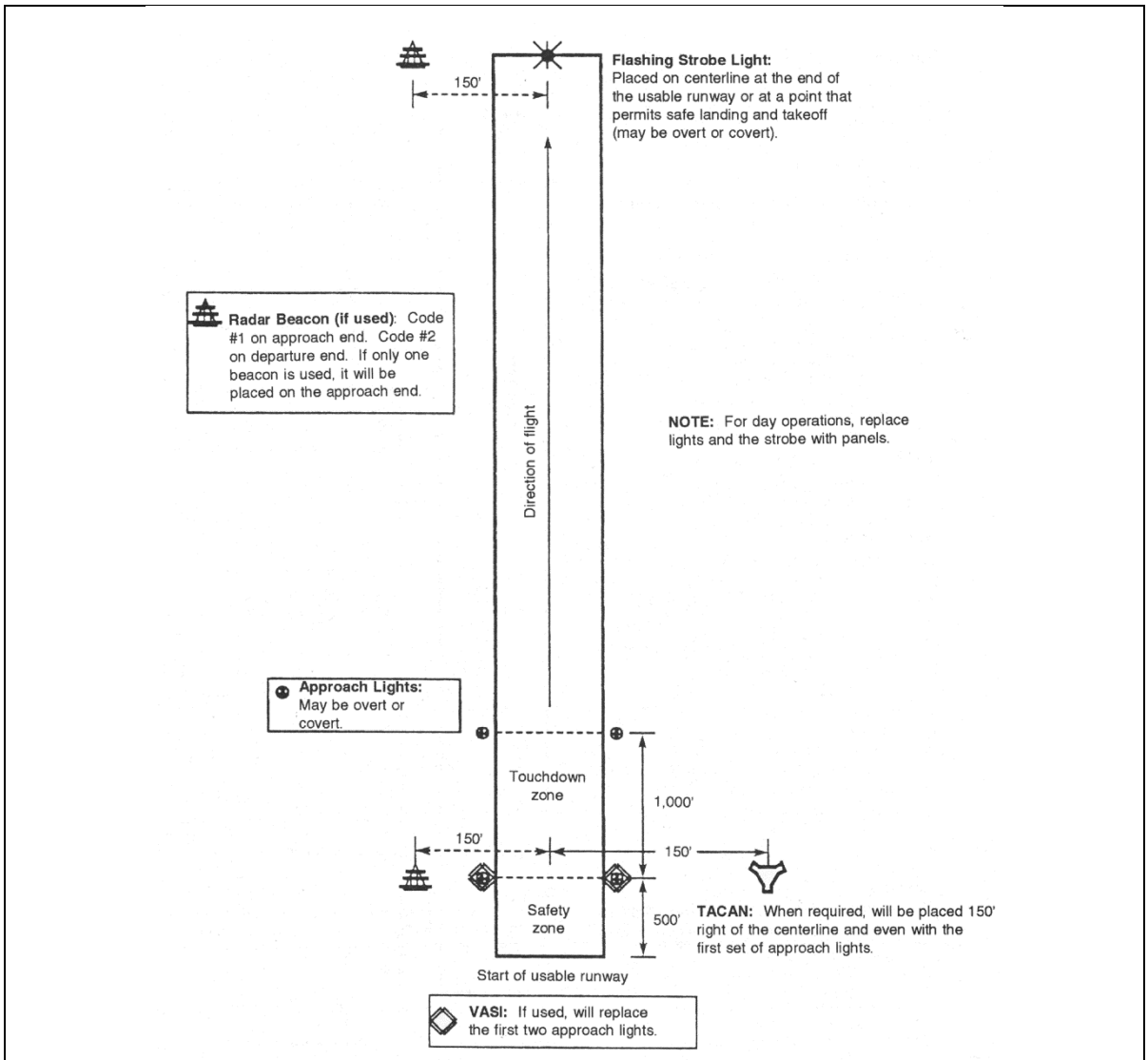
Notes.
1. Minimum operational criteria without a waiver during peacetime operations.
2. The length used for routine training is 3,500 feet.

Legend:
MC multimission transport
SOF special operations forces
SOLL special operations low-level



Legend:
RCL recognition control light

Figure 2-23. Runway marking pattern (SOF airfields)



Legend:

TACAN	tactical air navigation
VASI	visual approach slope indicator

Figure 2-24. Runway marking pattern (SOF airfields)

AIRFIELD BLACKED-OUT OPERATIONS

2-135. Airfields operating under blacked-out conditions are normally used by SOFs or special-mission aircraft where aircrews use NVG. For MC-130 aircraft used by SOF, the minimum airfield criteria are noted in table 2-12, page 2-42. Airfield marking patterns use no visual markings and are detailed in AFI 13-217 and ETL 09-6. For additional information on airfields where NVG are used, see FM 3-04.203.

LANDING ZONE BLACKED-OUT OPERATIONS

2-136. Consider the effects of ambient lighting for operations with NVG. Lighting that is planned to be permanent should be compatible with NVG. UFC 3-535-01 should be consulted for design details of light fixtures, light bases, cable, cable connections, controls, and other features associated with an airfield lighting system. See AFI 13-217 for C-130 NVG length and width requirements.

LOGISTICAL DATA ON PETROLEUM, OILS, AND LUBRICANTS FACILITIES

2-137. 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, and antitransient aircraft to be supported. The daily consumption of aviation fuels is a function of these factors, and these 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.

2-138. The per-person/per-day method of estimating ground fuel and lubricant requirements described in ATP 3-37.10 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.

Storage Facilities

2-139. Aviation and ground fuels are normally stored in drums; collapsible containers; or welded or bolted, aboveground 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. The following are recommended storage options for different construction types:

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

Construction Standards

2-140. 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 (see table 1-1, page 1-11). Temporary construction is authorized under combinations C, D, E, and F (see table 1-1).

Ground Fuels and Lubricants

2-141. 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 (see table 1-1). Temporary construction is authorized under combinations D, E, and F (see table 1-1).

Other Criteria

2-142. Information on fuel dispensing and distributing systems, TO pipeline systems, and tank-farm installations is given in TM 5-302-2. Petroleum handling operations are discussed in ATP 4-43.

LOGISTICAL DATA ON AMMUNITION STORAGE

2-143. Detailed computations of ammunition requirements and the consequent storage requirements depend on the mission, type, and number of airplanes, number of sorties, takeoff load, and estimated ammunition expenditure rate. Calculate the requirements using information furnished by the theater commander.

2-144. Temporary construction uses covered revetments, and initial construction uses unrevetted stacks. The layout of an explosive storage area is according to DOD 6055.09-M.

LOGISTICAL DATA ON STRUCTURES

2-145. Detailed information about space requirements and criteria for maintenance, supply, and administrative facilities is contained in publication. The AFCS allows the military planner and logistician to determine the Class IV materials required for engineer support of Army requirements.

VEHICLE PARKING AREA

2-146. Provide all-weather vehicle parks for squadron bomb trucks and fuel units, flight-control vehicles, engineer firefighting equipment, service-team vehicles, squadrons, and group headquarter motor transports. Except for fuel unit and bomb truck areas, locate vehicle parks away from the taxiway system.

ACCESS AND SERVICE ROADS

2-147. At least one access road connecting the airfield site with the existing road net or 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

2-148. Provide tentage for initial construction. As construction progresses, portable, prefabricated 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 according to the base dispersal policy.

2-149. 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

2-150. Conduct air-base damage repair operations, including emergency or rapid runway repair, as outlined in TM 3-34.48-1. Further detailed information can be found in AFI 10-210, AFI 20-211, DODD 4270.5, and TC 5-340.

UNMANNED AIRCRAFT SYSTEMS DESIGN

2-151. ETL 1110-3-510 provides guidance and criteria for planning and designing airfields that support operations of DOD. These aircraft are shown in table 2-13, page 2-46.

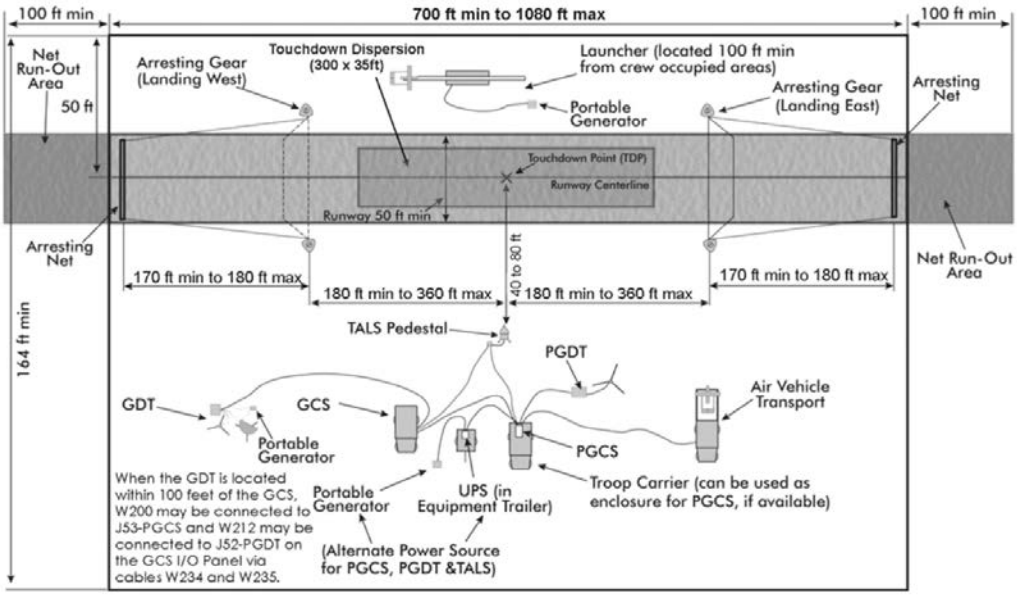
Table 2-13. Aircraft by Service

Service	*Aircraft*
Air Force	RQ-4 Global Hawk
	MQ-9A Reaper
	RQ-1B/MQ-1B Predator
Army	RQ-7B Shadow 200
	MQ-1C Gray Eagle MQ-5B Hunter
Navy/Marine Corps	MQ-8B Fire Scout
	RQ-4 Global Hawk

2-152. All of the aircraft require paved runways, taxiways, and aprons except the RQ-7B Shadow 200 and the MQ-8B Fire Scout. Characteristics of these aircraft are shown in table 2-1, page 2-2, and table 2-2, page 2-3.

2-153. Procedures and requirements for site investigation; base, subbase, and subgrade; frost design; and stabilization should follow those outlined in UFC 3-260-02. It is expected that the Global Hawk, Reaper, Predator, and Gray Eagle will only operate on surfaced pavements. Design curves for flexible and rigid pavements for the Global Hawk are shown in ETL 1110-3-510. Designs for the Reaper, Predator, and extended range multipurpose aircraft should follow the minimum thickness requirements for both rigid and flexible pavements as outlined in UFC 3-260-02. The Pavement-Transportation Computer Assisted Structural Engineering (PCASE) software program is recommended for detail pavement structural design, but manual designs are as follows:

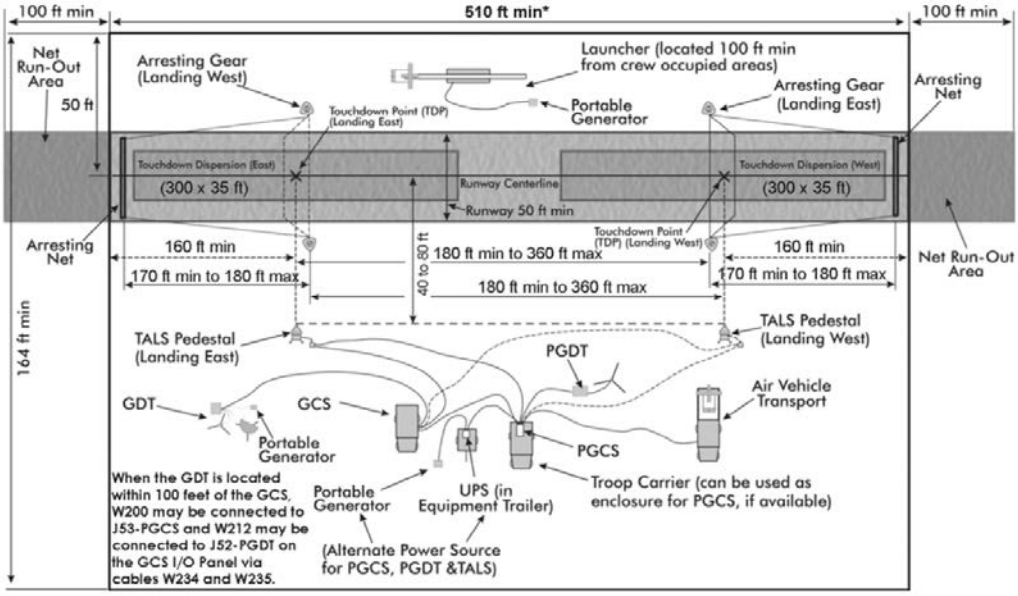
- **Shadow 200.** The launch and recovery site requires a clear, flat area, large enough for the required landing touchdown dispersion and runway length and width. The overall site must be at least 1,000 feet which includes net run out on each end in length and 164 feet in width. The site should be aligned with the prevailing wind direction. Maximum permitted tail wind during landing is 5 knots. The overall site length includes at least 100 feet of rollout space beyond the barrier net. The rollout space shall be provided to permit air vehicle net arrestment without any obstacles or ruts larger than 2 inches in size. The minimum overall site length may be reduced to 650 feet if the grade (slope) along the runway centerline is near zero. The runway direction slope may not exceed ± 1.7 percent grade within the entire runway and rollout space. The slope perpendicular to the runway direction must also fall within the ± 1.7 percent grade. Typical layouts for the long field and short field are shown in figures 2-23, page 2-42, and figure 2-24, page 2-44. In addition to runway dimension and grade restrictions, obstacle/terrain clearances must also be observed. Figures 2-25 through 2-27, pages 2-47 through 2-48, describe the required clearances. All obstacle and terrain height restrictions are measured relative to the touchdown point elevation (see figure 2-28, page 2-49).
- **Fire Scout.** The Fire Scout is designed to be launched from a ship or from land. The Fire Scout can utilize any cleared area to launch and recover. The limited-use helipad (50 feet by 50 feet) described in UFC 3-260-01 is acceptable for this aircraft. Line of site in any launch and recovery area to the ultrahigh frequency/very high frequency antennas connected to the ground control station is mandatory. Performance and clearance requirements are being developed.
- **Taxiways and aprons.** The widths and turning radius of taxiways should conform to the Class B requirements for the Global Hawk and the Class A requirements for the Reaper, Predator, and Grey Eagle. Parking areas for the RQ-4 Global Hawk should be designed with dimensions shown in ETL 1110-3-510.



Legend:

ft	feet	PGCS	portable ground control station
GCS	ground control station	PGDT	portable ground data terminal
GDT	ground data terminal	TALS	Tactical Automated Landing System
I/O	input/output	UPS	universal power supply
max	maximum		
min	minimum		

Figure 2-25. Shadow 200 launch and recovery site (long field)

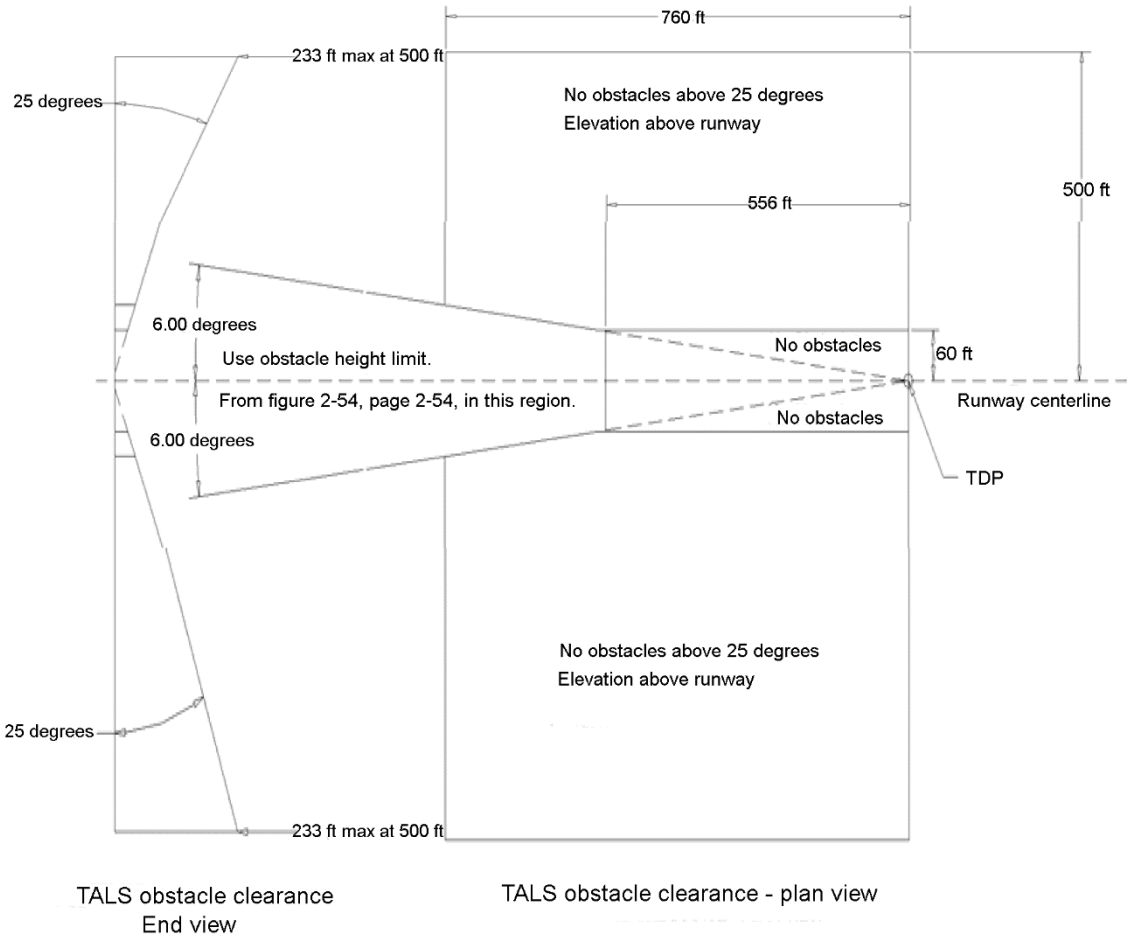


Legend:

ft	feet	Min	minimum
GCS	ground control station	PGCS	portable ground control station
GDT	ground data terminal	PGDT	portable ground data terminal
I/O	input/output	TALS	Tactical Automated Landing System
max	maximum	UPS	universal power supply

Figure 2-26. Shadow 200 launch and recovery site

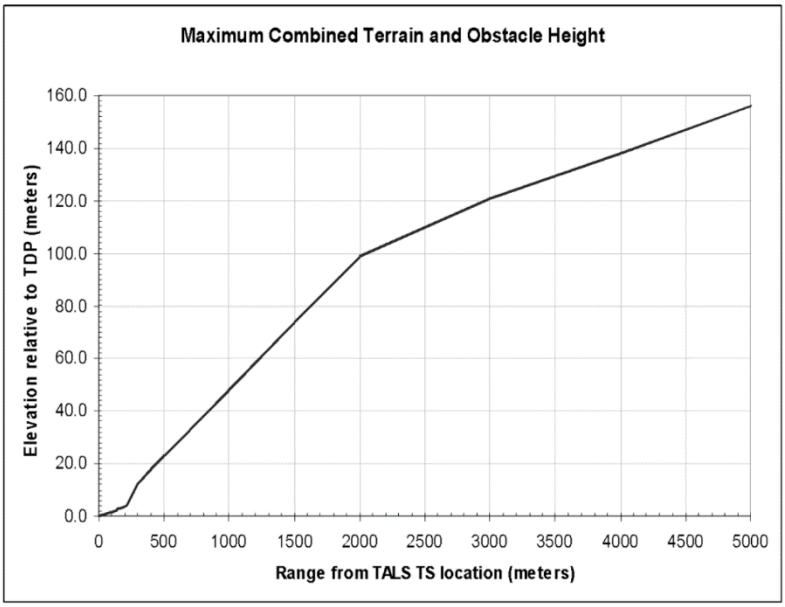
Note. The approach-direction distance from runway edge to touchdown point may be reduced from 160 feet to 100 feet if the approach terrain is of an appropriate grade. This will reduce the overall length from 710 feet to 650 feet and the runway length from 510 feet to 450 feet. There is no limitation on the maximum approach-direction distance from runway edge to touchdown point.



Legend:	
ft	feet
m	meter
TALS	Tactical Automated Landing System

Figure 2-27. Shadow 200 lateral obstacle clearances

Range from TS (feet)	Range from TS (meters)	Maximum Combined Terrain and Obstacle Height (meters)
0	0	0.0
100	30	0.5
200	61	1.1
300	91	1.6
400	122	2.1
500	152	2.7
600	183	3.2
700	213	3.7
800	244	6.7
984	300	12
	400	18
	500	23
	600	28
	700	33
	800	38
	900	43
	1000	48
	1500	74
	2000	99
	3000	121
	4000	138
	5000	156



Legend:

TALS Tactical Automated Landing System

TDP touchdown point

TS tracking subsystem

Figure 2-28. Shadow approach obstacle clearances

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Chapter 3

Airfield Marking and Navigation

The information below provides layout and dimensional criteria for airfield pavement markings under military control. Consult ETL 04-2 and UFC 3-260-5A for additional information and specifications as applicable.

AIDS TO NAVIGATION

3-1. Aids to navigation are visual and nonvisual. Nonvisual (radio) aids are required to guide and control flying activities (particularly with IFR) when weather or other conditions require instrument flying. Visual aids are necessary with VFR when flight operations are conducted at night or under reduced visibility conditions. For additional detailed discussion of aids to navigation, see UFC 3-535-01. The primary aids to navigation are airfield markings, airfield lighting equipment, airfield signs, and radio (electronic) aids. Control towers are categorized with electronic NAVAIDs.

3-2. Airfield marking and lighting aids to air navigation are considered airfield elements. They are related to construction stages as follows:

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

3-3. Electronic NAVAID facilities are related to construction types as follows:

- The initial construction of electronic NAVAID facilities is authorized under combinations A and B (see table 1-1, page 1-11).
- The temporary construction of electronic NAVAID facilities is authorized under combinations C, D, E, and F (see table 1-1).

AIRFIELD MARKING

Note. This section implements STANAG 3158 and STANAG 3534.

3-4. The airfield marking system is a visual aid in landing aircraft. It requires illumination from an aircraft lighting system or from daylight. The Army and Air Force have adopted airfield marking standards. Determination of an airfield marking system is a TOs responsibility and is a prerogative of the theater commander. The following methods and configurations are those most commonly applicable to TO use. For a more detailed discussion of airfield marking, see UFC 3-260-05A, TM 5-302 series, AFCS facility drawings, and AFI 32-1044.

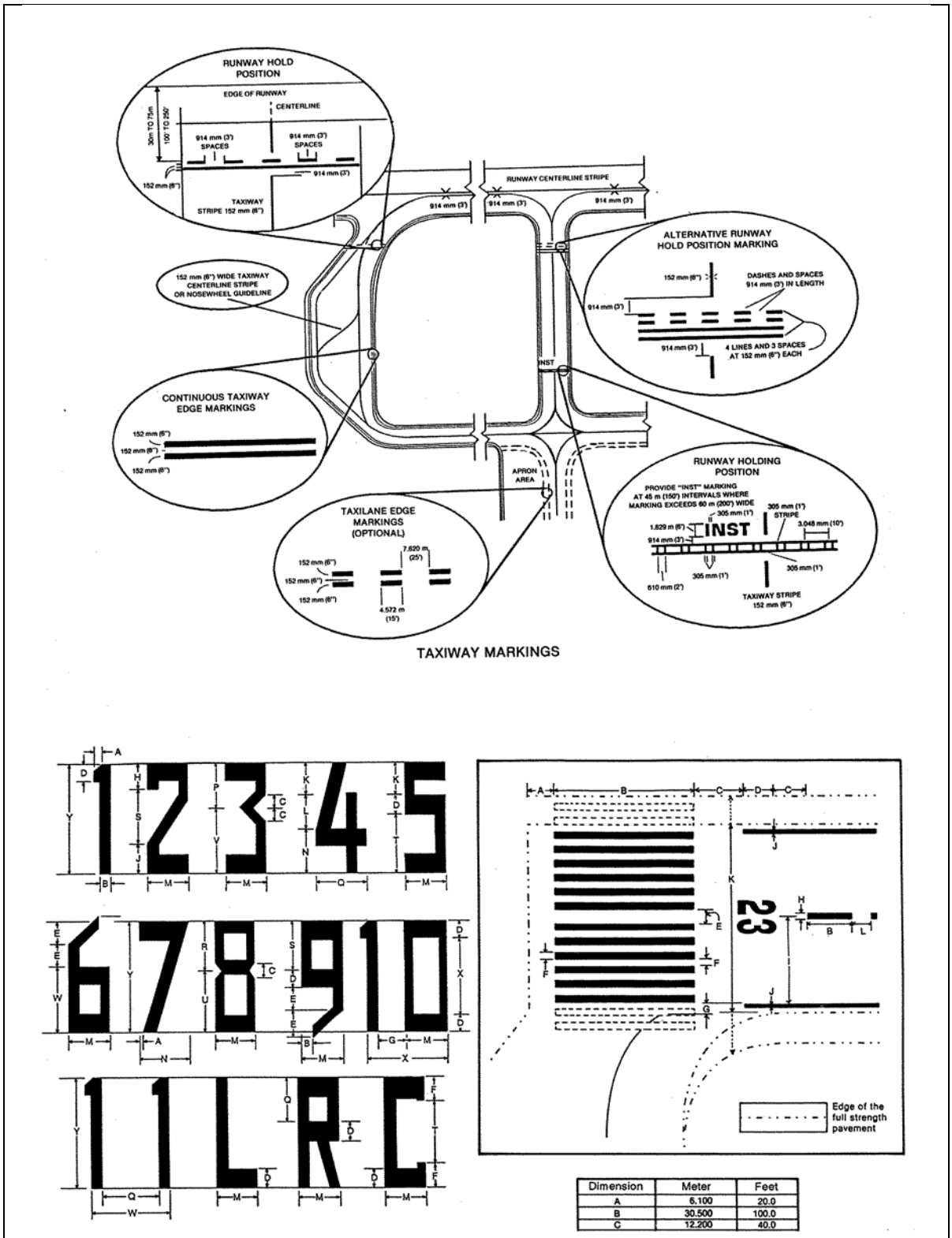
Airfield Runway Markings

3-5. The following markings apply to common runways. See figure 3-1, page 3-3, for proper use of the markings.

- **Centerline markings.** A 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 runways (basic, precision, and nonprecision instrument). They are not required on minimum operating strips or short-field assault strips. The numbers designate the direction of the runway and accent the end limits of the landing and takeoff area. Figure 3-2, page 3-5, shows the dimensions and forms of

standard direction numbers. The number assigned to the runway is the whole number closest to one-tenth of the magnetic azimuth of the runway centerline, measured clockwise from magnetic north. A zero precedes single digits.

- **Threshold markings.** A threshold marking is required on precision and nonprecision instrument runways. Threshold markings for runways that are at least 150 feet wide are shown in figure 3-2, page 3-5. On runways less than 150 feet wide, threshold markings should start 10 feet from each edge of the runway. Other widths should be reduced in proportion to the reduction in the overall width of the threshold marking.
- **Touchdown-zone markings and edge stripes.** Touchdown-zone marking and edge stripe use in the TO should be kept to a minimum because of the time and effort required to obliterate them if necessary. They are required on runways served by a precision instrument approach.
- **Fixed-distance markings.** Fixed-distance markings are rectangular painted blocks that are 30 feet wide by 150 feet long beginning 1,000 feet from the threshold. They are placed equidistant from the centerline, 72 feet apart at the inner edges. They are required on runways that are 150 feet wide or wider, 4,000 feet long or longer, and used by jet aircraft.



Legend:
inst instrument

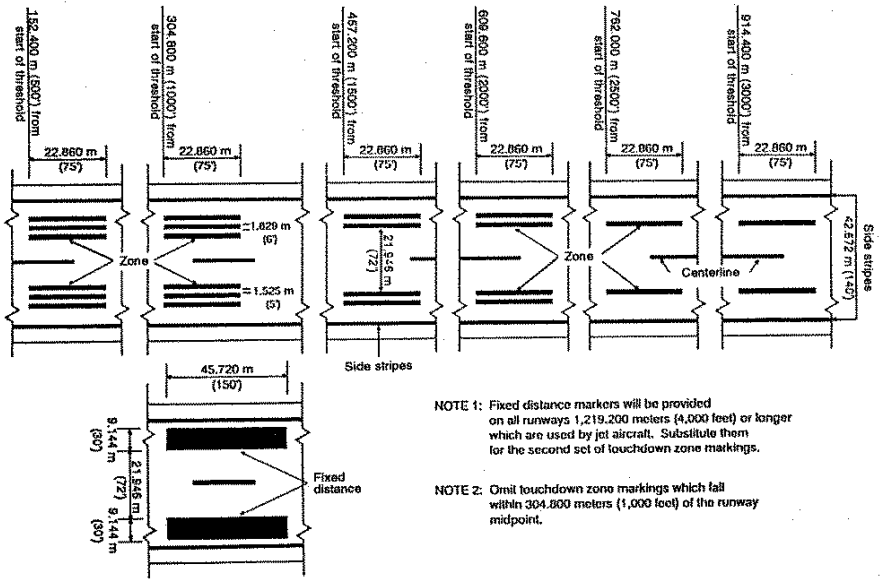
Figure 3-1. Markings for Army runway and LZ

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			

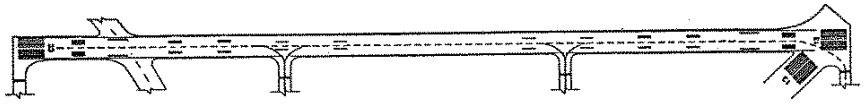
RUNWAY DESIGNATION NUMBERS AND LETTERS

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.

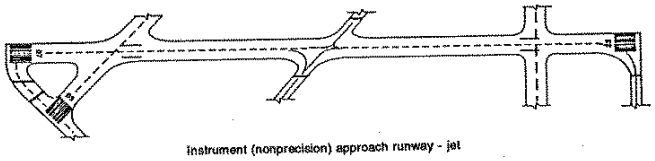
THRESHOLD , DESIGNATION NUMBER, EDGE STRIPE, AND CENTERLINE LAYOUT



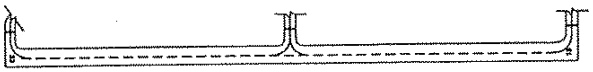
TOUCHDOWN ZONE AND FIXED DISTANCE MARKINGS



Precision approach runway - jet



Instrument (nonprecision) approach runway - jet



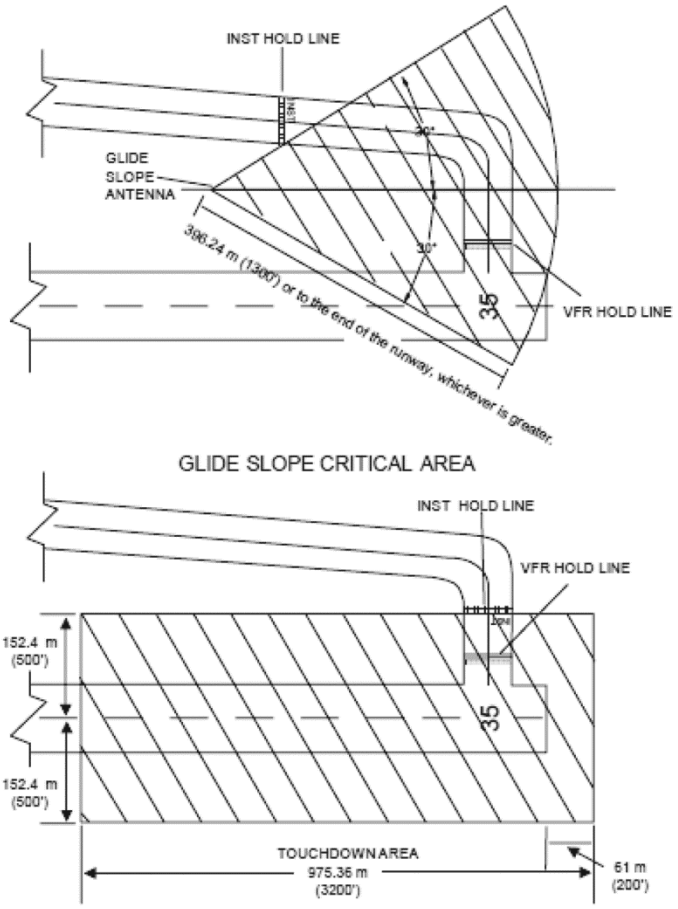
Basic runway - nonjet

RUNWAY MARKING SCHEMES

Legend:

m meters

Figure 3-1. Markings for Army runway and LZ (continued)



Legend:

m	meters	inst	instrument	VFR	visual flight rules

Figure 3-2. Locating instrument hold line positions

Airfield Taxiway Marking

3-6. Mark taxiways to conform to the following requirements as shown in figure 3-1, page 3-3:

- **Centerline stripes.** Each taxiway is marked with a single, continuous stripe along the centerline. The stripes should be at least 6 inches wide. 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 positions.** Holding positions are necessary on pavements that lead to an active runway or helipad. They designate a boundary to protect the runway or helipad environment from incursions and to prevent interference with signals transmitted by electronic NAVAIDs. There are two basic patterns for marking hold positions—one is used to mark hold positions used for VFR conditions, and the other is used to mark instrument hold positions. Figure 3-2 shows two ways to mark a VFR hold line and the layout for an instrument hold line. For VFR holding positions, the double-dashed and double-solid hold position marking is preferred and should be programmed for the next marking cycle if not already in use. It replaces the outdated North Atlantic Treaty Organization single-dashed and single-solid hold position markings. VFR and instrument holding positions are marked from edge to edge of the pavement surface, including paved shoulders.
- **VFR runway holding position.** The VFR runway holding position is located 100 feet to 250 feet from the near edge of the runway. The minimum setback from the runway edge is 100 feet. This distance is measured perpendicular to the long axis of the runway. Distances from the runway

centerline are calculated by dividing the published runway width by 2 and adding the required clearance distance. Where practicable, setback distances for the VFR runway holding position should be increased for instrument runways and where the wingspan of the controlling aircraft is greater than 79 feet. Suggested increased setback distances from the runway edge are—175 feet for controlling aircraft with wingspans from 79 feet up to 171 feet; and 205 feet for controlling aircraft with wingspans greater than 171 feet. Increase these distances by 1 foot for each 100 feet of airfield elevation above sea level. The hold position may be placed parallel to the runway centerline on taxiways that enter at an angle to the runway.

Note. Specific setback distances for VFR hold positions based on aircraft wingspan are relatively new. Therefore, hold positions at many existing airfields will not meet the above distances. Additionally, because many airfields were constructed under previous standards, strict application of these increased setback distances may not be possible or operationally practicable at every installation. The information provided above should not be viewed as a basis for an immediate or mandatory change in the location of VFR holding positions at any given base. Furthermore, if VFR holding positions are relocated, obliteration by painting over the old marking is not acceptable; they must be completely removed. Changes in VFR holding position locations should be implemented during a normal remarking cycle to minimize costs.

- **Instrument holding position.** Runways served by precision instrument navigation aids may require an instrument holding position be marked in addition to the VFR holding position. Where practicable, collocate these markings and mark only the VFR holding position. If required, locate the instrument holding position further from the active runway to prevent taxiing or holding aircraft from interfering with signals transmitted to inbound aircraft during IMC. This hold position is configured differently from a VFR hold position and is augmented with the letters INST on the runway side of the line. The letters are to be read when facing the runway. They are marked in block letters 6 feet high by 2 feet wide, spaced 1 foot apart. The letters are formed with a 6-inch stroke. The INST designator must be placed symmetrically between the taxiway centerline and the taxiway edge or edge marking on the left side of the centerline. For hold lines over 200 feet long, mark the INST designator at intervals not exceeding 150 feet. Locations for the instrument hold line vary, depending on the type and capability of the landing aid; locate them according to the following paragraphs:
  - **Instrument holding position (runway served by Instrument Landing System).** If the height above touchdown is 200 feet or greater (ask the airfield manager), mark the instrument holding position at the edge of the glide slope critical area. If the height above touchdown is less than 200 feet, mark the holding position at the edge of the touchdown area or the glide slope critical area, whichever is farther from the edge of the runway. The glide slope critical area and touchdown area are shown in figure 3-2, page 3-5. The instrument hold line must be at least 500 feet from the runway centerline when the touchdown area criteria apply.
  - **Instrument holding position (runway served by precision approach radar).** Establish the instrument hold line at the edge of the touchdown area (see figure 3-2) if the precision approach radar serving that runway has a height above touchdown less than 200 feet. If the height above touchdown is 200 feet or greater, no instrument hold position is needed. Ensure that a VFR hold position is marked between instrument hold positions and the active runway. However, mark a VFR hold line only if 1) the runway hold line and the instrument hold line happen to fall at the same location, or 2) the additional taxi time required to move from the instrument hold position to the runway is operationally acceptable under VFR.
- **VLZMP.** Various systems are used during daytime operations to provide visual cues to pilots about the location and dimensions of the LZ runway. The type of marker panels selected depends on the mission requirements and anticipated duration of LZ use.

Minimum Marking Requirements for Temporary Applications

3-7. LZ runways intended for short-term or temporary use should be marked with one of the arrangements of airfield marking patterns defined in AFI 13-217. The special tactics team (STT) will decide which

arrangement of panels will be installed. Airfield marking pattern (AMP) 2 is defined in AFI 13-217. The AMP-2 configuration will not be used for newly constructed temporary or permanent LZs by the Air Mobility Command. AMP-4 does not require any marker panels or lights and is only used for appropriate special operations.

- **Materials and size.** Temporary panels may be constructed of fabric, wood, or other materials determined to be suitable by the STT. Panel faces will be at least 66 inches wide and 17 inches tall.
- **Orientation and color.** Marker panels should be erected upright and facing toward the aircraft approach to increase visibility to the pilot. The panels should be orange (fluorescent orange, Army shade 230), cerise (fluorescent red, Army shade 229), or other color acceptable to the STT. The specific color used and layout must be briefed to participating units before operations commence.
- **Frangibility.** For temporary applications, frangible marker panels and supports are preferred to avoid excessive damage if struck by an aircraft. If available, VS-17 marker panels (NSN 8345-00-174- 14 6865, part number MIL-P-400-61) should be used to mark temporary LZs for daytime operations.

Marking Requirements for Long-Term Applications

3-8. LZs intended for long-term use should have permanently installed panels of the type described below. Panel locations are derived from the patterns shown in AFI 13-217. In AMP-1, spacing should be consistent through the intermediate panels. If a conflict with the panels exists on one or both sides of the LZ (for example, at locations where a taxiway connects to the LZ), that panel should be omitted. For bidirectional operations, panels of the appropriate color should be attached to each side of the support posts. Panels should be 6 feet apart at locations where panels are placed in pairs.

Materials and Size

3-9. Panel surfaces may be constructed of any lightweight yet durable material suitable for the environment. Panel surfaces will be at least 66 inches wide and 24 inches tall.

Orientation and Color

3-10. Marker panels should be erected upright and facing toward the aircraft approach to increase visibility to the pilot. The panels should be covered with reflective sheeting material or painted orange (fluorescent orange, Army shade 230), or cerise (fluorescent red, Army shade 229), the colors indicated in figure 3-3, page 3-8, and figure 3-4 page 3-9.

Note. Alternate colors may be used if all participating units are briefed and concur with the color selection. For example, all panels may be orange. Reflective sheeting should be 3MTM diamond grade or equivalent. Panels must be designed to withstand jet blast effects. A panel design that has been used successfully is illustrated in figure 3-5, page 3-10.

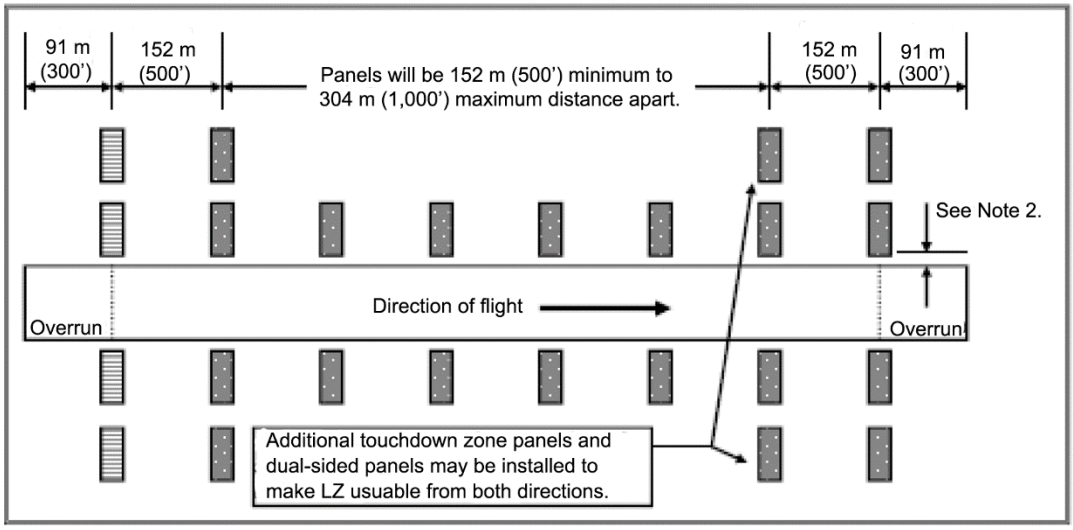
Foundations

3-11. A reinforced concrete foundation pad should be used to support and anchor the panel support posts. See figure 3-6, page 3-11.

Support Posts

3-12. Support posts are needed to hold the panels upright. Posts must be strong enough to withstand jet blast and also frangible to break away upon impact. Posts should meet the frangibility definitions, acceptance criteria, analysis, and testing requirements defined in FAA 150/5345-44K. The support posts should have frangible points located 2 inches or less above the concrete pad. The frangible points should withstand wind loads due to jet blasts of 200 miles per hour, but will break or give way before reaching an applied static load over the surface of the sign of 1.3 pounds per square inch. Two examples of post materials are described below.

- **Galvanized steel support posts.** Galvanized steel support posts should include a breakaway hinge point or frangible coupling 2 inches above the foundation pad to make the entire panel frangible. Each frangible coupling should be permanently marked with the name of the manufacturer and the size of the sign for which the coupling is intended.
- **Polycarbonate support posts.** Polycarbonate support posts should be impact-resistant and dimensionally stable from -30 degrees Fahrenheit to 150 degrees Fahrenheit. The top section of the post should be orange and connected to the ground anchor with a polyurethane hinge. The hinge should be self-recovering, have an internal memory, and remain dimensionally stable from -30 degrees Fahrenheit to 150 degrees Fahrenheit. The bottom of the hinge should be positioned 2 inches or less above the concrete foundation pad. Additional details are shown in figure 3-5, page 3-10.



Airfield Marking Pattern 1 (Day)

= Orange panel

= Cerise panel

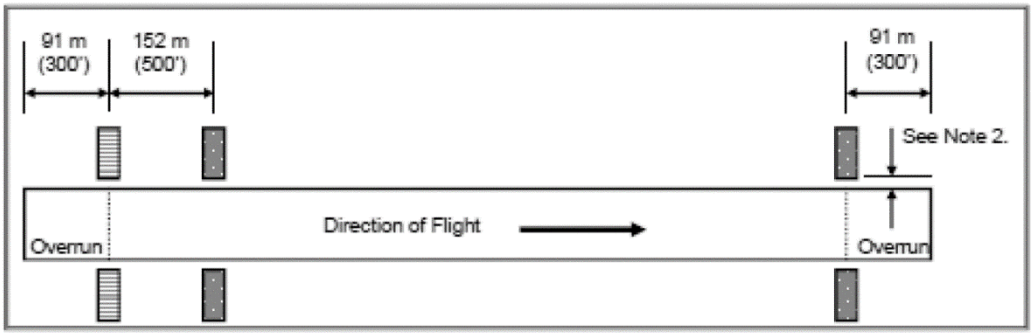
Note 1: Overrun distances are not included in stated runway length, or useable runway length.

Note 2: Panels are placed 4' - 10' from operational edge of runway.

Legend:

LZ	landing zone	m	meter

Figure 3-3. Airfield marking pattern 1



Orange Panel

Cerise Panel

Notes:
1. Alternate colors may be used if all participating units are briefed and concur with the color selection. For example, all panels may be orange.
2. If runway edge lights are not installed on the LZ, place inner edge of panels 1.2 m (4') minimum, 3 m (10') maximum from the edge of the runway. If runway edge lights are installed, place inner edge of panels 3.6 m (12') minimum, 9 m (30') maximum from the edge of the runway so that panels do not block view of the runway edge lights.

Airfield Marking Pattern 3 (Day)

Legend:			
LZ	landing zone	m	meter

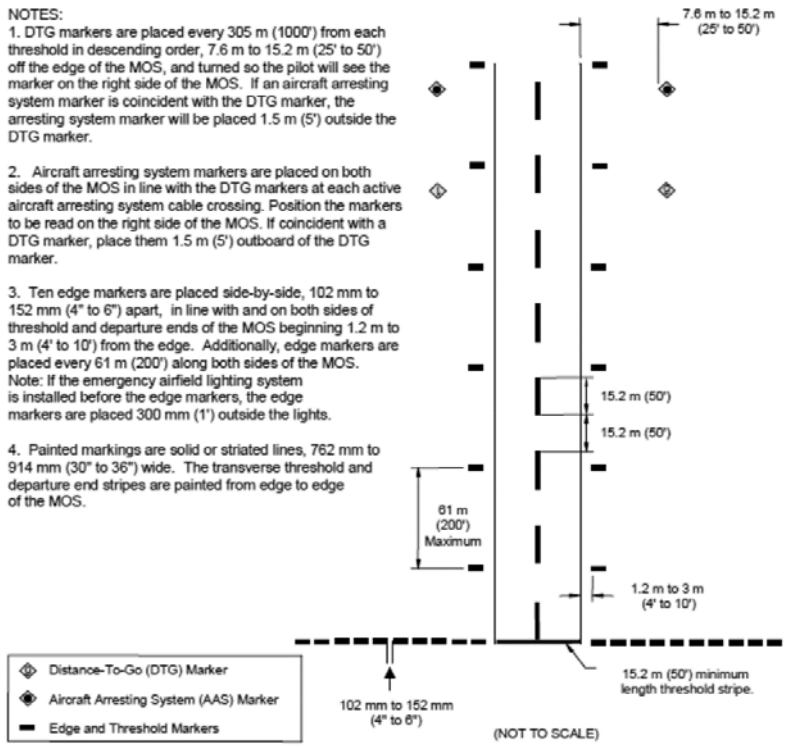
Figure 3-4. Airfield parking pattern 3 (day)

Minimum Operational Strip Marking

3-13. For expedient construction, surfacing is normally soil-stabilized pavement or airfield landing mat. Runway direction numbers on landing mat surfaces are not given. Minimum operational strip markings are rapidly developed to support operations in situations of urgent need, but they also support varying operations. The minimum operational strip is developed for base recovery after an attack to allow the launch and recovery of fighter aircraft. The schemes for marking these airfields are described below:

- **Minimum operational strip markings.** Minimum operational strip markings consist of threshold and centerline pavement markings, edge markers, and aircraft arresting system location and distance-to-go markers. Pavement markings and markers may be used together or independently. Minimum operational strip marking system components are shown in figure 3-5, page 3-10.
- **Pavement markings.** When pavement markings are used, the threshold is marked with an inverted "T" formed with a transverse stripe 50 feet long centered between the edges of the minimum operational strip at the designated beginning of the threshold. The centerline joins the transverse stripe at its midpoint and extends 50 feet toward the center of the minimum operational strip. Stripes may be solid or striated and form a marking that is at least 30 inches wide, but not more than 36 inches wide. Centerline stripes and spaces are 50 feet long. The last centerline stripe may be up to 100 feet long on strips laid out in even increments of 100 feet.
- **Edge and threshold markers.** The minimum operational strip threshold is identified by placing ten markers adjacent to each other, spaced 4 inches to 6 inches apart and perpendicular to the minimum operational strip centerline on each side of and in line with the threshold. Individual markers are placed 4 feet to 10 feet from the edge of the minimum operational strip and opposite each other on both sides of the minimum operational strip, at intervals not exceeding 200 feet. Each marker must have a minimum viewed surface area of 4 square feet.

- **Distance-to-go markers.** When distance-to-go markers are used for minimum operational strip applications, they should be placed to be read on the right side of the runway only. Markers are placed at least 1,000 feet apart to indicate the distance remaining for a takeoff or landing. If the minimum operational strip has an odd length (uneven multiple of 1,000 feet), any distance remaining that is less than 1,000 feet should be equally divided and added to the distance between the threshold and the first distance-to-go marker. This means that distance-to-go markers will be coincident across the runway even though they are only viewed on the right side. Lateral placement will be a minimum of 25 feet and a maximum of 50 feet from the edge of the minimum operational strip.
- **Aircraft arresting system markers.** Aircraft arresting system warning markers are placed on both sides of the minimum operational strip in line with the distance-to-go markers at each active aircraft arresting system cable crossing. Position the markers to be read on the right side of the minimum operational strip. If coincident with a distance-to-go marker, place them 5 feet outboard of the distance-to-go marker.

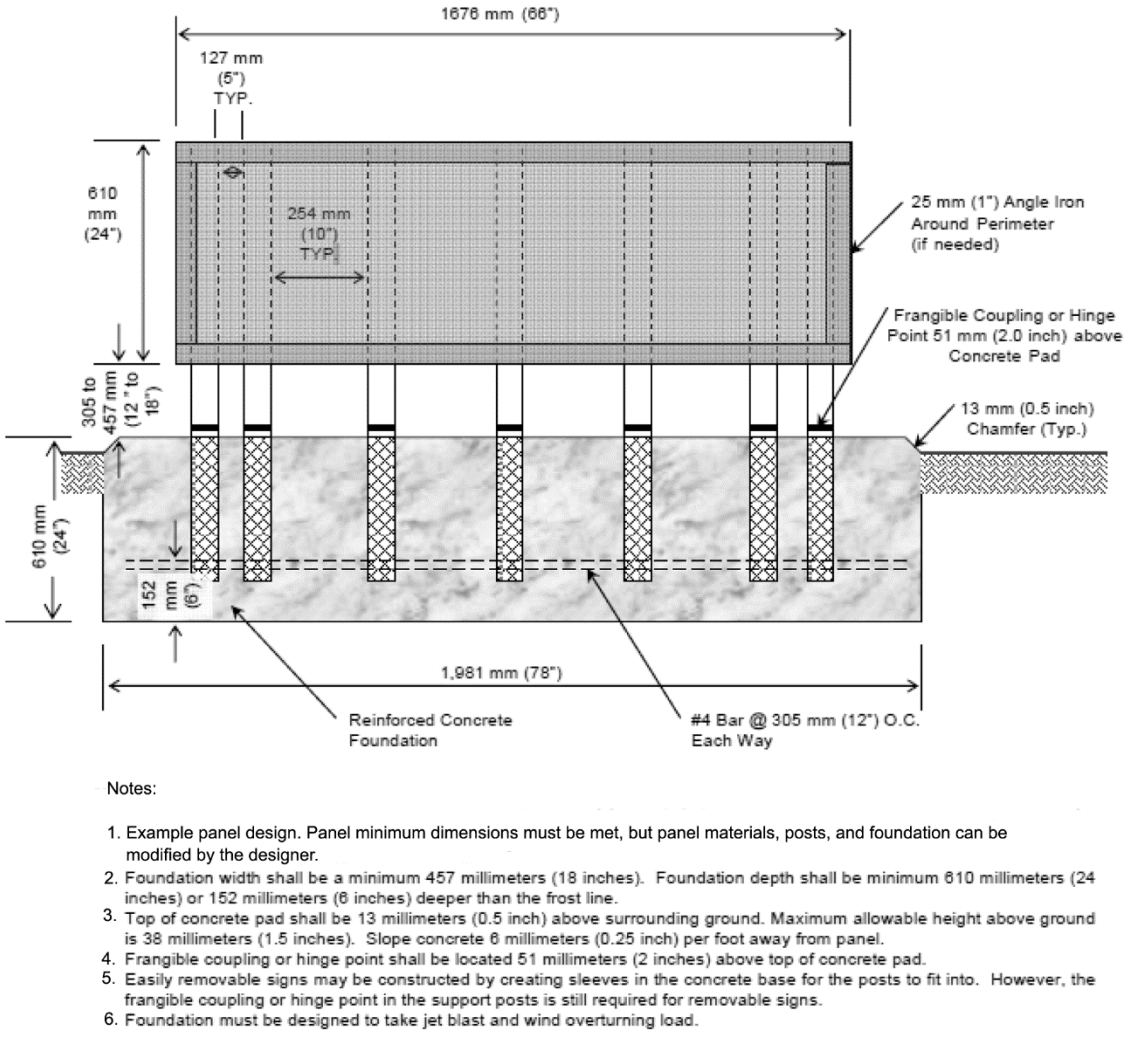


MOS Markings

Legend:

DTG	distance-to-go	mm	millimeter
m	meter	MOS	minimum operational strip

Figure 3-5. Minimum operating strip markings



Notes:

1. Example panel design. Panel minimum dimensions must be met, but panel materials, posts, and foundation can be modified by the designer.
2. Foundation width shall be a minimum 457 millimeters (18 inches). Foundation depth shall be minimum 610 millimeters (24 inches) or 152 millimeters (6 inches) deeper than the frost line.
3. Top of concrete pad shall be 13 millimeters (0.5 inch) above surrounding ground. Maximum allowable height above ground is 38 millimeters (1.5 inches). Slope concrete 6 millimeters (0.25 inch) per foot away from panel.
4. Frangible coupling or hinge point shall be located 51 millimeters (2 inches) above top of concrete pad.
5. Easily removable signs may be constructed by creating sleeves in the concrete base for the posts to fit into. However, the frangible coupling or hinge point in the support posts is still required for removable signs.
6. Foundation must be designed to take jet blast and wind overturning load.

Legend:

mm	millimeter	O.C.	on center	Typ	typical

Figure 3-6. Example VLZMP on concrete base detail

Marking Materials and Methods

3-14. 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 (earth 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.

3-15. Use yellow flags to show temporary obstructions caused by flying accidents or enemy actions. 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.

3-16. 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.

3-17. All expedient markers should be lightweight and constructed to break readily if struck by an aircraft. They should never be hazardous to aircraft. Figure 3-7 shows several expedient marker types. 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.

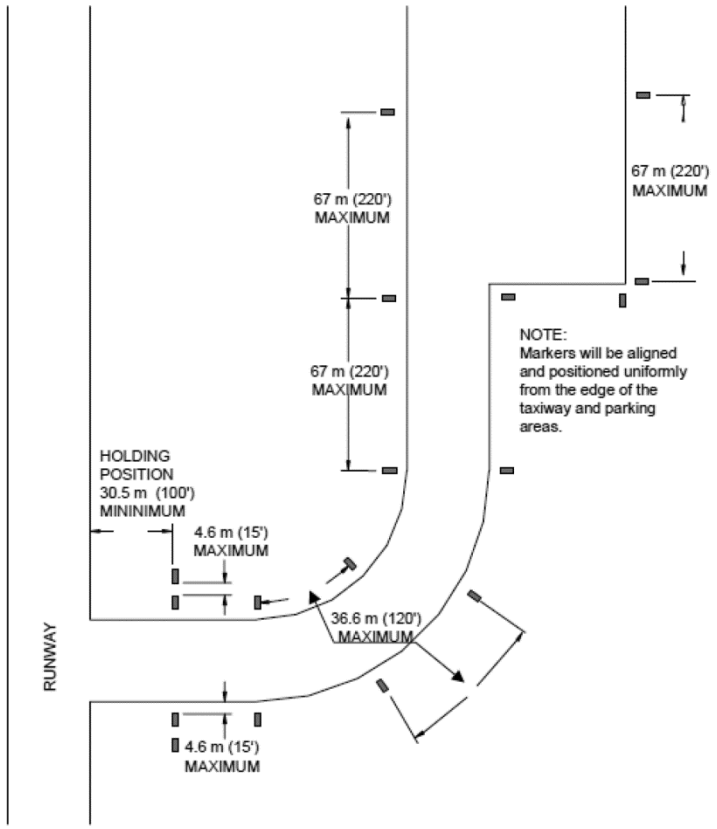
Expedient Taxiway Markings

3-18. Where expedient taxiway markings are required, taxi lines are marked with a single 6-inch-wide continuous stripe. Unless there is a lack of contrast with the surrounding terrain, the stripe is only applied in critical areas, such as curves and intersections. Holding positions on taxiways are marked with a transverse stripe at least 30 inches wide, but not more than 36 inches wide.

3-19. Where markers are required along taxiways, place them as close to the edges of taxiways as practicable and equidistant laterally from its centerline. Intervals between the markers are not to exceed 220 feet on straight taxiway sections and 120 feet on curves. Markers are placed opposite each other on both sides of the taxiway, excluding insides of curves where every other marker may be omitted. At holding positions, double markers are provided on both sides of the taxiway. Do not locate the outer markers more than 15 feet laterally from the inner row of markers. Figure 3-7 and figure 3-8, page 3-15, show a typical layout scheme for these markers.

Landing Zone Markings

3-20. It is generally not practical to apply paint to unpaved surfaces. However, markings are desirable to delineate the edge of operational surfaces, particularly turnaround areas. If the semiprepared surfaces are stabilized, then painted markings may be feasible, but will likely require frequent repainting. Alternatively, *stake chasers* can be installed along the edges of semiprepared surfaces. Stake chasers are 6-inch flexible plastic bristles that attach to a 60-penny (60d) nail or a wooden stake. They are available in a variety of colors and can be purchased from survey supply stores. When used, the stake chasers should be installed at 25 to 50 feet ± 5 feet intervals and driven into the ground so that only 4 inches of the 6-inch whiskers are visible (exposed length may be dependent on soil conditions). This will help ensure that the stakes are not dislodged by traffic or jet blast. When possible, install stake chasers with colors corresponding to the edge light (white = runway edge, blue = taxiway and turnaround edge). Stake chasers are illustrated in ETL 09-6.



Legend:

m meters

Figure 3-7. Minimum operating strip markings (continued)

Marking Requirements for Long-Term Use on Pavements

3-21. The specifications below are used when marking long-term pavement surfaces.

- **Marking materials.** Use paint to apply markings to paved LZs, turnarounds, aprons, and taxiways. Paint should be applied at 12 to 13 mils wet film thickness for a desired dry film thickness of approximately 8 mils. At this rate, coverage will be approximately 121 square feet per gallon. Normally, LZ markings should not be reflective to improve realism for operating on a semiprepared LZ. However, for LZs that need additional reflectivity, glass beads (Type I) should be applied at a rate of approximately 8 to 9 pounds per gallon of paint.
- **Threshold bars.** White threshold stripes may be marked at each end of the LZ runway to distinguish between the overrun and LZ runway surface. The marking should be 4 feet wide and extend from edge to edge of the LZ surface.
- **LZ edge stripes.** White side stripes should only be painted when there is no visual distinction between the LZ runway surface and the paved shoulder (for example, both LZ runway and shoulder are asphalt). Edge stripes should be 1 foot wide and extend along the entire length of the LZ runway.

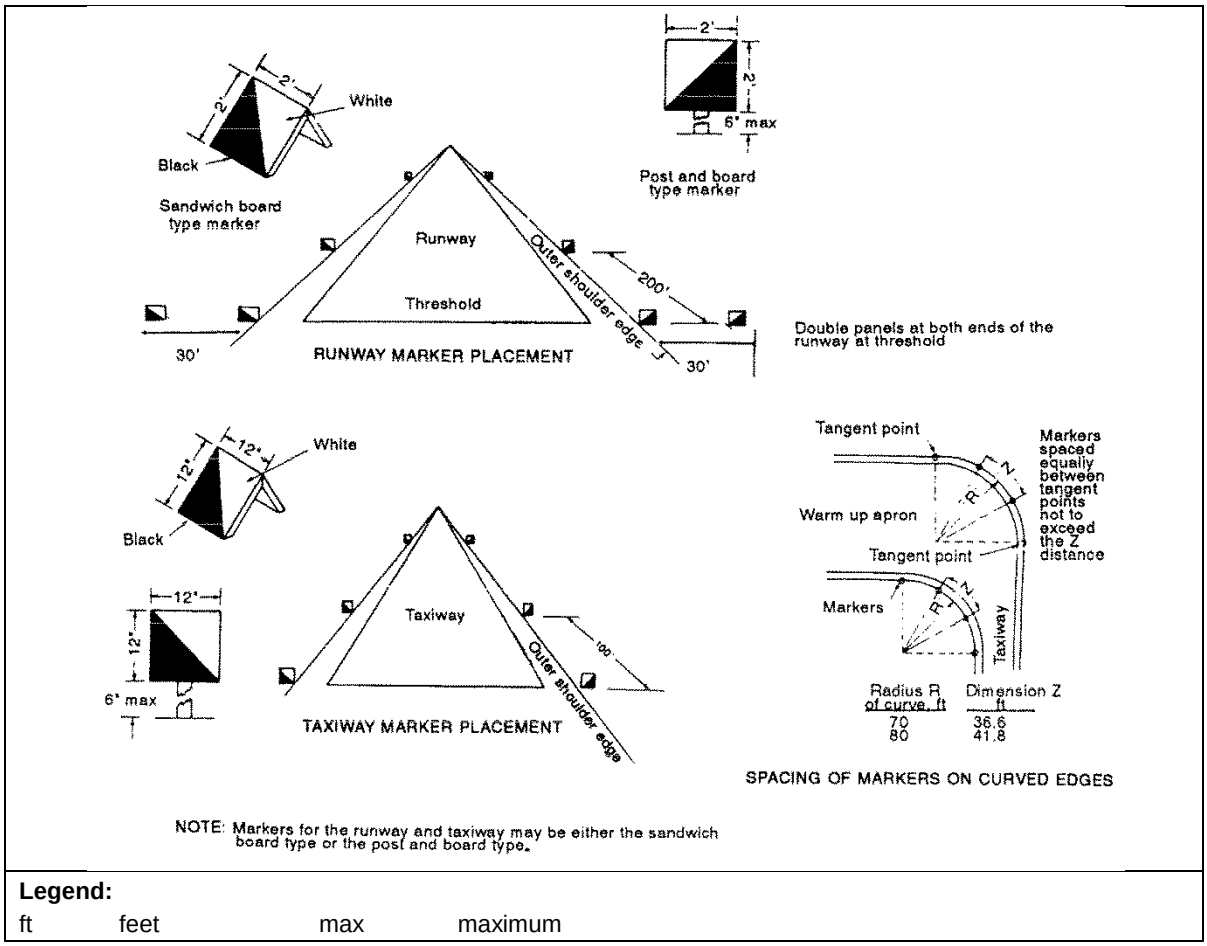
- **Taxiway centerlines.** If the LZ runway has connecting taxiways, the taxiway centerline turn radius should not be extended onto the LZ runway surface.
- **Taxiways, aprons, and turnaround edge stripes.** If taxiways, aprons, or turnarounds have paved shoulders and there is no visual distinction between the edge of load-bearing pavement and the shoulder, the edge of the full-strength pavement should be marked with two 6-inch-wide yellow stripes separated by a 6-inch-wide gap.
- **Holding position markings.** This holding position is located a minimum of 100 feet from the near edge of the runway. This distance is measured perpendicular to the long axis of the LZ. For holding position marking dimensions, see ETL 04-2.
- **Touchdown box markings (optional).** When desired by the airfield manager, touchdown box markings may be applied. These markings consist of 3-foot-wide white stripes that extend transversely across the entire width of the runway surface. The stripes are located 100 feet and 500 feet from the approach end threshold.
- **Runway designation markings (optional).** When desired by the airfield manager, runway designation numerals may be painted at each end of the runway. See ETL 04-2 for numeral locations and dimensions.
- **Runway centerlines (optional).** When desired by the airfield manager, runway centerline stripes may be applied. Stripes are 1.5 feet to 3 feet wide and 100 feet long, with a 60-foot gap between stripes.
- **LZ markings on standard operational runways.** In some cases, it may be desirable to use a standard full-length runway for LZ training operations. For this purpose, the LZ marking scheme illustrated in figure 3-5, page 3-10, should be applied
- **LZ marking dimensions.** Nonreflective white markings, 10 feet by 5.5 feet are applied in the same pattern as VLZMP for the AMP-3 configuration.
- **LZ runway locations.** When possible, the LZ threshold should be sited so the LZ touchdown area is within the first 1,000 feet of the runway pavement, and the 300-foot LZ overrun falls on the runway surface (not overrun). This will ensure that aircraft loads are concentrated on the portion of the runway designed for heavier loads. Siting the LZ threshold 300 feet from the runway threshold will accomplish this objective.
- **LZ marking conflicts with standard runway markings.** The LZ should be sited so the markings do not conflict with the threshold markings, runway designation markings, touchdown zone markings, or fixed distance markings. An ideal location for the LZ threshold is 300 feet from the runway threshold. This will position the LZ markings in the gaps between the standard runway markings. See ETL 04-2 for standard airfield pavement marking criteria.

VISUAL LANDING ZONE MARKER PANELS

3-22. Vertical, colored panels are installed along runway edges to indicate the threshold location and distance remaining (see ETL 09-6). Various systems are used during daytime operations to provide visual cues to pilots about the location and dimension of the LZ runway. The market panels selected depend on the mission requirements and anticipated durations of LZ use.

Minimum Marking Requirements for Temporary Applications

3-23. LZ runways intended for short-term or temporary use should be marked with one of the four arrangements of airfield marking pattern defined in AFI 13-217. These four patterns are designated AMP-1 through AMP-4. The STT will decide which arrangement of panels will be installed. AMP-1 layout is illustrated in ETL 09-6. Refer to AFI 13-217 for other layouts.



Legend:

ft	feet	max	maximum

Figure 3-8. Expedient airfield markers

Material and Size

3-24. Temporary panels may be constructed of fabric, wood, or other materials determined to be suitable by the STT. Panel faces will be at least 66 inches wide and 17 inches tall.

Orientation and Color

3-25. Marker panels should be erected upright and facing toward the aircraft approach to increase visibility to the pilot. The panels should be orange (fluorescent orange, Army shade 230), cerise (fluorescent red, Army shade 229), or other color acceptable to the STT. The specific color used and layout must be briefed to participating units before operations commence.

Frangibility

3-26. For temporary applications, frangible marker panels and supports are preferred to avoid excessive damage if struck by an aircraft. If available, VS-17 marker panels (NSN 8345-00-174-6865, part number MIL-P-400-61) should be used to mark temporary LZs for daytime operations.

Minimum Marking Requirements for Long-Term Applications

3-27. LZs intended for long-term use should have permanently installed panels of the type described below. Panel locations are derived from the patterns shown in AFI 13-217. Panels should be installed at the locations shown in ETL 09-6 depending on the desired AMP. In AMP-1, spacing should be consistent through the intermediate panels. If a conflict with the panels exists on one or both sides of the LZ (for example, at

locations where a taxiway connects to the LZ), that panel should be omitted. For bidirectional operations, panels of the appropriate color should be attached to each side of the support posts. See ETL 09-6 for the distance between the panels and the runway edge. Panels should be 6 feet apart at locations where panels are placed in pairs.

Materials and Size

3-28. Panel surfaces may be constructed of any lightweight, yet durable material suitable for the environment. Panel surfaces will be at least 66 inches wide and 24 inches tall.

Orientation and Color

3-29. Marker panels should be erected upright and facing toward the aircraft approach to increase visibility to the pilot. The panels should be covered with reflective sheeting material or painted orange (fluorescent orange, Army shade 230), or cerise (fluorescent red, Army shade 229), the colors indicated in ETL 09-6.

Note. Alternate colors may be used if all participating units are briefed and concur with the color selection. For example, all panels may be orange. Reflective sheeting shall be 3MTM diamond grade or equivalent. Panels must be designed to withstand jet blast effects.

Foundations

3-30. A reinforced concrete foundation pad should be used to support and anchor the panel support posts. Sample details for a foundation are shown in ETL 09-6.

Support Posts

3-31. Support posts are needed to hold the panels upright. Posts must be strong enough to withstand jet blast and also frangible to break away upon impact. Posts shall meet the frangibility definitions, acceptance criteria, analysis, and testing requirements defined in FAA 150/5345-44K. The support should have frangible points located 2 inches or less above the concrete pad. The frangible points should withstand wind loads due to jet blasts of 200 miles per hour, but will break or give way before reaching an applied static load over the surface of the sign of 1.3 pounds per square inch. Two examples of post materials are described below.

- **Galvanized steel.** Galvanized steel support posts should include a breakaway hinge point or frangible coupling 2 inches above the foundation pad to make the entire panel frangible. Each frangible coupling should be permanently marked with the name of the manufacturer and the size of the sign for which the coupling is intended.
- **Polycarbonate.** Polycarbonate support posts should be impact-resistant and dimensionally stable from -30 degrees Fahrenheit to 150 degrees Fahrenheit. The top section of the post should be orange and connected to the ground anchor with a polyurethane hinge. The hinge should be self-recovering, have an internal memory, and remain dimensionally stable from -30 degrees Fahrenheit to 150 degrees Fahrenheit. The bottom of the hinge should be positioned 2 inches or less above the concrete foundation pad. 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, 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.

AIRFIELD LIGHTING

3-32. 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 (IMC). In general, airfield lighting is comprised of runway lighting, approach lighting, taxiway lighting, obstruction lighting, beacons, lighted wind direction indicators, and special signal lights. Not all these items are included in TO airfields.

Normally, lighting (except certain obstruction lighting) is controlled from the control tower. The lighting system includes control devices, circuit protective devices, constant current regulators, isolation transformers, mounting devices, and accessories needed to produce a working facility.

3-33. The configuration, colors, and spacing of runway, approach, and taxiway lighting systems are to be uniform regardless of the anticipated length of service of the installation, the mission of the tenant organization, or the method of installation. When paved surfaces such as PCC or flexible (asphalt) paving are used, install hard-wired airfield lighting that has an external power source, conductors protected from traffic, and photometrics meeting (as a minimum) those for medium intensity lights. The lights are to be installed at the same time as the pavement.

3-34. 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.** Blue is used for taxiway lighting.
- **Clear.** Clear (white) is used for the sides of a usable landing area, combination yellow and white the last 2,000 feet on each end.
- **Green.** Green is used for the ends of a usable landing area (threshold lights). When used with a beacon, green indicates a lighted and attended airfield.
- **Red.** Red is used for hazard, obstruction, runway end, or area unsuitable for landing.
- **Yellow.** Yellow is used as a caution. When used with a beacon, yellow indicates a water airport.

Note. Airfield lighting requirements are detailed in UFC 3-535-01.

Runway Lighting

3-35. 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 runway edge lights—two parallel rows of white, and white and yellow 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. Threshold/end lights provide positive identification of the beginning and the end of the operational runway surface. Use green lights on the approach end of the runway and red on the departure end.

3-36. Space runway threshold lights along the threshold line, which is from zero to 10 feet from the end of the runway and perpendicular to the extended runway centerline. Runway lighting is divided into two classes—high intensity to support aircraft operations on runways utilizing precision IFR approach procedures and medium intensity to support aircraft operations on VFR runways or runways with nonprecision IFR approaches.

Approach Lighting

3-37. 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 for the primary approach to the Stage II runway. Its use is generally confined to installations that are or will be provided with precision or nonprecision, electronic, approach facilities. It is recommended that approach lighting not be used with a medium-intensity runway lighting system.

Taxiway Lighting

3-38. When an airfield becomes fully operational, lights and reflectors are used to increase safety in ground movements of the aircraft. Taxiway lighting is standardized and is required on PCC or flexible (asphalt) paving. In general, blue taxiway lights mark the lateral limits, turns, and terminals of taxiway sections.

3-39. Reflectors are also used to delineate taxiways that are not paved with PCC or flexible (asphalt) paving. Standard taxiway reflectors are panels approximately 12 inches high by 9 inches wide. Both sides of the panels consist of a retro reflective 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.

3-40. 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.

Landing Zone Lighting

3-41. Airfield lighting systems are used during nighttime operations to provide visual cues to pilots about the location and dimensions of the LZ runway. The type of lighting system installed may vary between the minimum requirements for temporary applications and the long-term-use system. Equipment selection will depend on available equipment and mission requirements. Lights are not required if night operations are not anticipated. Lighting that is planned to be permanent should be compatible with NVG. UFC 3-535-01 should be consulted for design details of light fixtures, light bases, cable, cable connections, controls, and other features associated with an airfield lighting system.

Minimum Lighting Requirements for Temporary Applications

3-42. Airfields are often few and far between in disaster areas, war zones, and developing countries. Temporary lights make it possible to deliver air power where it is needed quickly and safely.

Lights

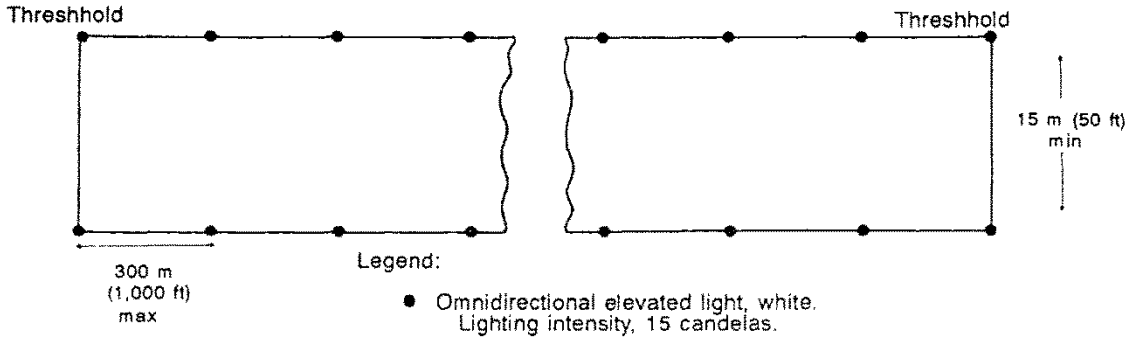
3-43. If available, lights should be omnidirectional, steady-burn, or flashing with a minimum output rating of 15 candela for night operations. According to AFI 13-217, virtually any type of overt lighting system is acceptable if all participating units are briefed and concur with its use. Contingency lighting kits, emergency airfield lighting systems, or other materials may be used as available and determined to be suitable by the STT.

Location

3-44. Only AMP-1 and AMP-3, as defined in AFI 13-217, will be used in this manual. AMP-4 is lights-out, no markings, and used only for appropriate special operations. The STT will decide which arrangement of lights will be installed. Although AMP-2 is also defined in AFI 13-217, the AMP-2 configuration will not be used for newly constructed temporary or permanent LZs by Air Mobility Command. When constructing new LZs, even if the immediate operational need is for AMP-3, consideration should still be given to installing the light bases and conduits to support the AMP-1 configuration.

Lighting Requirements for Permanent Applications

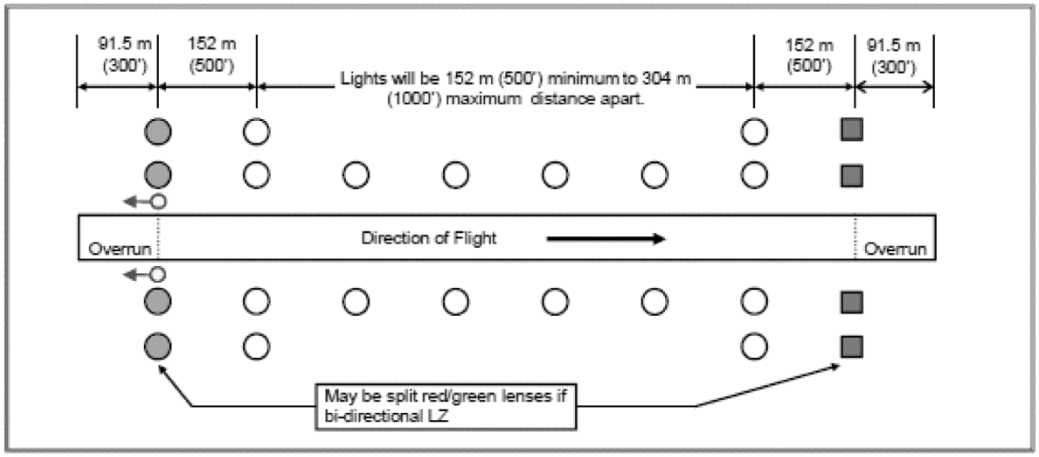
3-45. When intended for long-term use, use permanently installed lights of the type and in the locations described in figures 3-9 through 3-19, page 3-19 through 3-25.



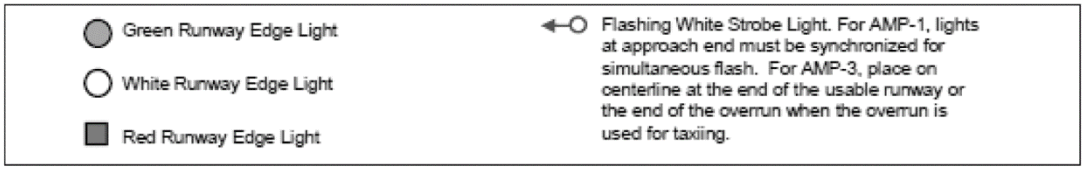
Legend:

ft	feet
m	meters
max	maximum
min	minimum

Figure 3-9. Expedient airfield lighting layout—Type 1 system



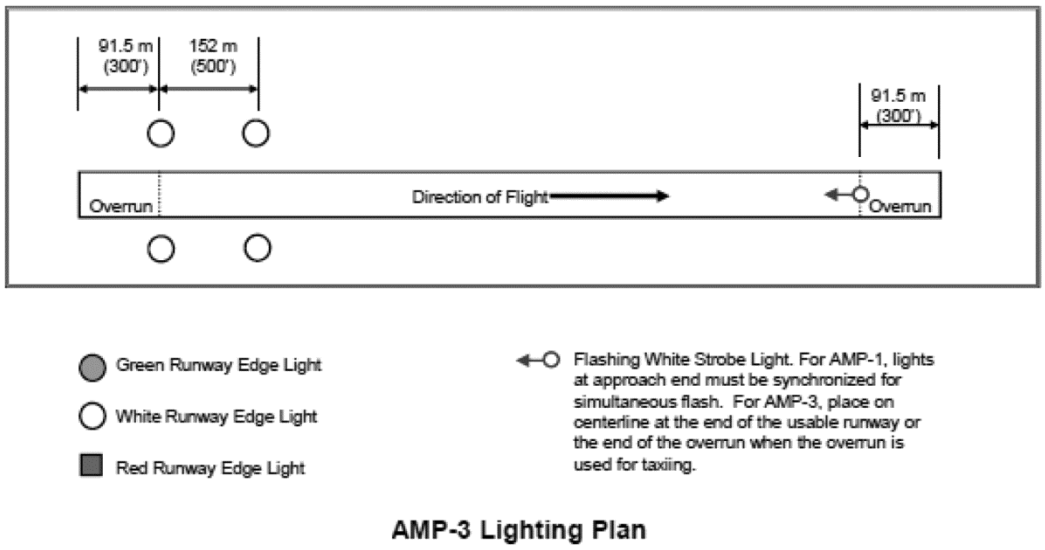
AMP-1 Lighting Plan



Legend:

LZ	landing zone	m	meter

Figure 3-10. AMP-1 lighting plan

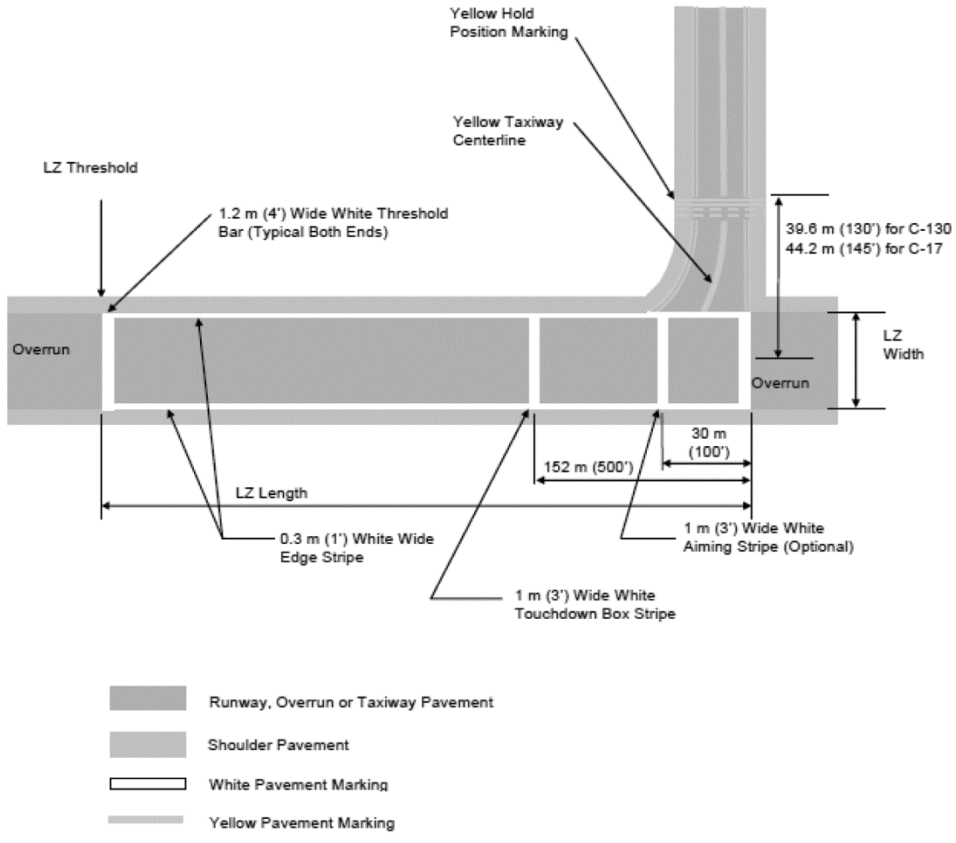


AMP-3 Lighting Plan

Legend:

AMP	airfield marking pattern	m	meter

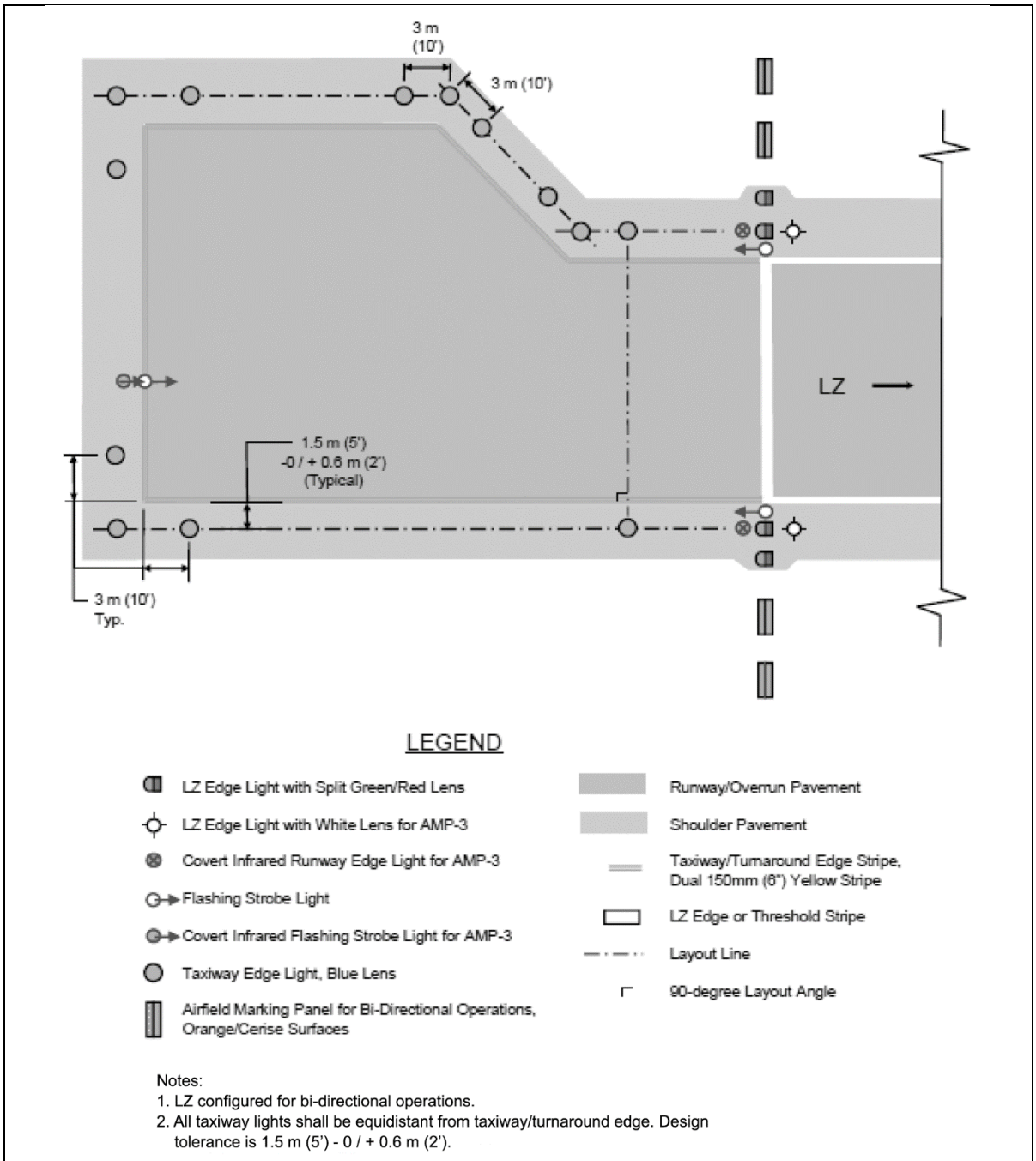
Figure 3-11. AMP-3 lighting plan



Legend:

LZ	landing zone	m	meter

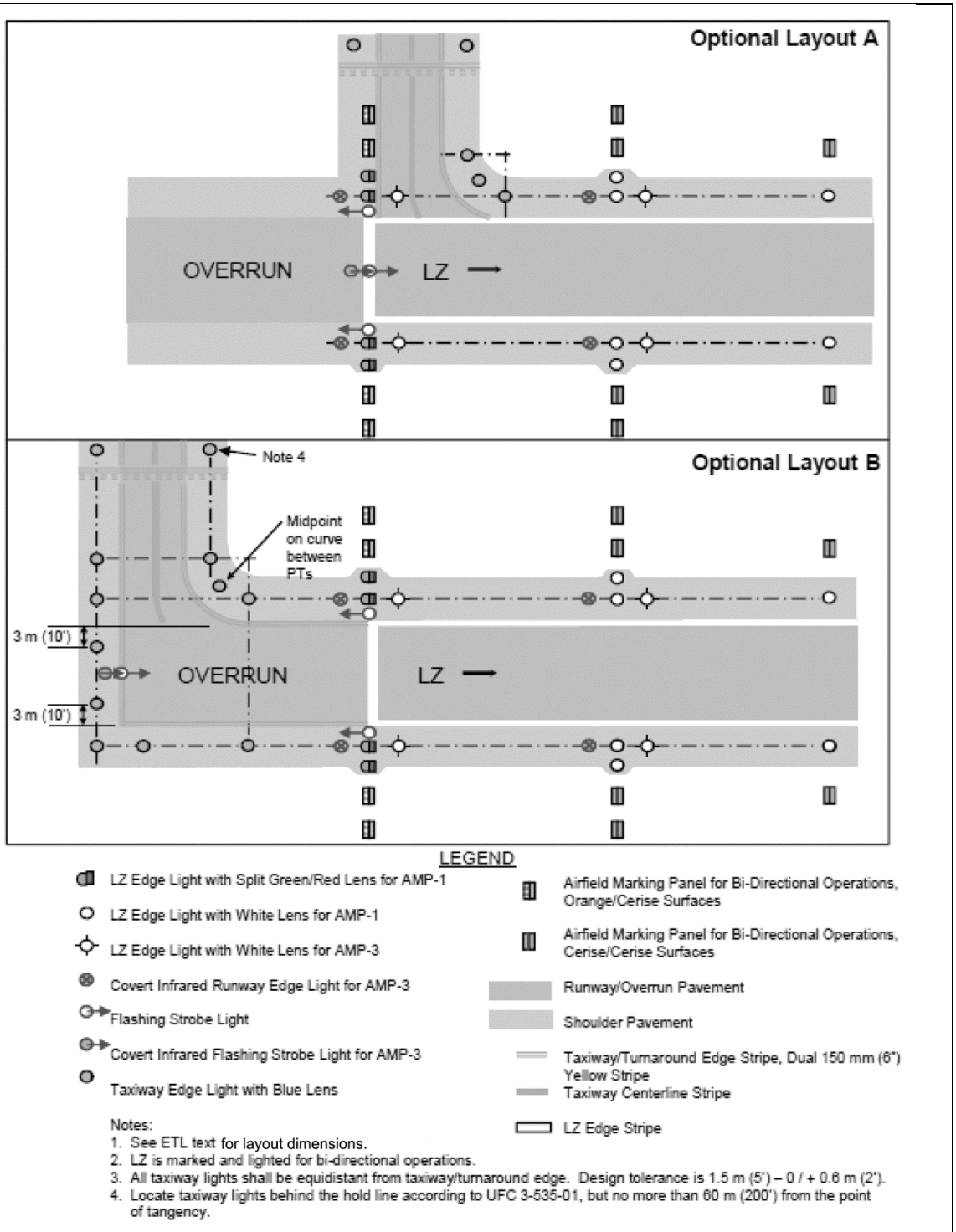
Figure 3-12. LZ painted marking layout



Legend:

LZ	landing zone
m	meter
mm	millimeter
Typ	typical

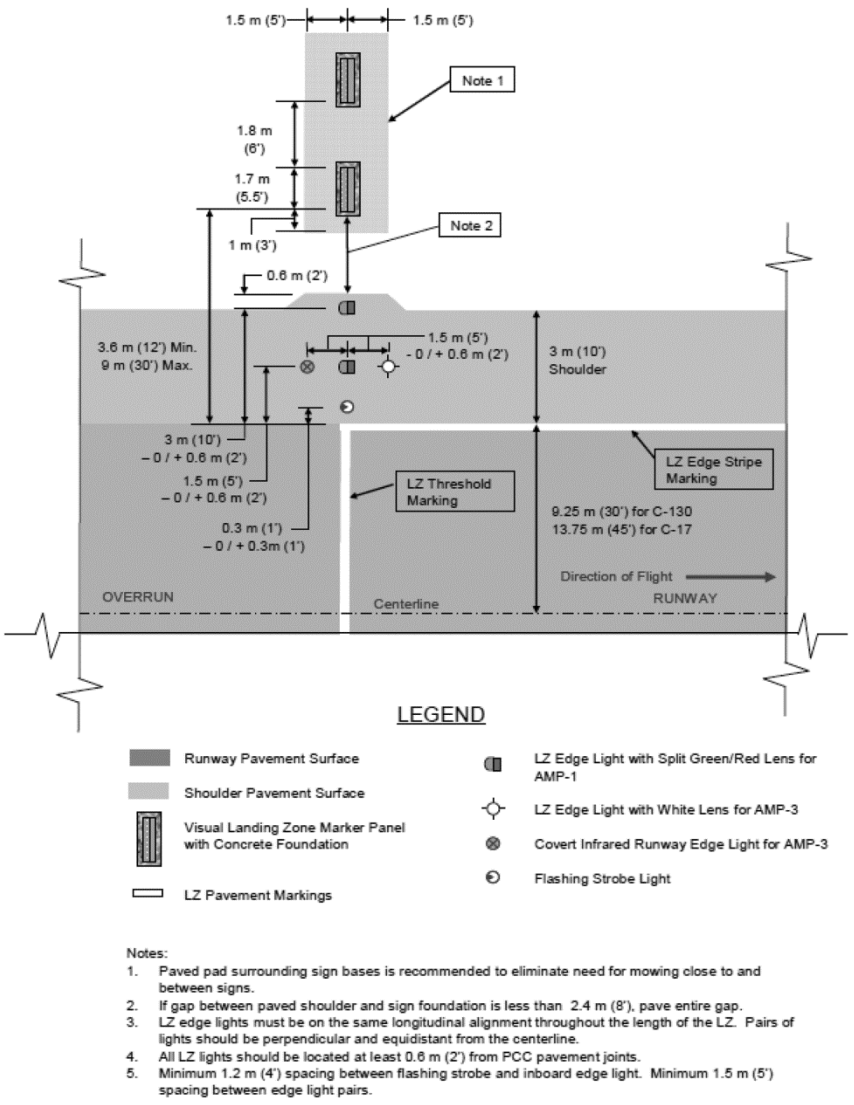
Figure 3-13. Typical turnaround marking and lighting layout



Legend:

AMP	airfield marking pattern
LZ	landing zone
m	meter
mm	millimeter
PT	point

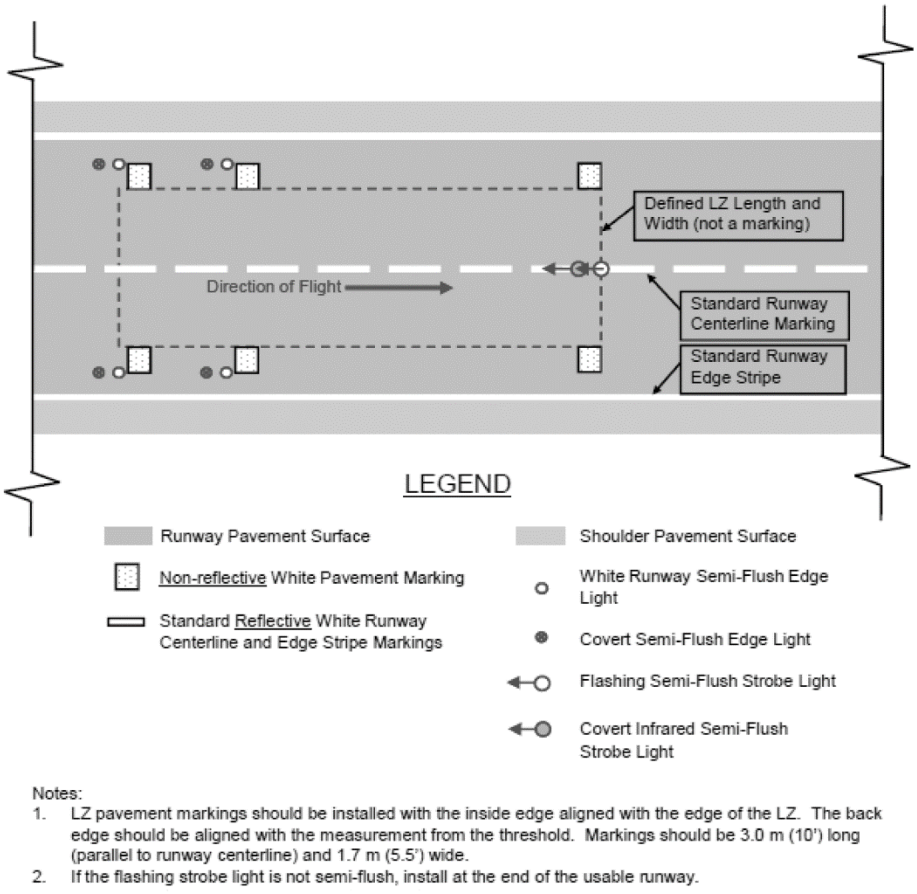
Figure 3-14. Typical bi-directional runway/taxiway marking and lighting layout



Legend:

AMP	airfield marking pattern
LZ	landing zone
m	meters
max	maximum
min	minimum

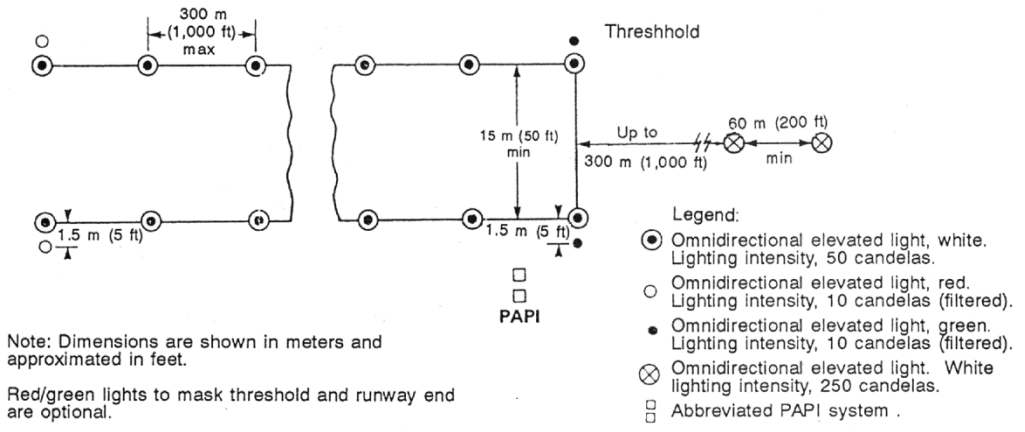
Figure 3-15. Light and marker panel layout detail on a LZ with combination AMP-1, AMP-3 overt, and AMP-3 covert



Legend:

LZ	landing zone	m	meters

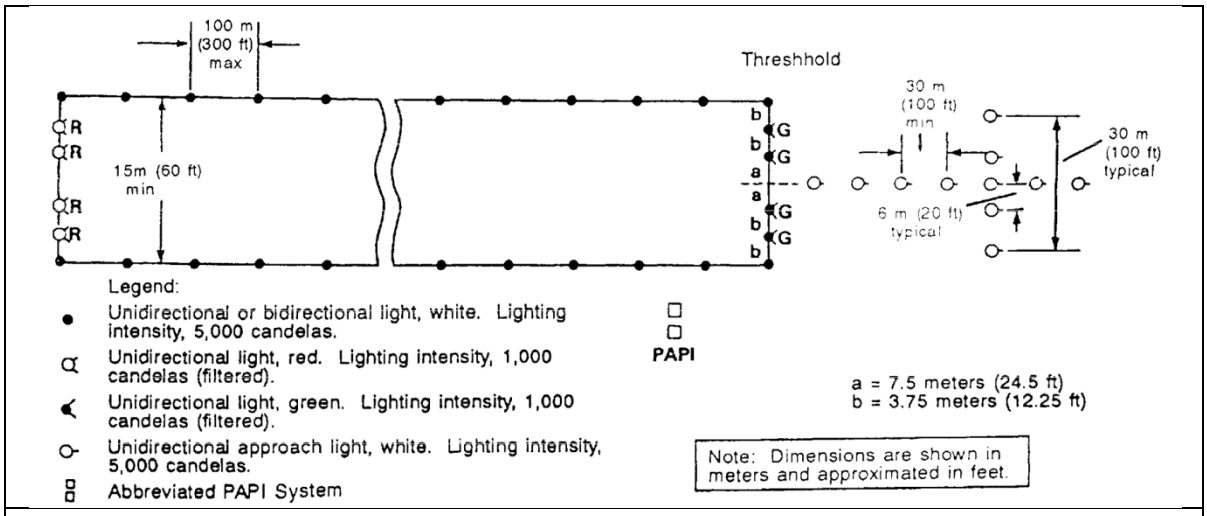
Figure 3-16. AMP-3 lighting and marking scheme for LZ superimposed on standard Class B runway



Legend:

ft	feet	max	maximum
m	meters	PAPI	precision approach path indicator

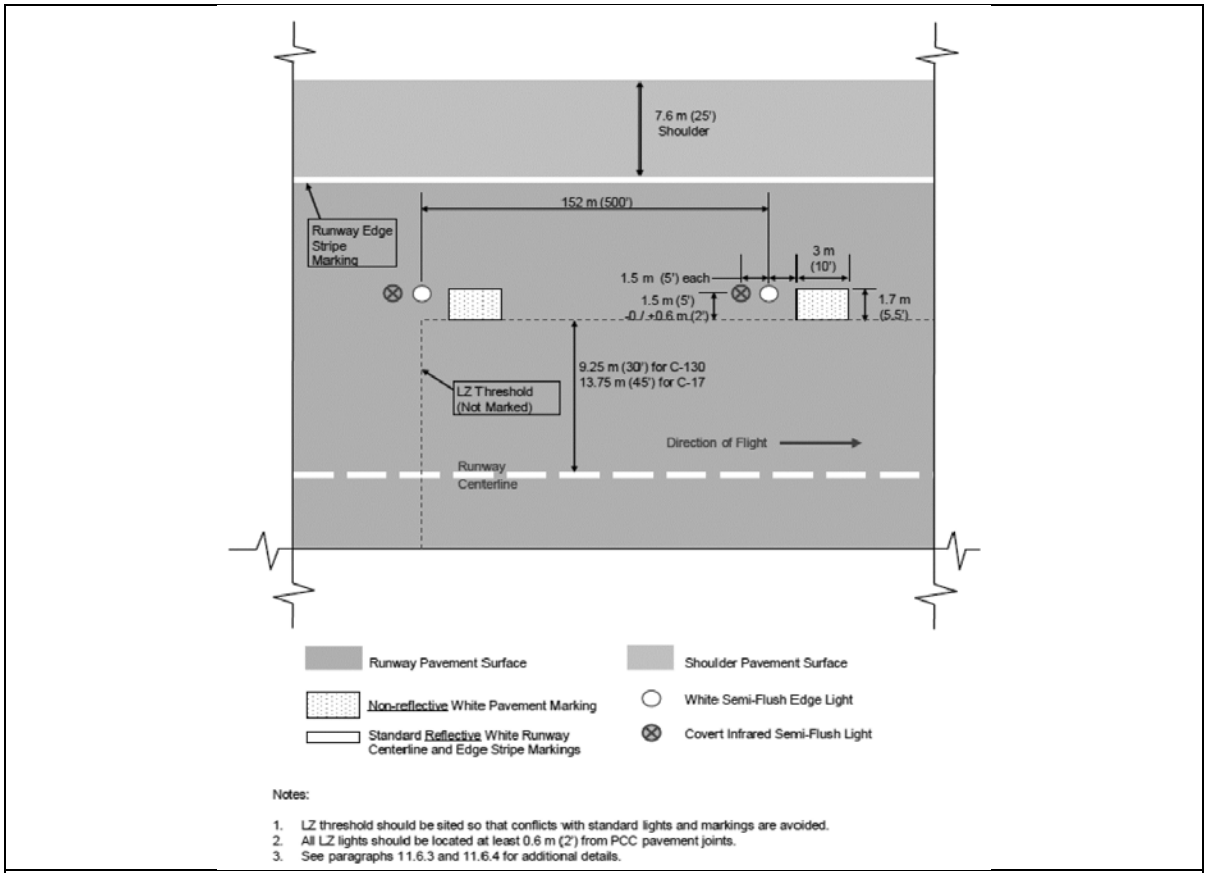
Figure 3-17. Expedient airfield lighting layout—Type 2 system



Legend:

ft	feet	max	maximum
m	meters	PAPI	precision approach path indicator

Figure 3-18. Expedient airfield lighting layout—Type 3 system



Legend:

LZ	landing zone	PCC	portland cement concrete
m	meters		

Figure 3-19. AMP-3 overt and covert lighting and marking layout detail for LZ superimposed on standard Class B runway

Light Fixtures

3-46. All light fixtures shall be certified and listed in FAA Advisory Circular 150/5345-46D and FAA Advisory Circular 150/5345-53D. Fixtures shall be used with infrared filters as covert fixtures.

3-47. Runway high-intensity edge light fixtures should be used for permanent LZ lighting installations. Runway edge lights should be elevated to FAA Type L-862. Use the L-850C when an insert light is required in place of the L-862. If edge lights are semiflush edge lights, use the FAA Type L-850A, Style 3 (runway, unidirectional) towards the approach. Where circling guidance is needed, bidirectional light fixtures may be used.

3-48. Taxiway medium-intensity edge light fixtures should be used for permanent lighting installations. Taxiway edge lights should be elevated to FAA type L-861T. If needed, semiflush edge lights should be FAA Type L-852T, Style 3 (taxiway, omnidirectional). Taxiway and turnaround edge light lenses shall be blue. Three-step regulators should be installed for intensity control.

- **Flashing strobe lights.** These light fixtures are located at the end of the LZ in the AMP-3 configurations and at each side of the approach threshold in the AMP-1 configuration. These lights are unidirectional and must flash at a rate of 28 to 34 flashes per minute, producing a white light. Semiflush fixtures (FAA-E-2952, Style A, white) should be installed with the edge of the fixture extending no more than 0.0625 inch below and 0.0 inch above the pavement top. Aim the fixture(s) down the runway parallel to the centerline for AMP-3 and towards the approach for AMP-1.
- **Light bases.** Light fixtures shall be attached to full-depth light bases (L-868, Class IB). Light bases shall be offset so the fixture center is a minimum of 2 feet from any pavement joint. Light bases shall be installed according to UFC 3-535-01. For elevated light fixtures, provide steel adaptor rings.

Example

Light construction tolerances are—

Longitudinal ± 13 millimeters (0.5 inch) from stationing

Transverse ± 13 millimeters (0.5 inch) transverse from centerline

Base orientation Parallel to T/W centerline ± 0.5 degree

Elevation +0 to –0.0625 inch from finished pavement surface, flush with the surrounding grade or pavement.

Light Locations

3-49. In times of emergency, when standard airfield lighting is not available and aircraft activities must be performed at night, it may be necessary to resort to the use of portable lighting devices to support the operations.

- **LZ lights.** If the LZ is built on an existing runway or taxiway where normal flight operations are conducted then use semiflush light fixtures.
- **AMP-1.** Lights shall be placed at each threshold and at 500 feet from each threshold. Intermediate lights shall be 500 feet minimum/1,000 feet maximum spacing throughout the length of the runway. Spacing should be consistent through the intermediate lights. If a conflict with the lights exists on one or both sides of the LZ (for example, at locations where a taxiway connects to the LZ), that light should be a semiflush light. Steady-burning light fixtures should be installed at 5 feet plus 2 feet to minus 0.0 foot from the edge of the LZ surface (such as within the shoulder pavement). Light pairs shall be perpendicular and equidistant from the runway centerline to be symmetrical about the runway or LZ centerline.
- **AMP-3.** Light locations and colors are derived from the AMP-3 configuration in AFI 13-217. Steady-burning lights should be placed at the threshold and at 500 feet from the approach end threshold, forming a box. A field lighting system is also installed on the centerline of the departure end threshold not more than 5 feet from the threshold or overrun end. Locate the FSL as close to the runway centerline as possible. Steady-burning light fixtures should be installed at 5 feet plus

2 feet to minus 0.0 foot from the edge of the LZ surface (for example, within the shoulder pavement).

- **Turnaround, taxiway, and apron edge lights.** All lights should be installed at 5 feet plus 2 feet or minus 0.0 foot from the edge of the load-bearing surface. On straight sections of taxiway or turnaround, lights should be spaced evenly with a maximum of 500 feet between lights. Light spacing should be reduced to between 10 feet and 35 feet on curves and at corners or intersections. On curved sections, lights should be evenly spaced from point of tangency to point of tangency, with the maximum spacing between lights equal to half the taxiway width. For corners and all curves exceeding 30 degrees of arc, there should be a minimum of three lights. See UFC 3-535-01, for additional edge light location details.
- **Overrun edge lights.** Overruns do not normally require edge lights; however, for overruns used as taxiways or turnarounds, edge lights may be installed. The first pair of edge lights installed on overruns should not be more than 100 feet from the runway threshold.
- **Light circuits and controls.** Designers should investigate required configurations of lighting (AMP-1, AMP-3, and infrared AMP-3) and develop a circuit and control system that can achieve the required configurations.

Ferroresonant Regulators

3-50. New regulators used for LZ lighting systems shall be ferroresonant.

Multi-Regulator Systems

3-51. In a multiregulator system configuration, separate regulators will be needed to control lights for AMP-1, AMP-3 overt, AMP-3 covert, and taxiway circuits.

Single-Regulator Systems with Addressable Lights

3-52. Systems are now available to have *assignable control* of individual lights via a carrier signal. For this configuration, LZ runway lights could be powered by one regulator, with each configuration assigned to a different control setup.

Light Reflector Panels (Optional)

3-53. Light reflectors may be installed at the midpoint between LZ runway edge lights or taxiway edge lights. Contact the STT for information on obtaining light reflector panels.

Overt AMP-3 Landing Zone Lights Superimposed on Standard Operational Runways

3-54. In some cases, it may be desirable to use a standard full-length runway for LZ training operations. Only the AMP-3 configuration should be installed in this situation. The LZ lighting scheme is illustrated subject to the following conditions:

- **LZ light fixtures.** High-intensity light fixtures must be installed flush with the pavement surface to allow traffic to pass over them. Semiflush lights shall be Federal Aviation Administration (FAA) Type L-850A, Style 3, unidirectional, or an International Civil Aviation Organization equivalent. LZ light lens colors shall be white. Five-step regulators should be installed on the LZ circuit(s) for light intensity control compatible with NVG operations.
- **LZ location on the runway.** When possible, the LZ threshold should be sited between 300 feet and 500 feet from the runway threshold. This will ensure aircraft loads are concentrated in the portion of the runway designed for heavier loads and avoid conflicts with runway pavement markings.
- **LZ lighting conflicts with standard runway markings**. The LZ should be sited so the LZ light fixtures do not conflict with threshold markings, runway designation markings, touchdown zone markings, or fixed distance markings. An ideal location for the LZ threshold is 300 feet from the runway threshold. This will position the LZ light fixtures in the gaps between the standard runway markings. If LZ lights fall within a standard marking, the light fixture should be masked whenever repainting occurs.

- **LZ lighting conflicts with approach lights and touchdown zone lights.** Runway approach lights and touchdown zone lights are spaced every 100 feet throughout the overrun and for the first 3,000 feet of the runway. Touchdown zone lights are installed in groups of three, starting 36 feet each side of the runway centerline and spaced over a 10-foot light bar. LZ lights for C-17s will not conflict with touchdown zone lights because LZ lights are 50 feet each side of the centerline. C-130 LZ lights are installed 35 feet each side of the centerline, so conflicts should not occur. If touchdown zone lights are installed on the runway, move the LZ lights closer to the LZ edge to position them inside the touchdown zone lights.

AMP-3 Covert Infrared Lights

3-55. At some locations, infrared lights may be needed in addition to standard visual spectrum lights. Infrared lights can be installed according to table 3-1.

Table 3-1. Infrared transmitting filter specifications

Spectral Transmittal Limits	
Wavelength Nanometer	***Transmittance***
740 or less	<.01
800 ± 9	>.45
900	>.80

	Physical Properties	
	Nominal thickness range	4-6 millimeters 0.17-0.23 inch
	Thermal linear expansion	110 x 10^{-7}/^{o} C (30-300^{o} C) (86-572^{o} F)
	Refractive index (n)	1.53
	Density	2.67 g/cc
	Strain temperature	492^{o}C (918^{o} F)
	Transition temperature	510^{o}C (950^{o} F)
	Anneal temperature	526^{o}C (979^{o} F)
	Deformation temperature	563^{o}C (1,045^{o} F)

Legend:

C	Celsius
F	Fahrenheit
g/cc	grams per cubic centimeter

Infrared Light Fixtures

3-56. These fixtures should be FAA L-850A Style 3 fixtures, with a special infrared filter installed on the lens. Infrared transmitting filters shall meet the specifications listed in table 3-1 and be certified to comply with the specifications of an FAA-approved laboratory. Before installation on-site, the manufacturer shall supply an FAA-approved laboratory report certifying compliance.

Beacons

3-57. Airport beacons are not commonly used in combat zones. They may be used in sustaining areas of the TOs. 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

3-58. Lighted wind-direction indicators provide pilots with visual information about wind directions. Under radio silence or radio out conditions, the indicators are the only means available to the pilot to determine the direction of landing and takeoff and the magnitude of crosswinds. Use FAA L-806, Style 1, Size 1 or L-807, Style 1, Size 2 wind cone or approved equal.

Special Signal Lights

3-59. 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

3-60. Expedient lights 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.

Minimum Lighting Requirements for Temporary Applications

3-61. If available, lights should be omnidirectional steady-burn or flashing with a minimum output rating of 15 candela for night operations. According to AFI 13-217, virtually any overt lighting system is acceptable if participating units are briefed and concur with its use. Contingency lighting kits (emergency airfield lighting system) or other materials may be used as available and determined to be suitable by the STT.

3-62. 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 that its beam shines down the runway to light it.

3-63. Portable airfield lighting is available for use. It is normally used when permanent lighting has been damaged or is not available. Table 3-2 and tables 3-3 and 3-4, page 3-30, show portable marking standards (also refer to figures 3-20 through 3-26, pages 3-31 through 3-39). Table 3-3 indicates portable markings for fixed-wing LZs.

Table 3-2. 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

Legend:

km	kilometers
m	meters
met vis	meteorological visibility
vis	visibility

Table 3-3. 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	Directional or bidirectional	5,000	Runway edge, approach

Table 3-4. Portable lighting requirements (light-system specifications)

System type	*Light type*
1	A (Runway edge)
2	B (Runway edge) C (Approach) High intensity visual glide slope indicators
3	D (Runway edge, approach) High intensity visual glide slope indicators

Expedient Lighting and Communication Cables

3-64. 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 the quarter points, for example, three places—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 opposite 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 modified or ducts may be added if required by field conditions.

3-65. The cable duct should be 4 to 8 inches in diameter or an equivalent rectangle. It may be made with conduit 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 hand hole or conduit box with a heavy plank cover to keep earth out and to eliminate hazards to aircraft wheels (see figure 3-20).

LANDING ZONE LIGHTING

3-66. The airfield lighting system for LZs vary based on operational use, available equipment, and mission requirements. If night operations are not anticipated, no lights are required. A permanent system should be compatible with NVG usage.

3-67. For temporary applications, any available lighting system is acceptable. If available, omnidirectional lights with a minimum output rating of 15 candela should be used. Contingency lighting kits or other materials may be used if available and determined suitable by the STT. ETL 09-6 shows the preferred airfield lighting pattern, AMP-1, from AFI 13-217. Three other airfield lighting patterns, AMP-2, AMP-3, and AMP-4, are shown in AFI 13-217. For long-term operations and permanent applications, permanently installed lights should be used.

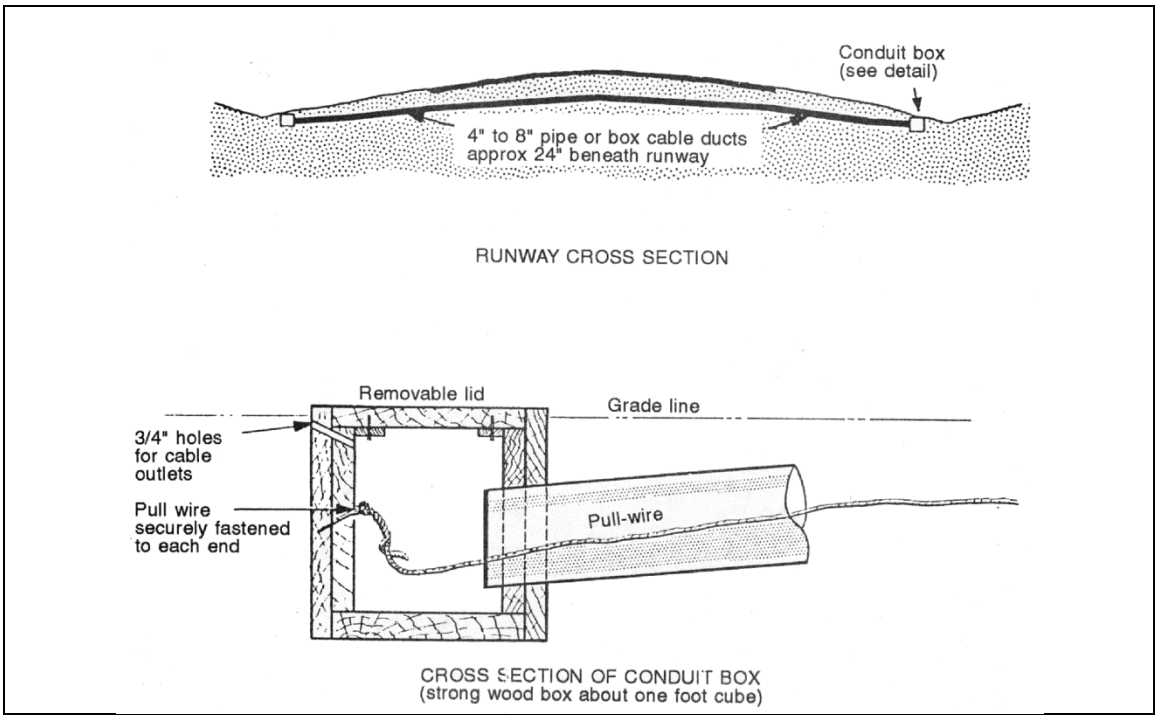


Figure 3-20. Cable duct details

Lights

3-68. If available, lights should be omnidirectional steady-burn or flashing with a minimum output rating of 15 candela for night operations. According to AFI 13-217, virtually any overt lighting system is acceptable if participating units are briefed and concur with its use. Contingency lighting kits (emergency airfield lighting system) or other materials may be used as available and determined to be suitable by the STT.

Locations

3-69. Light locations and colors are derived from the AMP-1 configuration in AFI 13-217.

Landing Zone Lights

3-70. Lights should be placed at each threshold and at 152 meters from each threshold. Intermediate lights should be 500 feet minimum/1,000 feet maximum spacing throughout the length of the runway. Spacing should be consistent through the intermediate lights. If a conflict with the lights exists on one or both sides of the LZ (for example, at locations where a taxiway connects to the LZ), that light should be an in-pavement light. Light fixtures shall be installed a maximum of 8 feet from the edge of the LZ surface (for example, within the shoulder pavement). Where lights are installed in pairs, lights should be 6 feet apart.

Turnaround, Taxiway, and Apron Edge Lights

3-71. All lights should be installed a maximum of 8 feet from the edge of the load-bearing surface. On straight sections of the taxiway or turnaround, lights should be spaced evenly with a maximum of 500 feet and a minimum of 75 feet between lights. See ETL 09-6 for typical turnaround and taxiway edge light locations. Light spacing should be reduced to between 25 feet and 35 feet on curves and at corners or intersections. On curved sections, lights shall be evenly spaced from point of tangency to point of tangency, with the maximum spacing between lights equal to half the taxiway width. For corners and curves exceeding 30 degrees of arc, there shall be a minimum of three lights. See UFC 3-535-01 for additional edge light location details.

Overrun Edge Lights

3-72. Overruns do not normally require edge lights; however, for overruns used as taxiways or turnarounds, edge lights may be installed using the location criteria stated. In addition, the first pair of edge lights installed on overruns should not be more than 100 feet from the runway threshold.

Light Reflector Panels (Optional)

3-73. Light reflectors may be installed at the mid-point between the LZ runway edge lights or the taxiway edge lights. Contact the STT for information on obtaining light reflector panels. For additional LZ light information see ETL 09-6.

OBSTRUCTION MARKING AND LIGHTING

3-74. Obstruction 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 UFC 3-535-01 and FAA Advisory Circular 70/7460-1.

OBSTRUCTION MARKING

Note. This section implements STANAG 3346.

3-75. 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 with 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 is colored in alternate bands of aviation-surface orange and white.

3-76. 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. The bands should have a width of not more than 40 feet or 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. Figure 3-21 and figure 3-22, page 3-34, show the color requirements.

Checkerboard Pattern

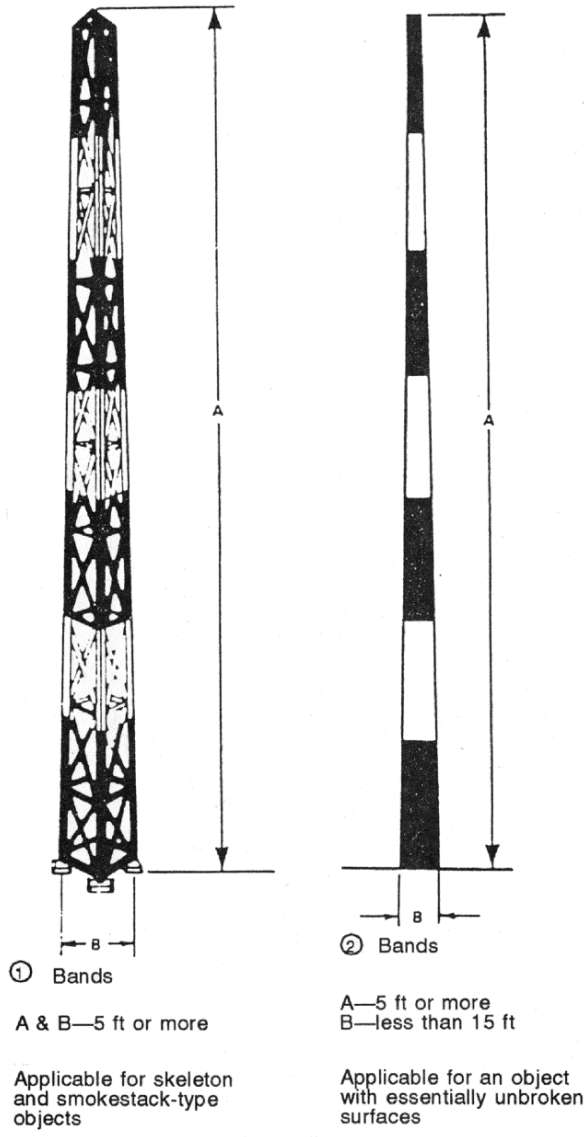
3-77. Objects with unbroken surfaces whose projection on any vertical plan is 15 feet or more in both dimensions are colored to show a checkerboard pattern of alternate rectangles of aviation-surface orange and white (see figure 3-22). The rectangles are not less than 5 feet and not more than 20 feet 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 structural surface. Ensure that the dimensions of the modified rectangles remain within the specified limits.

Marking by Markers

3-78. 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.

3-79. 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.

3-80. Position markers so that 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 highest wire level 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.



Legend:
ft feet

Figure 3-21. Painting of towers, poles, and similar obstructions

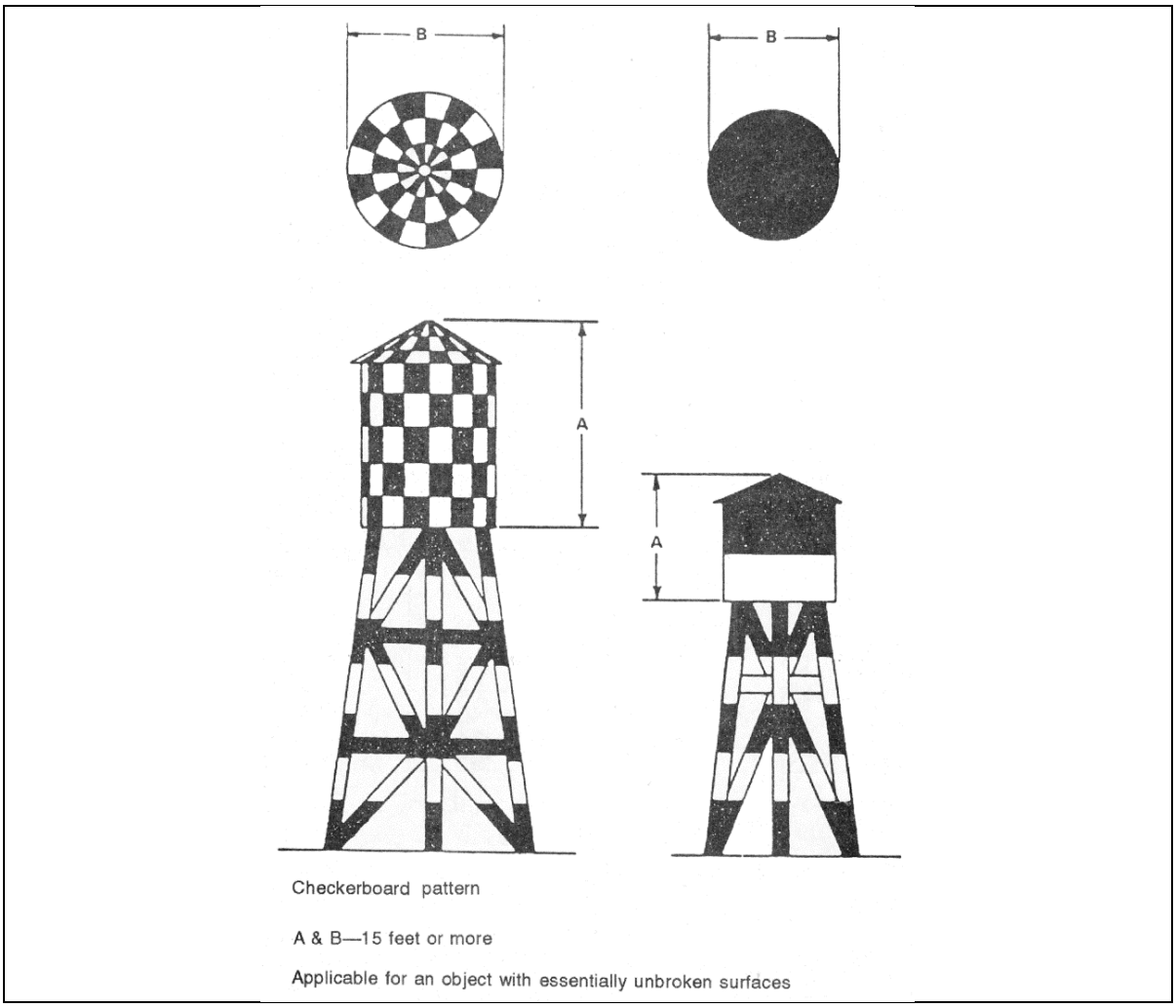


Figure 3-22. Painting of water towers

Marking by Flags

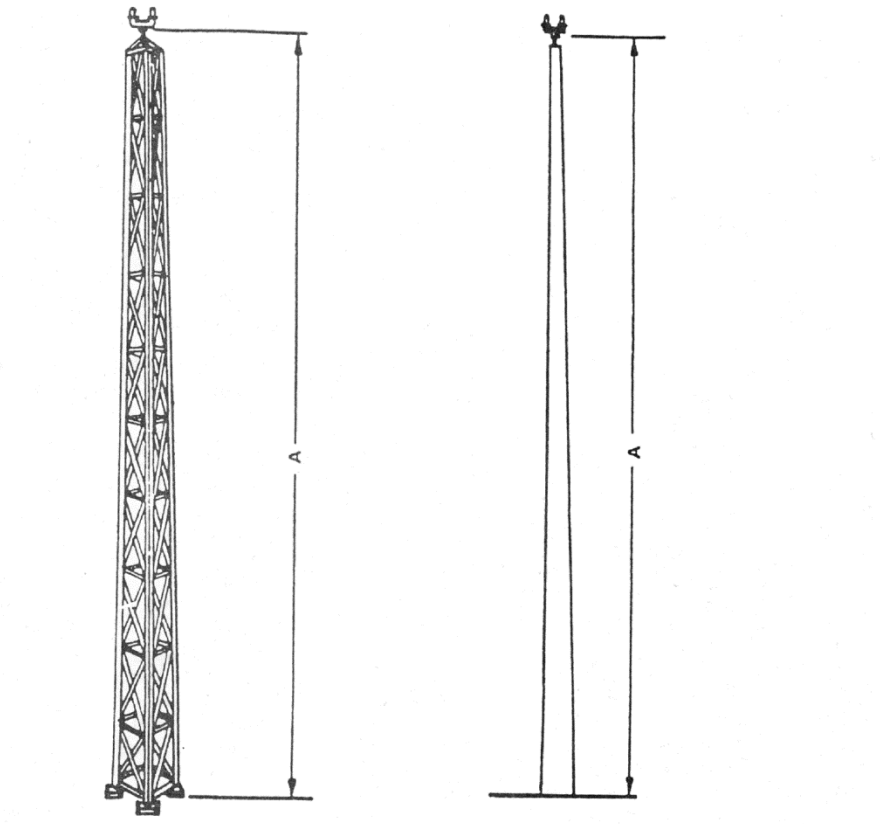
3-81. Use flags to mark temporary obstructions or obstructions that are impractical to mark by coloring or by markers. The flags should be rectangular and have stiffeners to keep them from drooping in calm or light wind. Use one of the following patterns on flags marking obstructions:

- 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.

3-82. 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

3-83. Obstruction lights show the existence of obstructions. These lights are aviation red, with an intensity of not less than 32.5 candelas. The number and arrangement of lights at each level should be such that the obstruction is visible from every angle. Figure 3-23 and figures 3-24 through 3-25, pages 3-36 through 3-37, illustrate methods of obstruction lighting.

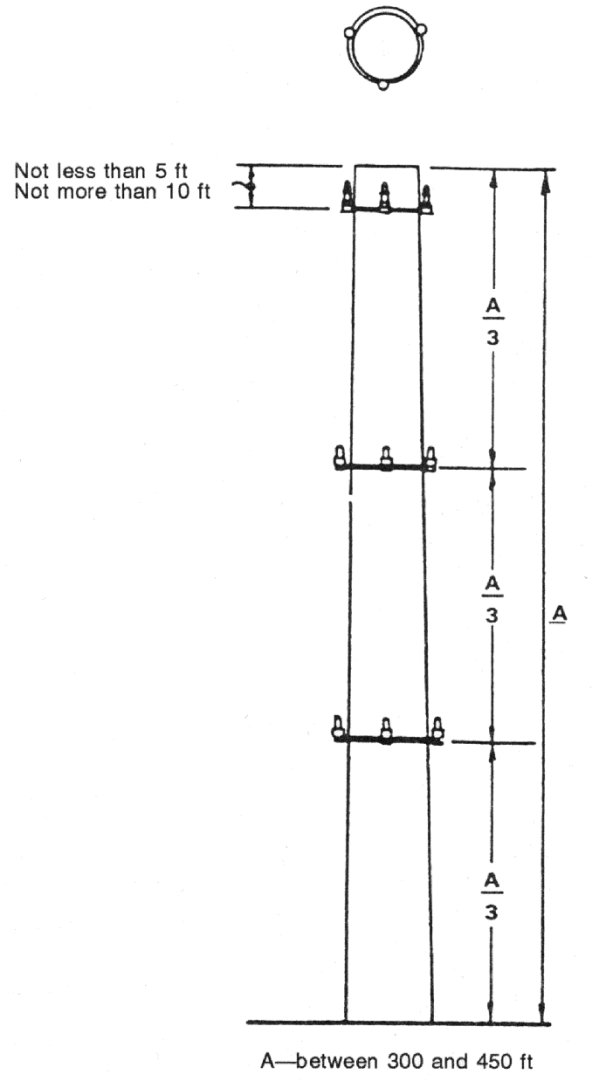


Legend:
ft feet

Figure 3-23. Lighting of towers, poles, and similar obstructions

Vertical Arrangement

3-84. Locate at least two lamps at the top of the obstruction, by 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 aboveground 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.



Legend:
ft feet

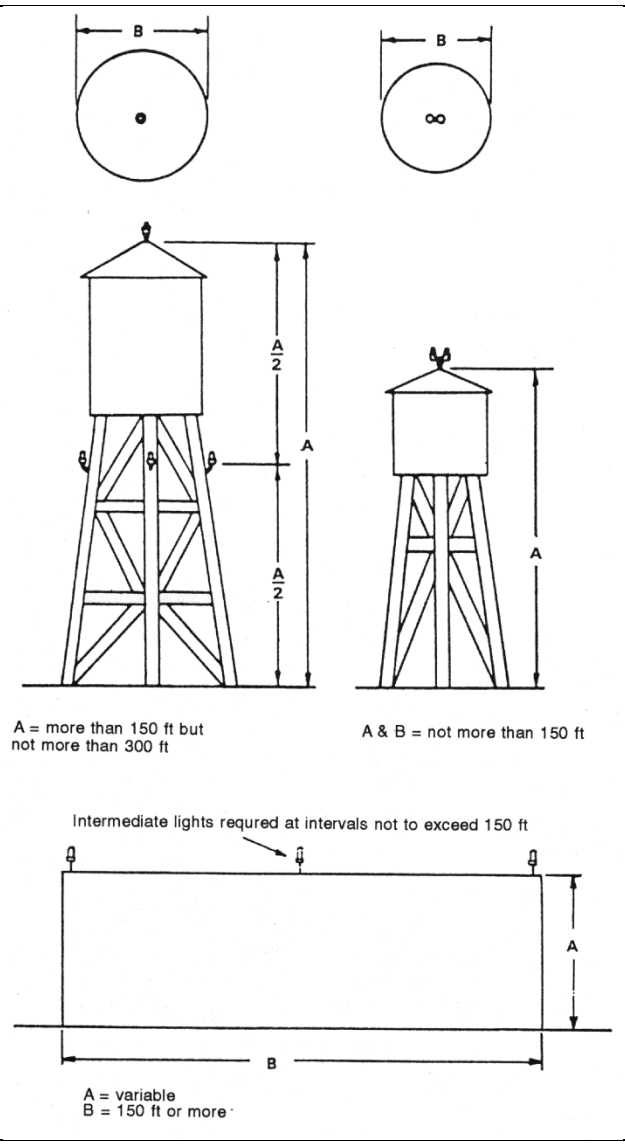
Figure 3-24. Lighting of smokestacks and similar obstructions

Horizontal Arrangement

3-85. 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 that 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

3-86. 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.



Legend:
ft feet

Figure 3-25. Lighting of water towers and similar obstructions

METHODS OF LIGHTING CONSTRUCTION AREAS

3-87. The following three methods are used for lighting construction areas:

- **Method A.** 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.** Method B is an upgrade of Method A when emergency repairs might take longer 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.** Method C is used when installing airfield lighting. Construction should approach the standards outlined in AFI 32-1044 and UFC 5-535-01. 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.

RADIO NAVIGATIONAL AIDS

3-88. Radio NAVAIDs refer to the ground equipment and supporting facilities that provide electronic (radio and radar) assistance in the navigation of aircraft. Electronic NAVAIDs consist of components of equipment, housing, and utilities. Each component serves a specific mission in directing or assisting the direction of airborne aircraft.

3-89. The electronic NAVAIDs used in a TO include—

- Mobile and air-transportable surveillance and precision approach radar ground-controlled approach.
- Radio homing beacons (nondirectional beacon).
- Ultrahigh frequency direction finders, very high frequency omnirange and tactical air navigation.
- Racons.
- Remote receiver and transmitter buildings for temporary construction (used with control tower).
- Control tower.

Criteria and Requirements

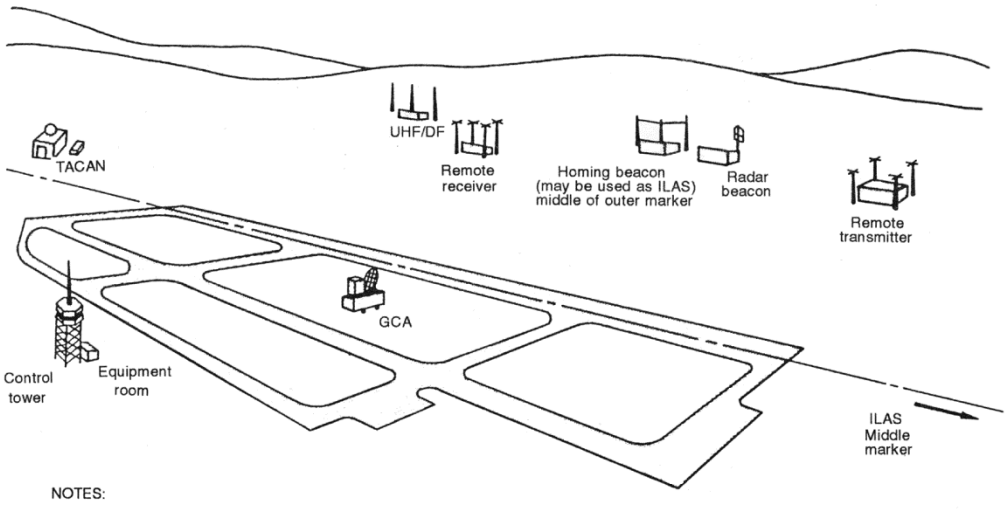
3-90. Not all systems listed are required at any one base. Requirements are determined by factors such as base mission, aircraft type, geographic location, terrain, and meteorological conditions. Final selection of the facilities required is made by the theater commander and requires technical determination by the AFCS or the United States Army Aeronautical Services Agency.

3-91. 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 electronic NAVAIDs are the minimum desirable for planning and obstruction design purposes:

- Priority 1—Mobile ground-controlled approach and homing beacon or tactical air navigation.
- Priority 2—Ultrahigh frequency direction finder.
- Priority 3—Racon.

3-92. Most electronic 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 equipment, cables, and antennas. United States Army Aeronautical Services Agency personnel provide technical assistance only.

3-93. The construction force provides and constructs prefabricated housing, access roads, hardstands, and foundations (bases) for antennas. The construction force also cuts ditches or trenches for laying cable; although, AFCS personnel supported by construction forces do the actual cable laying and antenna erection. AFCS and the United States Army Aeronautical Services Agency personnel do the final siting of facilities. In this section, only approximate siting is given. Thus, electronic NAVAIDs are considered in planning the layout of other facilities on a base (see figure 3-26).



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.

Legend:

DF	directional finder
GCA	ground-controlled approach
ILAS	Instrument Landing Aid System
TACAN	tactical air navigation
UHF	ultrahigh frequency

Figure 3-26. Typical location of NAVAID facilities

3-94. The adoption of standard electronic NAVAID buildings (T-0, T-1, T-2, T-3) has been made by using fractions of the basic 20- by 48-foot prefabricated building. The building used depends on the power supply generators required. In all-field and intermediate facilities requiring a shed for a power unit, cable is laid on the ground between the power shed and the equipment. For temporary construction, direct burial power cable is used. Remote cable is buried only in temporary construction.

3-95. The selection of the cable size depends on the distance over which the cable must carry power. Cable is not listed in the bill of materials, but it must be considered in planning and logistics.

Equipment and Power

3-96. Table 3-5, page 3-40, is a summary of commonly used electronic NAVAID equipment and the power requirements for each group of related equipment:

Table 3-5. NAVAID power requirements

Equipment	*Electrical Power Requirement*	*Load*
AN/FRN-43 VORTAC Navigational Set	120 VAC, ± 10%; 60 ± 3 Hz; 3 wires	8 kVA
AN/FRN-44 VOR Navigational Set	120 VAC, ± 10%; 60 ± 3 Hz; 3 wires	8 kVA
AN/FRN-45 TACAN Navigational Set	120 VAC, ± 10 %; 50 ± 3 Hz/60 ±3 Hz; 3 wires	8 kVA
AN/GPN-12 Radar Set	105 to 130 VAC (or 182 to 226 VAC 3-phase); 60 ± 2 Hz;	25 amps per phase; 3 kVA per phase
AN/GPN-20(V) Radar Set	120/208 VAC; 50/60 Hz; 3-phase; 4 wire; emergency power: 25.2 VDC from internal rechargeable 25 amps/hour battery bank	75 amps per phase; 9.0 kVA per phase
AN/GPN-23(V) Radar Set Display Segment (RAPCON Equipment)	120/280 VAC, 3-phase, 4-wire, 50/60 Hz	—
AN/GPN-23(V) RAPCON Equipment	120/280 VAC, 3-phase, 4-wire, 50/60 Hz	—
AN/GRN-30(V) Localizer Station	115/225 VAC, ±10%; 50 ±3-Hz or 60 ±3-Hz; 3 wire;	100 amps
AN/GRN-31(V) Glide Slope Station	115/225 VAC, ±10%; 50 ±3-Hz or 60 ±3-Hz; 3 wire;	100 amps
AN/GRN-32(V) Radio Beacon Set	103.5 to 126 VAC; single-phase; 47 to 63 Hz	240 watts (80 watts additional for battery heaters where required)
AN/GSN-12(V) Central Communications	120/208 VAC; 50/60 Hz; 3-phase; 4 wire	156 amps per phase; 18.7 kVA per phase

Legend:

amp	ampere
kVA	kilovolt-ampere
Hz	hertz
RAPCON	radar approach control
TACAN	tactical air navigation
V	volt
VAC	volts alternating current
VDC	voltage direct current
VOR	very-high-frequency omnidirectional radio (range)
VORTAC	very-high-frequency omnidirectional range tactical air navigator

Chapter 4

Airfield Pavement Design

This chapter provides information to help select, design, and construct airfield pavements. Decisive, support, and sustaining area TO airfields are designed according to specific aircraft characteristics and requirements governing the thickness, strength, and quality of materials. Airfield location and soil strength determine minimum pavement thicknesses and design procedures. The proper placement of the base, subbase, and subgrade determine the effectiveness of the airfield under climatic and seasonal conditions.

AIRFIELD STRUCTURE

4-1. Airfield structures fall into the categories of expedient-surfaced, aggregate-surfaced, and flexible-pavement. Expedient-surfaced and aggregate-surfaced airfields are used primarily in decisive, support, and sustaining areas. These airfields are also referred to as contingency airfields. Flexible-pavement airfields are usually constructed in the sustaining area.

PRELIMINARY INFORMATION

4-2. Traffic requirements, field conditions, and soil strengths are the most important pieces of information used to determine the feasibility of constructing an airfield at a particular location.

Traffic Requirements

4-3. Mission requirements typically dictate the type and number of aircraft required to satisfy mission objectives. The type and number of aircraft selected significantly affects the geometric and structural designs of the airfield. The suitability of a particular site is affected by the type and number of expected aircraft. Specific geometric requirements for individual aircraft are outlined in chapter 1. The structural requirements for individual aircraft are described in the paragraphs below.

Field Conditions

4-4. The knowledge of current field conditions is essential when designing and constructing an airfield. A proper description of the field conditions of a proposed construction site include—

- Overall environments (deserts).
- Obstructions (vegetation).
- Natural slopes.
- Existing drainage methods.
- Soil types.
- Soil moisture contents.
- Potential problems (dust, foreign object damage [FOD]).

4-5. Information about the climate, expected rainfall, type and amount of ground cover, slope, and estimated moisture content is used to estimate the construction effort required for a specific airfield. The potential for dust and FOD should be determined to predict possible problems at the site. Soil type and moisture content estimates are required to calculate the amount of water required for construction.

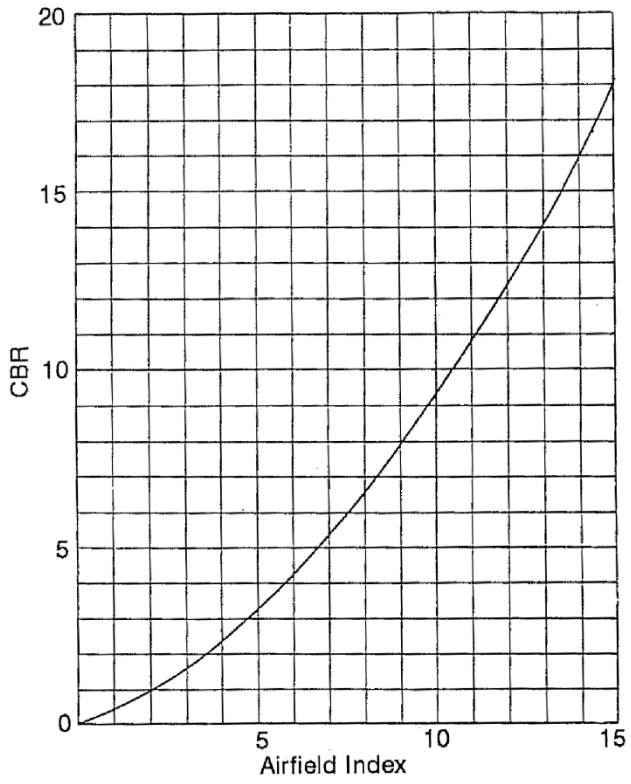
Soil Strength

4-6. The soil strength of an airfield is measured in terms of shear resistance or shear strength. The soil strength and bearing capacity of an airfield is determined by its ability to withstand aircraft loads. For most TO applications, the California Bearing Ratio (CBR) value of a soil is used as an index of its shear strength. The CBR is determined by a standardized penetration shear test and is used with curves for designing and evaluating airfields. The CBR test is usually performed on laboratory-compacted test specimens for use in pavement designs. For pavement evaluations, destructive test pits are usually excavated to determine in-place CBR values for each pavement layer.

4-7. For TO applications, laboratory and field in-place CBR tests are time-consuming and impractical. Therefore, alternatives to these tests have been derived to provide an indication of soil strength. The penetrometers that are currently in use include the airfield cone penetrometer, the trafficability cone penetrometer, and the dual-mass dynamic cone penetrometer (DCP).

4-8. The airfield cone penetrometer is used to determine an index of soil strength. The airfield cone penetrometer consists of a 30-degree cone with a 0.2-square-inch base area. The force required to penetrate to various soil depths is measured by a spring.

4-9. The airfield index (AI) is read directly from the penetrometer. The airfield cone penetrometer has an AI range of 0 to 15 (CBR value of 0 to 18). The AI-CBR correlation is shown in figure 4-1. The airfield cone penetrometer is compact and 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 courses, or gravel layers that may overlie soft soil layers. Relying on the surface, AI readings could cause the loss of vehicles and aircraft.



Legend:
CBR California Bearing Ratio

Figure 4-1. Correlation of AI and CBR

4-10. The trafficability penetrometer is a standard item in the soil test set. The trafficability penetrometer has a dial load indicator (0 to 300 range) and is equipped with two cones: One is a 0.5-inch-diameter cone with a cross-sectional area of approximately 0.2 square inch, and the other is a 0.8-inch-diameter cone with a cross-sectional area of 0.5 square inch. The trafficability penetrometer will not penetrate gravelly soils or aggregate soil layers, but may be used on fine-grained subgrade materials. The trafficability penetrometer can be used to obtain an AI value for the material. To obtain the AI for a material using the trafficability penetrometer, a conversion is necessary. For the 0.2-square-inch cone, the measured load must be divided by 20. For the 0.5-square-inch cone, the load must be divided by 50.

4-11. The dual-mass DCP described in appendix G will overcome some of the shortfalls associated with the trafficability and airfield cone penetrometers. The DCP is capable of penetrating soil layers having CBR strengths ranging from 1 to 100 percent. The DCP is a powerful, relatively compact device that can be used by inexperienced military personnel to determine soil strength. The correlation of the DCP index to CBR is shown in figure 4-2, page 4-4. The DCP kit can be procured using NSN 6635-01-436-6096. Test procedures for using the DCP are provided in appendix H.

4-12. For expedient-surfaced airfields in the decisive, support, and sustaining areas, the laboratory CBR test is inappropriate due to time and equipment constraints. One of the field-expedient methods described above should be used in the TO. If the proper device cannot be procured, the Unified Soil Classification System correlation can be used to estimate a suitable CBR for a given soil type. For each soil classification, empirical studies have determined a range of possible CBR values. These ranges can be found in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFMAN 32-1034_IP_. These typical CBR ranges are only estimates, and the lowest CBR value in the range should be used. Additionally, the soil type typically varies across the entire airfield.

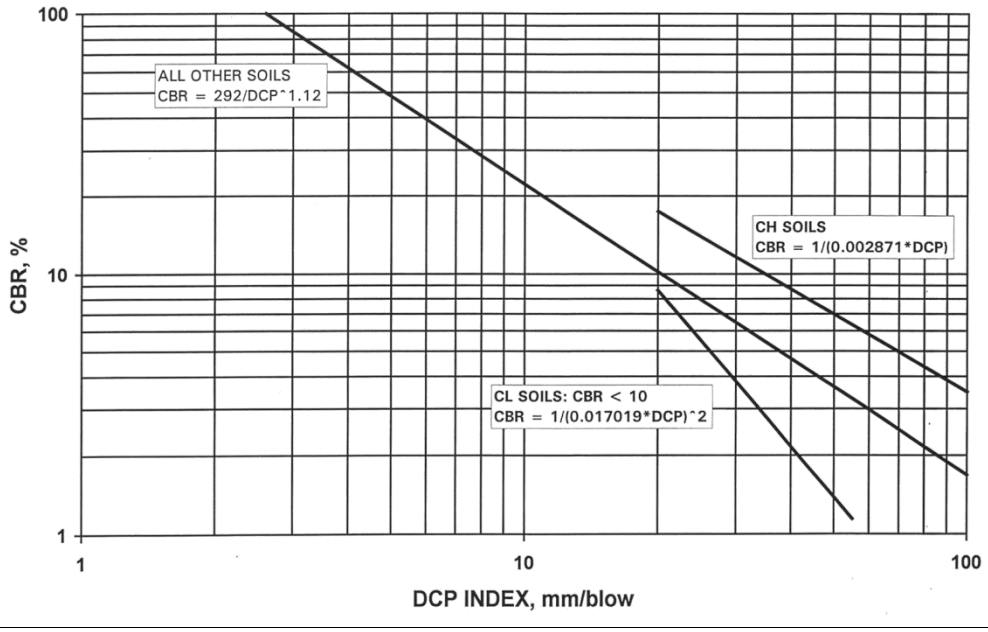
4-13. The soil strength of a material is dependent upon its moisture content and compaction. In order to improve the load-bearing capacity of a material, the soil strength must be improved. The primary method of improving soil strength to prevent rutting is to compact the material. High soil strength is generally associated with a high degree of compaction. However, obtaining and maintaining a desired strength in soils is contingent upon the moisture content at the time of construction and throughout the period of usage. The relationship between moisture content and compaction varies for different materials. Some basic moisture-density relationships for cohesive and cohesionless soils are discussed in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034. Generally, for airfields it is desirable to compact materials to the compactive to 55 blows per layer (CE 55), while it is in the desired moisture content range. The desired moisture content range of optimum ±2 percent and the resulting density range of 5 percent are derived from laboratory compaction curves developed from initial soil tests. These values compose the specification block in the design.

4-14. Soils may be treated to improve their engineering properties. Soils may be treated to improve material strength, reduce the effects of plasticity, provide dust control, and provide waterproofing. During construction, the soil treatment is determined by soil characteristics and the availability of stabilizing materials. See TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034 for additional information.

DESIGN CONSIDERATIONS

4-15. The design of airfield structures is based on—

- Airfield location/mission.
- Traffic areas.
- Design aircraft and associated gross weight.
- Expected number of passes of aircraft.
- Correlation plots of CBR versus DCP index (see figure 4-2).
- Strength of subgrade and available construction materials.
- Susceptibility of geographic area and construction materials to frost action.



Legend:

CBR	California Bearing Ratio
CH	clay high plasticity
CL	clay low plasticity
DCP	dynamic cone penatrometer
mm	millimeter

Figure 4-2. Correlation plot of CBR versus DCP index

Airfield Location/Mission

4-16. The location of the airfield within the TO is broken down into three major areas, as described in chapters 2 and 3. The mission of the airfield designates these areas as the—

- Decisive area.
- Support area.
- Sustaining area.

Traffic Areas

4-17. On expedient-surfaced airfields (see figure 4-3) in the decisive, support, and sustaining areas, traffic areas are Type A. The airfield is capable of supporting missions as soon as the runway is constructed. If the airfield is designed for C-130 aircraft traffic, the turnarounds must have a minimum diameter of 75 feet. For airfields designed to support C-17 aircraft operations, a hammerhead turnaround must be constructed on each end of the runway. The hammerhead must be at least 180-feet long and 165-feet wide. Since turnaround procedures are detrimental to the airfield surface, the hammerheads should be constructed using the maximum effort and available resources. Taxiways and aprons should be continually developed to support continuous traffic.

4-18. On aggregate-surfaced airfields in the support area, traffic areas are designated as shown in figure 4-3. Type A areas include primary taxiways, parking aprons, wash rack 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 account for some of the aircraft load, Type C areas are designed for only 75 percent of the total load.

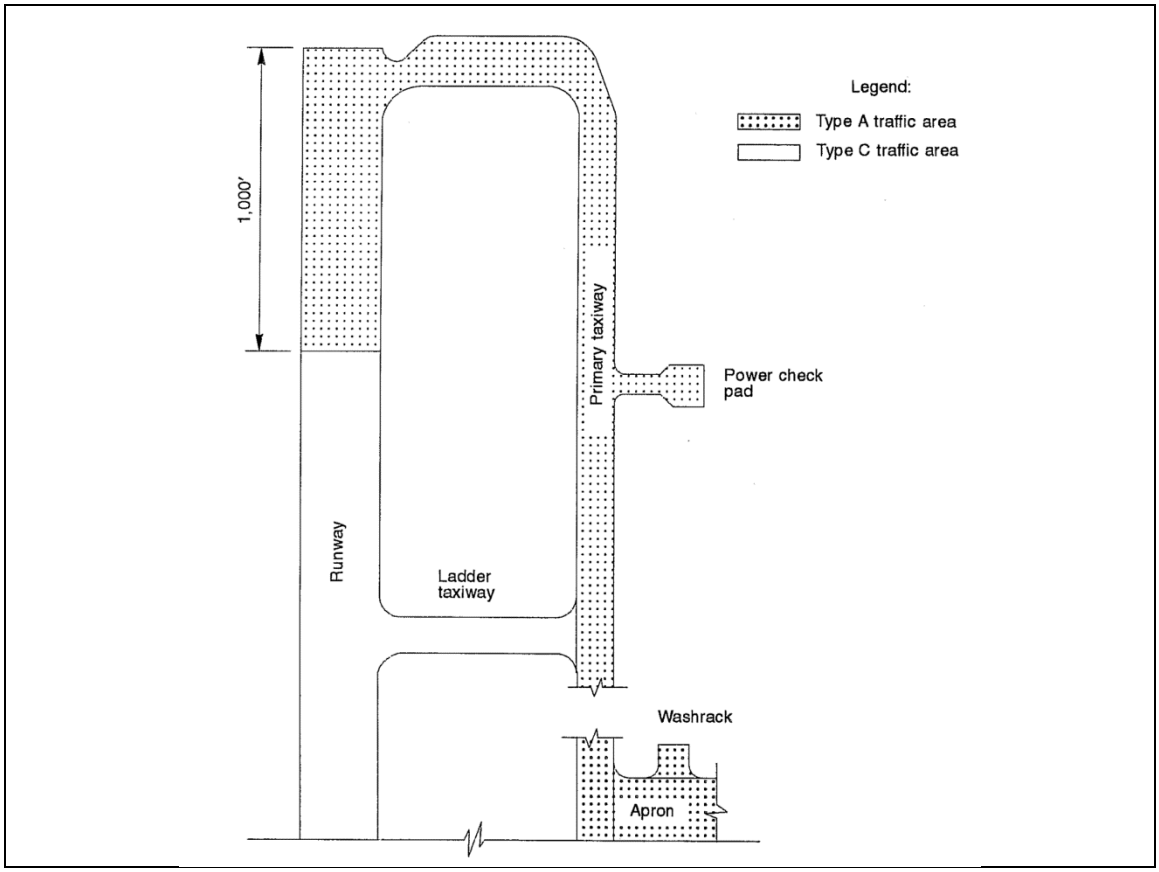


Figure 4-3. Typical layout for expedient-surfaced airfield in close battle and support areas

4-19. On paved airfields in the sustaining support 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 4-4, page 4-6.

4-20. Type A traffic areas include 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 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 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. Wash rack 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.

4-21. 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.

Design Aircraft and Associated Gross Weight

4-22. In TO airfield design, the design aircraft is based on airfield location and mission. 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 table 4-1, page 4-6, which can possibly use the airfield, the design aircraft is the one that presents the most extreme load distribution characteristics.

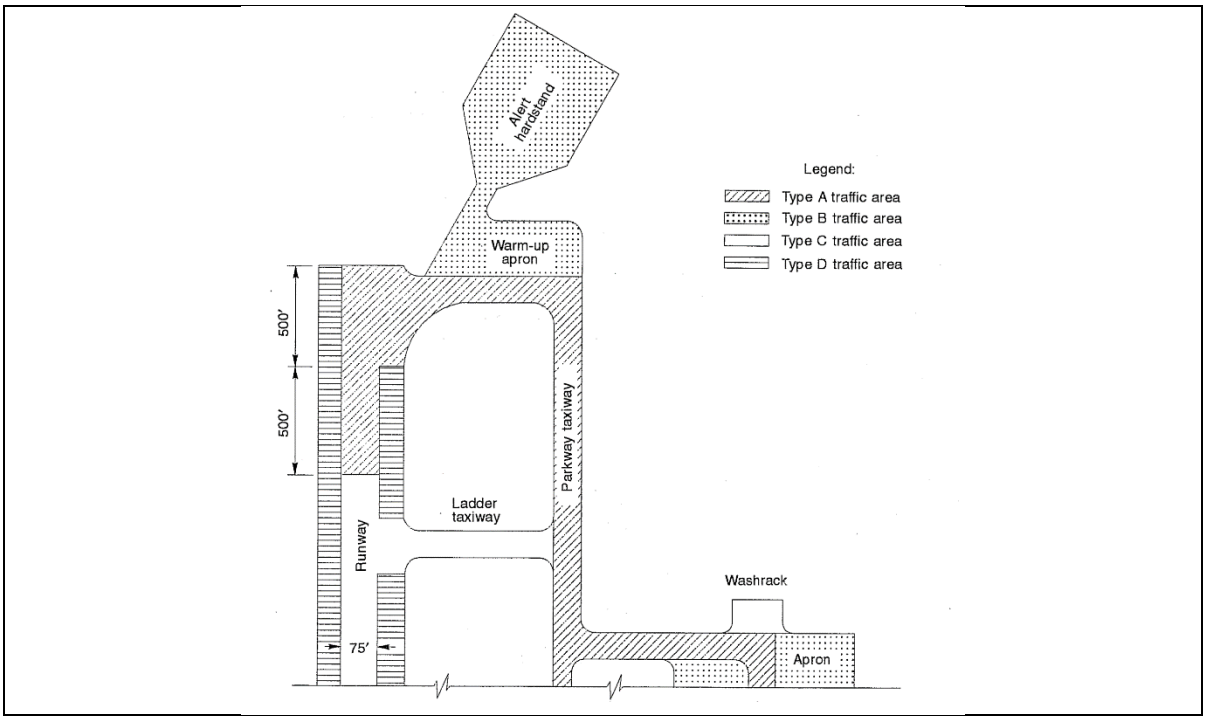


Figure 4-4. Typical layout of flexible-pavement airfields in the support area

Table 4-1. Design aircraft

Airfield location	*Design aircraft (thickness design)*	*Gross weight (kips)*
Decisive area	C-130E	130
	C-17A	447
Support area	C-130E	130
	C-17A	447
Sustaining area	C-17A	586

Notes.

1. The C-17 is the design when both aircraft are anticipated on the airfield.
2. These design aircraft should not be confused with constraining aircraft for takeoff ground run.

Expected Number of Passes

4-23. 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 runway and parking apron. At single runway airfields, the pass level of the runway, taxiway, and apron should be the same.

4-24. For airfields that do not have a parallel taxiway, the number of design passes should be doubled to account for additional load repetitions due to taxi movements that will take place on the runway. 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 that measures are taken to improve 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.

Soil Strength

4-25. 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 TM 3-34.48-1. 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

4-26. 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. The following three conditions must exist simultaneously for detrimental frost action to occur:

- The soil must be frost-susceptible.
- The temperature must remain below freezing for a considerable period time.
- An ample supply of groundwater must be available. Precise methods for estimating the depth of freeze and thaw in soils are contained in TM 5-830-3/AFM 88-17. In addition, TM 5-822-7/AFM 88-6 contains the criteria and procedures for the design and construction of pavements subject to seasonal frost action. Specific design procedures for frost are discussed in detail in the aggregate-surfaced and flexible-pavement airfield design sections.

EXPEDIENT SURFACED AIRFIELDS

4-27. Unsurfaced deserts, dry lakebeds, 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.

4-28. Expedient-surfaced airfields are primarily used for the movement of troops and supplies in the decisive, support, and sustaining 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 decisive 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 for a limited number of operations. Therefore, expedient-surfaced airfields are designed either for the C-130 or the C-17.

4-29. Since the main 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 steps to determine the expedient surface type and its expected service life:

- **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. Potential LZ areas fall into the three following 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 lakebeds, and flat valley floors).
  - **Surfaced.** Unsurfaced airfields requiring a matting surface because of the in-place soil or to increase the service life of the airfield.

  United States Air Force special tactics teams (STTs) are trained to perform airfield evaluations in support of C-130 and C-17 aircraft operations. STTs gather available information on potential sites and then perform site visits to evaluate the geometrics of the site and the load-bearing capacity of the airfield. STTs are equipped with hand-held pocket transits, clinometers, and levels to check clearances and slopes. Airfield cone penetrometers and DCPs are used to determine the

strength and thickness of existing soil layers of unsurfaced ALZs. STTs are not qualified to evaluate existing paved surfaces. STTs present an ALZ survey package containing the site information and a recommendation for the approval/rejection of the use of the proposed airfield site. The final decision is made by the appropriate Air Force command center.

An engineering team using theodolites, auto levels, and Philadelphia rods should survey airfields that require precise determination of gradients. Alternatively, differential GPS surveying techniques and equipment with subcentimeter vertical accuracy may be used.

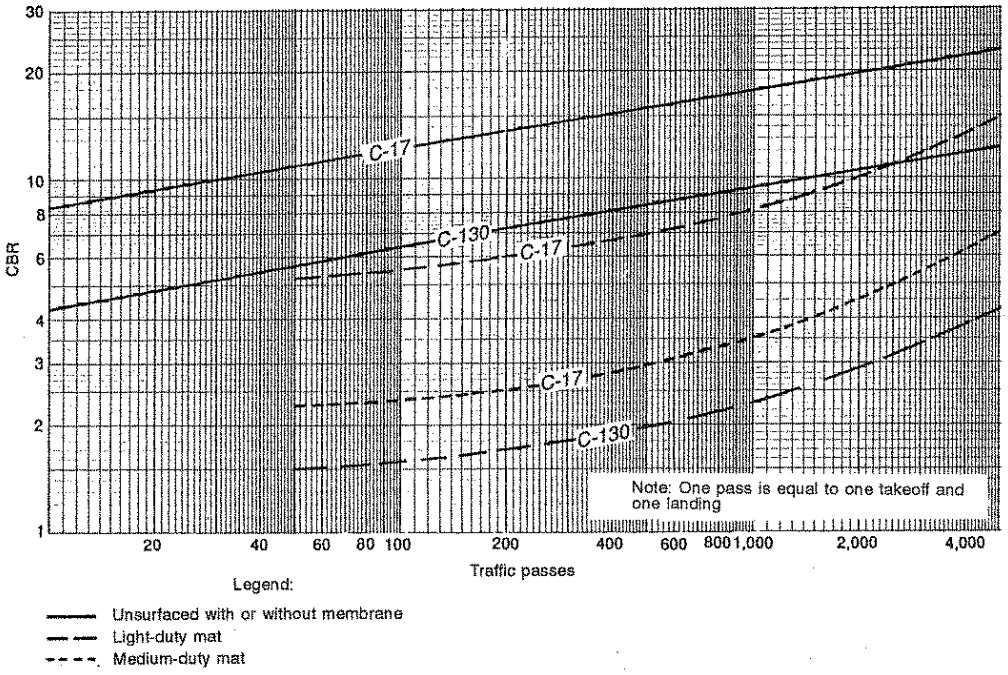
After a potential airfield site has been selected, it must be tested to ensure its suitability. The reconnaissance leader must first determine the alignment of the airfield and the location of the runway, hammerhead turnaround, taxiway, and parking apron (if any). Airfield approach zones also must be evaluated for satisfactory glide angles. (See TM 3-34.48-1.) 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.
- **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 organic and loose granular soils 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 may indicate a problem. Additionally, animal burrow holes, areas prone to flash flooding, previously forested areas, and dry lakebeds may 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 areas. Appendix G 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 the design examples below.
- **Step 4. Determine the required number of passes.** From the mission statement or an estimate of the situation, determine the maximum 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, one can determine the airfield surface 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 see appendix J.
- **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 it into figure 4-5 and determining the number of allowable passes. The surface type (unsurfaced or mat surfaced) 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 the service life of the soil. 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 AM2 mat curve. 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.



Legend:

CBR California Bearing Ratio

Figure 4-5. Subgrade strength requirements for C-130 and C-17

DESIGN EXAMPLES

4-30. The design step examples depict how to derive required CBR for aircraft.

Example 1

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

Solution 1

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

Step 2. From table 4-1, page 4-6, 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 4-1, page 4-2, 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 4-5. 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 surface. In this case, the unsurfaced curve is less than 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 447 kips in the support area (table 4-1, page 4-6).

Step 3. DCP index is 60. From figure 4-2, page 4-3, CBR = 3.

Step 4. The required number of passes is 600.

Step 5. From figure 4-5, page 4-9, the intersection of the unsurfaced curve and the soil CBR yields zero passes. The only surface available for this low CBR and runway operations is AM2 mat. The allowable number of passes for a C-17 weighing 447 kips on AM2 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. By improving the index only slightly, the service life can be met using compaction only. Consider stabilization or adding a base course as other methods if compaction alone is not enough.

EXPEDIENT AIRFIELD DESIGN—SPECIAL CASES

4-31. 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 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

4-32. 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, consider stabilizing the subgrade. See TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034 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 main battle area. Gross weight is 130 kips. The soil-strength profile is shown below.

Depth (Inches)	California Bearing Ratio
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 main 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 4-5, page 4-9, to determine the surface type and allowable number of passes. For a CBR = 5.5, an unsurfaced airfield allows only 42 passes. If AM2 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 AM2 mat.

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

4-33. 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.

4-34. 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. Airfield personnel must carefully monitor this. The maximum rutting depth is 3 inches and is based on the orientation of the ruts and the soil strength.

4-35. If the very soft layer is more than 4 inches thick, grading to at least 4 inches should reduce the soft layer. If the depth of the soft layer cannot be reduced 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; the soil-strength profile is shown below.

Depth (Inches)	Airfield Index (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, 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 4-1, page 4-2, is 5.4.

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

Step 5. The surface type is AM2 mat, capable of supporting 5,000 passes from figure 4-5, page 4-9.

Note. If the CBR was high enough to justify an unsurfaced airfield, airfield personnel should carefully monitor the runway to ensure ruts do not exceed the maximum depth of 3 inches.

Hard Layer Over a Softer Layer

4-36. Some soils may yield a profile that shows a hard layer over a soft layer. This type of 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.

4-37. 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.

4-38. 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.

4-39. 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 main 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 through 3. Main 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 4-5, page 4-9) for an unsurfaced airfield.

Example 6

Design an airfield in the support area for use by both C-130s (130 kips) and C-17s (447 kips) for 1,000 passes. The soil analyst used a DCP to determine the soil strength profile. The soil-strength profile is shown below.

Depth (Inches)	Airfield Index (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 = main 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 4-1, page 4-2).

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

Step 5. From figure 4-5, page 4-9, an unsurfaced airfield allows 130 passes for a soil CBR = 13. Since this does not meet commander guidance, check other surfaces. AM2 mat can be used in this situation.

4-40. A hard soil layer over a soft layer can usually be found in dry lakebeds 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

4-41. 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 lakebeds or where the groundwater can be found close to the surface. Areas such as these may also be subjected to seasonal fluctuation if the water table causes the soil profile to change.

4-42. Determine the critical CBR for this type profile by evaluating various layers to a depth of 24 inches. Determine the critical CBR of the profile by choosing the lowest average CBR from the following layers: 6 to 18 inches, 8 to 20 inches, 10 to 22 inches, and 12 to 24 inches.

4-43. 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 4-5, page 4-9, the allowable number of passes = 180 (unsurfaced) and 5,000 passes (AM2 mat).

Example 7

Determine the number of allowable C-130 traffic passes on an airfield in the main battle area, with a gross weight 130 kips, and a soil strength profile shown below.

Depth (Inches)	Airfield Index (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 = main 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:

$$\frac{10.5 + 10.5 + 9 + 8 + 8 + 8}{7} = 8.9$$

$$\frac{10.5 + 9 + 8.5 + 8 + 8 + 8 + 7}{7} = 8.4$$

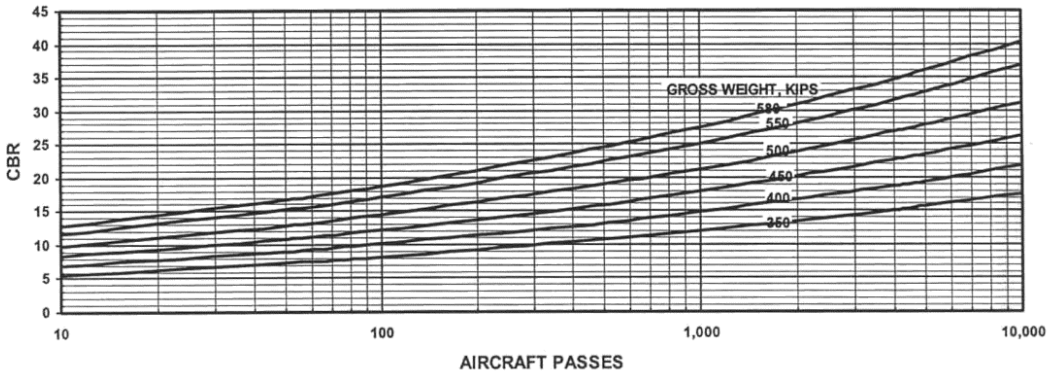
$$\frac{8.5 + 8 + 8 + 8 + 7 + 6}{6} = 7.6$$

$$\frac{8 + 8 + 8 + 7 + 6 + 6.5 + 7}{7} = 7.2$$

UNSURFACED DESIGN FOR C-17 AIRCRAFT

4-44. The criteria presented herein describe the design of unsurfaced contingency airfields (close battle and support areas). The first step in the design is to obtain the site reconnaissance or investigation data to determine existing site conditions. Divide the subsurface soil strength data into layers of varying thickness by grouping materials possessing similar CBR values. The second step in the design of contingency airfields for the C-17 aircraft is to determine the design aircraft loading and the number of aircraft passes required to support mission requirements. The steps above are also applicable to the design of AM2 mat-surfaced and aggregate-surfaced contingency airfields which will be presented later.

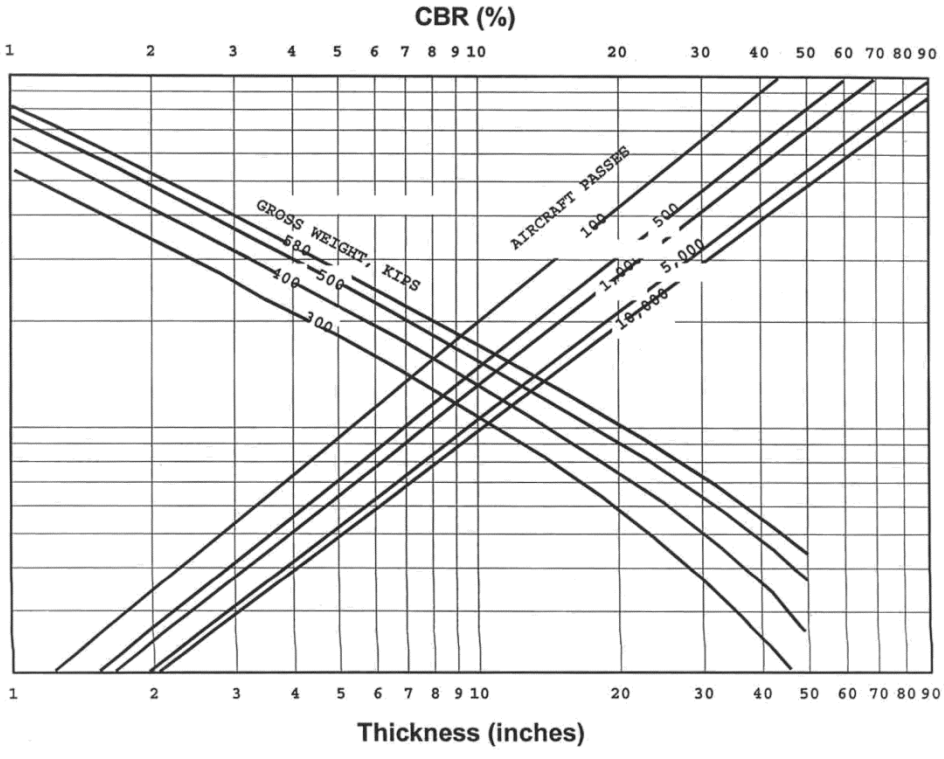
4-45. The unsurfaced designed criterion consists of the determination of a minimum surface CBR value and a minimum thickness of material equal to or greater than the minimum surface CBR over a lower strength material. Existing soil conditions must meet both the surface CBR requirement and the thickness requirements. To determine if the surface CBR is sufficient to sustain the design traffic, enter figure 4-6 with the required number of aircraft passes. Proceed vertically until the pass level intersects the appropriate design gross weight of the aircraft. Finally, trace a horizontal line from this intersection to the required subgrade CBR value. The CBR obtained is the surface soil strength required to support the design aircraft load at the required pass level. If the CBR obtained from figure 4-6 is greater than the in-place subgrade CBR determined from the preliminary site investigation, the airfield will require structural improvement to support mission requirements. If the CBR obtained from table is equal to or less than the in-place subgrade CBR, the surface CBR requirement is met. If the in-place surface CBR is only slightly less than the minimum CBR, scarify and compact the in-place material. Then, reevaluate the subgrade soil strength by one of the methods described above and compare the compacted in-place CBR to the required CBR from figure 4-6. Next, determine the minimum thickness of the required CBR from table 4-14, page 4-49. Enter figure 4-7 at the top with the in-place subgrade CBR and draw a vertical line down until it intersects the design gross weight of the aircraft. Then, draw a horizontal line from this point until it intersects the required design passes. Finally, draw a vertical line down from the required pass level until it intersects the required thickness. This thickness is the required thickness in inches of a material of the minimum surface CBR determined from, figure 4-6, necessary to support mission requirements. If the in-place subgrade CBR is equal to or greater than the minimum subgrade CBR determined from figure 4-6 and the preliminary site investigation revealed that the depth of the in-place subgrade CBR is equal to or greater than the thickness determined from figure 4-7, then the airfield is structurally adequate to support the design traffic. If a weaker soil layer is encountered at some depth below the surface soil layer, the thickness of material required to protect the weaker soil layer should be checked using figure 4-7. Enter figure 4-7 with the CBR of the weak layer rather than the CBR of the surface layer. If the thickness of the surface layer is not sufficient to protect the underlying weak layer, the airfield requires structural improvement to withstand the design traffic. Structural improvements for contingency airfields include the addition of an aggregate or select fill layers(s), stabilization of the natural subgrade or the use of AM2 matting. The design criteria for mat-surfaced and aggregate-surfaced airfields are presented later.



Legend:

CBR California Bearing Ratio

Figure 4-6. Unsurfaced strength requirements for the C-17 aircraft



Legend:

CBR California Bearing Ratio

Figure 4-7. Aggregate or select or fill surface fill thickness requirements for C-17 aircraft

Example 8

Design an airfield in the TO for 200 operations of a C-17. A special tactics team determined that the in-place CBR of the soil was 16 for a depth of approximately 24 inches beyond which there is a 12-inch layer of 10 CBR material. The geometric design of the airfield does not include a parallel taxiway.

Solution 8

Note. The number of required passes should be multiplied by 2 to account for the aircraft taxing down the runway to takeoff or unload cargo.

Step 1. The design aircraft has been designated as the C-17. The design gross weight of the C-17 is 447 kips which seems reasonable in regard to mission requirements.

Step 2. The design aircraft passes stated were 200; however, for design purposes (as noted above) 400 passes will be used to account for taxi movements.

Step 3. Using figure 4-7, page 4-17, determine the minimum required subgrade strength to support 400 passes of a 447 kip C-17 aircraft. Enter figure 4-7 with 400 passes and draw a vertical line to just below the 450 kip gross weight curve. From this point, draw a horizontal line to the vertical axis to determine the required CBR. The required subgrade CBR for 400 passes of a 447 kip C-17 is approximately 15 CBR.

Step 4. Since the minimum required CBR is less than the in-place CBR (15 < 16), then the in-place subgrade surface strength is sufficient to support mission requirements. It must also be determined if adequate thickness of 16 CBR material is available. Enter figure 4-7 at the top with the in-place subgrade 16 CBR and draw a vertical line down until it intersects the design gross weight of the C-17 or 447 kips. Next, draw a horizontal line from this intersection until it intersects the design pass level of 400 passes. Finally, draw a vertical line from this intersection downward until the required thickness is intercepted. Seven inches of 16 CBR material is required to support 400 passes of a 447 kip C-17 aircraft. Because the in-place soil has 24 inches of 16 CBR material, the unsurfaced airfield can support the design aircraft for the design passes without structural improvement.

Step 5. Because there is a 12-inch layer of weaker material underlying the surface layer, it must be determined if the surface soil layer has adequate thickness to protect the underlying, weaker layer. Enter figure 4-7 with the weaker layer 10 CBR, and draw a vertical line down until it intersects the design gross weight of the aircraft or 447 kips. Next, draw a horizontal line from the intersection until it intersects the design pass level of 400 passes. Finally, draw a vertical line from this intersection downward to the intercept of the required material thickness. Nine inches of a 15 CBR material is required to protect the weak subsurface soil layer. Since the in-place soil has 24 inches of a 16 CBR material, the weak layer is adequately protected and the design is valid.

Example 9

TO developments require a second contingency airfield design to support 200 passes of a C-17. The special tactics team determined that the in-place CBR of the soil at the second site is 12 for a depth of approximately 20 inches beyond that which the CBR of the material increased. This airfield will not possess a parallel taxiway.

Solution 9

Step 1. The design aircraft has been designated as the C-17. The design gross weight of the C-17 is 447 kips, which seems reasonable in regard to mission requirements.

Step 2. The design aircraft passes were 200; however, for design purposes (as noted in Example 8), 400 passes will be used to account for taxi movements.

Step 3. Using figure 4-7, page 4-17, determine the minimum required subgrade strength to support 400 passes of a 447 kip C-17 aircraft. Enter figure 4-7 with 400 passes, and draw a vertical line to just below the 450 kip gross weight curve. From this point, draw a horizontal line to the vertical axis to determine the required CBR. The required subgrade CBR for 400 passes of a 447 kip C-17 is approximately 15 CBR.

Step 4. Since the required CBR is greater than the in-place CBR (15 > 12), then the subgrade must be improved structurally to support mission requirements. First, determine the thickness of 15 CBR material required above the subgrade to support mission requirements. Enter figure 4-7 at the top with the in-place subgrade 12 CBR and draw a vertical line down until it intersects the design gross weight of the C-17 or 447 kips. Next, draw a horizontal line from this intersection until it intersects the design pass level of 400 passes. Finally, draw a vertical line from this intersection downward until the intercept of the required thickness. The design requires 8 inches of 15 CBR material be placed over the in-place subgrade in order to support 400 passes of a 447 kip C-17 aircraft.

SMOOTHNESS REQUIREMENTS FOR UNSURFACED AIRFIELDS

4-46. While unsurfaced airfields require little preparation, both the C-130 and the C-17 require relatively smooth surfaces for takeoff and landing. The overall grades, grade changes, and slopes must be within the limits indicated in table 4-2, page 4-20. 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 rutting depth that can be traversed safely is 3 inches.
- 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.

4-47. 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 MAT-SURFACED AIRFIELDS

4-48. Many high-performance Air Force and Navy 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 FOD and soil strength requirements. Matting can alleviate some of these problems. Mats currently in the military inventory include AM2, ACE-Mat™, Mobi-Mat®, and Tactical Helimat airfield

matting systems. Mobi-Mat and Tactical Helimat are only used for dust control and FOD protection for rotary-wing operations. ACE-Mat systems are capable of supporting both fixed-wing and rotary-wing aircraft operations, but are limited by aircraft weights and underlying soil strength. These mats are only approved for taxi and parking operations by fixed-wing aircraft, but may be used for rotary-wing vertical takeoff and landing operations if proper anchoring is provided. AM2 mats are approved for all fixed-wing and rotary-wing aircraft operations when proper installation and certification procedures are followed. A thorough discussion on matting placement and certification is contained in NAVAIR 51-60A-1 and NAWCADLKE-MISC-48J200-0011 which have been adopted as governing documents for mat placement for all Services. Table 4-2 lists general characteristics of current approved matting systems.

Table 4-2. Airfield mat properties

	AM2	***ACE-Mat***	***Mobi-Mat***	***Tactical Helimat***
National stock number	5680-01-176-9076	5675-01-476-8989	—	—
Panel placing dimensions (W x L), feet	2.0 x 12.0	6.0 x 6.0	13.7 x 33	20.0 x 20.0
Panel depth (D), inches.	1.5	0.35	0.50	4.5
Panel weight, pounds	145.5	115	183	50.6
Placing area per panel, square feet	24	36	452	400
Weight per square foot in place, pounds	6.1	3.19	0.41	0.13
Placing rate, square foot per man-hour:	—	—	—	—
On 1 ½ percent crown	163	350	1500	1500
On 3 percent crown	112	350	1500	1500

Smoothness Requirement for Mat-Surfaced Airfields

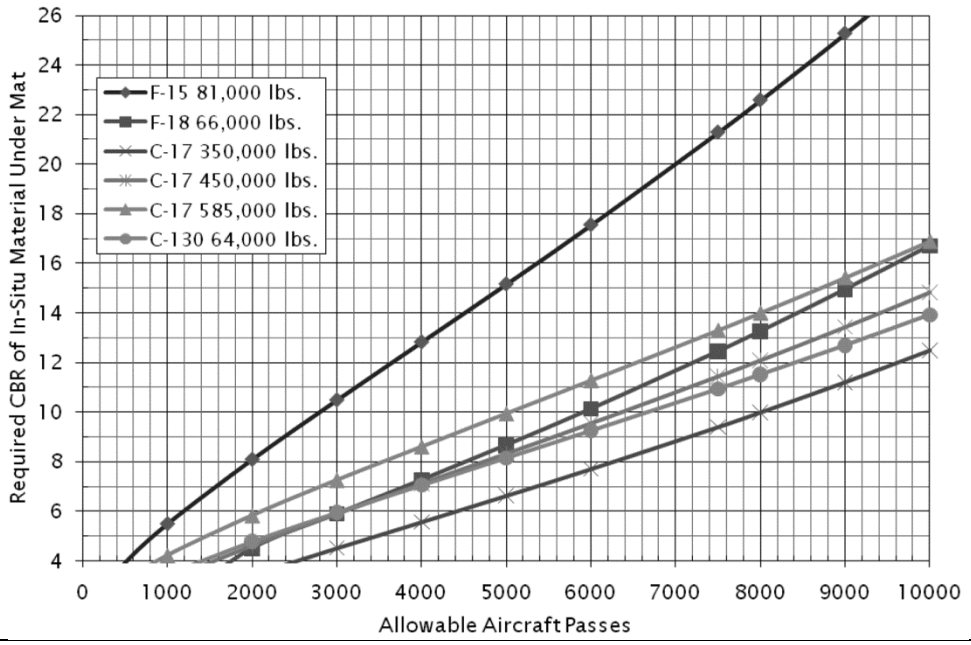
4-49. Mat surfacing provides a smooth, well-drained, fine-graded surface free of local depressions or potholes. Surface smoothness requirements for this airfield category apply to the surface of the subgrade before the placement of the airfield mat. For satisfactory performance, the airfield mat must be supported by the subgrade and must not be required to bridge over depressions or potholes. Prepare a satisfactory surface for the airfield mat by compacting and fine grading to a predetermined grade. See NAWCADLKE-MISC-48J200-0011 for gradation requirements. Grade runways and the taxiway to provide a crown section or transverse slope that meets the design standards are outlined in NAWCADLKE-MISC-48J200.

MAT—SURFACED DESIGN FOR C-17 AIRCRAFT

4-50. Heavy cargo aircraft may not be able to operate on unsurfaced airfields due to the soil strength requirements. The use of a mat surfacing may be a plausible solution. Current military inventories consist of AM2 and ACE-Mat matting systems for fixed-wing aircraft. These mats are discussed in detail in NAVAIR 51-60A-1. For satisfactory performance, the airfield mat must be supported by the subgrade and must not be required to bridge over depressions. To determine if the subgrade is capable of supporting a mat-surfaced airfield, the minimum required subgrade CBR must be determined from figure 4-8, and compared to the in-place subgrade CBR. Enter figure 4-8 at the bottom with the required number of aircraft passes and draw a vertical line to the intersection of the appropriate design gross weight curve. Then, draw a horizontal line to the vertical axis to determine the minimum required subgrade CBR. Now that the required subgrade CBR has been determined, it is necessary to check the subgrade thickness requirements. Use figures 4-9 through figure 4-13 (pages 4-22 through 4-24) to find the thickness of the subgrade that is required at the predetermined soil strength (from figure 4-8) for different design gross weights of the aircraft. Use the in-place subgrade CBR when using figures 4-9 through figure 4-13 to determine the minimum thickness requirements. For example, enter figure 4-11, page 4-23, for a C-17 aircraft with a design gross weight of 450,000 pounds at the bottom with the in-place subgrade CBR. Draw a vertical line from the in-place subgrade CBR to the intersection of the appropriate design pass level. Then, draw a horizontal line from this

intersection to the vertical axis to determine the thickness of subgrade (at the required strength) that must exist beneath the matting. If the preliminary site investigation indicates that the in-place subgrade CBR is greater than or equal to the minimum required CBR obtained from figure 4-8 and that the in-place soil strength is consistent for a depth equal to or greater than the thickness required in figure 4-9 through figure 4-13, pages 4-22 through 4-24, then a mat surfacing will be adequate to sustain the design traffic of the mission. Otherwise, matting will not provide sufficient structural improvement to the natural subgrade to support the design aircraft operations. Figure 4-9 through figure 4-13 should be used with caution for Navy and Marine airfields since their criteria require a minimum CBR of 25 under mat-surfaced airfields to reduce subgrade maintenance requirements).

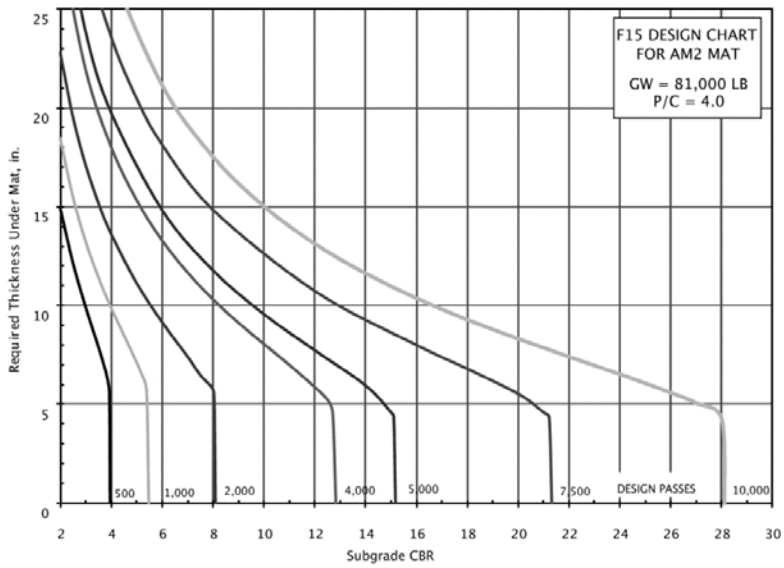
Note. Only AM2 airfield mats can be used for runway operations.



Legend:

CBR	California Bearing Ratio
lbs	pounds

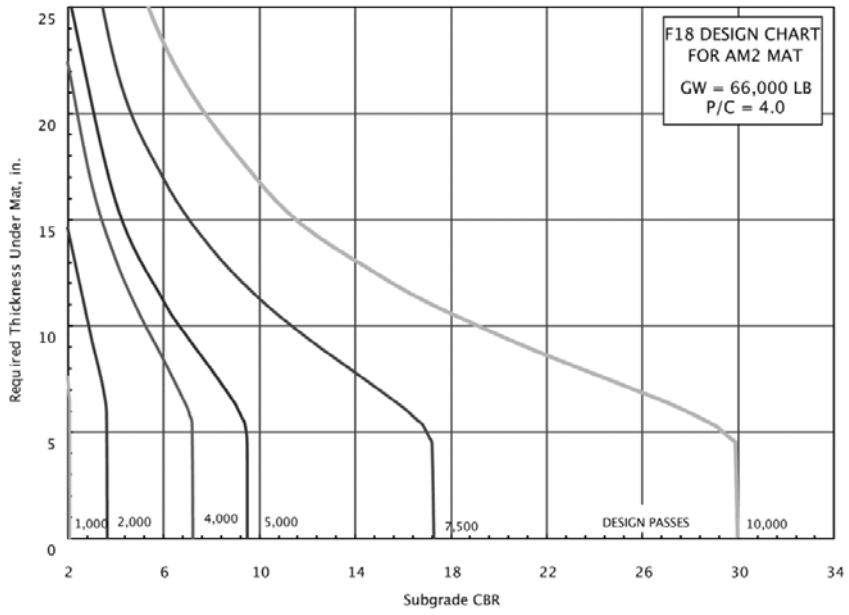
Figure 4-8. Required CBR vs allowable passes for select aircraft



Legend:

CBR	California Bearing Ratio
GW	gross weight
in	inch
lbs	pounds
P/C	pass curve

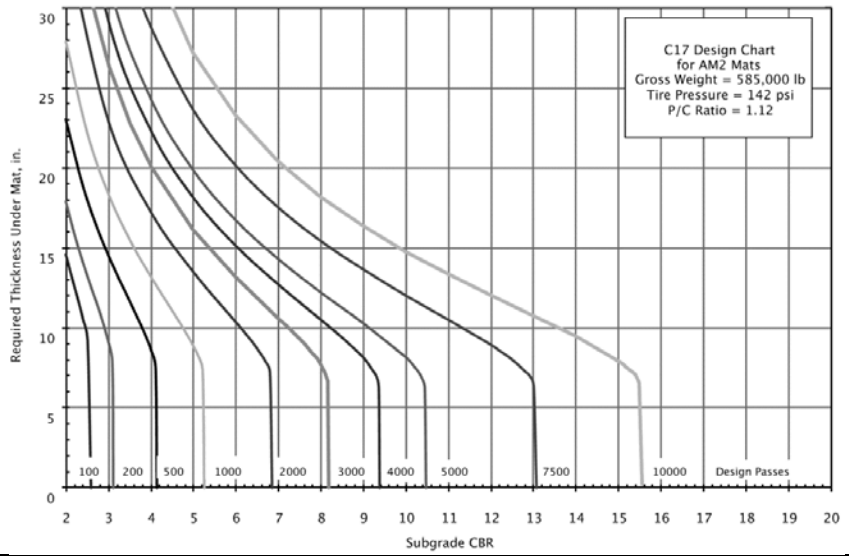
Figure 4-9. F-15 AM2 design chart



Legend:

CBR	California Bearing Ratio
GW	gross weight
in	inch
lb	pounds
P/C	pass curve

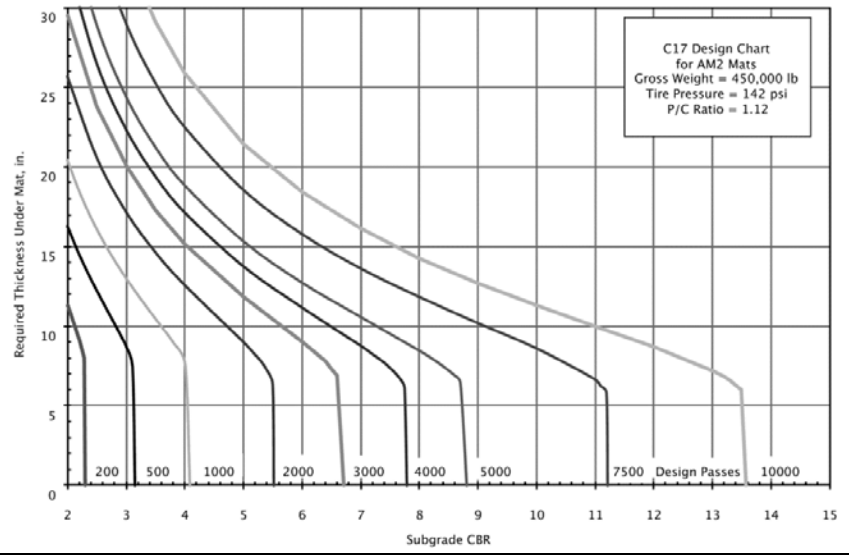
Figure 4-10. F-18 AM2 design chart



Legend:

CBR	California Bearing Ratio
GW	gross weight
in	inch
lbs	pounds
P/C	pass curve

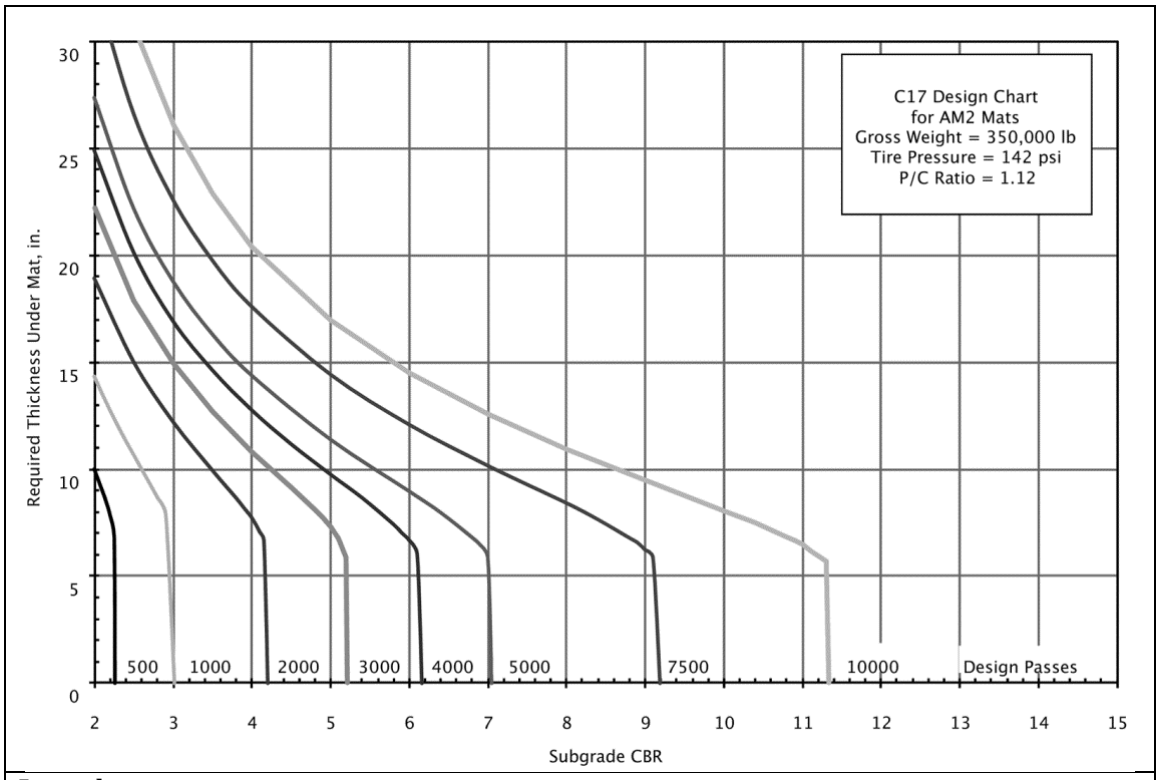
Figure 4-11. C-17 585,000 pound AM2 design chart (draft)



Legend:

CBR	California Bearing Ratio
GW	gross weight
in	inch
lbs	pounds
P/C	pass curve

Figure 4-12. C-17 450,000 pound AM2 design chart (draft)



Legend:

CBR	California Bearing Ratio
GW	gross weight
in	inch
lbs	pounds
P/C	pass curve

Figure 14-13. C-17 350,000 pound AM2 design chart (draft)

Example 10

Developments have led to the need for a contingency airfield constructed of AM2 mat. Estimation of the mission suggests that the design pass level should be 2,000 passes of a 447 kip C-17. The only available site has a CBR of 4 for a depth of 12 inches where it increases to an 8 CBR for an additional 24 inches.

Solution 10

Note. The mission requirements include plans for a parallel taxiway and a small apron. Thus, the number of required passes should remain at 2,000 due to the probability that the aircraft will use the taxiway and apron for movements other than takeoffs or landings.

Step 1. The design aircraft has been designated as the C-17. The design gross weight of the C-17 is 447 kips which seems reasonable in regard to mission requirements.

Step 2. The design aircraft passes stated were 1,000. All pavements are A type traffic areas and will use the same design.

Step 3. Using figure 4-8, page 4-21, determine the minimum required subgrade strength to support 1,000 passes of a 450 kip C-17 aircraft. Enter figure 4-8 with the 1,000 pass curve and see where it intersects the X-axis CBR value. The 1,000 pass curve intersects at approximately 4 CBR, therefore a 4 CBR minimum subgrade is required for a 1,000 pass design mission.

Step 4. Since the required CBR is equal to the in-place CBR (4 = 4), then the subgrade is adequate to support mission requirements.

Example 11

Information provided by headquarters indicates that the airfield in Example 10 will be required to support 5,000 passes of a C-17 rather than the original 1,000 passes. Redesign the airfield accordingly.

Solution 11

Step 1. The design aircraft and its design gross weight are denoted as a 447 kip C-17.

Step 2. Due to changes in mission requirements, the design pass level was increased from 1,000 passes to 5,000 passes.

Step 3. Using figure 4-8 determine the required subgrade strength to support 5,000 passes of a 450 kip C17 aircraft. Enter figure 4-8 with the 5,000 pass curve and see where it intersects the X-axis CBR value. The 5,000 pass curve intersects at approximately 9 CBR. Since required CBR is greater than the in-place CBR (9 > 4), the in-place subgrade must be improved structurally to support the design traffic of the mission.

Step 4. To determine the required thickness of material 9 CBR or greater required, enter figure 4-12, page 4-23, with 4 CBR and draw a vertical line until it intersects the 5,000 pass curve. From this intersection, draw a horizontal line to the left until it intersects the Y-axis. The intersection gives the required thickness of approximately 19 inches of select fill layer of at least a 9 CBR to be placed above the in-place subgrade material. Since the CBR increases to 8 after 12 inches, see what is required above the 8 CBR. Using the above procedure, 8 inches of 9 CBR or greater is required above the 8 CBR subgrade. Therefore, removing the 12 inches of 4 CBR subgrade above the 8 CBR material and replacing it with select fill greater than or equal to 9 CBR is acceptable. Thus, the design of the airfield includes either—(1) addition of 19 inches of select fill 9 CBR or greater above the existing subgrade, or (2) removing 12 inches of the subgrade and replacing it with compacted select fill 9 CBR or greater. In many instances, the removed material can be dried or wetted to optimum moisture content and compacted to achieve the desired result without bringing in additional material. When higher CBRs are required, cement or lime stabilization may be required to achieve the necessary result. Alternate designs incorporating various layers of differing soil strengths may be considered provided that they meet the criteria presented herein.

DESIGN IMPROVEMENTS FOR EXPEDIENT-SURFACED AIRFIELDS

4-51. 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.

4-52. The easiest way to increase the allowable number of passes is by compacting 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 TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034. After increasing 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.

4-53. 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 TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034.

4-54. 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 major types of stabilization are stabilization expedients (or geosynthetics), mechanical stabilization, and chemical stabilization. Choosing the best one depends on soil characteristics and available resources. Specific information on each type of stabilizer can be found in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034. Stabilizing an in-place soil is most commonly done to increase the CBR of the soil, but it can also be used to negate the harmful effects of dust and water. Table 4-3 summarizes the possible functions of stabilizers in traffic and nontraffic areas on expedient surfaces.

Table 4-3. 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*
Main Battle Area						
No mat	X	X	X		X	
With landing mat					X	
Support Area						
No mat				X	X	X
With landing mat	X			(X)	(X)	(X)
With membrane				(X)	(X)	(X)

Notes.
1. References to the use or no use of a 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 that receive little or no traffic.

Dust Control and Waterproofing

4-55. 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

4-56. 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 aircraft 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.

4-57. On unsurfaced airfields, the dust source 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.

4-58. 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 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.

4-59. 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 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

4-60. Water may enter a soil by—

- Leaching of precipitation or ponded surface water.
- Capillary action of underlying groundwater.
- A rise in the water table.
- Condensation of water vapor and the accumulation of moisture under a vapor-impermeable surface.

4-61. 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.

4-62. A 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.

4-63. 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

4-64. 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.

4-65. A summary of the various materials and a guide to their applications as a dust-control agent or soil waterproofer are given in table 4-4. This summary is the best estimate of the applicability of the materials based on existing information. The column descriptions below identify what information is required for tracking of waterproofing and dust control agents.

- **Column 1.** Column 1 identifies the material.
- **Column 2.** Column 2 indicates the usual form in which the material is supplied.
- **Column 3.** 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.** 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.** 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.** 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/AFM 88-17.
- **Column 10.** Column 10 indicates the minimum curing time requirements.

AGGREGATE SURFACED AIRFIELDS

4-66. While time and resources are limited in the main 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 main battle area is redesignated as a support area and upgraded to an aggregate surface for ensuing operations.

4-67. 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.

4-68. Design the layout of aggregate-surfaced airfields like expedient-surfaced airfields. The runway with turnarounds should be constructed as shown in chapter 3. As time permits, complete the airfield layout according to figure 4-3, page 4-5.

Table 4-4. 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 Penetration	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	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 for proper emulsion break. Dilutions up to 5:1 by water are used.
(Anionic)		Penetration	Gravel to silty sand	X	X		X	0.10-0.50	0.8-4.0	Several hours	

Table 4-4. Dust-control and waterproofing applications (continued)

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 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.
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 vicious; requires special spray nozzles; forms thin, moderately flexible film on surface when cured; curing depends on temperature and humidity.
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	

Table 4-4. Dust-control and waterproofing applications (continued)

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 V: Miscellaneous Materials											
Water	Liquid	Penetration	All	S	S		"	As needed	"	0	Temporary measure only.
Various oils	Liquid	Penetration	All	S	X		"	0.5-1.0	"	0	Temporary measure only; may require frequent application.
[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%.											

MATERIALS

4-69. Materials used in aggregate airfields must meet the requirements stated in TM 3-34.48-1 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. The layers in an airfield design require a minimum layer thickness of 6 inches and should conform to the CBR and compaction criteria shown in ETL 09-6. See table 4-5.

Table 4-5. Compaction criteria and CBR requirements for aggregate-surfaced airfields

California Bearing Ratio Requirements	*Layer*	*Compaction Requirements*
80-100	Base course	Asphalt: 98-100% Soil: 100-105%
20-50	Subbase	100-105%
0-20	Select material	Cohesive: 90-95% Cohesionless: 95-100%
—	Compacted subgrade	Cohesive: 90-95%Cohesionless: 95-100%
—	Uncompacted subgrade	—

Subgrade

4-70. 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.

4-71. Determine the soil CBR profile as discussed previously for expedient surfaces. Like road design, the CBR of the subgrade determines the thickness of the whole design. If the CBR can be improved using 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

4-72. 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 4-6 which are the same criteria used for roads.

Table 4-6. Maximum permissible values for subbases and select materials

Material	Maximum permissible value					
	Maximum design CBR	Size (inch)	Graduation 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
Legend: CBR California Bearing Ratio No. number						

Base Course

4-73. Only good quality materials should be used in base courses of aggregate airfields. Because the base course is also the surface course, it must meet specifications for both strength and gradation. The minimum CBR for an airfield base course is 80 (see table 4-6). Since CBR tests require time, use one of the base-course materials shown in table 4-7 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.

Table 4-7. 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
Legend: CBR California Bearing Ratio		

4-74. Gradation requirements for aggregate-surfaced layers are given in table 4-8, page 4-34, where the specifications depend on the maximum size aggregate. These are the same gradation requirements as given in TM 3-34.48-1 for base courses for aggregate-surfaced roads.

Table 4-8. 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 ½-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
Legend: No. number				

FROST CONSIDERATIONS

4-75. 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 paragraphs below.

4-76. 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.

4-77. In general, frost-susceptible soils are those with a considerable amount of fines or with at least 6 percent of materials finer than 0.02-millimeter grain size by weight. Do not relocate or find another soil; instead, adjust the thickness design to compensate for the frost action. When water in a subgrade freezes, additional water travels by capillary rise and increases the ice lens. Ice lenses can disturb the compacted layers enough to create large voids during the next thaw cycle.

THICKNESS DESIGN PROCEDURE

4-78. 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.

Step 1. Determine the Airfield Location

4-79. The airfield location is always the support area. While aggregate-surfaced airfields are too resource intensive for the main battle area (unless they are existing airfields), they do meet support area surface requirements.

Step 2. Determine the Design Aircraft and Gross Weight

4-80. The C-17 and C-130 are the only possibilities for design aircraft in the support area. Aggregate surfaces are considered a semiprepared surface where only the C-17 and C-130 can land. Because the support area is primarily a connector of the support and close combat areas, the design aircraft are able to land in all three

areas. The aircraft also have the same design weights for support and close combat areas, as shown in table 4-1, page 4-6.

Step 3. Check Soils and Construction Aggregates

4-81. 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 TM 3-34.48-1. Conduct soil tests on any borrow sites to determine the soil CBR, gradation, and liquid and plastic limits. Compare these values to table 4-6, page 4-33, 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 4-8.
- **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.

4-82. For frost design purposes, soils have been divided into seven groups (see table 4-9). 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.

Table 4-9. Soil classification for frost design

Frost group	*Type of soil*	*% by weight <0.02 mm*	*Typical soil types under the USCS*
NSF	(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, GP-GC
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 CL, CH, ML-CL
—	(c) Clays (PI > 12)	—	—
F4	(a) Silts	—	ML, MH, ML-CL
—	(b) Very fine sands	15	SM, SC, SM-SC
—	(c) Clays (PI < 12)	—	CL, ML-CL
—	(d) Varied clays and other fine-grained, branded sediments	—	CL, or CH layered with ML, MH, SM, SC, SM-SC, or ML-CL

Table 4-9. Soil classification for frost design (continued)

Legend:	
CH	clay high plasticity
CL	clay low plasticity
e	void ratio
GC	clayey gravels, gravel-sand-clay mixtures
GM	silty gravels, gravel-sand-silt mixtures
GP	gravel poorly graded, gravel-sand mixtures, little or no fines
GW	gravel well-graded, gravel-sand mixtures, little or no fines
MH	silt high plasticity
ML	silt low plasticity
mm	millimeter
PI	plasticity Index
NFS	nonfrost susceptible
SC	clayey sand, sand-clay mixtures
SM	silty Sands, sand-silt mixtures
SP	poorly graded sands, gravelly sands, little or no fines
SW	well-graded sand, gravelly sands, little or no fines
USCS	Unified Soil Classification System

4-83. 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.

4-84. 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.

4-85. If a subgrade is frost susceptible, determine its frost group from table 4-10, and find the frost area soil support index (FASSI) from table 4-10. This value is needed to adjust the thickness design in Step 8.

Table 4-10. FASSI

Frost group of soils	*Frost area soil support index*
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

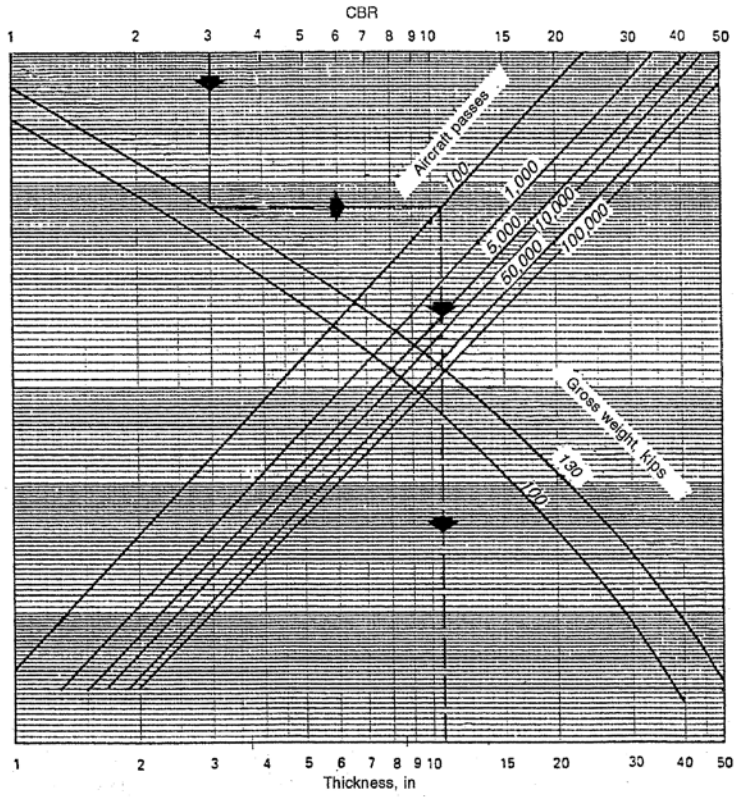
Step 4. Determine the Number of Passes Required

4-86. Unlike the design for expedient surfaces, control the thickness design by increasing the number of passes required. As the number of passes increases, so do the thickness design and, consequently, the construction effort. The required number of passes may be given in a mission statement or it may be adjusted based on the thickness design.

Step 5. Determine the Total Surface Thickness and Cover Requirements

4-87. The total thickness of the aggregate structure is a function of the subgrade CBR, the design aircraft, and the number of passes. Because 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, borrow materials would be used to fill all but the top 6 inches. The CBR of each soil used in the design determines the required cover.

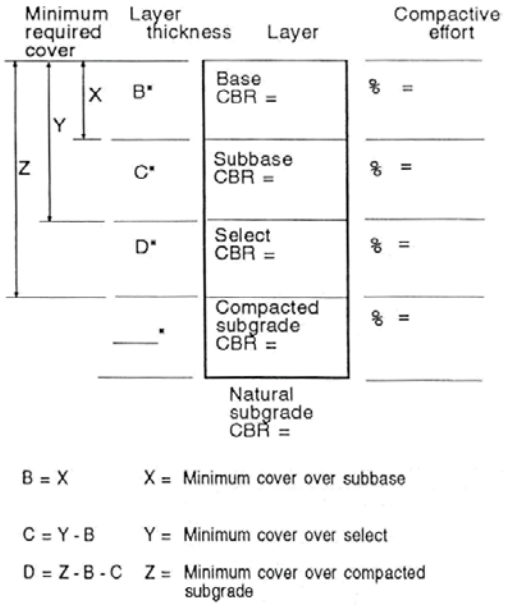
4-88. After evaluating the available soils and determining the number of passes, enter figures 4-14 and figure 4-15 with the subgrade CBR until it intersects the gross weight of the design aircraft. Trace a line horizontally until the intersection of the desired number of passes, and determine the minimum cover required over the subgrade from the horizontal axis. Establish the minimum cover required over each soil that could be used in the design.



Legend:

CBR California Bearing Ratio in inch

Figure 4-14. C-130 design curves for gravel-surfaced airfields



Legend:

CBR California Bearing Ratio

Figure 4-15. Thickness design procedure

Step 6. Complete the Temperate Thickness Design

4-89. After finding the cover requirements, complete the thickness design without considering the effects of frost. The method is similar to road design for determining 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 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 subbase and select materials are readily available nearby, they may not be necessary for the airfield design. Figure 4-15, page 4-37, illustrates the relationship between minimum cover and layer thickness.

Step 7. Adjust Thickness Design for Frost Susceptibility

4-90. If not designing in a frost area or if the subgrade in a frost area is not frost susceptible, go to Step 9. Since the freeze-thaw cycles associated with frost areas weaken soils, 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.

4-91. Determine the frost-area soil-support index from table 4-10, page 4-36. Use the index to enter figure 4-14, page 4-37, or figure 4-15, page 4-37, instead of the compacted CBR.

4-92. 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 4-14 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.

4-93. 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 4-10 to determine the soil support index of 3.5. Since 3.5 is greater than 3, it requires thinner design (determined by figure 4-14).

4-94. After choosing the thicker of the two designs, 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.

4-95. 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. If the material exhibits different strengths in perpendicular directions, the lowest value is used. 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

4-96. The layer thickness of an in-place soil is the depth to which adequate compaction is ensured. Determine the depth by entering table 4-11 with the appropriate traffic area and soil information.

Table 4-11. Depth of compaction required for subgrades

Traffic area	*Minimum compacted depth below surface (inches)*	
	Cohesive soils	*Cohesionless soils*
B	21	25
C	17	21

4-97. The actual depth of subgrade compaction is the difference between the total thickness above the subgrade and the value from table 4-11 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 (see table 4-11) – 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.

4-98. 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. The specifications for each layer in the design are listed in table 4-5, page 4-32.

4-99. Remember, there are special cases for subgrades that lose strength when being remolded. These are generally soil types CH and OH. See TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034, for more information on these soils.

Step 9. Draw the Final Design Profile

4-100. 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 fill sections, which is the same soil as the subgrade. Figure 4-16 shows the specific detail included in the profile.

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

_____" Subbase[1] CBR_____ @ 100 - 105% CE 55

_____" Select Material[1] CBR ___ @__%__ % CE 55

_____" SCRIP[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.

Legend:

CBR	California Bearing Ratio
CE	compaction effort
SCRIP	scarify and compact in place
TDF	total depth of fill

Figure 4-16. Final design profile

Example 12

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. The 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, one potential borrow site has 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: The nearby civilian batch plant has been leased by the United States; well-graded, crushed limestone is available with the gradation specifications:

Sieve	Percent Passing
2 inch	100
1.5 inch	93
1 inch	63
3/4 inch	54
Number 4	42
Number 10	18
Number 200	6

Solution 12

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

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

Step 3. Check construction aggregates.

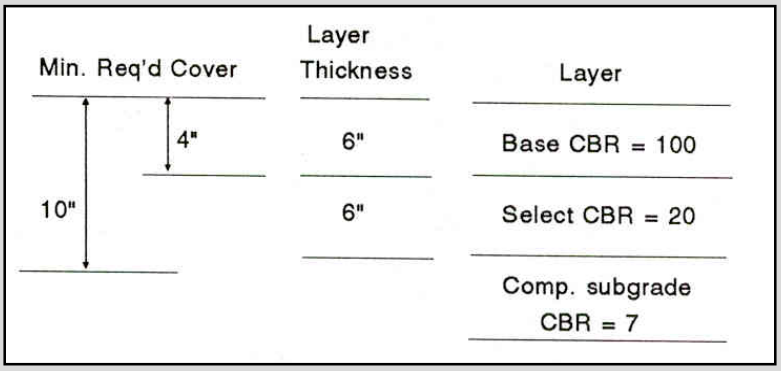
- Check materials for use as select/subbase. Since there is only one potential source, check it according to table 4-7, page 4-33. Since PI = 6, the soil does not meet the Atterberg criteria for a subbase. Therefore, determine whether it meets select material criteria. Since its LL < 25 and the PI < 12, it can be used as a select material CBR = 20.
- Determine the base course CBR. From table 4-8, page 4-34, since the base course material is a well-graded, crushed aggregate (limestone), the CBR = 100.
- 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 4-14, page 4-37, to determine the cover requirements.

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

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, already there are 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.



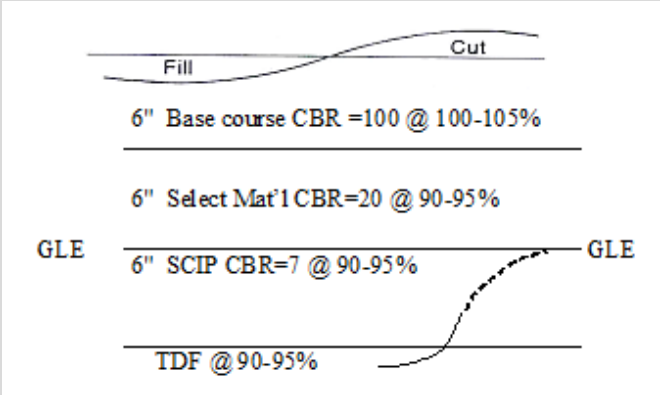
Step 7. Not applicable since the airfield is located in a nonfrost area.

Solution 12 (continued)

Step 8. Determine the subgrade depth and compaction requirements. (See table 4-11, page 4-38, 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 4-5, page 4-32) for the three layers is shown below:

Layer	Compaction Requirement
Compacted subgrade	90 – 95%
Select material	90 – 95%
Base course	100 – 105%

Step 9. Draw the final design profile.



AGGREGATE-SURFACED DESIGN FOR C-17 AIRCRAFT

4-101. The design of an aggregate-surfaced contingency airfield for the C-17 aircraft is necessary if the in-place subgrade CBR cannot support the design mission requirements. The first step was accomplished by evaluating the proposed site for the unsurfaced criteria. Doing so provides the designer with the minimum required CBR to support C-17 operations at the design pass level. The next step is to use figure 4-15, page 4-37, to determine the minimum required thickness of the minimum CBR determined from figure 4-6, page 4-16.

Example 13

Design an airfield for contingency operations of a C-17 in an area susceptible to frost action. Fifty passes are expected during the spring thaw period. Preliminary site investigations identified that the subgrade was classified as clay low plasticity (CL) with a PI of 15 and an in-place subgrade CBR of 10 for 36 inches. No taxiways will be constructed.

Solution 13

Step 1. The design aircraft is a 447 kip C-17.

Step 2. The expected number of aircraft passes is 50, but the airfield will not have any taxiways so the design pass level is adjusted to 100 (see note in example 8, page 4-17).

Step 3. The first step in designing for frost is to determine the frost group to which the subgrade belongs. Using the site investigation data and table 4-11, page 4-38, it is determined that the subgrade is in the F3 frost group. The next step is to determine the FASSI for the subgrade. Using table 4-10, page 4-36, the FASSI for an F3 material is 3.5.

Step 4. Since the FASSI is less than the in-place subgrade CBR (3.5 < 10), then the FASSI must be used in lieu of the in-place CBR for determining soil strength and thickness requirements. Enter figure 4-5, page 4-9, with the design passes (100) and the gross aircraft weight (447 kips) to determine the subgrade surface CBR required to support the design mission traffic. Following the steps in example 8, step 3, it is determined that a minimum surface CBR of 12 is required to support 100 passes of a 447 kip C-17.

Step 5. Since the minimum required surface CBR is greater than the in-place subgrade CBR for frost design (12 > 3.5), the subgrade requires structural improvement to withstand the design traffic. Using figure 4-7, page 4-17, enter the chart with an in-place subgrade CBR of 3.5 to determine the thickness of 12 CBR material required above the subgrade to support the design traffic. Following the guidance in example 8, step 4, it is determined that 15 inches of 12 CBR material is required above the 3.5 CBR (frost) subgrade.

At this point, an analysis of available construction materials would determine whether 15 inches of a 12 CBR nonfrost-susceptible material would be plausible. If not, the design procedure for the use of AM2 matting should proceed if sufficient mat is available. Otherwise, alternate means of strengthening the in-place subgrade should be explored as discussed earlier.

SPECIAL DESIGN CONSIDERATIONS

4-102. Structures built in connection with airport drainage are similar to those used in conventional construction, but these structures must be capable of supporting the heaviest design aircraft wheel load. Although standard-type structures are usually adequate, special structures will be needed occasionally.

Stabilized Soil Design

4-103. The use of stabilized soil layers for aggregate-surfaced pavement structures (as described in TM 3-34.48-1/MCRP 3-17.7A-1/NTRP 4-04.2.10-1/AFMAN 32-8013-1 and TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034) 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.

4-104. 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.

Minimum Thickness

4-105. The minimum thickness requirement for a stabilized base or subbase is 6 inches.

Application of Equivalency Factors

4-106. 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.

Drainage Requirements

4-107. Adequate surface drainage should be provided in order to minimize moisture damage. Quickly 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 that 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.

4-108. 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.

4-109. 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.

4-110. 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

4-111. 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 TM 3-34.48-1.

Dust Control

4-112. 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 one half inch will result in the virtual destruction of any thin layer or shallow penetration dust-palliative treatment. The abrasive action of the aircraft landing gear may be too severe for the use of some dust palliative in a traffic area.

4-113. 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/AFM 88-17.

FLEXIBLE PAVEMENT AIRFIELDS

4-114. 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.

4-115. Each airfield in the basic airfield complex has a specific purpose. The type, volume, composition, and character of anticipated traffic is much greater in the support 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 support 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.

4-116. 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 I 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. The evaluation of pavements is discussed later in this chapter.

Pavement Types and Uses

4-117. The descriptions, uses, advantages, and disadvantages of bituminous pavements and surfaces presented in UFC 3-250-03 are applicable to TO construction except as modified in the paragraphs below.

Hot-Mix Bituminous-Concrete Pavements

4-118. 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 UFC 3-250-03.

Cold-Laid Bituminous-Concrete Plant Mix

4-119. 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

4-120. 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

4-121. A typical flexible-pavement structure is shown in TM 3-34.48-1 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

4-122. If time and conditions permit, investigate subgrade conditions; borrow areas; and 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.

SELECT MATERIALS AND SUBBASES

4-123. 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 minimum required cover of the subgrade must satisfy the requirements for a given layer that are listed in tables 4-6 and 4-7, page 4-33. (See TM 3-34.48-1 for more specific information.)

Base Courses

4-124. Although a base course can be bituminous or aggregate, the latter is more common because of its availability and the resources involved. Specifications for an aggregate base course in a flexible-pavement structure are the same as the base course in an aggregate-surfaced airfield. Because a flexible pavement transfers most of a 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 4-8, page 4-34. Gradation specifications are listed in table 4-9, page 4-35. (See TM 3-34.48-1 for more information.)

Bituminous Pavements

4-125. 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 AC wear surface. For most aircraft in the support area, an aggregate structure is suitable only when it has a smooth, water-shedding surface like AC.

4-126. 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, design for intermediate courses based on table 4-12. Table 4-13 shows the recommended pavement thicknesses based on the traffic area and the strength of the base course.

Table 4-12. Intermediate asphalt courses

Pavement thickness (inches)	*Intermediate (binder) course thickness (inches)*	*Surface course thickness (inches)*
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 4-13. Minimum thicknesses, pavement, and base course

Traffic area	*Minimum thicknesses (inches)*			
	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
Legend: CBR California Bearing Ratio				

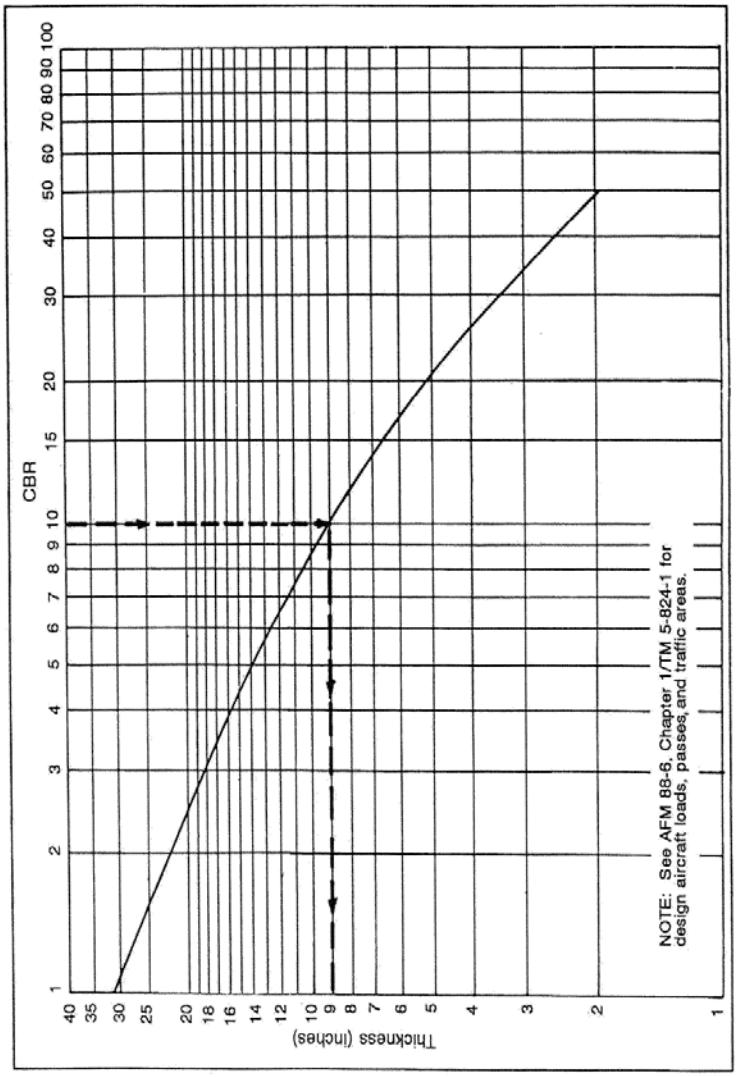
4-127. Generally, if the thickness of the bituminous layer is greater than 2 inches, place it in two lifts to ensure that each is properly compacted. Compacting a lift greater than 2 inches may result in the asphalt cooling before it is compacted to the required density. The compaction requirement for AC is 98 to 100 percent of the laboratory density. 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. 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.

4-128. 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 equation. Mix design is further discussed in UFC 3-250-03.

TRAFFIC AREAS

4-129. For previous airfield designs, only Types B and C were considered. Since support 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 4-4, page 4-6 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, 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 wash rack pavements are 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 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 usually 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 4-17, page 4-48, which is valid for all design aircraft. Enter the figure with the compacted CBR of the subgrade and intersect 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.



Legend:

AFM	Air Force manual
CBR	California Bearing Ratio

Figure 4-17. Flexible-pavement design curves for shoulder pavement

THICKNESS DESIGN PROCEDURE

4-130. The design procedure for flexible-pavement surfaces is almost identical to that of aggregate surfaces. However, because flexible pavements exist only in the support area, they are subjected to fighter and cargo aircraft. While some of the curves and specifications may be different, the design steps are the same.

Step 1. Determine the Airfield Location

4-131. Flexible pavements are only constructed in the support area. While existing airfields may provide flexible-pavement surfaces in support or main battle areas, the support area requires a flexible-pavement surface to support fighter aircraft and large cargo aircraft.

Step 2. Determine the Design Aircraft and Gross Weight

4-132. While previous airfield types limited aircraft based on their landing capability, the support 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 and small fighter aircraft with large tire pressures. Because of the diverse mission and service life (six months to two years) of the support area, it is logical to design the airfield for the most constraining aircraft, the C-17. While it is not the heaviest aircraft in the support area, its gross weight (586 kips) is not distributed like that of the C-5.

Step 3. Check Soils and Construction Aggregates

4-133. 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 4-6, page 4-33, 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 4-7, page 4-33, while the gradation of a soil must meet the specifications in table 4-8, page 4-34, based on the maximum size aggregate. 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 table 4-9, page 4-35, and table 4-10, page 4-36.

Step 4. Determine the Number of Passes Required

4-134. Since the support area is considered a 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

4-135. The procedure for designing the total thickness for flexible pavements differs in two ways. First, since the design aircraft is different, use a different curve. Enter the curve for the appropriate traffic area with the soil CBR and number of required passes. The thickness design curves for the C-17 are found in figure 4-18, page 4-50, and figure 4-19, page 4-51. 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 4-13, page 4-47.

Steps 6 and 7

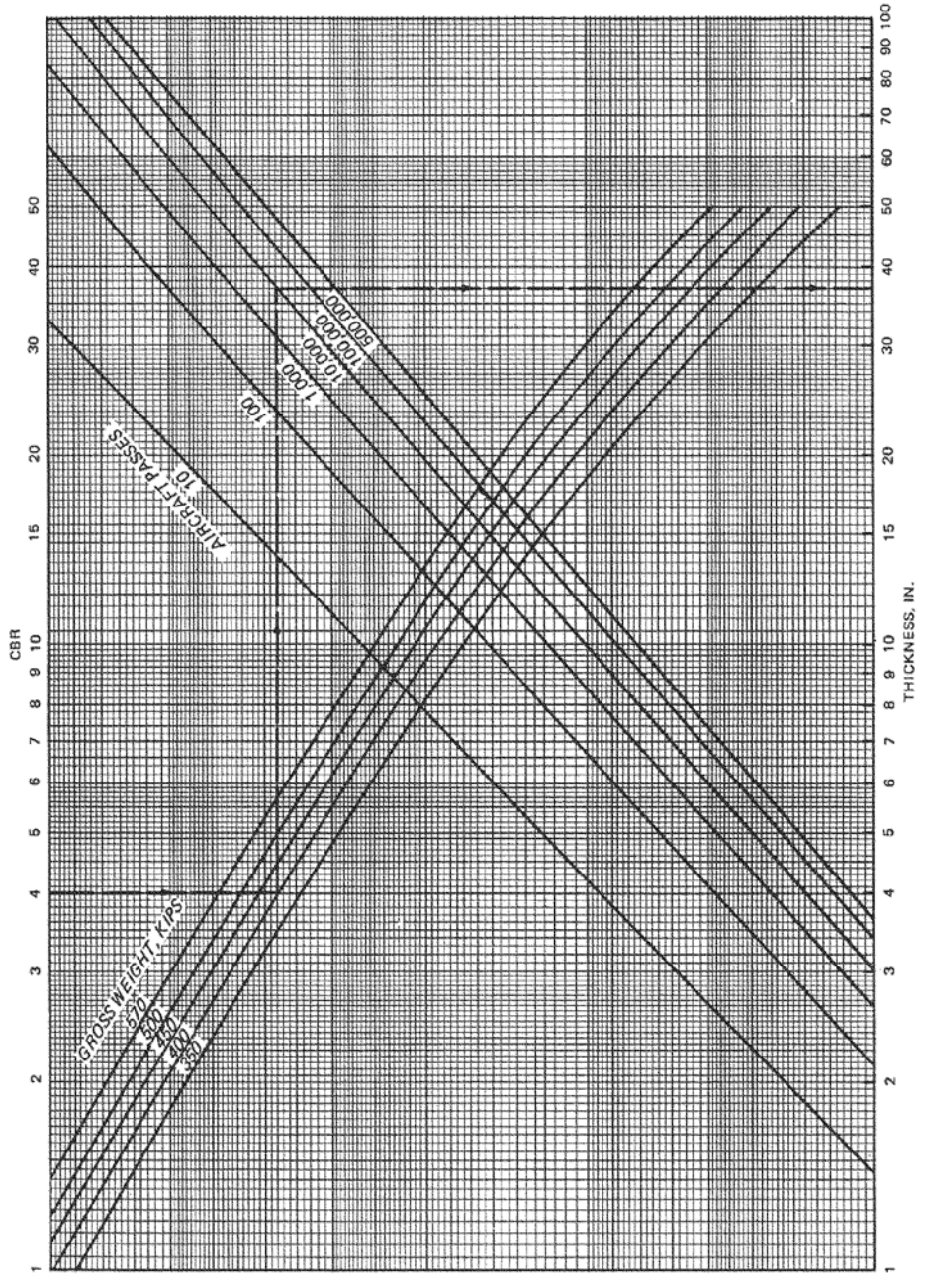
4-136. These design steps are the same as previously discussed for aggregate-surfaced airfields.

Step 8

4-137. 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 support area. Table 4-14 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.

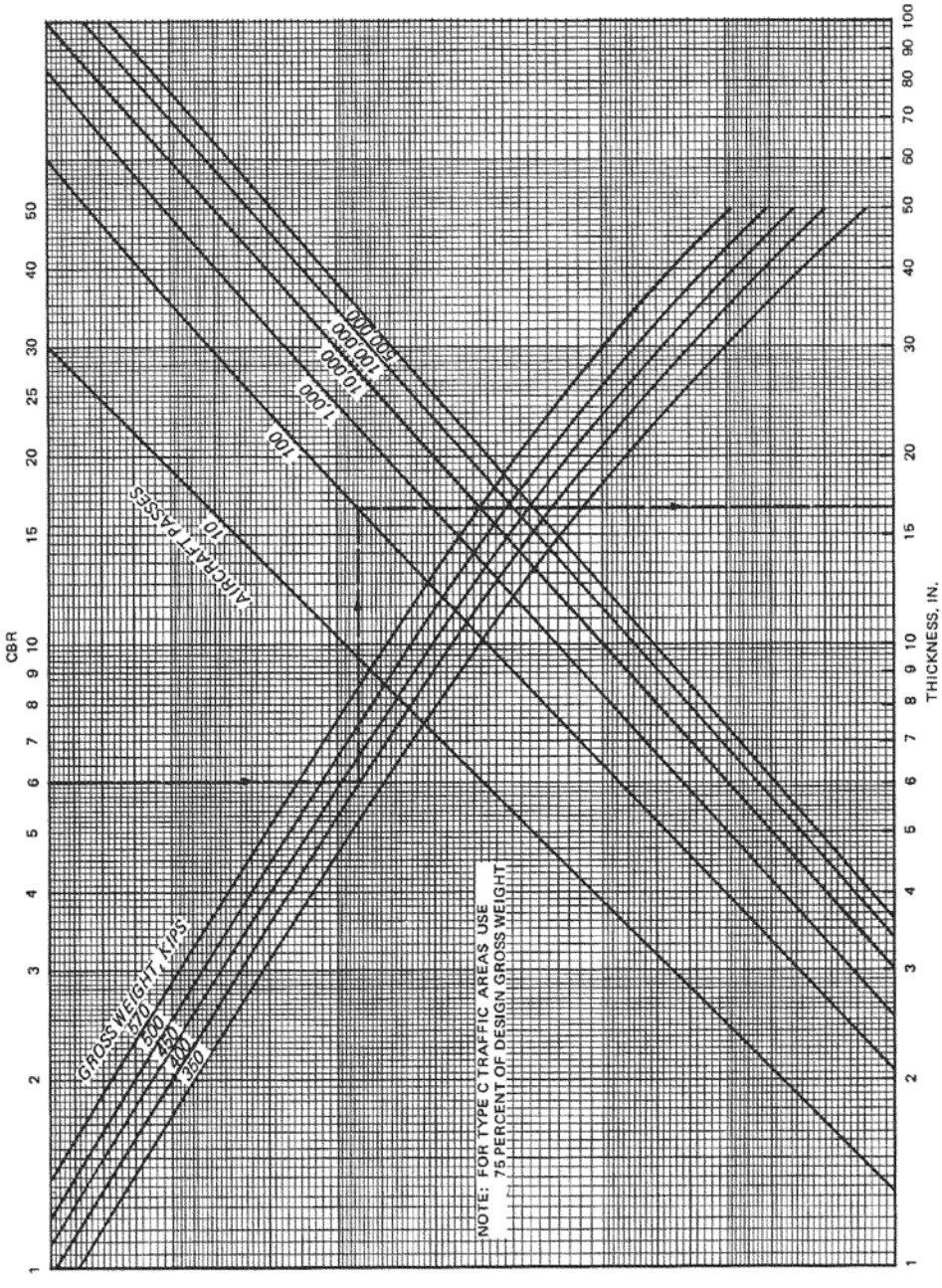
Table 4-14. Depth (inches) of required subgrade compaction below the surface of support area flexible-pavement airfields

Traffic area	*Minimum compacted depth below surface (inches)*	
	Cohesive soils	*Cohesionless soils*
A	48	54
B	42	48
C	36	42
D	24	30



Legend:
CBR California Bearing Ratio in inch

Figure 4-18. Flexible-pavement design curves for C-17 aircraft, type A traffic area



Legend:

CBR	California Bearing Ratio
in	inch

Figure 4-19. Flexible-pavement design curves for C-17 aircraft, types B, C, and D traffic areas

Step 9. Draw the Final Design Profile

4-138. Draw the final design profile as previously shown for aggregate airfields.

Example 14

Design a support area airfield in Central America, Type B traffic area, capable of handling 100,000 passes of a C-17 aircraft. The soils analyst has already determined soil layers, as follows:

- 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 maximum size aggregate (table 4-10, page 4-36).

Solution 14

Step 1. Airfield location (given) = support area/Type B traffic area.

Step 2. Design aircraft (always) = C-17/586 kips.

Step 3. Check soils and construction aggregates:

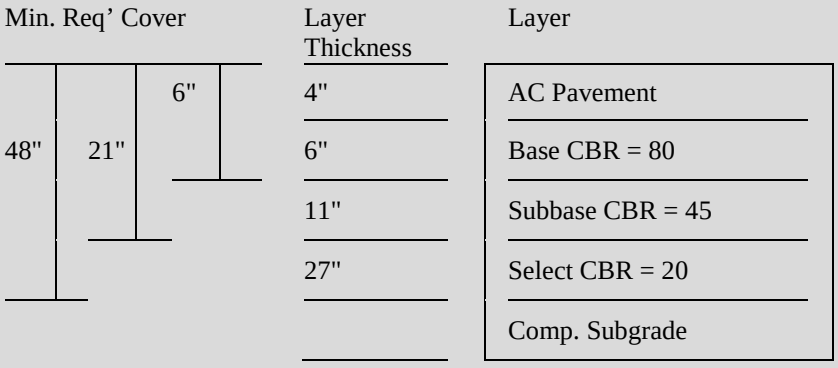
- Select and subbase (given): Borrow A, select material CBR = 15: borrow B, subbase CBR = 40.
- Base course: Limestone, CBR = 80; meets gradation.
- Frost is not a concern in Central America.

Step 4. Number of passes (given) = 100,000.

Step 5. Determine the thickness requirements from figure 4-17, page 4-48 (Type B traffic area):

Material	*Minimum Required Cover*
Compacted subgrade CBR 5	48 inches
Select material CBR 15	20.5 inches – 21 inches
Subbase CBR 40	6 inches

Step 6. Complete the temperate thickness design.



See table 4-14, page 4-49,with the traffic area (B) and the base course CBR (80) to find that the thickness of the AC pavement = 4 inches. See table 4-12, page 4-46, 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 21 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 11 inches.

Solution 14 (continued)

Step 7. Frost adjustment is not applicable.

Step 8. Determine subgrade depth and compaction requirements using the table below.

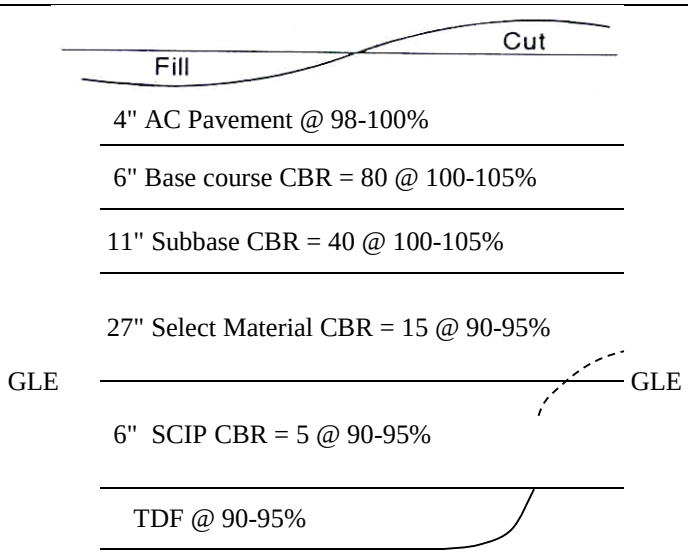
Layer	*Compaction Requirement*
Compacted subgrade	90 – 95 %
Select material	90 – 95 %
Subbase	100 – 105%
Base course	100 – 105%
AC pavement	98 – 100%

From the table below, 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 48 inches; therefore, the depth of subgrade compaction is 6 inches (6 inches is a minimum). Next, determine the compaction requirements for each layer using the table above.

CBR requirements	*Layer*	*Compaction requirements*
—	Asphalt concrete	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 (scarify compact in place [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 asphalt compaction is a percent of laboratory density.
5. Percent soil compaction is a percent of the maximum density.

Step 9. Draw the final design profile (see figure 4-20, page 4-54).



Legend:

AC	asphalt concrete
CBR	California Bearing Ratio
GLE	ground level elevation
SCIP	scarify compact in place
TDF	total depth of fill

Figure 4-20. Solution design profile

SPECIAL DESIGN CONSIDERATIONS

4-139. Over the years engineers have tried different methods to stabilize soils that are subject to fluctuations in strength and stiffness properties as a function of fluctuation in moisture content. Stabilization can be derived from thermal, electrical, mechanical, or chemical means. The first two options are rarely used.

STABILIZED SOIL DESIGN

4-140. 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 TM 3-34.48-1) pertains to airfield flexible pavements as well. As such, only examples of procedural applications for flexible-pavement airfields are discussed in the paragraphs below.

Design Example

4-141. Assume that a conventional flexible-pavement airfield has been designed. The airfield 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 that has an unconfined compressive strength of 890 pounds per square inch.

4-142. 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 is 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.

4-143. 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, time can be saved by stabilizing a soil and using equivalency factors to reduce the thickness design.

FROST REGIONS

4-144. Pavements frequently break up or are severely damaged when subgrade 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 great or intolerable from the strategy standpoint. The design engineer for support area airfields must decide whether to design for frost, given the increased thickness and material quality requirements.

Investigational Procedures for Frost Action

4-145. Field and laboratory investigations conducted according to TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034 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 paragraphs below.

Soil

4-146. 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

4-147. The depth to which freezing temperatures penetrate below the surface of a pavement kept cleared of snow and ice primarily depends on the magnitude and duration of below-freezing air temperatures, underlying material properties, and the amount of water that becomes frozen. Methods are described in EM 1110-3-138.

Water

4-148. A potentially troublesome water supply for ice segregation is present if the highest groundwater at any time of the year is within 5 feet of the proposed subgrade surface or the top of a 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.

4-149. Consider 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

4-150. 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

4-151. 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 TM 3-34.48-1.) 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

4-152. 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.

4-153. Another method (successful, though expensive) is to excavate to the frost line, lay prefabricated bituminous surfacing, 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

4-154. 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

4-155. 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

4-156. 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.

4-157. If both areas are free of snow, freezing will begin in the shoulder area because it is not protected by the 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

4-158. Base courses may be made of granular, unbound materials; bound materials; or a combination. 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

4-159. 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 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

4-160. If the structural criterion 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 no 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 4-9, page 4-35.) 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 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 that 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

4-161. 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 subgrade. The thickness of F2 base material should not exceed the difference between the reduced subgrade strength thickness requirements over F2 and F3 subgrade. The thickness of F1 base should not exceed the difference between the thickness requirements over F1 and F2 subgrade. 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

4-162. 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.

Granular Filters

4-163. Granular filters 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 according to the following criteria to prevent movement of particles of the protected soil into or through the filter(s):

$$\frac{15 \text{ percent size of filter material}}{85 \text{ percent size of protected soil}} \leq 5$$

and

$$\frac{50 \text{ percent size of filter material}}{50 \text{ percent size of protected soil}} \leq 25$$

4-164. 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 DD Form 1207 (*Grain Size Distribution Graph-Aggregate Gradation Chart*).

4-165. To offset the tendency of segregation of the filter material, a coefficient of uniformity of not more than 20 will be required.

4-166. 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 a 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. Specify greater thicknesses when required to suit field conditions. Over weak subgrade, 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

4-167. 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 is as follows:

$$\frac{85 \text{ percent size of material adjacent to fabric}}{\text{equivalent size of fabric openings}} \geq 1$$

DESIGN OF PAVEMENTS FOR FROST ACTION

4-168. In the reduced subgrade strength method of design, the design curves for the C-17 (figure 4-18, page 4-50, and figure 4-19, page 4-51) 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 FASSIs shown in table 4-9, page 4-35. 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

4-169. 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

4-170. 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.

4-171. 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 create conditions tending to make both surface heave and subgrade thaw weakening as uniform as possible over the paved area.

4-172. The depth of subgrade preparation, measured downward from the top of the subgrade, should be the lesser of the following:

- Twenty four inches.
- Seventy two inches, less the actual combined thickness of pavement, base, and subbase.

4-173. Prepared subgrade must meet the compaction requirements stated in Step 8 of the flexible-pavement airfield design procedure. 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.

4-174. Exceptions to the basic requirement for subgrade preparation in the preceding paragraph are limited to the following:

- Subgrade 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 or 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

4-175. Perform gradation tests on questionable materials found during grading operations. In an otherwise NFS subgrade, remove pockets of frost-susceptible soils to the full depth of frost penetration. Replace frost-susceptible soils with NFS material when possible.

4-176. 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

4-177. 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 topsoil 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.

4-178. 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 Subgrade

4-179. 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 that no pockets are left in the rock

surface that permit ponding 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 than 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.

4-180. Where seepage is great, cover the rock subgrade with a high pervious gravel material so that 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

4-181. Where available, base-course materials (including any select and subbase layers) are clearly NFS; base-course construction control should be according to 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.

4-182. 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.

4-183. 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.

4-184. Avoid mixing base-course materials with frost-susceptible subgrades by ensuring that the subgrade is properly graded and compacted before placing the base course. Also, ensure that 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.

4-185. After completing each layer of the aggregate course, carefully inspect them before permitting placement of additional material. This ensures that 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

4-186. 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

4-187. 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

4-188. 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

4-189. 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, 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.

4-190. 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 factors such 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

4-191. 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 10 to 30 degrees Fahrenheit range. As the temperature decreases, particularly below0 degrees Fahreneit, the compaction effectiveness decreases, the rate of age hardening (or sintering) decreases, and equipment operational problems increase.

4-192. 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-17 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-17 aircraft. A design-and-testing manual for the construction of compressed-snow runway pavement can be found in the Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 89-10.

4-193. 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

4-194. The design of airfield pavement is based on covering a subgrade of given strength with an 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.

4-195. 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. Design the airfield for the design aircraft, but to ensure the suitability of the airfield to changing conditions, 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 support areas, where existing pavements may support missions short of the large cargo aircraft. For this reason, Appendix I includes flexible-pavement curves for most aircraft that normally operate on flexible pavements in the support area.

4-196. 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.

4-197. 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.

4-198. 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 a lesser life requirement.

4-199. 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

4-200. If the airfield to be evaluated was built by United States 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 according to the discussion in the paragraphs below.

OLD PAVEMENTS

4-201. 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.

TEST LOCATION SELECTION

4-202. 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.

4-203. 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.

4-204. 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 small holes about 500 feet apart. A wider spacing may be adequate when uniform conditions exist. Classify the samples according to the Unified Soil Classification System (see TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034). Determine the moisture content because variations in moisture content often indicate variations in soil strength.

4-205. 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 that test pits are placed where maximum information can be obtained with minimum testing.

4-206. 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.

4-207. When no weak areas are found, place test pits where traffic is heavy and loading conditions are most severe. These conditions are usually found in the 1,000-foot sections at runway ends, in the entire length of taxiways, and in taxi lanes on aprons. An airfield having a runway, 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

4-208. 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.

4-209. 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 that 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.

4-210. 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.

4-211. 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 that the density determinations are performed between adjacent CBR tests.

Moisture Content Determination

4-212. 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.

4-213. 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 plastic and liquid limits of the soil.

California Bearing Ratio Tests

4-214. Perform three in-place CBR tests (as described in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034) 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.

4-215. For example, test results of 6, 8, and 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.

4-216. 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

4-217. 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 wet density. For example, test results of 108, 111, and 113 pounds per cubic foot wet density are in reasonable agreement and can be averaged as 111 pounds per cubic foot.

Sampling

4-218. Obtain samples of typical pavement, base-course, and subgrade materials for laboratory tests. Take the base and subgrade samples to ensure representative materials.

Backfilling

4-219. 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.

4-220. 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.

4-221. 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

4-222. 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 tests below apply to both satisfactory and failed areas.

Pavement Tests

4-223. 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.

4-224. 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.

4-225. The stability of the 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.

4-226. 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.)

4-227. 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

4-228. 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 appropriate ASTM compaction test. Where available, include results of tests made on the soaked and unsoaked condition for possible future use.

MAKING THE EVALUATION

4-229. 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.

4-230. 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.

4-231. 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 UFC 3-260-03.

EXPEDIENT- AND AGGREGATE-SURFACED AIRFIELDS

4-232. 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.

Example 15

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 15

The aircraft, weight, and CBR are all given. Using figure 4-5, page 4-9), 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

4-233. 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 4-6, page 4-33, in the evaluation. The evaluation to determine the number of passes allowable is conducted using Figures I-1 through I-38, pages I-2 through I-39, because the evaluation may or may not be based on the C-17 (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-17/586 kips).
- Determine the traffic area to evaluate (see figure 4-4, page 4-6). 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. The CBR of the select, subbase, and base also could be established from construction drawings, the Air Force Civil Engineering Support Agency, or the Corps of Engineers evaluation reports. The CBR also can be estimated based on soil classification (see TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034). The physical properties on which the evaluation is based are presented in table 4-17. The evaluation for the runway is based on the pavement thickness in the central 100-foot width for gear configurations.
- Select the appropriate evaluation curve from appendix I. If there is no curve for the aircraft considered, use the curve for the controlling aircraft (C-17).
- 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.

Example 16

Determine the number of allowable aircraft passes for F-4 aircraft with a weight of 62,000 pounds. The test pit evaluation of a captured enemy airfield indicates the following conditions (refer to table below):

- 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)

Facility number and identification	*Pavement*		*Base*			*Subgrade*	
	Thick (in.)	*Description*	*Thick (in.)*	*Classification*	*CBR*	*Classification*	*CBR*
Primary runway, taxiway, and parking apron	4	Asphalt concrete	8 15	GW crushed stone GP stabilized gravel	100 50	CL clean clay	15

Solution 16

The aircraft type (F-4), weight (62 kips), traffic area (B), layer thicknesses, and CBR values have all been provided. Using figure I-4, page I-5, 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 104, 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 17

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 17

The subgrade controls the evaluation with 140 allowable passes.

Selection of Strength and Thickness Values

4-234. 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.

4-235. 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 equations 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.

4-236. 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.

4-237. When conditions are uniform, the lower quartile value from a cumulative distribution plot may be used. Where conditions are not uniform, the following 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 grade 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.

4-238. 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 TM 3-34.48-1). Use these CBR values for base-course material when the material meets quality requirements of the specification.

4-239. When evaluation tests are made less than three years after construction and indicate plasticity index (PI) 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 PI values greater than 5, use in-place values.

4-240. 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.

4-241. 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

4-242. The condition of a bituminous pavement, surface or binder course, is evaluated at the time of sampling by comparing the test data from the core samples with the design criteria in UFC 3-250-03. 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.

4-243. Assume that the thickness and aggregate gradation are satisfactory. The current density (cores) is relatively low, the flow is approaching the upper limit, the voids' (physical property of bituminous pavement) relationship is outside acceptable ranges, and the stability is satisfactory.

4-244. 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. 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

4-245. 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.

4-246. Weathering appears to increase pavement resistance to jet fuel penetration. Pavements about one year old or older usually perform better in this respect than new pavements.

4-247. 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.

4-248. 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 4-15 as a guide for evaluating the types of bituminous pavements from the standpoint of fuel spillage for use in areas throughout the airfield.

Table 4-15. Guidance for evaluating pavement types

Type pavement	*Texture*	*Uses*
Asphalt concrete	Not Applicable	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

Ability to Withstand Jet Blast

4-249. Tests have shown that about 300 degrees Fahrenheit is the critical temperature for AC and rubberized-tar concrete. About 250 degrees Fahrenheit is the critical temperature for tar concrete. Field tests simulating preflight checks at the ends of runways indicate the maximum temperatures induced in pavement tests; simulating maintenance checkups were 315 degrees Fahrenheit. Rubberized-tar concretes usually withstand these temperatures. No bituminous pavement resists erosion if afterburners are turned on when the plane is standing still.

4-250. 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

4-251. 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.

4-252. To evaluate the base, subbase, and subgrade from the standpoint of future compaction, compare in-place densities 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.

4-253. Low-density materials combined with low moisture content permit densification. 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

4-254. 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 pavement load-carrying capacities. In making these comparisons, consider the number of coverages produced by each type of plane and the effects of mixed traffic.

4-255. No criteria exist 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.

4-256. 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.

4-257. 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

4-258. 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 ASTM 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.

4-259. 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

4-260. An evaluation of a flexible-pavement airfield may determine that 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 18

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 support area 10,000-foot airfield for 1,000 passes. Therefore the airfield should have—

4-inch AC Pavement
6-inch Base Course CBR = 80
6-inch Select Material CBR = 20
Subgrade CBR = 7

Solution 18

The critical aircraft for the support area 10,000-foot airfield is the C-17, which has a gross weight of 586,000 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 4-19, page 4-51. This indicates whether the airfield is satisfactory as is or whether an overlay is needed.

Enter figure 4-19 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:

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 9 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. Therefore the airfield should have—

- 3-inch AC pavement
- 6-inch base course CBR = 100
- 4-inch AC pavement
- 6-inch base course CBR = 80
- 6-inch select material CBR = 20
- Subgrade CBR = 7

Another method to determine an overlay requirement is to use the evaluation curves, figures I-1 through I-38, pages I-2 through I-39. Enter these curves at the bottom with the number of aircraft passes, and read upward to the CBR value of the layer. 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 (inches)*	*Design Thickness (inches)*	*Overlay Thickness Requirement*
CBR 7 subgrade	16	25	9
CBR 20 select material	10	11	1
CBR 80 base	4	2.8	0

Thus, this method also would result in an overlay.

Soil Layer	*Existing Thickness Above Soil Layer (inches)*	*Design Thickness (inches)*	*Overlay Thickness Requirement*
CBR 7 subgrade	16	25	9
CBR 20 select material	10	11.5	1.5
CBR 80 base	4	3	0

NONRIGID OVERLAYS OVER RIGID PAVEMENTS

4-261. In the support areas of the TO, it may be necessary to evaluate existing rigid pavements and to bring them to required strengths by adding nonrigid overlays. 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.

4-262. 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.

4-263. 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 19

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-inch AC pavement
6-inch PCC
8-inch course CBR = 80
Subgrade CBR = 7

This sample airfield is to be used by C-17 aircraft for 5,000 passes. The design load is 586,000 pounds. Tests of the AC indicate that it meets design requirements for stability, density, gradation, voids relations, and other design requirements.

Solution 19

A design curve for traffic area Type B will be required. Enter figure 4-19, page 4-51, with this design load (in kips). It is found that the CBR = 7 subgrade requires 29 inches of cover, CBR = 40 requires 6.8 inches of cover, and CBR = 100 (PCC) requires no cover.

The total cover over the CBR = 7 subgrade is only 16 inches, whereas 29 inches is required. Therefore, the overlay must be 29 – 16 inches, or 13 inches thick.

PAVEMENT AND AIRFIELD CLASSIFICATION NUMBERS

4-264. 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 establish 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.

4-265. 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 PCN value. This is possible because ACN and PCN values are computed using the same technical basis.

DETERMINATION OF VALUES

4-266. The ACN/PCN is a reporting method for weight-bearing capacity and not an evaluation procedure. The National Imagery and Mapping Agency publishes weight bearing limits in terms of ACN/PCN in a flight information publication for civil and international use. The intent is to provide planning information for individual flights or multiflight missions which will avoid either overloading of pavement facilities or refused landing permission.

Pavement Classification Numbers

4-267. 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 is a process of converting that rating to a standard relative value. The PCN value is usable for reporting the pavement strength only.

Rigid Pavement Pavement Classification Number—Allowable Load Curves

4-268. 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 pounds per square inch. Four different subgrade strengths are considered: high, 554 pounds per cubic inch; medium, 295 pounds per cubic inch: low, 147 pounds per cubic inch: and ultra-low, 74 pounds per cubic inch. Using these parameters, a standard single-wheel load at a tire pressure of 181 pounds per square inch 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 Pavement Classification Number—Allowable Load Curves

4-269. 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 ultra-low, CBR = 3. A standard single-wheel load at a tire pressure of 181 pounds per square inch 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 Pavement Classification Number

4-270. 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 4-16, page 4-74, must be provided.

4-271. 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.

Table 4-16. 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	Ultra low	<4	<100

Code	*Category*	*Tire pressure (pounds per square inch)*
W	High	No limit
X	Medium	146 - 217
Y	Low	74 - 145
Z	Ultra low	0 – 73

Legend:
CBR California Bearing Ratio PCN pavement classification number

Guidance on Overload Operations

4-272. Pavement overload can result from loads that are too large, are 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 and 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.

4-273. Such overload movements should not normally be permitted on pavements exhibiting signs of distress or failure. Furthermore, overloading should be avoided during 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.

PAVEMENT-TRANSPORTATION COMPUTER ASSISTED STRUCTURAL ENGINEERING

4-274. The PCASE computer program was created for use in the design and evaluation of transportation systems. PCASE software automates day-to-day engineering tasks by giving engineers a software tool. This process allows engineers to try multiple design or evaluation scenarios without having to start over each time.

4-275. The PCASE software program saves time by incorporating all transportation criteria into a user-friendly computer format for designing and evaluating transportation systems, including airfields, roads, and railroads.

4-276. PCASE is necessary for performing pavement evaluations for Army, Air Force, and Navy facilities and in the TO. Determining airfield and roadway pavement life, required upgrades, and repair solutions is critical to determining if training operations and military missions can be conducted on the facilities.

Per the DOD UFC 3-260-11FA and UFC 3-260-02, PCASE is required to be used in design of all design-build airfields and pavements. The Army military construction process also requires the use of PCASE for military tracked vehicles. PCASE is essential in the required review of all airfield designs by the Transportation System Mandatory Center of Expertise per AR 95-2. To download the PCASE software, open an Internet browser and enter the Web site.

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Chapter 5

Design and Construction of Heliports and Helipads

This chapter presents information on the design and construction of operational facilities for rotary-wing aircraft (helicopters). 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 and soil-stabilization requirements. Procedures for marking and lighting heliports and helipads are also discussed.

TYPES OF HELICOPTERS

5-1. Army helicopters are classed as OH, UH, CH, and AH. Important characteristics of current United States military helicopters are shown in table 5-1. Design criteria given later in this chapter are based on use by the most critical aircraft (greatest pavement load). For a complete listing and characteristics of military helicopters see Technical Report TSC 13-2.

- **OH**. OHs are used for visual, photographic, or electronic observations and the adjustment of fires. OHs are also used for mission command; reconnaissance; surveillance; aerial wire laying; and a limited amount of resupply, evacuation, and aerial fire support.
- **UH.** UHs are used for missions such as troop and cargo lift, passenger transport, patient movement, mission command, and dissemination of material during psychological operations.
- **CH.** CHs are used to support air-movement operations and to transport troops, equipment, and supplies within the operational 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.
- **AH.** AHs provide direct aerial fires and escort troop-carrying helicopters and provide a suitable platform for various weapons.

Table 5-1. Characteristics of certain United States military helicopters

Helicopter	*Name*	*Length (feet)*	*Width (feet)*	*Height (feet)*	*Basic Weight (kips)*	*Maximum Takeoff Weight (kips)*	*Gear Type*
OH-58C	Kiowa	41.00	35.30	12.00	1.90	3.20	Skid
UH-72A	Lakota	42.75	36.08	13	3.95	7.90	Skid
UH-60	Blackhawk	64.83	53.67	17.50	11.04	20.25	Single-wheel main gear with trail wheel
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
AH-64	Apache	57.67	48.00	15.25	14.66	20.65	Single-wheel main gear with trail wheel
MQ-88	Fire Scout	31.67	6.2	9.75	2	3.2	Skid

Legend:
AH attack helicopter
CH cargo helicopter
OH observation helicopter
UH utility helicopter

HELIPORT TYPES, DESIGN CRITERIA, AND LAYOUT

5-2. 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 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 helicopters per site.

5-3. Locating heliports with large aircraft capacities at a fixed-wing airfield usually satisfies requirements in the underdeveloped areas of the world. This density is determined by security requirements, responsiveness to supported units, and reduction of airfield construction effort.

TYPES OF HELIPORTS

5-4. The five levels of heliport development in the TO are—LZs of opportunity, austere forward area fields, substandard but operational support area fields, deliberate support area fields, and helipads.

LANDING ZONE OF OPPORTUNITY

5-5. This type facility, normally located in the support 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 FORWARD AREA FIELD

5-6. 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 objects likely to be blown about by the rotor.

5-7. 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.

5-8. The location of an austere forward 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.

SUBSTANDARD BUT OPERATIONAL SUPPORT AREA FIELD

5-9. This construction standard provides conventional safety and efficiency of operations. Heliport traffic areas are normally surfaced with landing mat, and 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.

5-10. 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.

DELIBERATE SUPPORT AREA FIELD

5-11. These heliports are designed and constructed for all-weather operations. A deliberate support area field has a well-graded, thoroughly compacted base, and an expedient or conventional surface. The field is usually in the communications zone and is located at a fixed-wing airfield. Construction is done 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

5-12. 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 were developed for various helicopters.

FACTORS INFLUENCING DESIGN

5-13. The basic TO heliport complex, as visualized in development of design criteria for support and sustaining area heliports, is shown in figure 5-1, page 5-4. 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 5-1, page 5-1. Additionally, geometric requirements and minimum area requirements for each kind of helipad/heliport considered are shown in table 5-2, page 5-5, and table 5-3, page 5-7. Factors that influence the development of heliport design criteria are helicopter characteristics, operational considerations, and requirements for expedient airfield surfacing and dustproofing. Location, traffic area, and safety also affect the design of heliports.

Helicopter Characteristics

5-14. Helicopter characteristics that influence heliport strength requirements are weight, landing-gear configuration, and tire pressure. Ground run and dimension characteristics affect heliport geometric layouts.

5-15. 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 total wheel load and the dimensions of the tire area in contact with the heliport surface determine the loading for each wheel. The contact area dimensions are influenced by tire pressure. The heliport surface must have sufficient strength to resist repeated applications of maximum unit loads.

5-16. 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.

Operational Considerations

5-17. 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

5-18. 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.

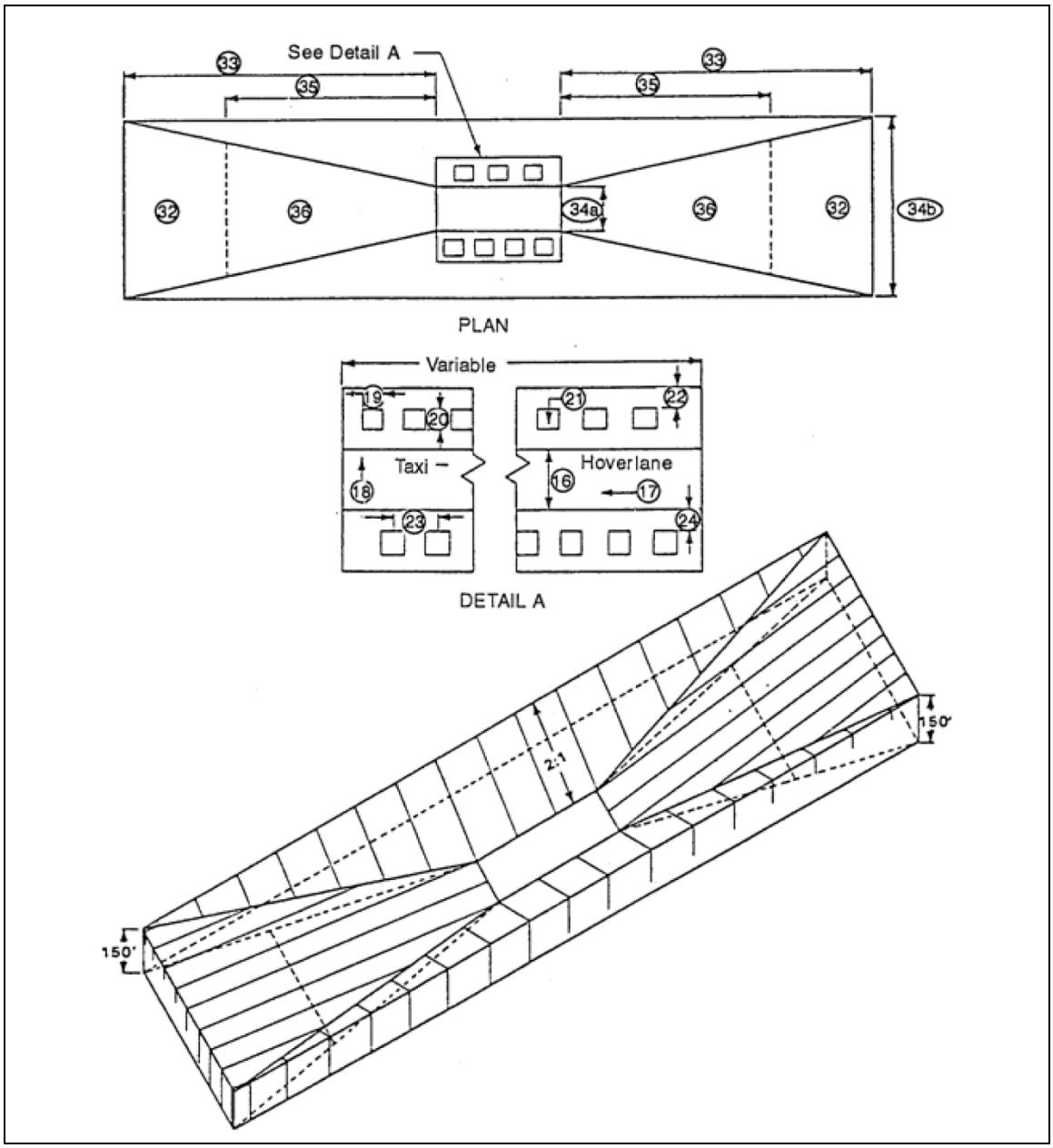


Figure 5-1. Heliport with taxi-hover lane

Location Requirements

5-19. 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 support areas, helicopter support facilities are provided, greater numbers of helicopters are accommodated, and heliport dimensions reflect less reliance on helicopter performance characteristics.

Table 5-2. Geometric requirements and minimum areas for heliports/helipads

Item No.	Description	Close Battle Area			Support Area			Rear Area		
		OH-58	UH-60	CH-47	OH-58	UH-60	CH-47	OH-58	UH-60	CH-47
	Heliport Runways									
1	Length, ft[1]	---	---	---	---	---	450	---	---	450
2	Width, ft	---	---	---	---	---	25	---	---	40
3	Longitudinal grade of runways and shoulders, percent	---	---	---	---	---	±2	---	---	±2
4	Transverse grade of runway, percent									
	Maximum	---	---	---	---	---	1.5	---	---	1.5
	Minimum	---	---	---	---	---	0.5	---	---	0.5
5	Shoulder width, ft	---	---	---	---	---	10	---	---	25
6	Transverse grade of shoulders, percent									
	Maximum	---	---	---	---	---	3	---	---	3
	Minimum	---	---	---	---	---	2	---	---	2
7	Clearance from runway CL to fixed or movable obstacles, ft	---	---	---	---	---	375	---	---	375
8	Cleared areas, slope, percent Maximum	---	---	---	---	---	5	---	---	5
	Heliport Taxiways									
9	Width, ft	---	---	---	---	---	25	---	---	40
10	Longitudinal grades of taxiways and shoulders, percent	---	---	---	---	---	2	---	---	2
11	Transverse grade of taxiway, percent									
	Maximum	---	---	---	---	---	1.5	---	---	1.5
	Minimum	---	---	---	---	---	0.5	---	---	0.5
12	Shoulder width, ft	---	---	---	---	---	10	---	---	25
13	Transverse grades of taxiway shoulders, percent									
	Maximum	---	---	---	---	---	3	---	---	3
	Minimum	---	---	---	---	---	2	---	---	2
14	Clearance from taxiway CL to fixed or movable obstacles, ft	---	---	---	---	---	375	---	---	375
15	Grade in any direction in taxiway cleared area, percent	---	---	---	---	---	5	---	---	5
	Taxi-Hoverlane									
16	Width, ft[2]	75	140	180	100	200	240	100	200	240
17	Longitudinal grade of taxi-hoverlane, percent maximum	10	10	10	5	5	5	5	5	5
18	Tranverse grade of taxi-hoverlane, percent									
	Maximum	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

Table 5-2. Geometric requirements and minimum areas for heliports/helipads (continued)

Item No.	Description	Close Battle Area			Support Area			Rear Area		
		OH-58	UH-60	CH-47	OH-58	UH-60	CH-47	OH-58	UH-60	CH-47
	Heliport Parking Pad									
19	Length, ft	12	20	50	12	20	50	25	40	50
20	Width, ft	12	20	25	12	20	25	25	40	100
21	Parking pad grade in any direction, percent Maximum Minimum	 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
22	Lateral clearance from rear and sides of parking pad to fixed and/or movable obstacles except other aircraft, ft	25	45	65	25	55	75	30	65	100
23	C-C spacing of parking 40 pads, ft	40	75	150	55	80	175	55	80	175
24	Spacing from edge of taxi-hoverlane to edge of parking pad, ft	10	20	20	10	20	20	10	20	20
	Heliport Overrun									
25	Length, ft	—	—	—	—	—	100	—	—	100
26	Length, ft	Same as runway, plus shoulders								
27	Longitudinal grade, percent	—	—	—	—	—	2	—	—	2
28	Transverse grade, percent Maximum Minimum	 — —	 — —	 — —	 — —	 — —	 3 2	 — —	 — —	 3 2
	Heliport Clear Zone									
29	Length, ft	—	—	—	—	—	100	—	—	100
30	Width, ft	—	—	—	—	—	250	—	—	250
31	Grades outside of overrun and shoulders, percent	—	—	—	—	—	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
33	Length, ft	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	 100 850	 200 850	 250 850	 100 850	 200 850	 250 850
35	Length, ft	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	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 as to require the least engineer effort.

Legend:

CH	cargo helicopter
CL	centerline
ft	feet
OH	observation helicopter
UH	utility helicopter

Table 5-3. Maximum area characteristics 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])*
Main 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
Main Battle Area Heliport							
UH-60	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
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
Avn. Brigade	120,432[4]	92,688	11,250	5,000	229,370	2,022,175	1,994,000
Support 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
Support 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
Avn. Brigade	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.
[4] Includes 80,000 square feet maintenance area.

Legend:

AH	attack helicopter
avn	aviation
CH	cargo helicopter
ft	feet
OH	observation helicopter
sq	square
UH	utility helicopter

Traffic Area Requirements

5-20. 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 satellited in the airfield operational area (see figure 5-2). Traffic areas for helicopters are assumed to carry the same requirements as the parking areas of the basic airfield complex.

Safety Criteria

5-21. 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

5-22. The geometric design requirements for helicopter landing areas can be simplified into four basic types—helipads, heliports with taxi-hover lanes, heliports with runways, and mixed brigade 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.

Helipads

5-23. The geometric layout and section views of a helipad are shown in figure 5-1, page 5-4. The minimum dimensional (geometric) requirements are in table 5-3, page 5-7. The circled numbers in figure 5-1 identify the item numbers listed in table 5-2, page 5-5. Use figure 5-1 with table 5-2 to determine the geometric requirements for each critical helicopter and each type of landing pad (main battle area, support area, and support area).

Heliports With Taxi-Hoverlanes

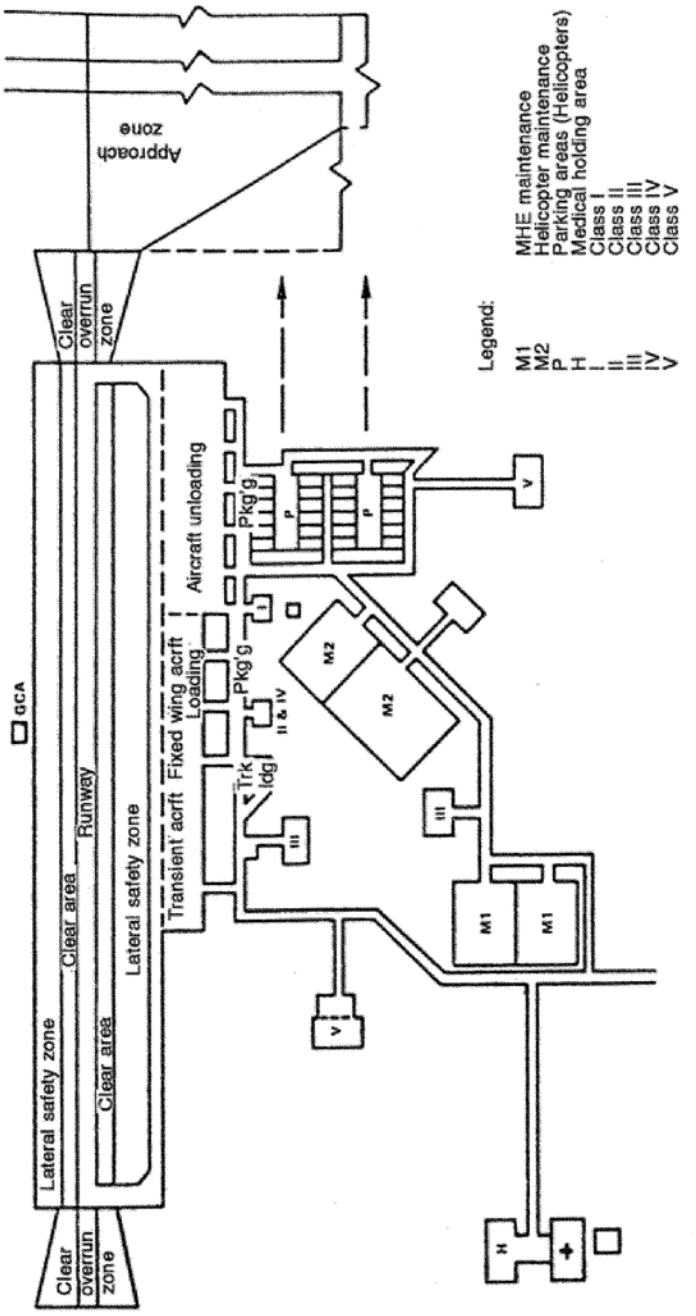
5-24. The geometric layout and section views of a heliport with a taxi-hoverlane are shown in figure 5-1. Parking and landing pads are offset midway across from each other on both sides of a taxi-hoverlane. Helicopters approach and depart this heliport via the hoverlane and approach/departure zone. The circled numbers refer to the item numbers in table 5-2 for the various types of heliports.

Heliports With Runways

5-25. The geometric layout and section views of a heliport with a runway are shown in figure 5-3, page 5-10. This heliport, normally located in support or support areas, is for the heavier wheeled cargo helicopters. The circled numbers in figure 5-3 identify the item numbers in table 5-2. 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 taxi lane. Helicopters normally approach and depart this heliport via the runway.

Mixed Battalion Heliport

5-26. The size of the mixed battalion heliport shown in figure 5-4, page 5-11, 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 of heliport must be separately designed to the requirements indicated previously. This facility normally is located only in support or support areas.



Legend:

GCA	ground controlled approach
ldg	loading
pkg'g	packaging
trk	truck

Figure 5-2. Schematic layout of satellite heliport

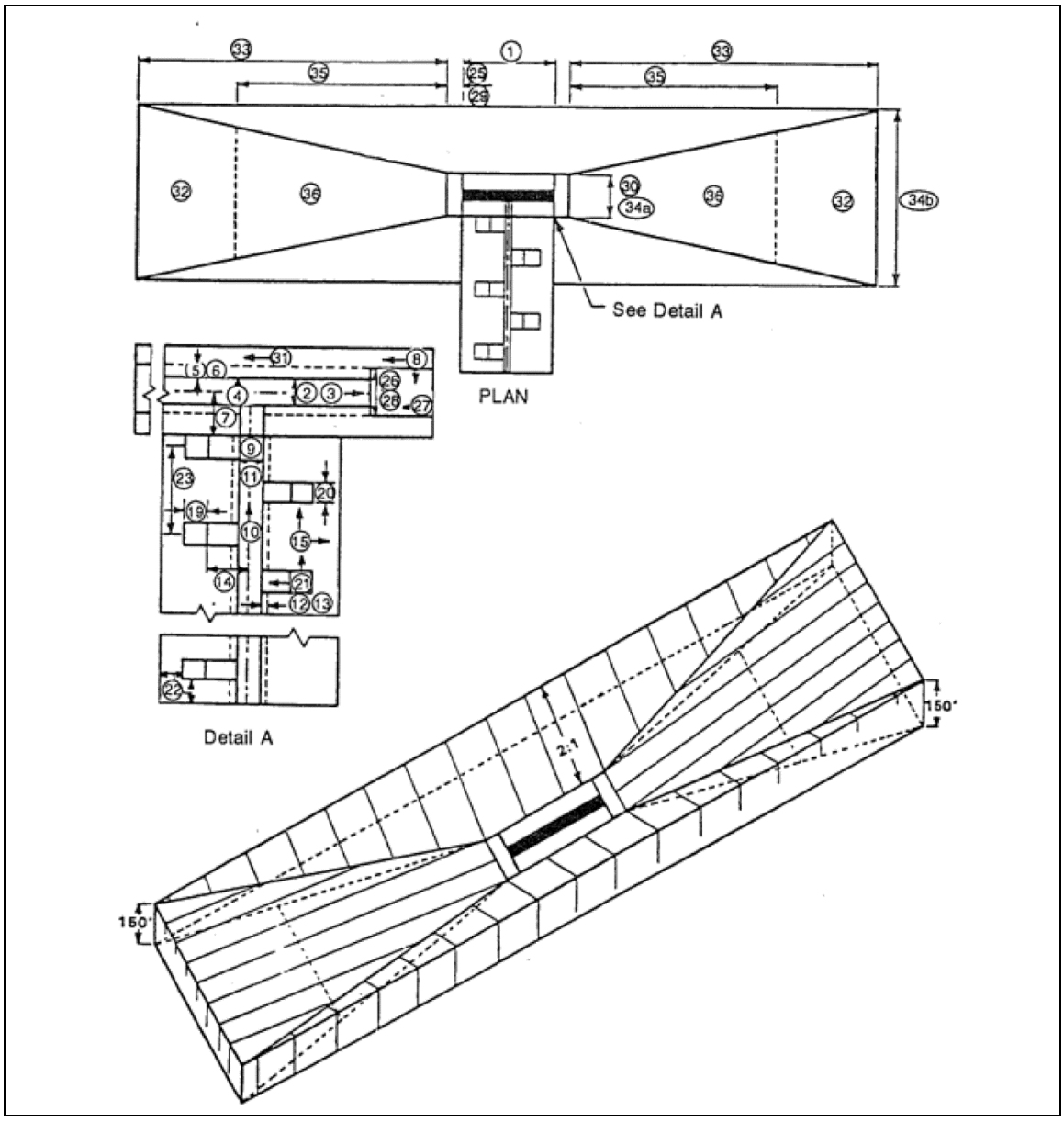
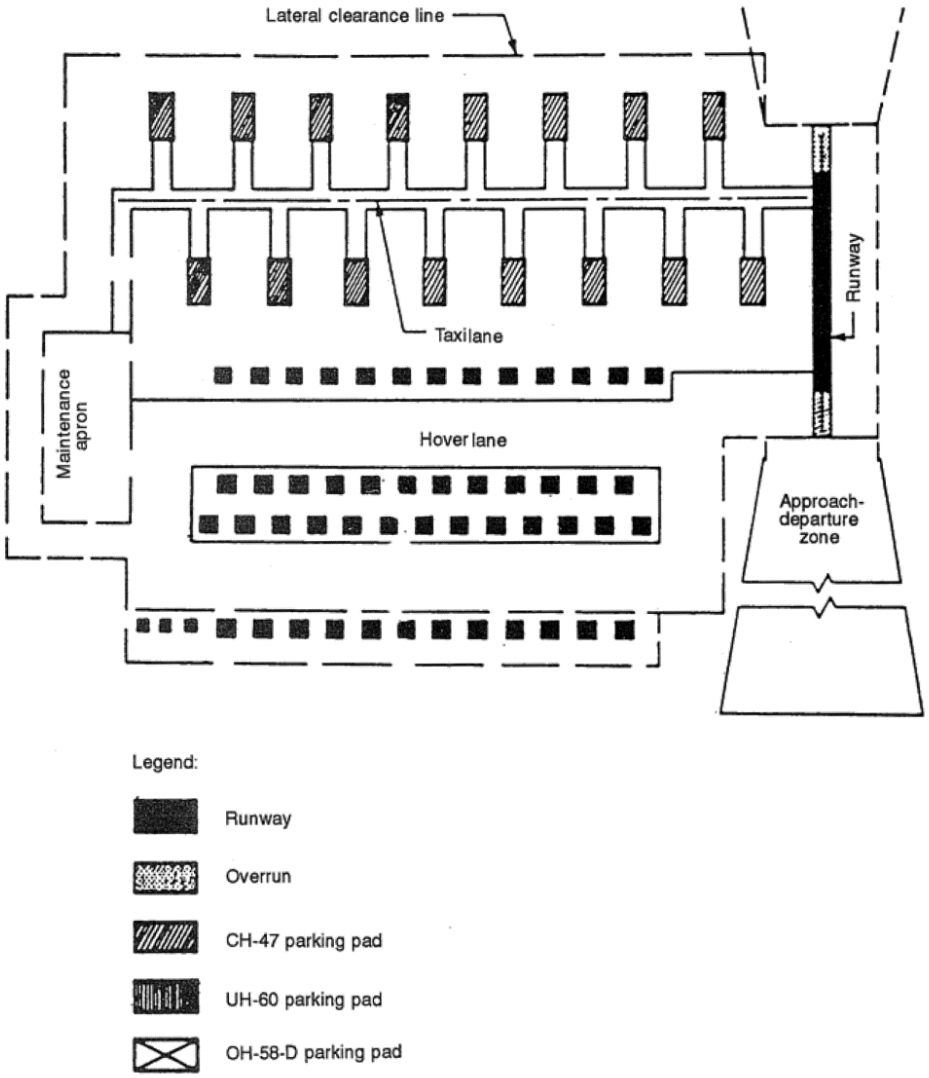


Figure 5-3. Heliport with runway

Runway Length

5-27. The runway lengths at sea level and 59 degrees Fahrenheit for helicopters considered are shown in table 5-2, page 5-5. Runways are not shown in layouts for skid-type helicopters or wheel-mounted helicopters in the main battle area, where the taxi-hoverlane is used for this purpose.

5-28. 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 degrees Fahrenheit 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 5-2, page 5-5, for each type heliport.



Legend:

CH	cargo helicopter
OH	observation helicopter
UH	utility helicopter

Figure 5-4. Mixed battalion heliport

Runway Orientation

5-29. 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 the wind through graphic analysis, often called a surface-wind rose analysis. Other factors permit aligning the runway as closely as possible with the prevailing wind.

Geometric Requirements

5-30. Geometric requirements for close battle, support, and rear area heliports and helipads are shown in table 5-2, page 5-5. 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. Table 5-2 and table 5-3, page 5-7, 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 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

5-31. Minimum area requirements for elements of a heliport are shown in table 5-3, page 5-7. 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 support areas. It is equal to only the parking pad areas for skid-mounted and wheel-mounted helicopters in the forward area.

5-32. 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 5-4. These values are for loose soil. Where other soil conditions exist, the requirements for dustproofing will be smaller.

Table 5-4. Required diameters for dustproofing areas

Helicopter	*Diameter of Dustproofing Area when Parked or on a Taxiway (feet)*	*Diameter of Dustproofing for Landing or Takeoff (feet)*
AH-64	150	300
OH-58	150	160
UH-60	150	264
CH-47	300	590

Legend:
AH attack helicopter
CH cargo helicopter
OH observation helicopter
UH utility helicopter

Design of Heliport and Helipad Surfaces

5-33. 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 locations of the materials. Generally, sieve analysis, specific gravity, hydrometer analysis, Atterberg limits, and CBR analysis test are required. Recommended procedures for treating materiels used in the layers of the pavement beneath surface course are presented in TM 3-34.48-1 and TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034.

Design of Unsurfaced Heliports

5-34. Unsurfaced areas (such as deserts, dry lakebeds, and flat valley floors) serve as possible heliport sites. Special procedures must be exercised to ensure that adequate dust control is used. Dust control is described in chapter 7 and later sections of this chapter. Site reconnaissance and smoothness requirements for heliports are the same as those described in chapter 1 for airfields.

5-35. Surfacing requirements for various subgrade strengths (CBR) for both unsurfaced areas and areas to be surfaced with landing mat are shown in table 5-5 for traffic areas (runway, taxiway, 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.

Table 5-5. Basic helipad and heliport surfacing requirements

Helipad or Heliport Type	*Anticipated Service Life*	*Runway, Taxiway, Apron, Helipad, and Road Surfacing Requirements for California Bearing Ratio*									
		0-1	*1-2*	*2-3*	*3-4*	*4-5*	*5-7*	*7-9*	*9-12*	*12-17*	*>17*
Main Battle Area Helipad											
OH-58	1-4 weeks	MS	U	U	U	U	U	U	U	U	U
CH-47	1-4 weeks	MS	MS	MS	MS	MS	MS	MS	U	U	U
UH-60, AH-64	1-4 weeks	MS	MS	MS	MS	MS	MS	MS	MS	U	U
Main Battle Area Heliport											
CH-47 company	1-4 weeks	MS	MS	MS	MS	MS	MS	MS	U	U	U
Support Area Helipad											
OH-58	1-6 months	MS	U	U	U	U	U	U	U	U	U
UH-1H	1-6 months	MS	MS	U	U	U	U	U	U	U	U
CH-47	1-6 months	**	MS	MS	MS	MS	MS	MS	U	U	U
UH-60, AH-64	1-6 months	**	**	MS	MS	MS	MS	MS	MS	MS	U
Support Area Heliport											
CH-47 company	1-6 months	**	MS	MS	MS	MS	MS	MS	U	U	U
UH-60 company	1-6 months	**	MS	MS	MS	MS	MS	MS	MS	MS	U
Aviation brigade	1-6 months	**	MS	MS	MS	MS	MS	MS	U	U	U
Support area Helipad											
OH-58	6-24 months	MS	MS	U	U	U	U	U	U	U	U
CH-47	6-24 months	**	MS	MS	MS	MS	MS	MS	MS	U	U
UH-60, AH-64	6-24 months	**	**	MS	MS	MS	MS	MS	MS	MS	U
Support area Heliport											
CH-47 company	6-24 months	*	MS	MS	MS	MS	MS	MS	MS	U	U
UH-60 company	6-24 months	**	MS	MS	MS	MS	MS	MS	MS	MS	U
Aviation brigade	6-24 months	**	**	MS	MS	MS	MS	MS	MS	U	U
Roads											
Closed battle	1-4 weeks	MS	MS	MS	MS	U	U	U	U	U	U
Disposal	1-6 months	MS	MS	MS	MS	MS	U	U	U	U	U
Staging and logistics	6-24 months	MS	MS	MS	MS	MS	U	U	U	U	U

* The surfacing requirements shown for the aviation brigade in the support and support 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.

** Improve soil strength and surface with mat.

Legend:

AH	attack helicopter	OH	observation helicopter
CH	cargo helicopter	U	unsurfaced soil with
MS	mat surfaced	UH	utility helicopter

5-36. Predicted traffic volume is a prime factor in determining surface requirements. However, a considerably larger volume of traffic 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 5-1, page 5-1. In such situations, the basic soil strength requirements in table 5-6, page 5-14, no

longer apply. In these cases, the required soil strengths for reasonable combinations of gross weight and traffic volume are determined through use of the subgrade strength requirements curve in figure 5-5.

Table 5-6. Strength and thickness requirements

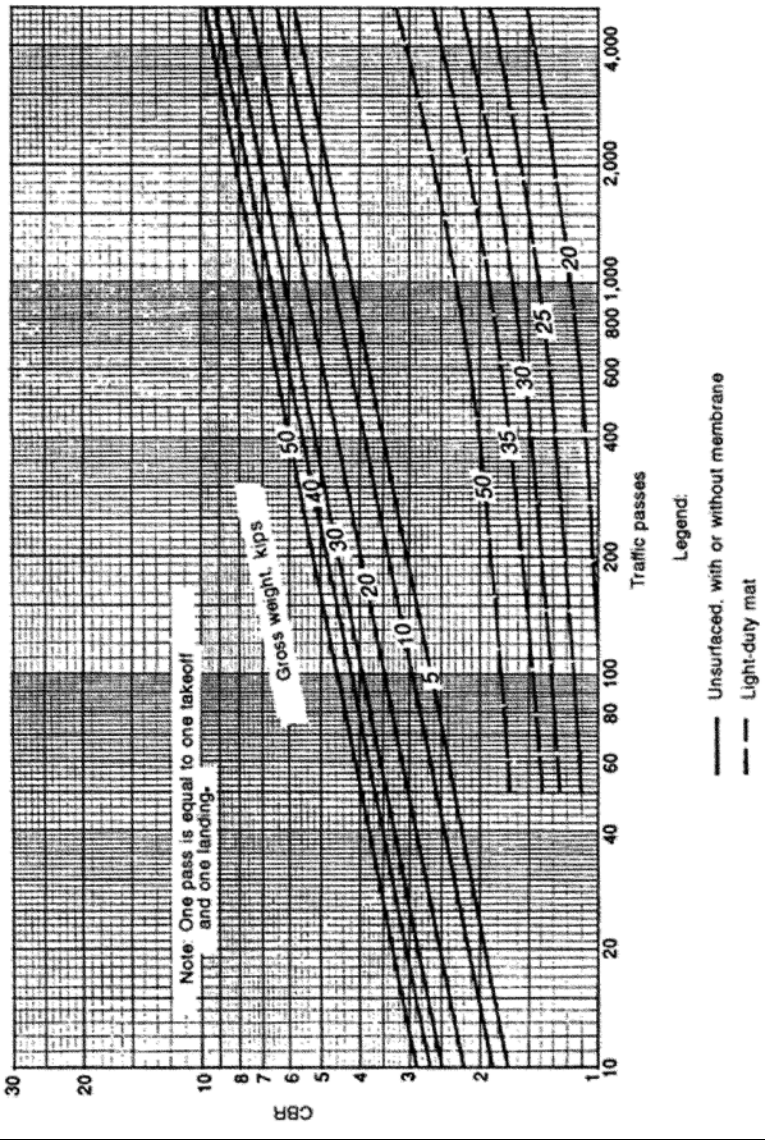
Helipad or Heliport Type	*Maximum* Stabilization Strength Required (inches)*	*Thickness of Stabilized Soil Layer Required (inches) for Runway, Taxiway, Apron, and Helipads for California Bearing Ratio*				
		4-5	*5-7*	*7-9*	*9-12*	*12-17*
Main Battle Area Helipad						
CH-47	10	10	9	7		
UH-60, AH-64	13	13	12	9	8	
Main Battle Area Heliport						
CH-47 company	10	10	9	7		
Support Area Helipad						
CH-47	11	13	11	8		
UH-60, AH-64	15	17	15	12	10	8
Support Area Heliport						
CH-47 company	11	13	12	9		
UH-60, AH-64	15	16	14	11	9	8
Aviation brigade	11	13	12	9		
Support Area Helipad						
CH-47	12	14	12	9	7	
UH-60, AH-64	15	18	16	13	11	9
Support Area Heliport						
CH-47 company	12	15	13	10	7	
UH-60, AH-64	15	17	15	12	10	9
Aviation brigade	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 California Bearing Ratio 4 is not usually practical.						
Legend: AH attack helicopter CH cargo helicopter UH utility helicopter						

5-37. The criteria and procedure used for improving soil strength to meet strength requirements in table 5-5, page 5-13, and table 5-6 are discussed in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034.

STABILIZATION

5-38. 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 TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034 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 airfield construction usually apply to heliports. Because differences of design and usage exist, this chapter presents information specifically for heliport development. This information and information in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034 describe the effective use of soil stabilization techniques.

5-39. 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.



Legend:
CBR California Bearing Ratio

Figure 5-5. Heliport and helipad subgrade strength requirements

Strength Improvement

5-40. 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 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.

5-41. Where stabilization for strength improvement is needed, certain basic design requirements must be met concerning the 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 5-6 are based on the traffic demands for operations in the areas by the CH-47 helicopters.

5-42. No strength or thickness requirements are shown for helipads for the OH-58 helicopters because these skid-equipped machines can operate satisfactorily on unsurfaced soils that have very low strength (see table 5-6, page 5-14). If the existing soil strength is less than the indicated minimum requirements for the OH-58 helicopter, the condition of the soil usually requires greater construction effort to achieve an acceptable stabilized facility.

5-43. Some soils have sufficient strength to support the OH-58 and 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 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.

5-44. 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.

5-45. Use the thickness data in table 5-6 to establish an adequate strength profile. Generally, a profile to a depth of 24 inches is sufficient to indicate the strength profile pattern.

STABILIZATION METHODS

5-46. Stabilization to improve the strength of an existing soil can be accomplished by mechanical or chemical methods. Mechanical stabilization methods include the compaction of an existing soil or the 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 most commonly used stabilizers that are used in heliport construction are portland cement, lime, and bituminous materials.

5-47. Two common 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.

5-48. 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

5-49. 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 areas of a heliport. Landing mats are often used to cover primary traffic areas of a heliport (runways, taxiways, aprons, parking pads). When this is the case, dust-control materials are used to control dust on remaining areas. Without a 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.

5-50. Dust-control and soil waterproofing materials are described in table 5-3, page 5-17, and TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034. Recommendations for their use and for guidance in selecting appropriate materials for traffic and nontraffic areas of a heliport are discussed in TM 3-34.43/MCRP 3-17.7H/NAVFAC MO 330/AFH 32-1034. When estimating material requirements, use table 5-3 to determine the areas for each heliport element.

5-51. Areas that may require dust control include runways, overruns, taxiways, aprons, taxi-hoverlanes, parking pads, roadways, and peripheral areas that are subjected to the downwash from helicopter rotors. All exposed ground within the entire heliport complex should be dust-free, and any area not protected by a landing mat requires dust-control treatment.

Soil Waterproofing

5-52. Areas that may require waterproofing to maintain soil strength include runways, overruns, taxiways, aprons, parking pads, and roadways for support vehicles.

Expedient Surface Design

5-53. 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.

Design Steps

5-54. The design steps for an expedient surface heliport or helipad are as follows:

- Determine the heliport location. Normally this is given in the mission statement as main battle area, support area, or support area.
- Determine the geometric requirements for heliport or helipad from table 5-2, page 5-5, and table 5-3, page 5-7.
- 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 5-1, page 5-1.

Note. Use 15 kips as the minimum weight for aircraft gross weight.

- Determine the strength of the subgrade in terms of critical CBR. This information is normally extracted from the battalion soils analyst or Air Force combat control teams or given as part of the mission statement. Determination of the critical CBR is described in detail in TM 3-34.48-1. Ensure that the subgrade thickness requirements from table 5-6, page 5-14, are met.
- Determine surface requirements from table 5-5, page 5-13, based on critical CBR.
- Determine the required strength from figure 5-5, page 5-15, in terms of the CBR based on the anticipated traffic passes for design aircraft (from the 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.

Step 1. Heliport location: Support area.

Step 2. Helipad geometric requirements: Given in support area UH-60 (table 5-2).

Step 3. Using aircraft: UH-60 Blackhawk

Gross weight: From table 5-1 20,250 pounds (20.25 kips)

Step 4. Critical CBR = 7 for uniform strength profile (given).

Step 5. Required CBR based on 200 anticipated traffic passes: From figure 5-5, the required CBR is 4, less than the critical CBR; therefore, this site is suitable for the mission.

Mat-Surfaced Heliports and Helipads

5-55. Many aircraft require the use of mats to operate successfully in low subgrade strength areas. Table 5-5 details basic surfacing requirements for the critical aircraft in the three heliport locations. Table 5-3 details the total area required for heliport construction. Contact Naval Air Systems Command (NAVAIR) or United

States Army Engineer Research and Development Center (ERDC) through reachback for on the latest matting information.

MAT REQUIREMENTS

5-56. It is possible to calculate and tabulate expedient matting requirements for specific facilities because heliport and helipad designs are standardized. Use the guide below to locate information required for this process.

Thickness Design Procedure

5-57. The design procedure for flexible surfaces for heliports and helipads is almost identical to that of discussed airfields as in TM 3-34.48-1.

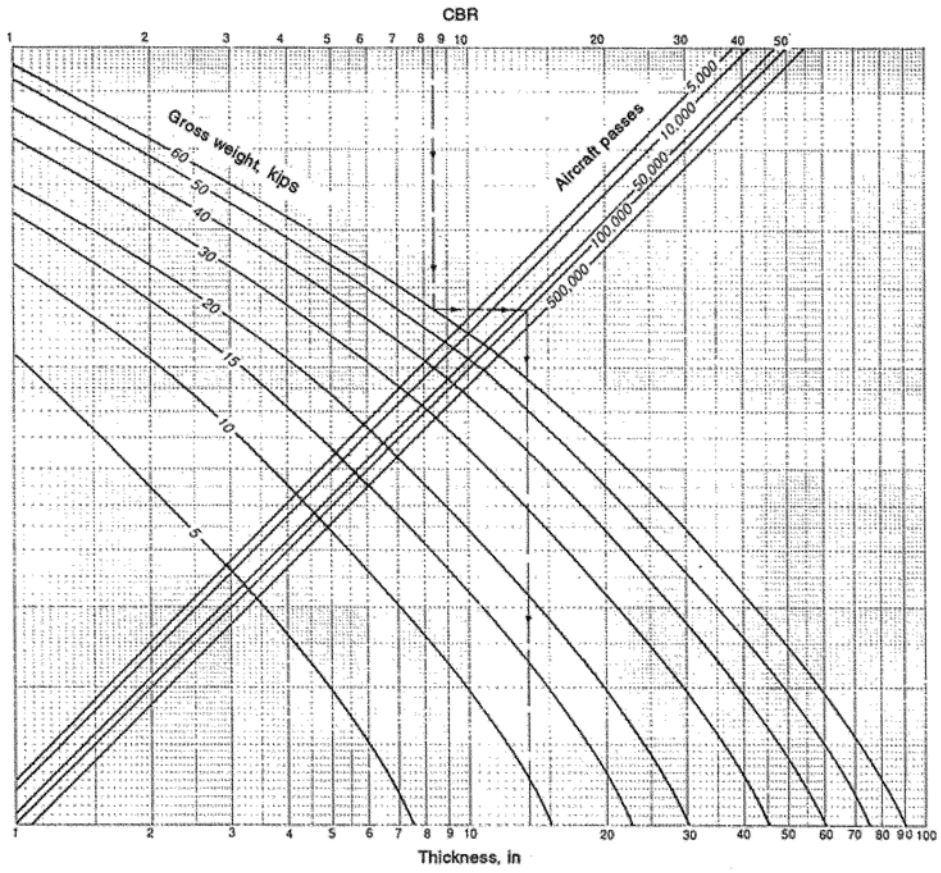
- **Step 1. Determine the heliport/helipad location.** Flexible pavements constructed for heliports/helipads are typically only in the sustaining area.
- **Step 2. Determine the design aircraft and gross weight.** Flexible-pavement structures have the capability to support large cargo helicopters with tremendous gross weights, and 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 only a specific aircraft will use the heliport/helipad, 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 4-7, page 4-33, 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 4-8, page 4-34, while the gradation of a soil must meet the specifications in table 4-9, page 4-35, based on the maximum size aggregate.
  - 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 table 4-10, page 4-46, and table 4-11, page 4-38.
- **Step 4. Determine the number of passes required.** Because the support area is considered temporary construction (6 to 24 months), flexible pavement heliports/helipads are designed to sustain an appropriate number of passes. See figure 5-6.

Note. One pass refers to one takeoff and one landing.

- **Step 5. Determine the total surface thickness and cover requirements.** Enter the curve in figure 4-5, page 4-9, for the soil CBR and number of required passes. The resulting thickness is the cover required above a particular soil layer to protect it from shear failure. The asphalt thickness (inches) is a function of the strength of the base course as follows:

  100 CBR Base: pavement 3 inches; base 6 inches
  80 CBR Base: pavement 4 inches; base 6 inches

- **Step 6. Complete the temperate thickness design.** Same as for fixed-wing aircraft.
- **Step 7. Adjust the thickness design for frost susceptibility.** These design steps are the same as previously discussed for fixed-wing airfields.



Legend:

CBR	California Bearing Ratio
in	inch

Figure 5-6. Flexible pavement design curve for heliports and helipads

- **Step 8. Determine the compaction requirements and subgrade depth.** The depth (in inches) of the 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, the 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.

Example

Design pavement for the parking/loading area of a support area heliport in Central America capable of handling 5,000 passes of a CH-47D aircraft. The soils analyst has already determined the soil layers.

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 maximum size aggregate (2-inch).

Solution

Step 1. Airfield location (given) = support area/Type C traffic area.

Step 2. Design aircraft = CH-47/50 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) = 5,000.

Step 5. Determine the thickness requirements from figure 4-5, page 4-9.

Material	*Minimum Required Cover*
Compacted subgrade CBR = 5	13 inch
Select material CBR = 15	5.7 inch round up to 6 inch
Subbase CBR = 40	2 inch

Step 6. Complete the temperate thickness design.

Minimum Required Cover			*Layer Thickness*	*Layer*
			4 inch	AC Pavement
		2 inch	6 inch	Base CBR = 80
	6 inch		0 inch	Subbase CBR = 40
13 inch			6 inch	Select CBR = 15
				Comp. Subgrade

See table 4-13, page 4-47, with the traffic area (C) and the base course CBR (80) to find that the thickness of the AC pavement = 4 inches. 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 4-5 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 the table below.

Layer	*Compaction Requirement*
Compacted subgrade	90-95%
Select material	90-95%
Base course	100-105%
AC pavement	98-100%

Solution (continued)

Step 9. Draw the final design profile.



4" Pavement @ 98-100%

6" Base Course CBR=80 @ 100-105%

6" Select Material CBR=15 @ 90-95%

GLE GLE

8" SCRIP CBR=5 @ 90-95%

TDF @ 90-95%

Special Design Considerations

5-58. Special airfield flexible-pavement design considerations (designing for frost areas, designing for arid areas, using stabilized soil layers discussed in chapter 4 also apply to flexible-pavement heliports and helipads. As such, no further discussion will be made on these areas. The evaluation of flexible pavements of heliports and helipads follow the same procedure as detailed in chapter 4.

Marking and Lighting of Heliports and Helipads

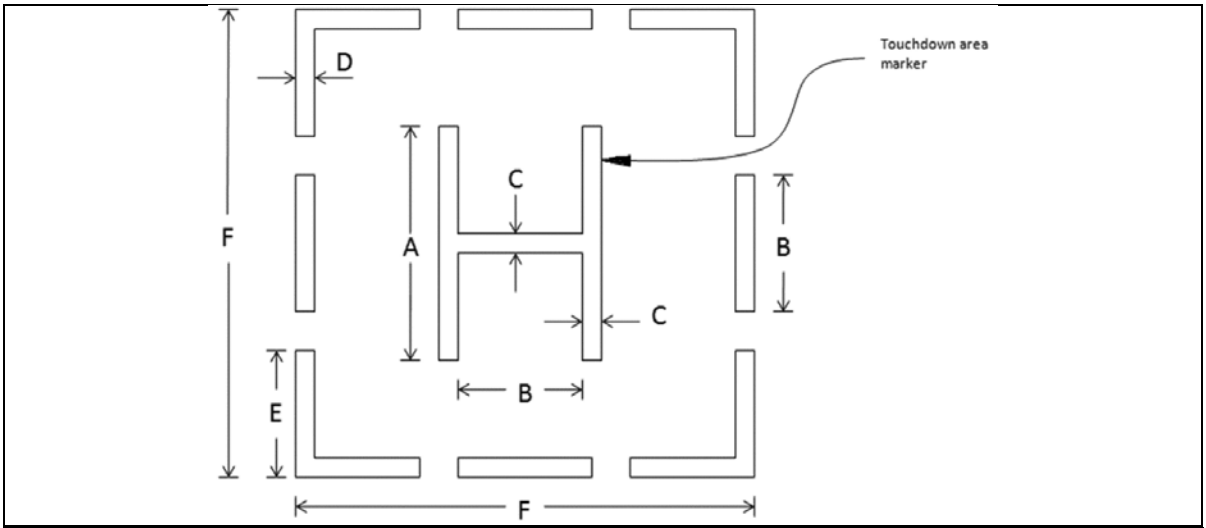
Note. This section implements STANAG 3619.

5-59. Depending on the tactical situation, the marking pattern defined here is placed on surfaced helipads or helicopter runways. If the traffic areas are surfaced with PCC or flexible (asphalt) pavement, utility- or generator-powered lighting units provide the lighting specified; otherwise, battery-powered lighting units are acceptable.

MARKING PATTERN

5-60. The touchdown area marker for helipads is shown in figure 5-7, page 5-22. The dimensions of the pattern compared with the pad size are also shown. On 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 and parallel to approach path. The marking pattern is also placed on both ends of 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.

5-61. The marking pattern should be white paint or tape, and it should be edged in black when placed on a light-colored surface. The broken-line or solid-line border around the perimeter of the pad must be included on helipads.



Helipad Size (F) (feet)	Pattern Line Width (C) (feet)	Border Edge Width (D) (feet)	Corner Edge Length (E) (feet)
12 - 19	1.0	0.5	4.6
20 - 39	2.0	1.0	4.6
40 - 59	3.0	1.3	4.5
60 - 79	4.0	2.0	7.0
80 - 99	4.5	2.0	10.0
100 - 150	6.0	2.5	12.0

Figure 5-7. Touchdown area marking

MARKING OF TEMPORARY HELICOPTER LANDING FIELDS

5-62. Temporary airfields are not usually marked. When they are marked, use the procedures shown below. See figure 5-7.

Corner Marking

5-63. Mark the four corners with regulation panels—0.50 by 0.65 meters (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.

Obstruction Marking

5-64. As far as possible, mark telephone wires, electric wires, and similar objects near the area. The direction of sun rays in relation to the direction of landing or takeoff may make it difficult for the pilot to see. See FAA Advisory Circular 70/7460-1 and UFC 3-535-01.

Indication of Wind Direction

5-65. Use FAA L-806 Style I, Size 1 or L-806 Style II, Size 1 or approved equal.

Expedient Indication of Wind Direction

5-66. This indication is of primary importance. The following methods can be used:

- Place a windsock outside of the area.
- Place smoke machines or fires emitting clearly visible smoke outside of the area. Arrange them to avoid risk of fire.

- Use a staff that is experienced with 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.

Note. Expedient conditions do not exist when there is portland concrete cement or asphalt airfield pavement placed for the purpose of heliport or helipad construction.

Identification of the Unit

5-67. Unit identity signals must be arranged outside of 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

5-68. The following discussion concerns helipad lighting for visual meteorological conditions. Helipad lighting for IMC is beyond the scope of TO construction. IMC helipad lighting is discussed in STANAG 3534, TM 5-811-5, NAVAIR 51-50AAA-2, and UFC 3-535-01. Additional information for visual meteorological conditions helipads can be found in UFC 3-535-01.

5-69. 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 according to the following requirements:

- Lights will not be less than 1 foot or more than 7.5 feet from the border of the landing pad and will be an equal distance apart on parallel sides.
- Lights on parallel sides will be placed opposite each other.

5-70. Table 5-7 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 by more than 10 feet between adjacent sides, the long side will contain at least one more light than the short side. Table 5-8, page 5-24, shows the application of these requirements to the helipads developed for the control helicopters used in this manual.

Table 5-7. Lights required for helipads

Length of side (ft)	*12-19*	*20-39*	*40-100*
Light placement	4 corners	4 corners plus 1 intermediate light per side	4 corners plus 3 intermediate lights per side

Helipad Approach Slope Indicator

5-71. A visual glide slope indicator should be provided for a helipad when obstacle clearance, noise abatement, or traffic control procedures require a particular approach slope angle be flown, when the environment of a helipad provides few visual cues, or when the characteristics of a particular helicopter requires a stabilized approach path. The recommended system is the Chase Helicopter Approach Path Indicator. However, a two-box precision approach path indicator is acceptable.

5-72. A Visual Glide Slope Indicator System should be provided to serve the approach whether or not there are other visual approach aids or by nonvisual aids where one or more of the following conditions exist, especially at night:

- Obstacle clearance, noise abatement, or traffic control procedures require a particular slope to be flown.
- The environment of the heliport provides few visual surface cues.
- The characteristics of the helicopter required a stabilized approach.

Table 5-8. Lighting requirements for helipads

		LandingPad (feet)	*Clear Zone (feet)*	*Light Perimeter (feet)*	*Number of Lights Per Side*	*Distance Between Lights (feet)*	*Number of Lights Per Pad*
Observation Helicopter (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	—
Utility Helicopter (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	16
	Length	40	400	44	3	22	—
Cargo Helicopter (CH)-47, Attack Helicopter (AH)-64 Close Battle	Width	25	125	29	3	15	10
	Length	50	150	54	3	27	—
Support	Width	25	150	29	3	15	10
	Length	50	150	54	3	27	—
Rear	Width	50	150	54	3	27	18
	Length	100	400	104	5	26	—

5-73. The Chase Helicopter Approach Path Indicator system consists of two transition light units projecting red, green, and white lights. They are located forward of the helipad on the extended centerline at a distance determined in order to project an on-glide path angle (usually 6 degrees) at the helipad hover point before touchdown. The units are positioned at approximately 20 feet apart lateral (horizontal). The Chase Helicopter Approach Path Indicator system must be constructed and mounted as low as possible and be sufficiently lightweight and frangible so as not to constitute a hazard to helicopter operations.

Helipad/Heliport Beacon

5-74. A helipad beacon should be provided when long-range guidance is considered necessary and not provided by other means, or helipad identification is difficult because of surrounding lights.

5-75. The beacon must contain a colored sequence of lights, double peak white flash, and a single peak green and yellow. The flash must be 10 to 15 sequences of flashes per minute. The time between each color should be one-third of the total sequence time. The beacon should not be installed within 1 mile of an existing airport beacon or other helipad area.

5-76. The beacon should be visible for a distance of 1 mile in 1 mile visual meteorological conditions visibility in daylight, 3 miles in 3 miles visual meteorological conditions at night, and at an altitude of 3,000 feet aboveground level. The beacon should be mounted a minimum of 50 feet above the helipad surface. Where a control tower or control area is used, the beacon should be no closer than 400 feet, or no further than

3,500 feet from that area and not located between the control tower and the helipad. The beacon will be installed so that the base is not less than 15 feet above the floor of the control tower or operations room.

5-77. The main light beam should be aimed a minimum of 5 degrees above the horizontal and should not produce light below the horizontal in excess of 1,000 candelas. Light shields may be used to reduce the intensity below the horizontal.

Helipad Wind Direction Indicators

5-78. When used, helipad wind direction indicators will enhance operational capabilities, increase safety, and reduce pilot workload during approach, hover, and takeoff operations.

5-79. A helipad should be equipped with at least one wind direction indicator that is located in a position which indicates the wind conditions over the final approach and take-off area. The wind indicator must be free from the effects of air flow disturbances caused by nearby objects or rotor wash. It must be visible from a helicopter in flight, in a hover, or on the movement area. Where a helipad may be subject to a disturbed air flow, additional indicators located close to the area may be necessary to indicate surface winds.

5-80. A wind direction indicator must be constructed to give a clear indication of the wind direction and a general indication of the wind speed. An indicator should be a truncated cone made of lightweight fabric. The approximate minimum dimensions are 8 feet long, 18 inches in diameter (large end), and 1 foot in diameter (small end). The color selected must make it clearly visible and understandable from a height of at least 650 feet above the helipad. When practical, the preferred colors should be white or orange. Where it is necessary to provide adequate conspicuity against varied backgrounds, combined colors (such as orange and white, red and white, or black and white) are permitted.

5-81. A wind direction indicator intended for use at night must be illuminated and have a red obstruction light mounted on the mast.

LIGHTING FOR HELICOPTER RUNWAYS

5-82. Lines of aviation white, bidirectional lights will be located on each side of the runway at a distance of not less than 5 feet and not more than 10 feet from the surfaced edge of the runway. The spacing within the line of lights will not be more than 100 feet.

5-83. 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 and not more than 15 feet. Lines of green threshold lights will be placed not less than 5 feet and not 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 and not more than 15 feet. There will be no fewer than six threshold lights in each line.

LIGHTING FOR TAXI-HOVERLANES

5-84. Heliports for company-size or larger units will normally be designed to permit mass landings on the taxi-hoverlane between the parking pads (figure 5-1, page 5-4). The lighting will be as follows:

- Place a landing pad at each side of the taxi-hoverlane that has a common centerline with the taxi-hoverlane. The largest control aircraft using the facility will determine the size of the helipad. Mark and light the landing pad according to 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

5-85. The following taxiway lighting system is required to designate paths followed by the helicopter in going between landing/takeoff, service, and parking areas. This lighting system will not be used on taxi-hoverlanes that are used for mass landings.

Lateral Limits

5-86. The configuration consists of a line of lights paralleling each side of the taxiway. Provide taxiway lighting for regularly used taxiing routes. Locate the line of taxiway edge lights on each side of the taxiway no more than 10 feet from the edge of the full-strength paving, and no closer than the edge of the full-strength paving. The line of lights on both sides of a taxiway must be the same distance from their respective taxiway sides. When a runway or a portion of a runway is part of a regularly used taxiing route, provide taxiway lights in addition to the runway lights. To determine the spacing of lights along the taxiway length, such as intersections with runways and other taxiways or changes in alignment or width, a discontinuity on one side of a taxiway applies to the other side as well. Place an edge light at each discontinuity. For intersecting pavements, place them at the point of tangency of each wooden frame. Place a companion light on the side opposite the discontinuity as well.

Straight Sections of Taxiways

5-87. Place edge lights along straight taxiway edges at uniform intervals between the lights. Where the length of the section is greater than 400 feet, the spacing must not exceed 200 feet. If the section under consideration is opposite an intersecting taxiway or apron area, the uniform spacing must not exceed one half the width of the intersecting taxiway or apron. Where the length of the section is less than 400 feet the spacing must not exceed 100 feet. Where the light spacing exceeds 100 feet, place one additional light 40 feet from each end of the section. Where the section is opposite an ending taxiway, the uniform spacing must not exceed one half of the width of the ending taxiway. Place companion lights along the opposite edge where there is no intersecting pavement. Place companion lights on lines perpendicular to the taxiway centerline.

Curved Sections of Taxiways

5-88. Place edge lights along all curved taxiway sections. Uniformly space the lights on the outer line. Place the lights on the inner line on radials from the outer line of lights, except where the resultant spacing would be less than 20 feet. In this case, select spacing not less than 20 feet for the inner line of lights and place the outer line of lights on radials from the inner line. Place uniformly spaced edge lights at all fillets. The spacing must not exceed one half the width of the straight taxiway section. On all curves exceeding 30 degrees of arc, there must be a minimum of three lights between the points of tangency.

Expedient Operations

5-89. Virtually any type of lighting may be employed as long as all participating units are briefed and concur. This is for use by STTs only.

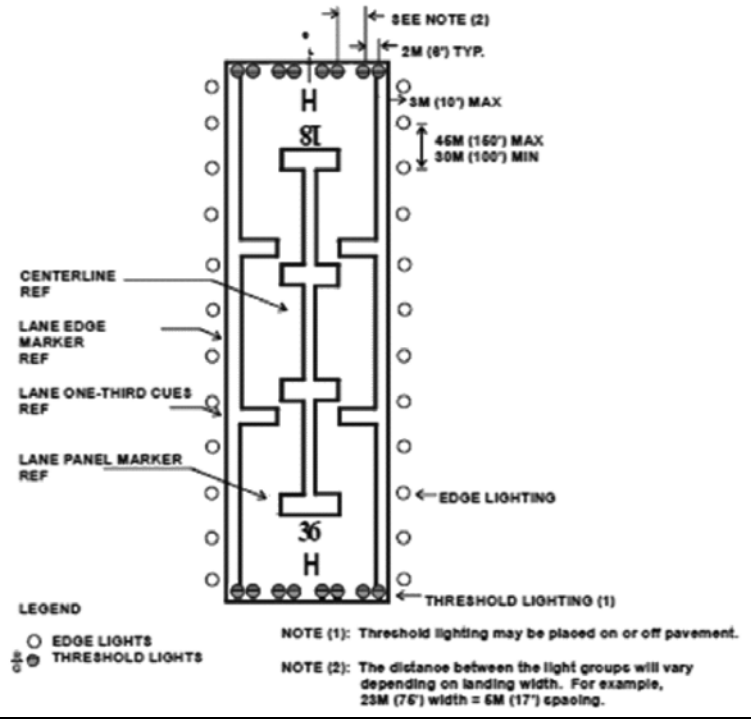
RECOMMENDED EQUIPMENT

5-90. Available equipment recommended to meet the lighting requirements in this manual is listed by Federal Aviation Administration (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.

5-91. The lights in each element of a system in a series circuit are connected by isolation transformers (60 hertz L-830 or 50 hertz L-831). A transformer and an L-823 connector kit will be required for each light fixture. The cable to be used can be (FAA L-824) Number 8 American wire gauge (AWG), stranded, 5 kilovolts, cross-linked polyethylene. The light fixtures recommended for each element in the lighting system are as follows (see figure 5-8 and figure 5-9):

- **Helipad.** The fixture recommended for the helipad perimeter light is the L-861 elevated with omnidirectional yellow lens.

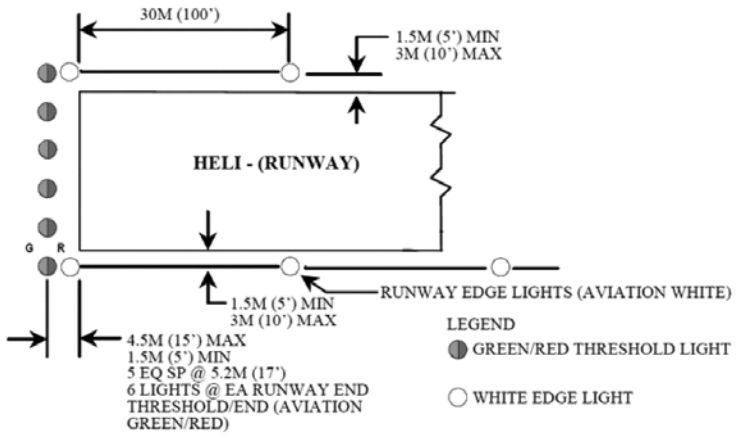
- **Rotary-wing landing lane.** The fixture recommended is the L-861 with the omnidirectional white for the edge lights and the L-861SE with bidirectional red/green lens for the threshold lights.
- **Taxiways.** The recommended fixture is the elevated L-861T.
- **Obstruction.** The fixture recommended for obstruction lighting is the L-810 base.



Legend:

m	meters	Ref	reference
max	maximum	TYP	typical
min	minimum		

Figure 5-8. Rotary-wing landing lane



Legend:

heli	helipad	max	maximum
m	meters	min	minimum

Figure 5-9. Heliport threshold and edge light details

HELIPADS IN HEAVILY FORESTED AREAS

5-92. 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 under-slung boxes.

PERSONNEL

5-93. The squad consists of a noncommissioned officer-in-charge 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

5-94. The weight of the box, loaded with equipment, is approximately 333 pounds. The following equipment is contained in the box:

- Two chain saws.
- One brush hook.
- Three axes.
- One block-and-tackle set (1 single block and 1 double block).
- One set of climbers with safety straps.
- One can of gas.
- Sixteen 2-1/2-pound blocks of Composition C4.
- Two oil cans.
- Two hundred fifty feet of detonation cord.
- One galvanometer.
- One 10-cap blasting machine.
- Twenty electric caps (should be carried by personnel and will be stored separate from explosives and fuel).
- One brace and bit.
- One sledgehammer.
- Two wedges.
- Two screwdrivers.
- Two pliers.

PROCEDURE

5-95. The procedure is divided into two phases—delivery of equipment and personnel and preparation of the helipad.

Delivery of Equipment and Personnel

5-96. 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.

5-97. 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 an 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.

5-98. 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 3-99.

Preparation of the Helipad

5-99. 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.

5-100. The first person on the ground removes the rappelling rope from the equipment box. The noncommissioned officer-in-charge, 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 5-10, page 5-30, shows the tape layout and the configuration of the helipad.

5-101. Personnel are organized as described previously. Two teams, one per helicopter, with a noncommissioned officer-in-charge is 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.

5-102. 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.

5-103. Trees are felled as close as possible to the ground level, with the necessary climbing 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.

5-104. 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.

5-105. 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.)

5-106. 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 5-11, page 5-31, shows the correct placement of landing reference panels on the ground.

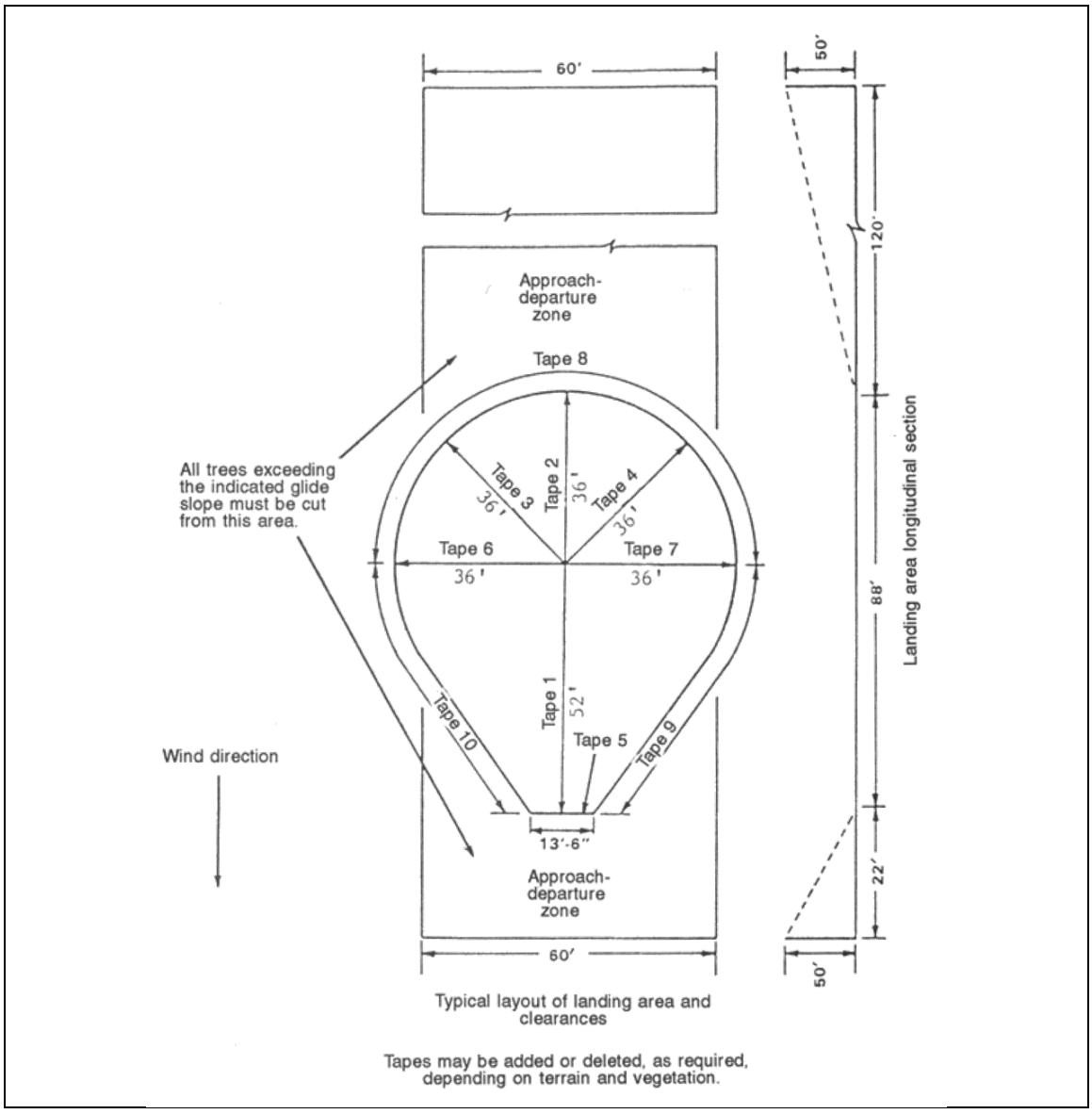


Figure 5-10. Helipad tape layout and configuration

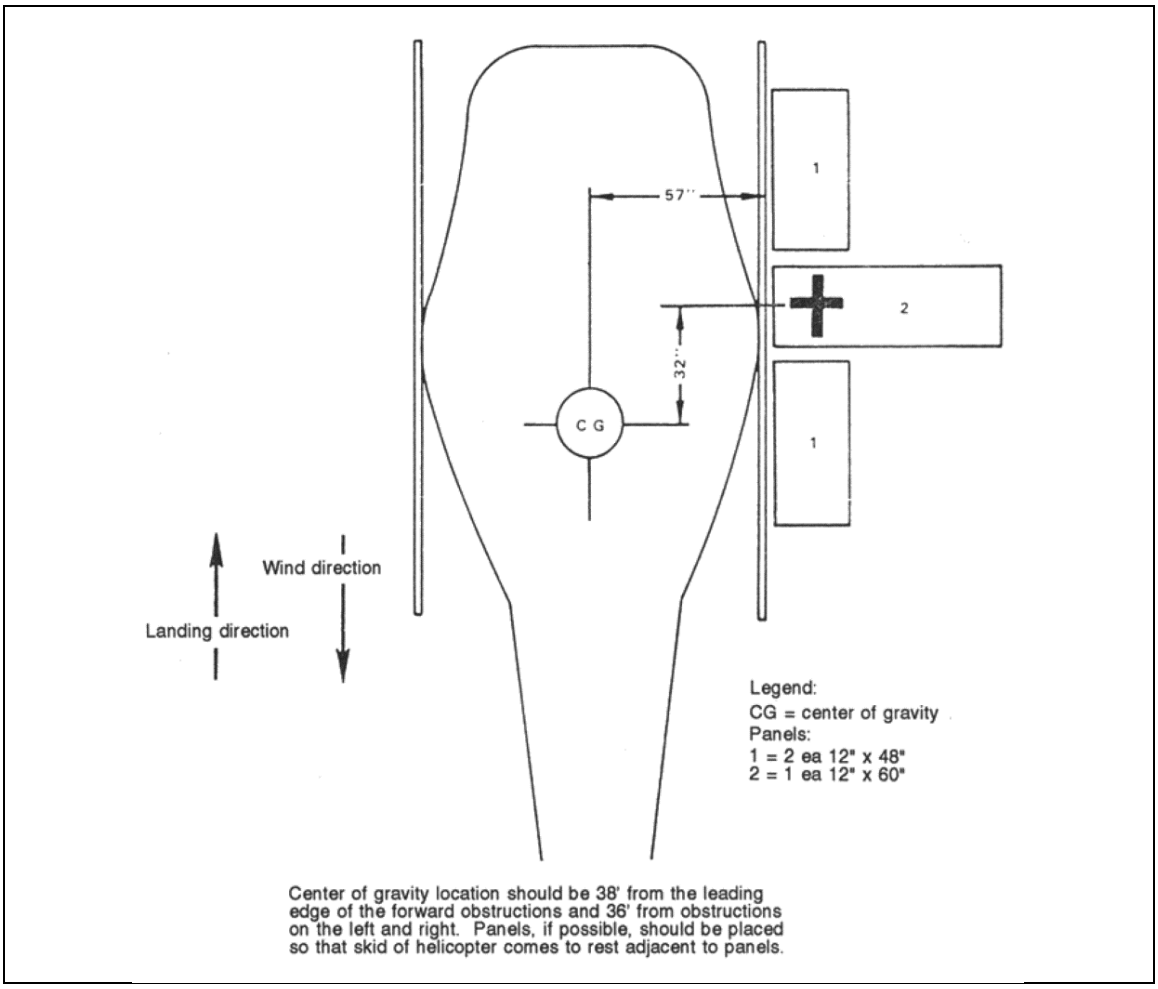


Figure 5-11. Panel placement

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Chapter 6

Fortifications for Parked Aircraft

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. This chapter applies to nonnuclear warfare only.

AIRCRAFT FORTIFICATIONS

6-1. Aircraft protection provided by fortifications does not usually include considerations of overhead protection or structures built to the height required to obscure the upper portions of rotary-wing aircraft. However, the fortification concepts outlined in this chapter can be adapted to different situations and can be constructed as large protective structures with heights that could provide protection for upper aircraft portions.

6-2. Revetments are walls designed to provide protection from the blast and fragment effects from near-miss threat weapons. One of the most efficient materials for stopping fragments is a dense, granular, dry soil (such as sand). Most revetment designs are variations of techniques to hold the soil in a vertical position. The primary method of using revetments to protect parked aircraft is in a free-standing wall design that can also be used to protect mission-critical aviation equipment (such as weapons storage and fuel bladders).

Note. Substantial quantities of earth or other protective materials are required to achieve minimum protection against threat weapons.

6-3. When planning the construction of aircraft fortifications, engineers must consider weather and topography, military considerations, protective construction materials, and design criteria. These items are discussed in the following paragraphs.

WEATHER AND TOPOGRAPHY

6-4. The susceptibility of soil-filled fortifications to heavy rains or other extreme weather conditions affects the planning, selection, and construction of revetments. Erosion over an extended period reduces penetration resistance. Periods of wet weather produce soil moisture that is typically high and changes materials strength. Soils with high moisture content have very little strength or penetration resistance. Dampness adversely affects most protective materials, including wood and steel. These materials require treatment or protection against deterioration for prolonged use.

6-5. Consider the topography of the area near an airfield when determining the protective requirements for parked aircraft. For example, surrounding high ground that offers good observation for effective rocket, artillery, mortar (RAM), or direct fire may negate the effectiveness of fortifications unless an active perimeter defense with counter fire capability is provided. Similarly, wooded areas, villages, or other sites that permit concealment close to parked aircraft enable counterinsurgents and saboteurs to assemble. Such cases require active and passive defense fortification measures.

MILITARY CONSIDERATIONS

6-6. Fortifications should be considered as a means of augmenting other forms of protection, including active defense measures, dispersion, and camouflage. The fortifications selected and constructed are governed by the tactical situation, enemy capabilities, materials availability, construction equipment, personnel requirements, and available construction areas. The effectiveness of fortifications and other passive

defense measures is substantially increased by an active perimeter defense. Therefore, it is best to confine protective construction to an area that can be adequately defended. An integrated, layered, defense-in-depth plan is essential for the effective protection of aircraft from threat weapons (such as RAM).

6-7. If aircraft dispersal is possible and consistent with active defense measures, varied parking patterns provide fewer lucrative targets for indirect-fire weapons. Prefabricated, hard parking surfaces (landing mats, bituminous materials, concrete) increase the lethality of bursting rounds due to fragmentation. 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.

6-8. Space is a limiting factor that affects airfield size, type, configuration, and fortification layout. Therefore, it is necessary to ensure that the airfield area, anticipated aircraft population, occupancy duration, and 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 fortification may require modification if there is insufficient space for aircraft dispersal. For example, some airfield areas may permit construction of one fortification, while other areas may only permit construction of less protective fortification.

PROTECTIVE CONSTRUCTION MATERIALS

6-9. The selection of construction materials for fortifications is influenced by availability. If a choice of materials is available, base the selection on the protective characteristics of the different materials or on 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. The protective qualities of typical materials are described below. Cross reference to Protective Design Center USACE, DA Pamphlet 385-64 is for nondeployed location safety considerations

Soils

6-10. Dry soils significantly minimize the amount of debris produced by explosive blasts and penetrations from threat weapons. Dry soil resists penetration better than wet soil. The thickness of wet soil must be approximately double that of dry-soil requirements to resist penetration by threat weapons. It is best to select dry soil for aircraft revetments. An expedient test to determine moisture content in soils is to observe the reaction of a handful of soil when it is 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 aircraft fortifications.

Concrete

6-11. Explosive blasts adjacent to concrete walls create large pieces of debris and fragments that can travel long distances and can increase the lethality of an attack; therefore, the potential for debris and fragment hazards should be considered when concrete materials are used for aircraft fortifications. Soil-backed concrete barriers will help mitigate debris and fragments. The mixture, placement, reinforcement, curing, and characteristics of concrete and the construction of forms are explained in TM 3-34.44. To avoid uneconomical use of critical materials, do not undertake concrete construction except under qualified supervision.

Timber

6-12. 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 penetration resistance. 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.

Plywood

6-13. Table 6-1 shows the effectiveness of plywood and a soil-filled plywood wall on providing protection from fragments. Although three layers of 3/4-inch thick plywood will stop a high percentage of fragments from the munitions shown, there are still a large number of lethal fragments that penetrate the plywood. However, if the plywood is used to construct a 1-foot thick soil-filled revetment, all fragments will be stopped. Brace and anchor the plywood to provide stability against blast and aircraft movement.

Table 6-1. Plywood protective walls

*Threat Weapon**	*1.91 Centimeter (3/4 Inch) Thick 1 Layer*	*3.8 Centimeter (1 1/2 Inches) Thick 2 Layers*	*5.72 Centimeter (2 1/4 Inches) Thick 3 Layers*	*32 Centimeter (1 Foot) Thick Soil-Filled Plywood Wall*
	*Percent Effective***			
81 millimeter mortar	60	82	91	100
82 millimeter mortar	64	86	97	100
120 millimeter mortar	60	84	91	100
107 millimeter rocket	47	71	86	100
122 millimeter rocket	No Data	No Data	No Data	100
*Assumed to detonate at a distance of 30 feet or more from the wall. ** Percent effective = 100 (1 – number. of fragments penetrating the wall/number of fragments impacting the wall)				

Steel

6-14. Steel, if available in forms (such as corrugated metal, sheet piling, or pierced landing mat) can be used as a retaining wall for earth revetments. Like concrete, the potential for debris and fragment hazard should be considered when steel materials are used for aircraft fortifications. Consider the thickness of these materials used to retain earth revetments when determining their resistance to penetration and blast. If the material has holes larger than 1/2 inch, disregard its resistance to penetration. Additional wales and vertical supports should be added to withstand the pressure of the earth fill and to correct its lack of rigidity.

Expedient Materials

6-15. Military shipping containers filled with moderately dry sand, gravel, or soil can be used to provide a substantial bulkhead fortification. These containers can be stacked to provide additional protection. 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.

DESIGN CRITERIA

6-16. The size and shape of a revetment is extremely important in the total effectiveness of a revetment system. These factors not only influence the level of blast and ballistic protection provided by the revetment system, but also directly affect operational aspects of aircraft use and maintenance.

6-17. Survivability studies have shown that the effect of revetment height greatly influences helicopter survivability; near-full height (fuselage/canopy high) revetments provide drastic improvements in survivability over lower (mid fuselage high) revetments. The number of revetment walls and the area inside the fortification also affect aircraft survivability. Smaller footprints and greater radial coverage provide increases in aircraft survivability. Safety requirements (10-foot standoff from rotary surfaces, operational requirements, mission constraints [threat, fly-in fly-out requirements, material and construction resources]) will drive the final fortifications design.

6-18. It is the responsibility of the commander to weigh these and other variables when fielding a protective design. The size and configuration of fortifications affect not only the survivability of the aircraft but also the geometric layout of the heliport (see chapter 5); the operational efficiency of the aircraft; and the safety of the pilots, crews, and ground support personnel. The inside area of the fortification should also provide for the largest aircraft to be used.

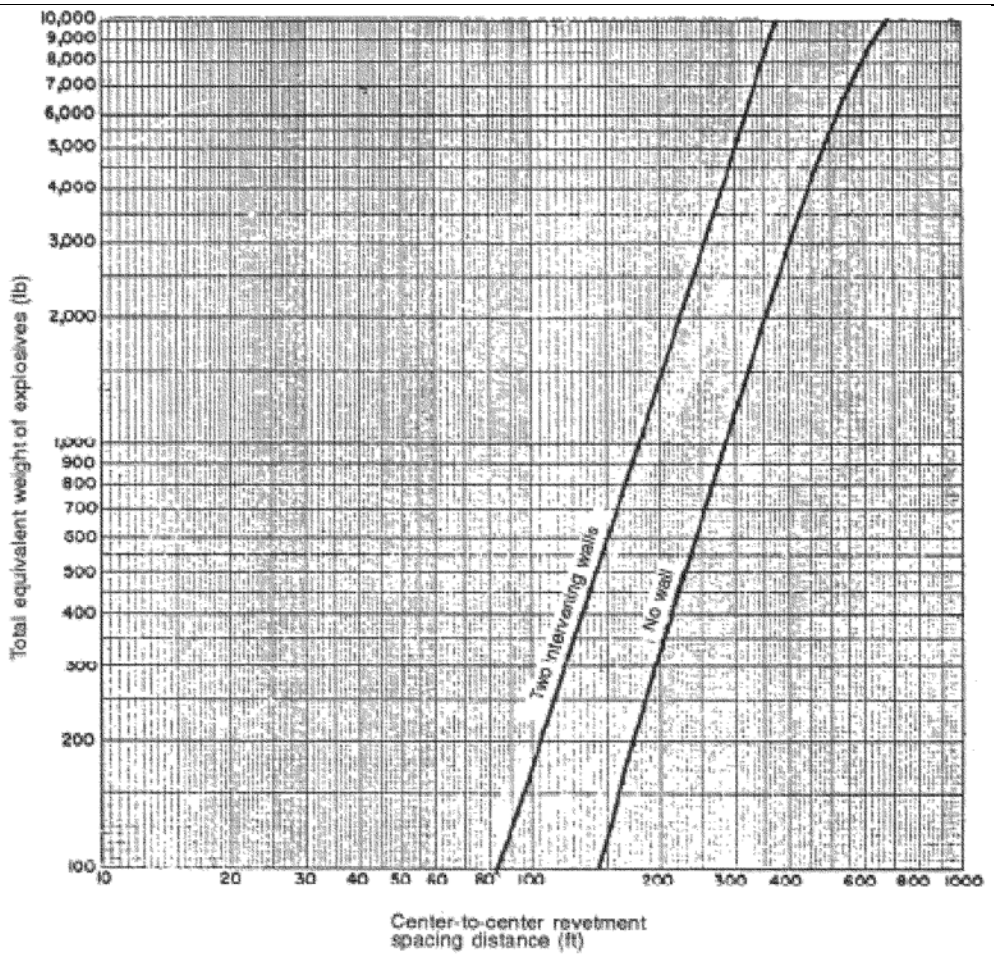
Designing for Effects of Ammunition

6-19. 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.

6-20. 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 6-2. 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 in figure 6-1 to determine theoretically safe distances with or without a protective barrier or wall between aircraft. Figure 6-2, page 6-6, shows how to orient fortifications to provide safe distances. Two intervening walls are required between the protected aircraft and the explosive before a reduction in safe distance is obtained.

Table 6-2. Equivalent explosive weights

Military Munitions	***Equivalent Explosive Weight Factors***
Shells (all types)	0.70
Rockets	0.70
Grenades	0.70
Small arms (ball and armor piercing ammunition)	0.40
Military Explosives	
Trinitrotoluene (TNT)	1.00
Composition C4	1.34
Sheet explosive	1.14
Tetrytol	1.20
Ammonium nitrate	0.42
Military dynamite	0.92
Note. Multiply the above factors by the estimated weight of the ammunition to derive equivalent explosive weight.	



Legend:
ft feet
lb pound

Figure 6-1. Revetment spacing distance

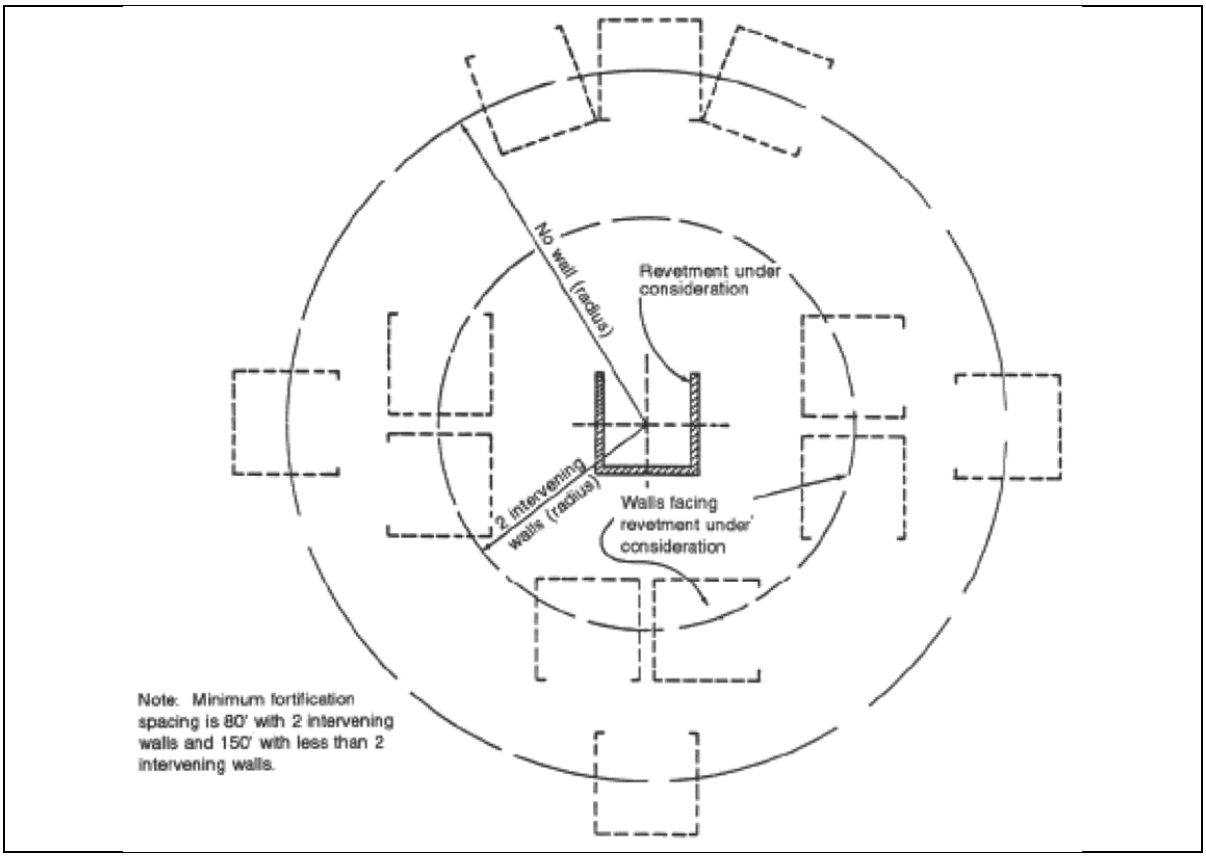


Figure 6-2. Orientation of fortifications to provide safe distances

Designing for Effects of Fuel

6-21. 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 otherwise. 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.

Spacing and Configuration of Fortifications

6-22. 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. Aircraft dispersal depends on the available area. Dispersal should cause the aircraft to be separated sufficiently to minimize the danger of interacting ammunition and fuel explosions. Avoid consistent patterns that facilitate the adjustment of high-angle fire on the aircraft.

REVETMENT DESIGNS

6-23. There are several types of revetment designs that can be used to protect parked aircraft. Some of the more common designs are discussed in the following paragraphs.

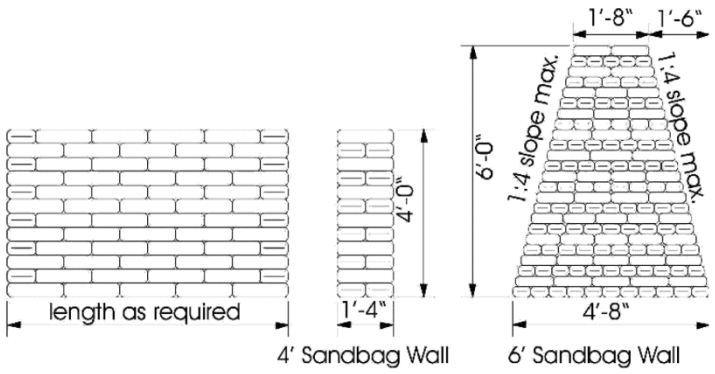
SANDBAGS

6-24. Sandbags are a traditional method to provide protection from fragmentation. A sandbag wall can be constructed to be freestanding or supported on one side by the structure it is protecting. One sandbag requires about 0.3 cubic feet (0.011 cubic yard) of sand. Twelve bags provide a wall 1 foot high by 4 feet long.

6-25. Numerous tests have shown that a minimum of two layers (approximately 16 inches thick) of sandbags should be used for protection from the blast and fragmentation of near-miss (4-foot) hits of the 82- and 120-millmeter mortars and 122-millimeter rocket.

6-26. Fill sandbags with clean, dry sand or a granular material. (Loose gravel or crushed rock is prohibited because it can become a secondary fragment source during a high-explosive threat). Stack filled sandbags in the manner indicated in figure 6-3. Stagger joints, and use header layers for a more stable wall. Tamp the top of each sandbag with a flat object to stabilize the wall. Place the closed end of the bag and side seams inward and away from the direction of the threat. Construct the sandbag wall high enough to protect the asset from incoming projectiles and fragment spray. Shovels are the only equipment required.

6-27. Constructing a sandbag wall is manpower intensive and time consuming. Depending on climate and sandbag material, sandbags may deteriorate rapidly. In some harsh climates, sandbags have been known to fail after two months. The proximity of the fill sand area to the site will greatly affect the construction speed and final cost. Use caution when constructing walls over 4 feet high because they may become unstable.



Legend:

max maximum

Figure 6-3. Freestanding sandbag revetment details

SOIL-FILLED WIRE AND FABRIC CONTAINERS

6-28. These wall sections consist of a series of large, linked, self-supporting cells. (See figure 6-4, page 6-8.) Each cell consists of collapsible wire mesh lined with a geotextile fabric. The cells are connected at the corners with spiral wire hinges that allow the wall sections to be expanded from a compact, folded storage configuration. The advantage of using this material is that the cells are collapsed during transport and are expanded and filled upon arrival at the final destination. This allows the walls to be transported at only 5 percent of the as-constructed volume. The wall sections can be connected to form longer walls, separated to form shorter sections, or stacked to increase wall height. (See table 6-3, page 6-8.)



Figure 6-4. Soil-filled wire and fabric containers used for sidewall protection

Table 6-3. Wire and fabric container kit dimensions

Height (feet)	*Width (feet)*	*Length (feet)*	*National Stock Number*
4.5	3.5	32.0	Beige color: 5680-99-835-7866 Green color: 5680-99-001-9396
2.0	2.0	4.0	Beige color: 5680-99-968-1764 Green color: 5680-99-001-9397
3.25	3.25	32.0	Beige color: 5680-99-001-9392 Green color: 5680-99-001-9398
3.25	5.0	32.0	Beige color: 5680-99-001-9393 Green color: 5680-99-001-9399
2.0	2.0	10.0	Beige color: 5680-99-001-9394 Green color: 5680-99-001-9400
7.25	7.0	90.0	Beige color: 5680-99-169-0183 Green color: 5680-99-126-3716
4.5	4.0	32.0	Beige color: 5680-99-335-4902 Green color: 5680-99-517-3281
3.25	2.5	30.0	Beige color: 5680-99-563-5949 Green color: 5680-99-052-0506
7.0	5.0	95.0	Beige color: 5680-99-391-0852 Green color: 5680-99-770-0326
Notes. 1. Approximate cost for each linear foot, based on kit cost and length. 2. National stock number cost data as of 25 March 2008 and subject to change. Contact Defense Logistics Agency for further information.			

6-29. Numerous tests have shown that a 2-foot thickness is adequate to stop fragments from 60-millimeter mortar through 122-millimeter rocket and 155-millimeter artillery rounds. Each shipment comes with detailed instructions. It is important to follow these instructions as closely as possible to ensure that the construction is stable, long-lasting, and requires minimal maintenance. Choose or provide a level surface with a subgrade of sufficient strength and drainage to support the structure. Otherwise, the earth-filled barrier may tip over and will have to be rebuilt. Units come flat-packed. Ensure that they are placed in the desired location and orientation before expanding them in the desired direction. The ideal fill is a dry sand and gravel mixture. Place fill in 6-inch to 12-inch lifts, and then compact it.

6-30. The wall requires a well-drained, flat, level, stable site to prevent sagging and tipping. If anticipated use is longer than 6 months, use an improved foundation. The proper placement of the sand infill is critical

to structure performance. If the infill is not properly compacted, the wall will sag and collapse in a few months or have a deformed appearance. Like sandbags, the fabric material liner is UV-sensitive and will degrade over time.

SOIL-FILLED METAL CONTAINERS

6-31. These revetments can be used for supplemental sidewall protection or in the construction of protective positions. (See figure 6-5.) Revetment kits are shipped flat in an unassembled state to be assembled on-site and filled to construct the desired protective structure. Each kit will consist of side, end, cross, and brace panels connecting pins, flaring tools, and corner containment materials. Revetment systems are based on the United States Air Force Metal Revetment Kit, Type B-1, which has been employed since the Vietnam War era. (See table 6-4.)



Figure 6-5. Examples of corrugated metal bin revetments

Table 6-4. Metal container kit dimensions

Height (feet)	*Width (feet)*	*Length (feet)*	*National Stock Number*
10	4	48	5450-01-537-7061
8	4	64	5450-01-535-7952
6	2	104	5450-01-535-7955

Notes.
1. Approximate cost for each linear foot, based on kit cost and length.
2. National stock number cost data as of 25 March 2008 and subject to change. Additional sizes available. Contact Defense Logistics Agency for further information.

6-32. Numerous tests have shown that the 2-foot thickness is adequate to stop fragments from near-miss 60-millimeter mortars through 122-millimeter rockets. By themselves, metal bin revetments will not defeat the effects of an antitank, rocket-propelled grenade (RPG). However, tests by ERDC have shown that these revetments can defeat an RPG-7 if used in conjunction with a vertical predetonation screen at sufficient standoff. Contact ERDC for information on the types of material and construction that can be used for a screen and the required standoff distances to prevent perforation.

6-33. If protection is needed from a near-miss of 122-millimeter rockets, laterally brace walls shorter than 24 feet in length to prevent wall toppling. Lateral bracing can be provided by 3-inch diameter, schedule 40 (minimum) steel pipe. (See figure 6-6, page 6-10.) Other materials possessing adequate strength, such as 4- by 4-inch timbers, can also be used. To prevent wall toppling in either direction, apply bracing on both sides of the wall.

6-34. A well prepared foundation is vital for the performance and durability of the revetment. It is essential that the ground surface be level, well compacted, and exhibit sufficient strength and stability to support the structure for its intended lifespan. If construction will not take place on an improved surface (concrete paving, asphalt paving, stabilized soil), the foundation area must be properly prepared.



Figure 6-6. Bracing metal revetment walls for near-miss 122-millimeter rocket threat

MODULAR REINFORCED CONCRETE WALLS

6-35. Prefabricated, reinforced concrete barrier walls are readily available at some locations and can be used for full-height sidewall protection around tents and trailers. (See figure 6-7.) These barrier sections are fabricated in a wide variety of sizes and configurations. The minimum recommended height for these walls is 6 feet, but taller units may be needed for trailers with crawl spaces. Prefabricated, reinforced, concrete barrier walls can also be used for physical antipersonnel barriers and obscuration along the airfield perimeter. They can also be used as antivehicle barriers or as part of the entry control point to channel traffic, mitigate blast and fragmentation, and protect personnel.

6-36. At 4,500 pounds per square inch and a 6-inch thickness, concrete walls will stop fragments from 60-millimeter mortar through 122-millmeter rocket at standoff distances of 10 feet or greater. Detonations within 10 feet may pose a hazard for blast and fragmentation-induced back-face spall. For additional protection, a spall liner of sheet steel (such as 16-gauge) can be used to reduce spall and increase fragment penetration resistance.

6-37. Provide a level, stable surface for placement. Ensure that there are no gaps between wall sections. Construct sections so that they can be connected together with cables if possible. Consider bracing tall sections to prevent toppling. To prevent gaps at corners, use sections with chamfered footings. (See figure 6-8.)

6-38. A level, stable foundation is required for prefabricated concrete walls. Fragments can penetrate gaps between wall sections. Close-in detonations of large mortars and rockets may breach the wall.

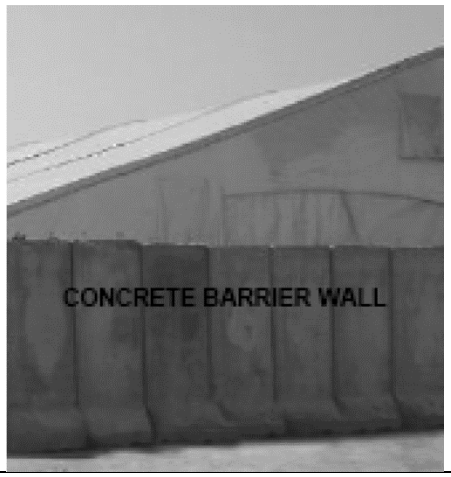
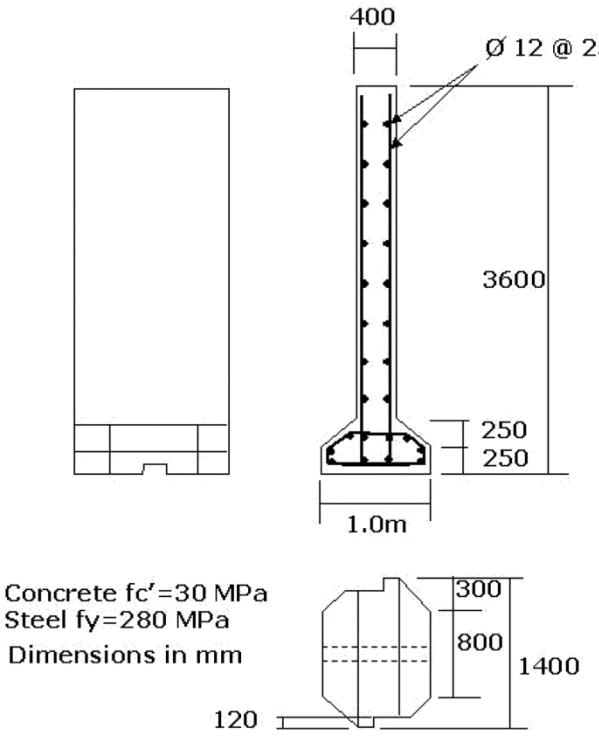


Figure 6-7. Modular reinforced concrete barriers used for sidewall protection



Legend:

fc	compressive strength of concrete
fy	yield strength
m	meter
MPa	meagpascals

Figure 6-8. Overlapping concrete revetment with chamfered footings

MAINTENANCE, REPAIRS, AND IMPROVEMENTS

6-39. Normal deterioration of construction materials exposed to weather necessitates periodic inspections. Erosion, rot, rust, and poor drainage reduce the protection that 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 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.
- Headwalls.

CONSTRUCTION GUIDE FOR PROTECTION OF PARKED AIRCRAFT

6-40. The design depicted in figure 6-9 uses soil-filled wire and fabric container revetments for making protective enclosures. These structures are designed to compartmentalize and protect helicopters from near-miss of RAMs, although they could be used for storage that does not require overhead cover. These designs were developed by the ERDC and the Directorate of Training, United States Army Engineer School.

6-41. The indicated time required for construction includes the time associated with basic foundation preparation and construction of the position. (See table 6-5.) Factors such as threat-based urgency, equipment and material availability, poor foundation soils, and construction technique knowledge can greatly affect time requirements. Therefore, the time indicated is an estimate only and should be used when actual performance data for similar positions under similar conditions are not available.



Figure 6-9. Soil-filled wire and fabric container design for helicopter protection

Table 6-5. Bill of materials and equipment, personnel, and time estimates for constructing soil-filled wire and fabric aircraft revetments

Aircraft	Container	Quantity Required	Length (feet)	Width (feet)	Infill Material (cubic yards)	Layout Diagram	Task	Equipment Required	Personnel Required*	Time Required
AH-64 Apache/ UH-60 Blackhawk	A	16	82	78	340	14-10	1	C	2	45 min
							2	D	Varies	Varies
							3	E	8	8 hr
OH-58 Kiowa Warrior	A	11	53	57	230	14-11	1	C	2	30 min
							2	D	Varies	Varies
							3	E	6	8 hr
AH-1 Cobra	A	14	78	64	300	14-12	1	C	2	45 min
							2	D	Varies	Varies
							3	E	8	7 hr
UH-1 Iroquois (Huey)	A	14	67	71	290	14-13	1	C	2	45 min
							2	D	Varies	Varies
							3	E	8	7 hr
CH-47 Chinook	B	4	126	91	1,000 (both layers)	14-14	1	C	2	1 hr 30 min
							2	D	Varies	Varies
2nd Layer	A	11	"	"			3	F	10	16 hr
CH-53 Super Stallion	B	4	112	112	1,000 (both layers)	14-15	1	C	2	1 hr 30 min
							2	D	Varies	Varies
2nd Layer	A	11	"	"			3	F	10	16 hr

* Excludes equipment operators

Wire and fabric container dimensions:
A: 4.5 ft x 3.5 ft x 32 ft; NSN 5680-99
B: 7.5 ft x 7 ft x 91 ft; NSN 5680-99-126-3716 (green color); 5680-99-169-0183 (beige/sand color)

Task:
1. Prepare site, and level foundation.
2. Haul infill material to site.
3. Erect walls, and place infill.

Equipment required:
C: Bulldozer, DEUCE, ACE
D: Dump trucks
E: Front-end loader, HMEE
F: Front-end loader w/ clamshell bucket, HYEX

Legend:

ACE	Armored Combat Earthmover	Hr	Hour
AH	attack helicopter	HYEX	Hydraulic Excavator
CH	cargo helicopter	min	minute
DEUCE	Deployable Universal Combat Earthmover	NSN	national stock number
ft	feet	OH	observation helicopter
HMEE	High Mobility Engineer Excavator	UH	utility helicopter

6-42. Metal containers of similar sizes can be used to construct these revetments. However, required quantities of materials may differ from the listed bills of materials. This is a result of different available dimensions for the equivalent metal containers. Plan for their construction accordingly.

SECTION LAYOUTS

6-43. Aircraft currently in use constitute a broad range of sizes and configurations. Specific layouts differ for each type of aircraft and are provide in figures 6-10 through 6-14.

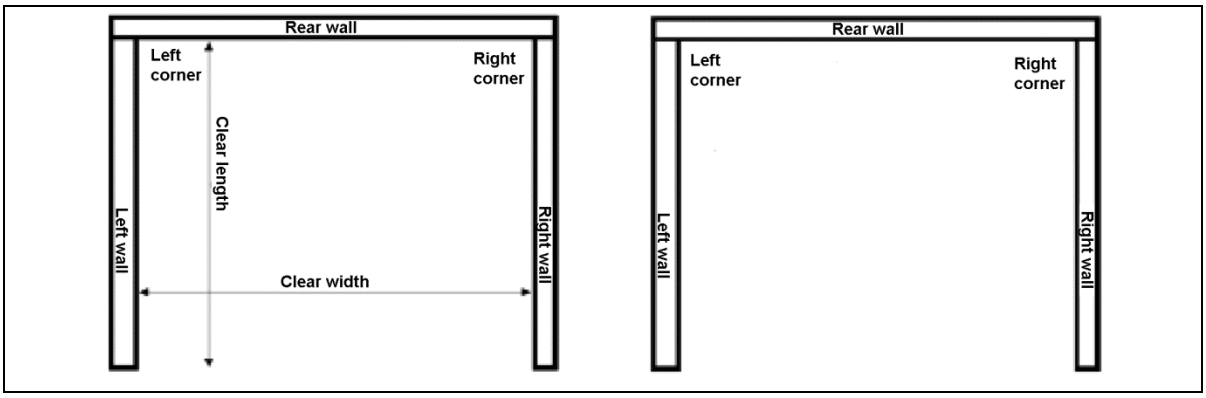


Figure 6-10. OH-58 Kiowa (left: first layer; right: second layer)

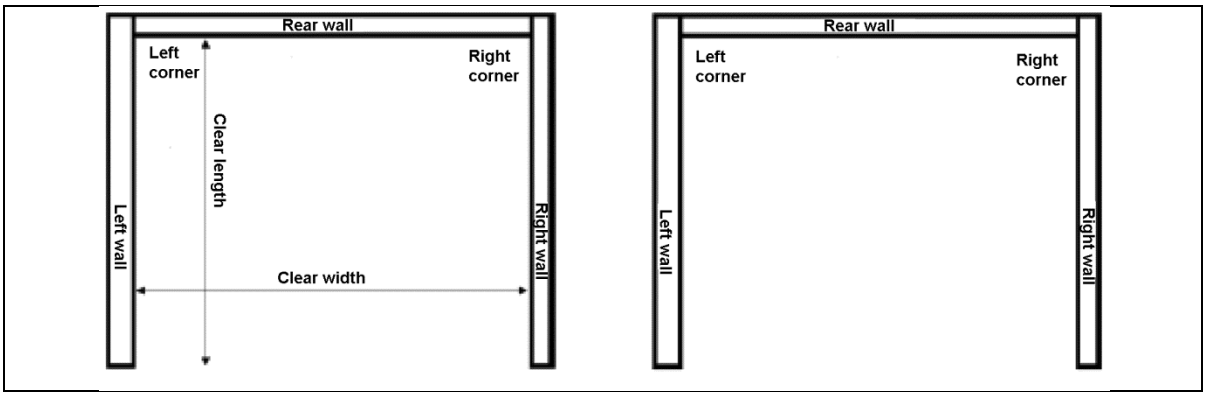


Figure 6-11. AH-1 Cobra (left: first layer; right: second layer)

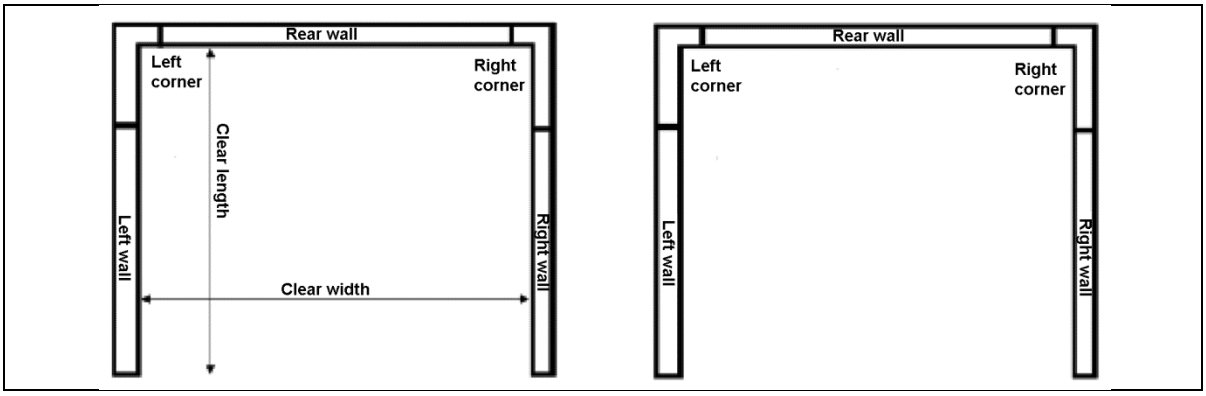


Figure 6-12. UH-1 Iroquois Huey (left: first layer; right: second layer)

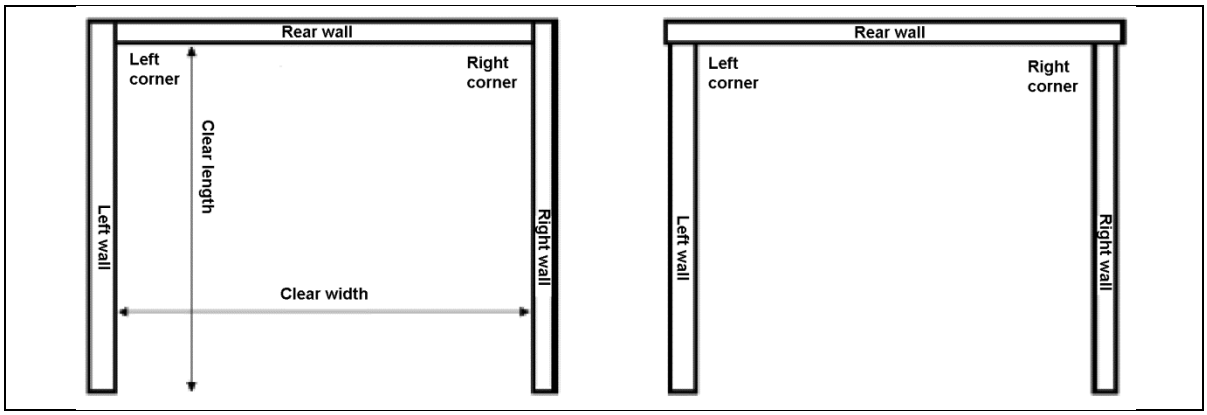


Figure 6-13. CH-47 Chinook (left: first layer; right: second layer)

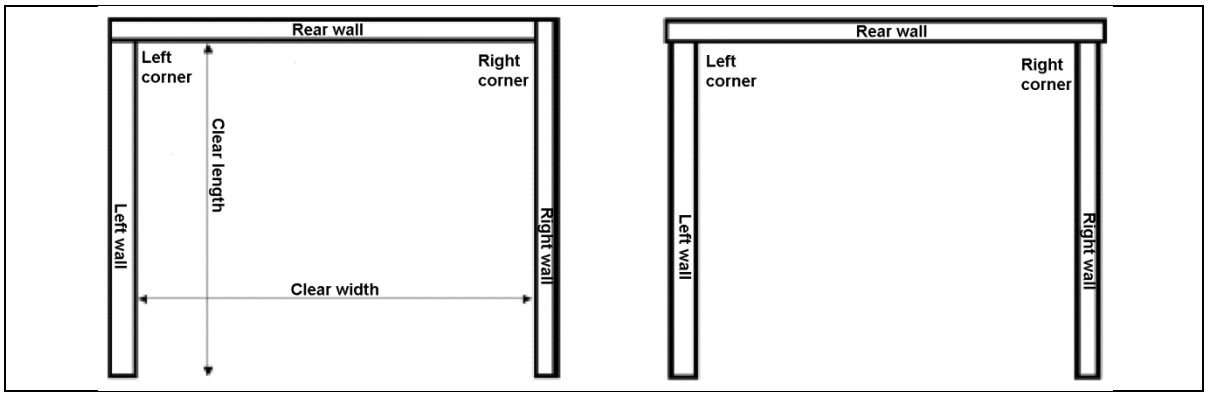


Figure 6-14. CH-53 Super Stallion (left: first layer; right: second layer)

GENERAL CONSTRUCTION STEPS

6-44. The figures below depict the general construction steps for the various aircraft revetments previously discussed. First, arrange and fill the first layer. (See figure 6-15.) Next, arrange and fill the second layer. Figure 6-16, page 6-16, shows the arrangement for the Apache, Blackhawk, Kiowa, Cobra, and Iroquois aircraft. Figure 6-17, page 6-16, shows the arrangement for the Chinook and Super Stallion aircraft.

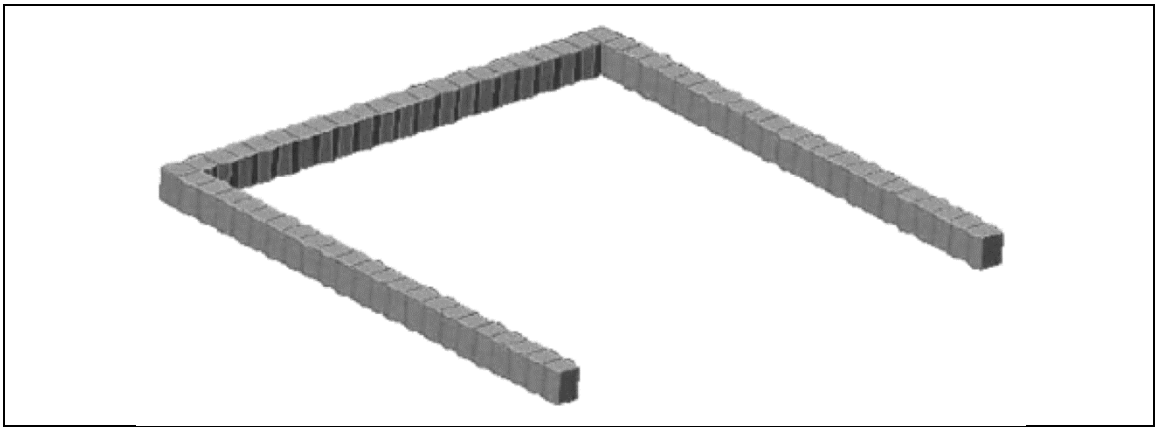


Figure 6-15. Arrange and fill first layer

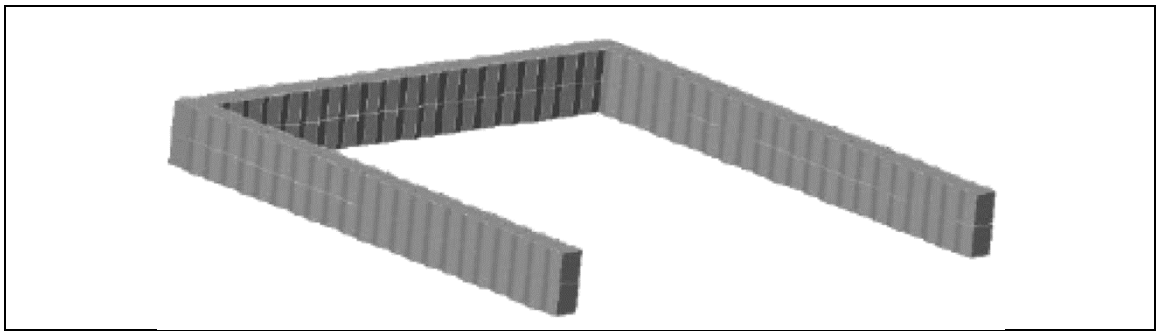


Figure 6-16. Second layer construction for Apache, Blackhawk, Kiowa, Cobra, and Iroquois/"Huey" aircraft

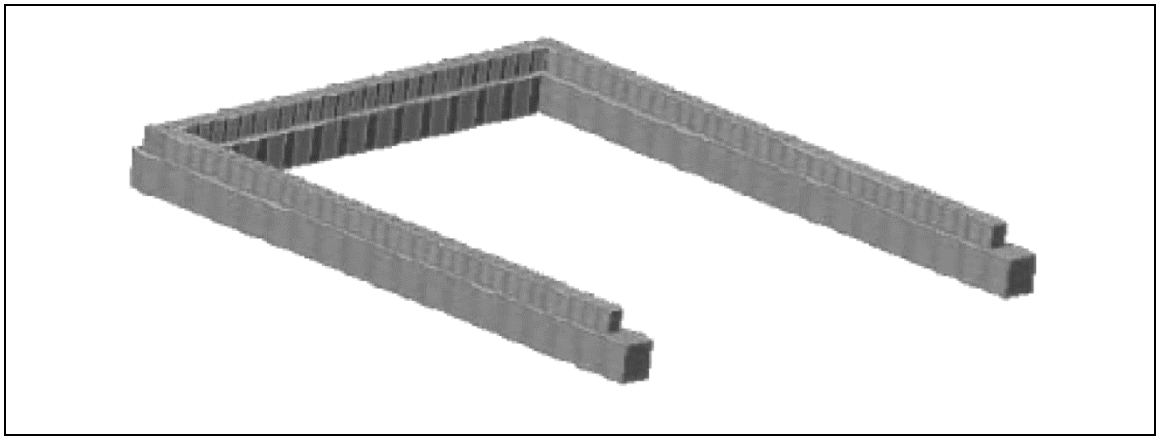


Figure 6-17. Second layer construction for Chinook and Super Stallion aircraft

Chapter 7
Dust Control

This chapter presents information on mitigating dust on airfields, helipads, roads, and other operational areas. Dust palliative types and application procedures are presented, along with potential product suppliers.

DUST CONTROL METHOD SELECTION

7-1. Selecting the appropriate dust palliative type depends on operational requirements. Table 7-1 provides primary and secondary recommendations for product categories for various applications.

Table 7-1. Recommended Product Applications

Application	*Primary Solution*				*Secondary Solution(s)*			
	Product Category	*Application Rate*	*Dilution Ratio*	*Application Type*	*Product Category*	*Application Rate*	*Dilution Ratio*	*Application Type*
Airfields	Synthetic fluid	0.4 gsy	NA	Topical	Polymer emulsion	1.2 gsy	3:1	Admix[#]
Lines of communication	Polymer emulsion	0.8 gsy	3:1	Admix	Synthetic fluid	0.6 gsy	NA	topical
					Chloride salt*	0.8 gsy	NA	topical
Helipads	Synthetic fluid	0.4 gsy	NA	Topical	Polymer emulsion	1.2 gsy	3:1	topical
					Powdered polymer	1.2 gsy	1.3 lb/gal	topical
Base camps	Synthetic fluid	0.4 gsy	NA	Topical	Polymer emulsion	0.6 gsy	3:1	topical
					Powdered polymer	0.6 gsy	1.3 lb/gal	topical
					Polysaccharide	0.6 gsy	3:1	topical

* Should not be used in excessively dry or excessively wet conditions.
[#] Depth of mixing should be a minimum of 4 inches.

Legend:
gal gallon
gsy gallons per square yard
lb pound
NA not applicable

DUST PALLIATIVE TYPES

7-2. Dust palliatives are described according to their physical and chemical properties in this chapter. The following paragraphs describe each type of dust palliative. Table 7-2, page 7-2, provides a summary of each product type.

Table 7-2. Dust palliative properties

Product	*Product description*	*Vendor information*	*Effective uses*	*Limitations*	*Shipping*
Chloride salt	Calcium, magnesium, or sodium chlorides dissolved in water. Absorbs moisture from air and locks down dust.	Dust Fyghter®	Lines of communication	Corrosive, may leach from soil during rain	275-gallon containers (2,900 pounds)
Lignosulfonates	Tree rosins suspended in water by surfactants. Binds soil grains.	Road Oyl®	Lines of communication	May leach from soil with precipitation Lower strength than polymer products	275-gallon containers (2,500 pounds)
Asphalt emulsion	Asphalt cement suspended in water by surfactants. Binds soil grains.	Regional asphalt distributors	Lines of communication	Requires specialized application equipment	Delivered in heated tankers
Polyacrylamides	Super-absorbent polymer. Absorbs moisture from air to lock down dust. May be known as TRI-PAM.	Poly Plus	Helipads	Cannot be mixed with water. Must be applied as powder. Requires incorporating into the soil.	Sold in desired quantities of powder.
Polysaccharide	Mixture of raw sugar and starches designed to bind soil grains. Product is water soluble, biodegradable, and capable of dilution with water.	Surtac®	Helipads base camps	Limited effective lifespan Lower strength than polymer emulsions May settle from solution during storage	275-gallons containers (2,500 pounds)
Powdered polymer	Water-soluble polymer designed to bind soil grains. Product is mixed at a rate of 1.3 pounds per gallon of water.	Powdered Soiltac®	Helipads lines of communication base camps	Poor penetration when applied topically Lower strength than polymer emulsions	Sold in 50-pounds bags Requires 350 pounds for equivalent mixture
Synethetic fluid	Blend of isoalkanes that forms a reworkable binder in soil. Will not mix with water. Effective for long-term use.	EnviroKleen® Durasoil®	Helipads lines of communication base camps airfields	More expensive than most products	275-gallon containers (2,000 pounds)

Table 7-2. Dust palliative properties (continued)

Product	*Product Description*	*Vendor Information*	*Effective Uses*	*Limitations*	*Shipping*
Polymer emulsion	Acrylic polymer suspended in water by surfactants. Water evaporates when placed on soil and leaves a bonded soil-polymer matrix. Prevents dust by binding soil grains.	Soil-Sement® Soiltac® Envirotac II©	Helipads, lines of communication, base camps	Short shelf life, application equipment requires immediate cleaning	275-gallon containers (2,600 pounds)

7-3. Chloride salts, calcium, magnesium, and sodium chlorides are commonly used chemicals for dust control. They absorb moisture from the air and maintain a wet appearance in the soil. These materials can be purchased as a powder, pellet, flake, or water solution. They do not work well in excessively wet or dry climates. In wet regions, they dissolve in water and leach from the soil. In arid regions, there is not sufficient humidity in the air for them to be effective. Calcium chloride and magnesium chloride require relative humidity levels to be in excess of 30 percent for adequate results. Sodium chloride requires even greater humidity levels and is used less frequently.

7-4. Lignosulfonates are derived from tree rosins and are a by-product of pulpwood processing. They provide dust control by physically binding soil particles. Lignosulfonates are usually sold diluted in water, but they can be purchased in powder form. They are characterized by a distinct odor and dark color. They are susceptible to leaching from the soil in areas of high moisture or precipitation. Lignosulfonates should not be mixed with gray or salt water for dilution.

7-5. Petroleum products are very effective for dust control but are often viewed as being detrimental to the environment. Diesel fuel, cutback asphalts, motor oil, and others have virtually been eliminated from use. Asphalt emulsions are one of the only remaining petroleum products currently used. They provide excellent dust mitigation by binding surface particles. They do not lose effectiveness through typical climatic variations. However, many asphalt emulsions require special application equipment and must be delivered in a heated tanker at around 180 degrees Fahrenheit. Typical asphalt emulsions used for dust control are cationic slow setting emulsions.

7-6. Polyacrylamides are water-soluble polymers that provide dust control through moisture retention. These materials are used as superabsorbents in baby diapers, chemical spill containment, and other applications. They are generally applied in powder or granular form because polyacrylamides cause very large increases in viscosity when dissolved in water. The solution has the consistency of mayonnaise and is difficult to apply to the soil. Polyacrylamides swell when they come into contact with water and may cause volume changes in the soil. For this reason, they are not recommended for use on roads.

7-7. Polymer emulsions used for dust control are generally vinyl acetate or acrylic-based copolymers suspended in an aqueous phase by surfactants. They typically consist of 40 to 50 percent solid particles by weight of emulsion. After they are applied, the polymer particles begin to coalesce as the water evaporates from the system, leaving a soil-polymer matrix that prevents small dust particles from escaping the surface. The polymers used for dust control typically have excellent tensile and flexural strength, adhesion to soil particles, and resistance to water. These materials are often limited by a short shelf life (less than 2 years). Polymer emulsions should not be mixed with gray or salt water for dilution.

7-8. Polysaccharides are solutions or suspensions of sugars, starches, and surfactants in an aqueous medium. They may be diluted with water depending on the intended use. Polysaccharides provide dust abatement by encapsulating soil grains and providing a binding network in the ground. They are considered to be biodegradable materials, and may leach from the soil with exposure to precipitation.

7-9. The powdered polymer discussed in this document is in the form of a water-soluble powder. It can be added to water at a rate of 1.3 pounds per gallon. The polymer undergoes a chemical reaction upon curing and forms a water-resistant film that binds soil grains.

7-10. Synthetic organic fluids are applied to a soil as received. These fluids are not miscible with water and therefore are unable to be diluted. They consist of isoalkanes that do not dry or cure with time. The reworkable binder is ready for immediate use upon application and maintains effectiveness over extended periods of time.

APPLICATION TECHNIQUES

7-11. The paragraphs below describe the considerations for applying dust palliatives in different areas:

- **Soil type.** The soil type will have some effect on the performance of dust palliatives. Of course, finer grained soils present a larger problem with dust generation, but they also may be more difficult to control. Higher specific soil surfaces require greater quantities of treatment products. Penetration may also be hindered by the small pore sizes between soil grains. Multiple light application rates may be required to treat fine-grained soils (silts and clays) to prevent ponding or surface runoff. Coarse-grained soils (sands and gravels) typically have higher infiltration rates to minimize ponding or runoff.
- **Intended use.** Choosing a dust palliative will ultimately be governed by the need for dust control that exists. Some products will work better for helipads, while others will be more effective on roads or airfields. Each type of chemical has benefits and limitations that should be considered before selecting a product. Table 7-1, page 7-1, lists some of the recommended products for different dust control needs.
- **Application rates.** Application rates should be chosen according to the soil type, the intended use of the treated area, and the necessary duration of use. In general, dust palliatives should be applied at a rate of 0.8 gallons per square yard. This should be sufficient for most applications. Synthetic fluids may be applied at lower rates for most projects because they contain 100 percent active ingredients. Polymeric materials may require application rates of greater than 1.0 gallons per square yard in areas of heavy traffic. For example, using polymer emulsions on helipads will require an application rate of near 1.5 gallons per square yard in order to produce thicker surface crusts (at least 1 inch penetration) to reduce FOD potential. See table 7-1 for detailed guidance on selecting application rates.
- **Dilution ratios.** Some products may require dilution with water. These are typically emulsified products (such as polymers and lignosulfonates). Diluting the emulsion will reduce the viscosity and improve penetration. In general, three parts water should be added for each part product. Adding additional water will not have much impact on penetration depth. Products such as synthetic fluids and chloride salts are intended for use as received and should be applied in concentrated form.
- **Topical method.** Topical applications are the most commonly used dust control techniques. Spraying the soil surface with a dust palliative will effectively solve most dust problems. Alternative methods should be used when the area to be treated is structurally deficient for the anticipated traffic or when greater durability is needed. Topical applications are accomplished by simply spraying the liquid dust palliative onto the native or prepared soil surface. It is imperative to maintain the greatest level of uniformity while dispersing the liquid. Application quantities are determined by estimating the area of ground surface to be treated and multiplying that area by the application rate suggested.
- **Admix method.** Admix methods are designed to incorporate dust palliatives deeper into the soil and to provide longer lasting dust abatement. These methods are usually necessary when heavy repetitive loading will be introduced to the soil. Roads and airfields (runways, taxiways, parking aprons) generally require admix applications to achieve the desired results. Admix depths should be at least 3 inches for roads and 4 inches for airfields.

7-12. The following procedure is recommended for incorporating the dust palliative into the soil:

- Grade the soil, if necessary, using a motor grader.
- Spray half of the total palliative application rate onto the soil surface.
- Use a rotary mixer to blend into the top 3 inches of soil.

- Use a steel-wheeled vibratory roller to compact granular materials.
- Spray remaining product onto the compacted surface.

7-13. This method will provide optimal performance of most palliatives. Alternative construction methods may not provide sufficient durability.

MITIGATING DUST ON HELIPADS—CARGO HELICOPTERS

7-14. Many dust control products achieve the desired effect when applied by spraying onto the surface of the helipad. This section describes the requirements for applying synthetic fluid dust palliative on cargo helicopter helipads.

7-15. The following is needed to apply 900 gallons of synthetic fluid topically to a 150 by 150 foot helipad:

- Medium tactical vehicle replacement (MTVR)/family of medium tactical vehicles (FMTV).
- Hydroseeder.
- Four 275-gallon totes dust palliative (synthetic fluid).
- Three Airmen/Marines/Soldiers.

7-16. Use the following procedure:

- Survey and visibly establish the area to be treated.
- Place 900 gallons of synthetic fluid into the hydroseeder.
- Position the MTVR/FMTV and the hydroseeder on the edge of the helipad.
- Use the tower gun and a long distance nozzle to spray half on the product to half of the helipad.
- Drive the MTVR to the opposite side of the helipad.
- Spray the remaining product on the other side of the helipad.
- Helicopters can land immediately, but best results occur after allowing the produce to set for one day.

MITIGATING DUST ON HELIPADS—UTILITY AND ATTACK HELICOPTERS

7-17. Many dust control products achieve the desired effect when applied by spraying onto the surface of the helipad. This section describes the requirements for applying synthetic fluid dust palliative on utility and AH helipads.

7-18. The following is needed to apply 450 gallons of synthetic fluid topically to a 100 by 100 foot helipad:

- MTVR/FMTV.
- Hydroseeder.
- Two 275-gallon totes dust palliative (synthetic fluid).
- Three Airmen/Marines/Soldiers.

7-19. Use the following procedure:

- Survey and visibly establish the area to be treated.
- Place 450 gallons of synthetic fluid into the hydroseeder.
- Position the MTVR/FMTV and hydroseeder on the edge of the helipad.
- Use the tower gun and a long distance nozzle to spray half of the product on half of the helipad.
- Drive the MTVR/FMTV to the opposite side of the helipad.
- Spray the remaining product.
- Helicopters can land immediately, but best results occur after allowing the produce to set for one day.

ALTERNATIVE METHOD FOR MITIGATING DUST ON HELIPADS—CARGO HELICOPTERS

7-20. Alternative methods achieve the desired effect by mixing and spraying other products onto the surface of the helipad. This section describes the requirements for applying polymer emulsion dust palliative on cargo helicopter helipads.

APPLY 3,000 GALLONS OF DILUTED POLYMER EMULSION TOPICALLY TO 150- BY 150-FOOT HELIPAD

7-21. The following is needed to apply 3,000 gallons of diluted polymer emulsion topically to a 150 by 150 foot helipad:

- MTVR/FMTV.
- Hydroseeder.
- Three 275-gallon totes dust palliative (polymer emulsion).
- 2,250 gallons of water.
- Three Airmen/Marines/Soldiers.

7-22. Use the following steps:

- **Step 1.** Survey and visibly establish the area to be treated.
- **Step 2.** Place 675 gallons of water into the hydroseeder.
- **Step 3.** Add 225 gallons of polymer emulsion.
- **Step 4.** Mix for 5 minutes using mechanical agitation.
- **Step 5.** Position the MTVR/FMTV and hydroseeder on the edge of the helipad.
- **Step 6.** Use the tower gun and a long distance nozzle to spray the product on 1/3 of helipad.
- **Step 7.** Refill the hydroseeder using steps 2 through 4.
- **Step 8.** Spray the product on the middle one third of helipad.
- **Step 9.** Repeat step 7.
- **Step 10.** Spray the product on the final one third of the helipad.
- **Step 11.** Use the remaining polymer and water near the center of the helipad.
- **Step 12.** Allow one day to cure before using the helipad (sooner if hard surface is achieved).

ALTERNATIVE METHOD FOR MITIGATING DUST ON HELIPADS—UTILITY AND ATTACK HELICOPTERS

7-23. Alternative methods achieve the desired effect by mixing and spraying other products onto the surface of the helipad. This section describes the requirements for applying polymer emulsion dust palliative on utility and AH helipads.

7-24. The following is needed to apply 1,350 gallons of diluted polymer emulsion topically to a 100- by 100-foot helipad:

- MTVR/FMTV.
- Hydroseeder.
- Two 275-gallon totes dust palliative (polymer emulsion).
- One thousand gallons of water.
- Three Airmen/Marines/Soldiers.

7-25. Use the following steps:

- **Step 1.** Survey and visibly establish the area to be treated.
- **Step 2.** Place 500 gallons of water into the hydroseeder.
- **Step 3.** Add 175 gallons of polymer emulsion.
- **Step 4.** Mix for 5 minutes using mechanical agitation.
- **Step 5.** Position the MTVR/FMTV and hydroseeder on the edge of the helipad.
- **Step 6.** Use the tower gun and a long distance nozzle to spray the product on half of the helipad.
- **Step 7.** Refill the hydroseeder using steps 2 through 4.
- **Step 8.** Spray the product over the remaining half of the helipad.
- **Step 9.** Allow one day to cure before using the helipad (sooner if hard surface is achieved).

MITIGATING DUST ON LINES-OF-COMMUNICATION AND MANEUVER SUPPLY ROUTES

7-26. Some of the same solutions used for dust control on helipads and airfields also serve to control dust on lines-of-communication and main supply routes. This section describes the requirements for conducting dust control using polymer emulsion.

7-27. The following is needed to apply 0.8 gallons per square yard polymer emulsion using admix construction procedure a:

- MTVR/FMTV/high mobility multipurpose wheeled vehicle (HMMWV).
- Hydroseeder.
- Polymer emulsion (quantities must be calculated based upon the length and the width of the road).
- Water (quantities must be calculated based upon the length and width of the road).
- Rotary mixer.
- Steel-wheeled vibratory compactor.
- Five Airmen/Marines/Soldiers.

7-28. Use the following steps:

- **Step 1.** Determine the length of road that can be treated per tank (hydroseeder capacity).
- **Step 2.** Length (yard) = hydroseeder capacity (gallon)/[application rate (0.4) road width (yard)].
- **Step 3.** Place 675 gallons of water into the hydroseeder.
- **Step 4.** Add 225 gallons of polymer emulsion.
- **Step 5.** Mix for 5 minutes using mechanical agitation.
- **Step 6.** Apply to road surface using distribution bar or wide fan nozzle on tower gun.
- **Step 7.** Immediately till the road surface to 3-inches deep using the rotary mixer.
- **Step 8.** Compact soil until desired density is achieved.
- **Step 9.** Repeat steps 2 through 4.
- **Step 10.** Spray over compacted road surface.
- **Step 11.** Repeat steps 1 through 10 for subsequent road lengths to be treated.

ALTERNATIVE METHOD FOR MITIGATING DUST ON LINES-OF-COMMUNICATION

7-29. Similar to the solutions used for dust control on helipads and airfields, alternate methods exist to control dust on lines-of-communication and main supply route. This section describes the requirements for conducting dust control using synthetic fluid.

7-30. The following is needed to apply 0.6 gallons per square yard synthetic fluid topically to the road surface:

- MTVR/FMTV/HMMWV.
- Hydroseeder.
- Synthetic fluid (quantities must be calculated based upon the length and the width of the road).
- Three Airmen/Marines/Soldiers.

7-31. Use the following steps:

- **Step 1.** Determine the length of road that can be treated per tank (hydroseeder capacity).
- **Step 2.** Length (yard) = hydroseeder capacity (gallon)/[application rate (0.6) road width (yard)]
- **Step 3.** Place 900 gallons of synthetic fluid into the hydroseeder.
- **Step 4.** Apply to road surface using distribution bar or wide fan nozzle on tower gun.
- **Step 5.** Repeat steps 1 through 4 for subsequent road lengths to be treated.

MITIGATING DUST IN BASE CAMPS AND NONTRAFFIC AREAS

7-32. The following is needed to apply 0.4 gallons per square yard synthetic fluid topically:

- MTVR/FMTV/HMMWV.

- Hydroseeder.
- Synthetic fluid (quantities must be calculated based on area).
- Three Airmen/Marines/Soldiers/Sailors.

Example Spreadsheet			
Length Feet (Yard)	**Width Feet (Yard)**	**Area Feet^2 (Yard^2)**	**Product Gallons**
300 (100)	300 (100)	90,000 (10,000)	4,000
30 (10)	300 (100)	9,000 (1,000)	400

7-33. Use the following procedure:

- Determine the area to be treated in square yards. One 900-gallon tank will mitigate dust on 2,250 square yards of soil (3,000 square yards for 1,200-gallon tank).
- Calculate the necessary quantity of synthetic fluid.
- Product (gallon) = area (square yard) application rate (0.4 gallon/square yard).
- Place 900 gallons of synthetic fluid into the hydroseeder.
- Apply to soil surface using the tower gun or handheld hose.
- Repeat as necessary.

DISTRIBUTION EQUIPMENT

7-34. A variety of equipment is available for distributing dust palliatives. Basic requirements are a liquid storage apparatus with a pressurized discharge mechanism.

DUST PALLIATIVE SELECTION TIPS

7-35. Many different vendors offer chemicals that they claim will eliminate dust in any circumstance. Most of the claims mentioned are only partially true at best. It is important to rely on experience and product reputation when choosing a product to use. The list of product names included in this document is only a fraction of those available. The task of choosing the best product is not easy.

7-36. The first decision should be based on which chemical type will best suit the project needs. This may be governed by funding, logistics (shipping volumes), performance, or other considerations. Table 7-1, page 7-1, lists recommended products for different applications based on field test results from the ERDC. The list is not necessarily inclusive, and other chemical types may be equally effective in certain conditions. It is merely a guide in the decisionmaking process.

7-37. Logistical considerations should be made when choosing liquid chemicals for dust control. It is important to consider the specific gravity of the product and the volume that is required. For example, synthetic fluids weigh around 7.4 pounds per gallon. Polymer emulsions weigh over 9 pounds per gallon. Chloride salt solutions weigh over 10 pounds per gallon. These differences can have a large impact on the shipping weights for a given volume of product. The chemicals will typically be shipped in 275-gallon containers. This brings the total weight for one container to approximately 2,000 pounds for synthetic fluids, 2,500 pounds for polymer emulsions, and 2,900 pounds for chloride salts. An additional consideration is the volume of product needed. Synthetic fluids and chloride salts will be used in their concentrated form. Emulsions will be diluted using three parts water to one part product. If water is not available on-site, it will have to be shipped.

7-38. The difference in products within chemical classes is generally indiscernible but can be quite significant. The most important aspect for many of the products is the concentration of active ingredients. For example, chloride salts should contain around 38 percent salt (possibly less for magnesium chloride). Polymer emulsions generally contain 40 to 50 percent solid polymer. Requesting product specifications can ensure that prediluted materials are not being sold for full market value. Other considerations (viscosity differences, chemical compositions) have been shown to contain only minor variations by ERDC research.

Ultimately, the decisionmaking process will rely on material cost unless relevant objections can be raised to eliminate a particular vendor from consideration.

7-39. It is important to realize that emulsified products have limited shelf lives. They consist of finely dispersed hydrophobic particles suspended in water. The dispersion is relatively unstable and may result in the settling of solid particles. Normal mixing procedures will not allow these particles to go back into a solution, and the product will not perform to its original properties. Emulsions should be kept away from extreme heat, ultraviolet light, and freezing temperatures. Chloride salts, polyacrylamides, powdered polymers, and synthetic fluids do not have limitations on shelf life.

APPLICATION EQUIPMENT SELECTION TIPS

7-40. Application equipment should be selected based on the types available for the project. Projects occurring on or near military installations are more likely to have a broader range of choices for equipment types. Expeditionary missions in active theaters may preclude the use of many types of machinery. The ultimate goal is to use equipment that will allow the most efficient progress for placing dust palliatives. Larger areas will need dispersion systems with large capacities. Liquid discharge is usually not the most time consuming process. A hydroseeder can be used to spray over 100 gallons per minute. Other systems using a distribution bar may spray around 50 gallons per minute. The time required to empty a tank at this rate will be relatively small. The process dominating the construction time (for topical applications) is transporting and filling the equipment. For large jobs it is important to use methods that can reduce these steps. For treating small areas, the time factor may not be as critical.

DUST PALLIATIVE APPLICATION TIPS

7-41. Dust palliatives are commonly applied topically to a soil. This technique is a rapid solution to typical dust problems. The distribution equipment available will dictate the method that is used for applying the product. Equipment with distribution bars should be calibrated by adjusting the speed to obtain the desired application rate (see the equation below). Distributing dust palliatives via hose or other spray systems requires the operator to monitor the fluid level of the product in the holding tank to estimate the coverage. These adjustments are relatively easy to regulate.

$$\text{Vehicle_Speed}\left(\frac{\text{ft}}{\text{min}}\right) = \frac{9 \cdot \text{Pump_Outlet}\left(\frac{\text{gal}}{\text{min}}\right)}{\text{Application_Rate}\left(\frac{\text{gal}}{\text{yd}^2}\right) \cdot \text{Spray_Bar_Width(ft)}}$$

7-42. Distribution equipment may have mechanisms that enable the operator to pump dust palliatives directly from shipping containers to the holding tank. If this is not possible, the ERDC recommends transferring palliatives using a small, multipurpose centrifugal pump with approximately a 5.5 horse power engine and 200 gallons per minute discharge capacity through a 2-inch hose. These pumps should be sufficient to transfer palliatives and provide adequate durability. The pump should be equipped with a rigid 2-inch hose and quick-connect fittings for rapid hookup and disassembly.

7-43. Dust palliatives are usually shipped in 275-gallon plastic containers with a discharge valve on the bottom. It is recommended that the procurement contract mandate that these containers be equipped with quick-connect fittings to easily link to suction hoses.

7-44. It is usually recommended that dust palliatives that consist of emulsified products be added to the container after the necessary dilution water is placed into the tank. If the emulsion is added first, excessive foaming may occur during the addition of dilution water.

7-45. Equipment should be thoroughly rinsed with water after transferring dust palliatives. Additionally, it is important to flush distribution systems with water after applying dust palliatives. Film-forming products (such as polymers and lignosulfonates) will coagulate within the distribution system and clog equipment. Cleaning the equipment after this occurs may require significant disassembly. Organic solvents may also be

required to completely remove remaining polymer. It is important to rinse equipment after spraying chloride salts because of their tendency to corrode metal and initiate rust formation. Rinsing may be optional when using synthetic fluids for dust control. They tend to lubricate equipment and have not been found to generate problems. Cleaning will be necessary if other liquids are to be placed into the equipment for other purposes.

7-46. Reapplication of dust palliatives may be necessary as product effectiveness diminishes over time. Areas treated with chloride salts or synthetic fluids may be rejuvenated by applying more palliative at approximately half the original application rate. Additionally, troublesome areas or exposed, untreated soils may be fixed by coating that particular region with small quantities of product. Reapplication on polymer-treated soil may require some site preparatory work before spraying. The existing polymer film, if undisturbed in some areas, will tend to repel the emulsion and prevent penetration of the new product. Using methods to pulverize or scarify the soil may improve reapplication.

7-47. Dust mitigation, particularly on communication lines, may require using the admix method to incorporate the dust palliatives into the soil for better performance. If a rotary mixer is not available, it may be best to simply compact the soil and topically apply the dust palliative. If the surface is hard and palliative ponding or runoff becomes a problem, try applying the dust palliative in successive treatments of lighter application rates until the total recommended rate is achieved. This is particularly true when using polymer emulsions. They have some adhesive properties and are difficult to mix using other techniques, such as windrowing with a motor grader. Applying polymer emulsions to the soil before compaction may cause the soil or product to stick to the compactor roller.

Appendix A

Metric Conversion Chart

This appendix complies with AR 25-30 which states that weights, distances, quantities, and measures contained in Army publications will be expressed in United States standard and metric units. Table A-1 is a metric conversion chart.

Table A-1. Metric conversion chart

United States Units	*Multiplied By*	*Equals Metric Units*
Acres	4,047	Square meters
Cubic feet	00.02830	Cubic meters
Cubic feet per second	00.28316	Cubic meters per second
Cubic yards	00.76460	Cubic meters
Feet	00.30480	Meters
Feet per minute	00.50800	Centimeters per square inch
Feet per second	00.30480	Meters per second
Gallons	03.78540	Liters
Inches	02.54000	Centimeters
Inches	00.02540	Meters
Inches	25.40010	Millimeters
Knots	01.85300	Kilometers per hour
Miles (statute)	01.60930	Kilometers
Miles (nautical)	01.85320	Kilometers
Miles per hour	01.60930	Kilometers per hour
Pounds	00.45359	Kilograms
Pounds per cubic yard	16.01846	Kilograms per cubic meter
Pounds per square inch	06.89476	Kilopascals
Square feet	00.09290	Square meters
Square inches	06.45160	Square centimeters
Square yards	00.83610	Square meters
Tons (short)	00.90700	Metric tons
Yards	00.91440	Meters

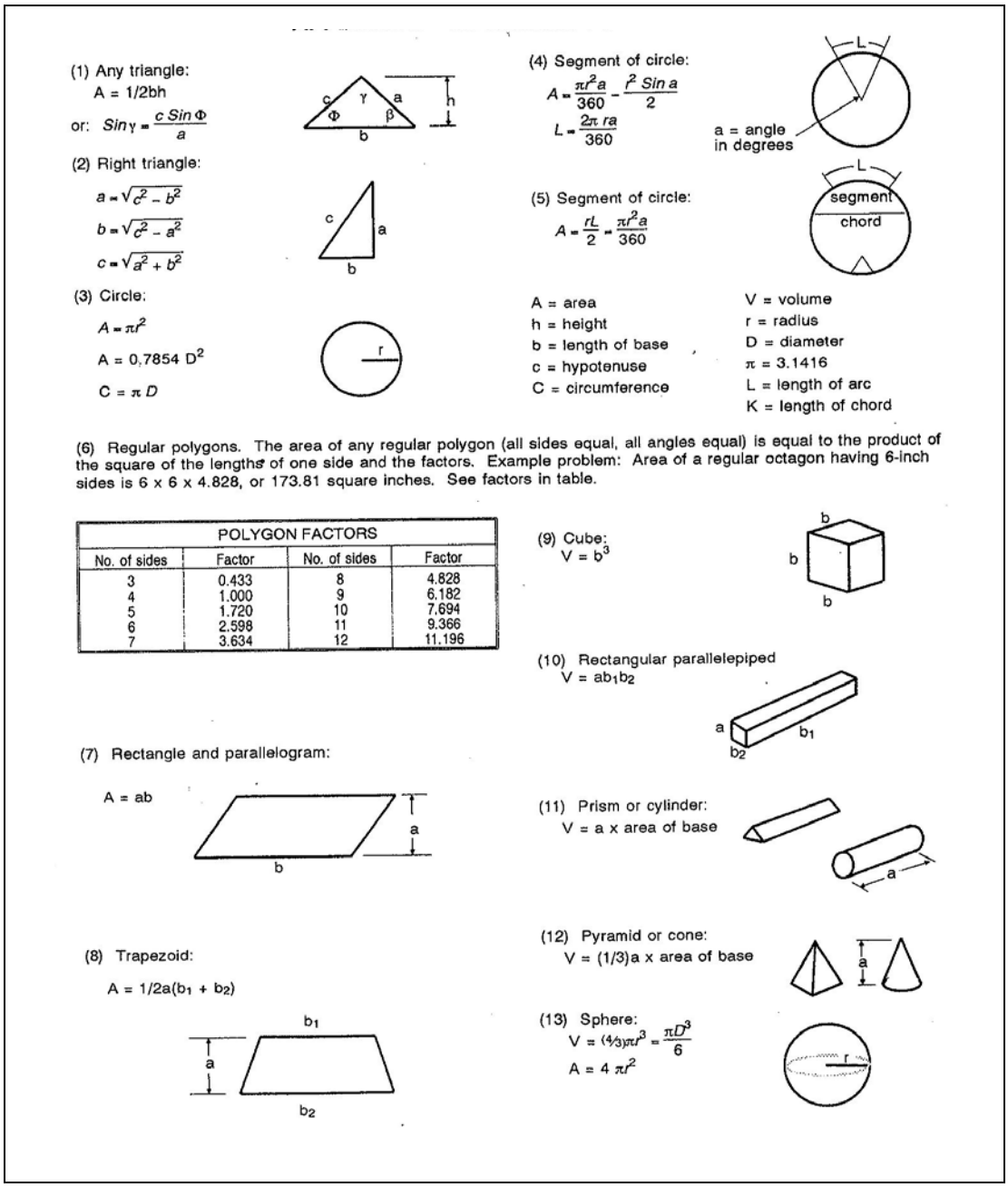
Table A-1. Metric conversion chart (continued)

Metric Units	*Multiplied By*	*Equals United States Units*
Centimeters	00.39370	Inches
Centimeters per square inch	1.969	Feet per minute
Cubic meters	35.31440	Cubic feet
Cubic meters	01.30790	Cubic yards
Cubic meters per second	35.3746667	Cubic feet per second
Kilograms	02.20460	Pounds
Kilograms per cubic meter	00.06243	Pounds per cubic yard
Kilometers	00.53960	Miles (nautical)
Kilometers	00.62137	Miles (statute)
Kilometers per hour	00.53960	Knots per hour
Kilonewton	00.22481	Kilopound
Kilopound	4,448.22160	Newton
Kilopascals	00.14493	Pounds per square inch
Liters	00.26420	Gallons
Meters	03.28080	Feet
Meters	39.37000	Inches
Meters	01.09361	Yards
Meters per second	3.28080	Feet per second
Metric tons	01.10200	Tons (short)
Millimeters	00.03937	Inches
Square centimeters	00.15500	Square inches
Square meters	02.47100 X 10^{-4}	Acres
Square meters	10.76400	Square feet
Square meters	01.19600	Square yards

Appendix B

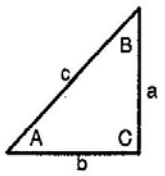
Geometric Equations

The geometric equations listed in figure B-1 are commonly used in the planning and designs of roads, airfields, and heliport design. These equations are required to calculate lengths, areas and volumes. Table B-1, page B-3, shows the trigonometric functions.



POLYGON FACTORS			
No. of sides	Factor	No. of sides	Factor
3	0.433	8	4.828
4	1.000	9	6.182
5	1.720	10	7.694
6	2.598	11	9.366
7	3.634	12	11.196

Figure B-1. Geometric equations

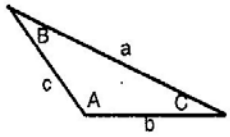


$a^2 = c^2 - b^2$ $\quad Sin\,A = \frac{a}{c}$

$b^2 = c^2 - a^2$ $\quad Cos\,A = \frac{b}{c}$

$c^2 = a^2 + b^2$ $\quad Tan\,A = \frac{a}{b}$

Right triangle							
To find							
Given	A	B	C	a	b	c	area
a,b	$\tan A = \frac{a}{b}$	$\tan B = \frac{b}{a}$	90			$\sqrt{a^2 + b^2}$	$\frac{ab}{2}$
a,c	$\sin A = \frac{a}{c}$	$\cos B = \frac{a}{c}$	90		$\sqrt{c^2 - a^2}$		$\frac{a}{2}\sqrt{c^2 a^2}$
A,a		90 - A	90		a cot A	$\frac{a}{\sin A}$	$\frac{a^2 \cot A}{2}$
A,b		90 - A	90	b tan A		$\frac{b}{\cos A}$	$\frac{b^2 \tan A}{2}$
A,c		90 - A	90	c sin A	c cos A		$\frac{c^2 \sin 2A}{2}$



$\frac{a}{Sin\,A} = \frac{b}{Sin\,B} = \frac{c}{Sin\,C}$

$S = \frac{a+b+c}{2}$

$a^2 = b^2 + c^2 - 2bc\,Cos\,A$

$b^2 = a^2 + c^2 - 2ac\,Cos\,B$

$c^2 = a^2 + b^2 - 2ab\,Cos\,C$

Oblique triangle						
Given	To find					
	A	B	C	b	c	area
a,b,c	$\cos\frac{A}{2} = \sqrt{\frac{s(s-a)}{bc}}$	$\cos\frac{B}{2} = \sqrt{\frac{s(s-b)}{ac}}$	$\cos\frac{C}{2} = \sqrt{\frac{s(s-c)}{ab}}$			$\sqrt{s(s-a)(s-b)(s-c)}$
a,A,B			180 - (A+B)	$\frac{a \sin B}{\sin A}$	$\frac{a \sin C}{\sin A}$	$\frac{a^2 \sin B \sin C}{2 \sin A}$
a,b,A		$\sin B = \frac{b \sin A}{a}$			$\frac{b \sin C}{\sin B}$	
a,b,c		$\tan A = \frac{a \sin C}{b - a \cos C}$			$\sqrt{a^2 + b^2 - 2ab \cos C}$	$\frac{ab \sin C}{2}$

Figure B-1. Geometric equations (continued)

Table B-1. Trigonometric functions

Degree of Angle	*Sine*	*Cosecant*	*Tangent*	*Cotangent*	*Secant*	*Cosine*	*Degree of Angle*
0	0.000		0.000		1.000	1.000	90
1	0.017	57.30	0.017	57.29	1.000	1.000	89
2	0.035	28.65	0.035	28.64	1.001	0.999	88
3	0.052	19.11	0.052	19.08	1.001	0.999	87
4	0.070	14.34	0.070	14.30	1.002	0.998	86
5	0.087	11.47	0.087	11.43	1.004	0.996	85
6	0.105	9.567	0.105	9.514	1.006	0.995	84
7	0.122	8.206	0.123	8.144	1.008	0.993	83
8	0.139	7.185	0.141	7.115	1.010	0.990	82
9	0.156	6.392	0.158	6.314	1.012	0.988	81
10	0.174	5.759	0.176	5.671	1.015	0.985	80
11	0.191	5.241	0.194	5.145	1.019	0.982	79
12	0.208	4.810	0.213	4.705	1.022	0.978	78
13	0.225	4.445	0.231	4.331	1.026	0.974	77
14	0.242	4.134	0.249	4.011	1.031	0.970	76
15	0.259	3.864	0.268	3.732	1.035	0.966	75
16	0.276	3.628	0.287	3.487	1.040	0.961	74
17	0.292	3.420	0.306	3.271	1.046	0.956	73
18	0.309	3.236	0.325	3.078	1.051	0.951	72
19	0.326	3.072	0.344	2.904	1.058	0.946	71
20	0.342	2.924	0.364	2.747	1.064	0.940	70
21	0.358	2.790	0.384	2.605	1.071	0.934	69
22	0.375	2.669	0.404	2.475	1.079	0.927	68
23	0.391	2.559	0.424	2.356	1.086	0.921	67
24	0.407	2.459	0.445	2.246	1.095	0.914	66
25	0.423	2.366	0.466	2.145	1.103	0.906	65
26	0.438	2.281	0.488	2.050	1.113	0.899	64
27	0.454	2.203	0.510	1.963	1.122	0.901	63
28	0.469	2.130	0.532	1.881	1.133	0.883	62
29	0.485	2.063	0.554	1.804	1.143	0.875	61
30	0.500	2.000	0.577	1.732	1.155	0.866	60
31	0.515	1.942	0.601	1.664	1.167	0.857	59
32	0.530	1.887	0.625	1.600	1.179	0.848	58
33	0.545	1.836	0.649	1.540	1.192	0.839	57
34	0.559	1.778	0.675	1.483	1.206	0.829	56
35	0.574	1.743	0.700	1.428	1.221	0.829	55
36	0.588	1.701	0.727	1.376	1.236	0.809	54
37	0.602	1.662	0.754	1.327	1.252	0.799	53
38	0.616	1.624	0.781	1.280	1.269	0.788	52
39	0.629	1.589	0.810	1.235	1.287	0.777	51
40	0.643	1.556	0.839	1.192	1.305	0.766	50
41	0.656	1.542	0.869	1.150	1.325	0.755	49
42	0.669	1.494	0.900	1.111	1.346	0.743	48
43	0.682	1.466	0.933	1.072	1.367	0.731	47
44	0.695	1.440	0.966	1.036	1.390	0.719	46
45	0.707	1.414	1.000	1.100	1.414	0.707	45

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Appendix C

Cone Index Requirements

The vehicle cone index (CI) is a metric for directly quantifying the ability of vehicles to traverse soft-soil terrain. See table C-1.

Table C-1. VCI for tracked vehicles

Vehicle Description	Vehicle Weight (kips)	VC_1	VCI_{50}
TRACKED VEHICLES			
Amphibious vehicles			
Carrier, cargo, amphibious, tracked, M116	10.9	7	18
Landing vehicle, tracked, command, M5 (LVTP5A1(CMD))	97.5	20	49
Landing vehicle, tracked, personnel, M5 (VTP5A1)	87.5	19	45
Armored bulldozers			
Bulldozer, earthmoving tank, tank-mounted, M9 (tank, combat, 105-millimeter gun, M60, and M60A1)	116.0	23	53
Tractor, armored, combat earthmover (ACE), M9	35.6	18	41

Notes.

1. Items listed include selected self-propelled vehicles as of January 1993. Certain items in final development or undergoing field testing have been included where the type of classification is pending.

2. The VCI values have been calculated from the equations, curves, and tables in NRMM. The vehicle weight was based on normal design loads or combat weights, equipment, cross-country tire pressures, and crews as the conditions would be under full operational deployment in typical off-road movements. Trucks, which could operate at lower tire pressures, would generate slightly lower VCI values with increased tire deflection.

3. Amphibious vehicles and engineer tractors have grousers greater than 1 1/2 inches; all other tracked vehicles have grousers less than 1 1/2 inches.

4. One kip equals 1,000 pounds (United States customary).

Table C-1. VCI for tracked vehicles (continued)

Vehicle Description	Vehicle Weight (kips)	VC_1	VCI_{50}
Combat vehicles			
Armored reconnaissance airborne assault vehicle (General Sheridan), M551	35.8	15	35
Howitzer, heavy self-propelled, full-tracked, 8-inch, M55 (T108)	98.0	20	47
Howitzer, heavy self-propelled, 8-inch, M110 (T236E1)	58.5	20	47
Howitzer, medium self-propelled, 155-millimeter, M109 (T196E1)	53.2	25	57
Howitzer, light, self-propelled, full-tracked, 105- millimeter, M37	46.0	NA	58
Howitzer, light, self-propelled, full-tracked, 105- millimeter,			
M52	53.0	NA	46
M52A1	53.0	NA	46
Howitzer, light, self-propelled, 105-millimeter, M108	46.9	NA	54
LAV-25, 8×8, light, armored vehicle	27.7	32	72
Mortar, infantry, self-propelled, full-tracked, 107-millimeter (4.2-inch), M84	47.1	NA	46
Tank, combat, full-tracked, 90-millimeter gun,			
M48	99.0	20	47
M48C	99.0	20	47
M48A1	104.0	21	49
M48A2	105.0	21	49
M48A2C	105.0	21	49
M48A3 (M48A1E2)	104.0	21	49
M48A5	106.0	22	50
Tank, combat, full-tracked, 105-millimeter gun,			
M60	110.0	21	48
M60A1	116.0	22	51
M60A3	110.0	20	46

Table C-1. VCI for tracked vehicles (continued)

Vehicle Description	Vehicle Weight (kips)	VC_1	VCI_{50}
Combat vehicles (continued)			
Tank, combat, full-tracked, 120-millimeter gun,			
M1	115.0	23	54
M1A1	125.0	25	58
M1A2	140.0	28	64
Vehicle, combat engineer, full-tracked, 165-millimeter gun, M729 (basic M60A1 tank)	115.0	N/A	54
Armored vehicle launched bridges			
Launcher, M48 tank chassis, transporting	96.0	NA	49
Launcher, M48 tank chassis, transporting, with bridge, armored vehicle launched, scissoring type, class 60, 60-foot	128.0	NA	65
Launcher, M60A1 chassis, transporting	86.3	15	36
Launcher, M60A1 chassis, transporting with bridge, armored vehicle launched, scissoring type, class 60, 60-foot	115.9	22	51
Carriers			
Carrier, cargo, tracked, 6-inch, M548	28.0	NA	37
Carrier, command post, light, tracked,			
M577	23.9	17	40
M577A1	24.4	17	40
Carrier, personnel, full-tracked, armored,			
M113	22.6	NA	48
M113A1	23.4	NA	49
M113A2	23.4	NA	49
M113A3	23.6	NA	49

Table C-1. VCI for tracked vehicles (continued)

Vehicle Description	Vehicle Weight (kips)	VC_1	VCI_{50}
Carriers (continued)			
Infantry fighting vehicle,			
M2A1	50.2	15	35
M2A2	66.0	16	37
Multiple Launch Rocket System	54.2	15	35
Recovery vehicles			
Recovery vehicle, full-tracked, medium, M88	112.0	21	50
Recovery vehicle, full-tracked, light, armored, M578	54.0	21	49
WHEELED VEHICLES			
Trucks			
Truck, utility, 1/4-ton, 4×4, M151	3.1	19	44
Truck, utility, 1 1/4-ton, 4×4, M998 (HMMWV)	7.5	20	47
Truck, cargo, 1 1/4-ton, 6×6, M561	9.6	19	44
Truck, cargo, 1 3/4-ton, 4×4, M1028 commercial utility cargo vehicle (CUCV)	9.3	31	70
Truck, cargo, 2 1/2-ton, 6×6, M34	17.2	27	61
Truck, cargo, 2 1/2-ton, 6×6, M35A1	19.2	26	59
Truck, cargo, 2 1/2-ton, 6×6, M923	32.5	30	68
Truck, cargo, 2 1/2-ton, 4×4 M520	43.4	43	97
Truck, cargo, 10-ton, 6×6			
M125	49.5	37	84
M125A1	49.5	37	84
Truck, cargo, 10-ton, 8×8 M977	60.4	36	79
Truck, cargo, 5-ton, 6×6 M1084	35.8	25	57

Table C-1. VCI for tracked vehicles (continued)

Vehicle Description	Vehicle Weight (kips)	VC_1	VCI_{50}
Trucks (continued)			
Truck, utility, 2 1/2-ton, 4×4, M1078	21.8	25	57
Truck, utility, 2 1/2-ton, 6×6, M47	19.2	28	64
Truck, utility, 5-ton, 6×6			
M51	32.7	32	72
M51A2	32.7	32	72
M929	32.7	30	68
Truck, tractor, 5-ton, 6×6,			
M52 (without payload)	17.8	21	48
M52A1 (without payload)	17.8	21	48
Truck, tractor, 10-ton, 6×6			
M123 (without payload)	28.9	21	48
M123C (without payload)	30.2	22	50
M123D (without payload)	30.2	22	50
Truck, van, expansible, 2 1/2-ton, 6×6, M292	25.1	NA	76
Truck, van, shop, 2 1/2-ton 6×6, M109A1	21.0	NA	65
Truck, van, shop, 2 1/2-ton 6×6, M220	20.4	NA	62
Truck, wrecker, crane, 2 1/2-ton, 6×6, M108	19.8	NA	63
Truck, tractor, wrecker, medium, 5-ton, 6×6, M246 (w/payload)	44.8	32	73
Truck, wrecker, medium, 5-ton, 6×6, M543	34.4	NA	76
Palletized Loading System, 10×10	86.6	34	77

Legend:

ACE	armored combat earthmover
CMD	command
CUCV	commercial utility cargo vehicle
HMMWV	high mobility multipurpose wheeled vehicle
NA	not applicable
NRMM	North Atlantic Treaty Organization Reference Mobility Model
VC_1	vehicle cone index one pass
VCI	vehicle cone index
VCI_{50}	vehicle cone index fifty passes

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Appendix D

Soil Trafficability Test Set

Soils trafficability is the capacity of soils to support military vehicles. This appendix includes information on a soil-trafficability test set, measuring trafficability with the results of the tests performed by the cone penetrometer and remolding equipment, and making trafficability estimates from terrain data (topography and soil data) and weather conditions.

TEST SET OVERVIEW

D-1. Trafficability measurements are made with a soil-trafficability test set. The main components of a test set include a cone penetrometer, a soil sampler, and remolding equipment. A canvas carrying case and a bag of hand tools are also included in the test set for use in transporting and maintaining major equipment items.

D-2. A 3/8-inch steel penetrometer shaft, a 5/8-inch aluminum penetrometer shaft, a 0.5-square-inch cone, and a 0.2-square-inch cone are included with the cone penetrometer. The remolding equipment includes a 2 1/2-pound drop hammer (mounted on a 5/8-inch steel shaft with foot and handle) and a remolding cylinder with a base and pin. The bag of hand tools includes a combination spanner wrench, a 1/4-inch screwdriver, two open-end wrenches, a 6-inch Stillson wrench, a 3/16-inch Allen wrench, and a 2-inch screwdriver with a 1/8-inch bit.

D-3. Figure D-1 shows test set items in their proper places in the canvas carrying case. The following paragraphs describe standard procedures for operating and maintaining the major equipment in the test set.

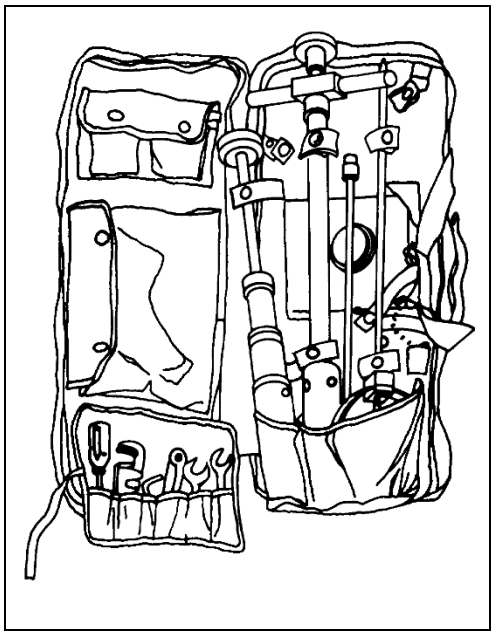


Figure D-1. Soil-trafficability test set

CONE PENETROMETER

D-4. The cone penetrometer consists of a 30-degree cone, a 19-inch long penetrometer shaft, a proving ring with mounting blocks, a dial indicator, and a handle (see figure D-2, page D-2). For the majority of

measurement applications, the cone penetrometer will be equipped with the 3/8-inch diameter steel penetrometer shaft and the cone with 0.5-square-inch base area.

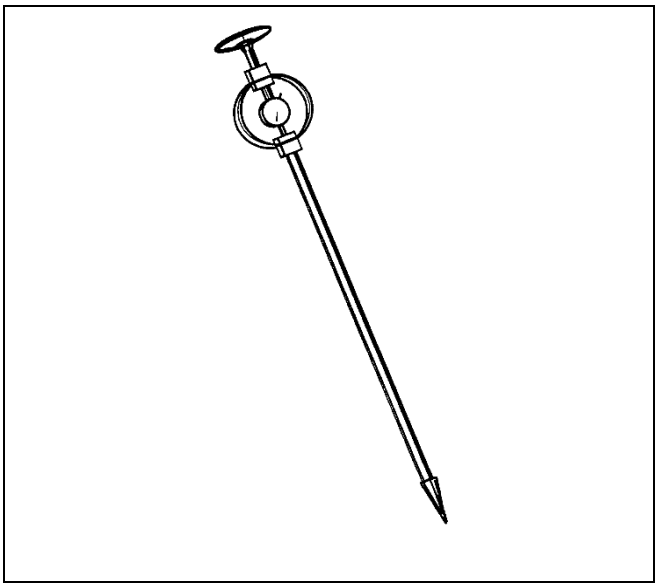


Figure D-2. Cone penetrometer

USE OF THE CONE PENETROMETER

D-5. The following paragraphs explain the process to inspect, zero and put the cone penetrometer into operation along with the key precautions to watch for.

Inspection

D-6. Inspect and adjust the cone penetrometer before use. Inspection involves making sure that nuts, bolts, and joints are tight and that the contact tip for the dial indicator plunger is in contact with the lower proving ring mounting block under zero load (see below).

Zeroing

D-7. Allow the penetrometer to hang vertically from its handle. Rotate the dial face until 0 is under the indicator needle. When the instrument is kept vertical between the fingertips and allowed to rest on its cone, the proving ring will register about 2 to 4 pounds (the total weight of the instrument), which translates to 4 to 8 pounds per square inch on the dial indicator needle when properly zeroed.

Operation

D-8. Operate the penetrometer as follows:

- Place one hand over the other, palms down, on the handle and approximately at right angles. This minimizes eccentric loading of the proving ring and helps keep the shaft vertical.
- Apply force until slow, steady, downward movement occurs (see figure D-3). The correct penetration rate is such that 6 inches of penetration will occur every 5 seconds. If the correct penetration rate is applied, four readings (surface, 6, 12, and 18 inches) can be measured in 15 seconds during a continuous penetration. It may not be possible to maintain this rate in relatively high strength soils, but that will not significantly or adversely affect the resulting CI measurements. Maintaining the appropriate penetration rate becomes more important in softer soils, where the tendency may be to push the penetrometer into the soil too fast.
- Take a dial reading just as the base of the cone becomes flush with the ground surface. Watch the cone descend until an instant before the cone base is expected to be flush with the ground surface, then immediately shift the vision to the dial face. Continue the slow, steady, downward movement.

Take successive dial readings at appropriate 6-inch intervals to a depth of 18 inches. If it is necessary to stop the downward progression of the cone penetrometer, progress may be resumed with no adverse effects on the cone penetrometer readings. Progression should be stopped between depths so that the next reading is taken only after downward progression has resumed. For example, when only one person is on the trafficability reconnaissance, it may be convenient to make two cone penetrometer readings, stop the penetration to record the readings, resume the penetration to obtain two additional readings, and then stop to record.

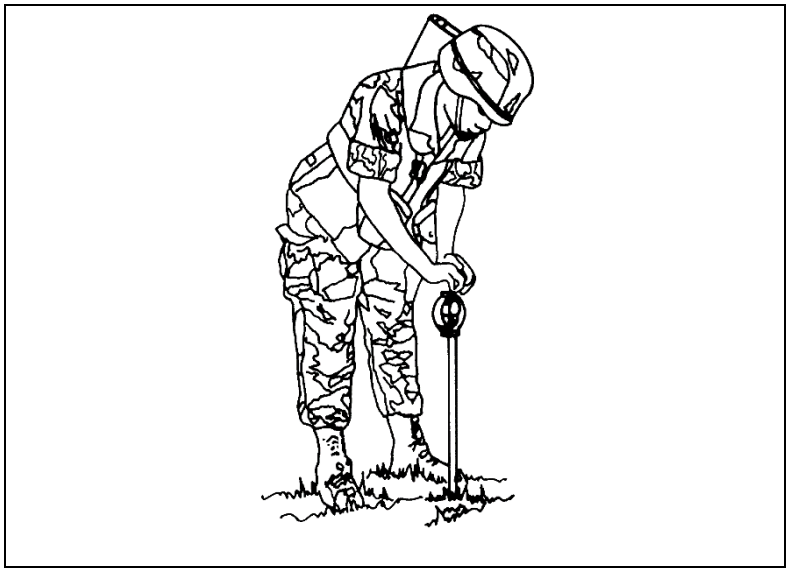


Figure D-3. Using a cone penetrometer in the upright position

Note. Using an operator assistant increases the speed with which measurements can be made and recorded and usually diminishes the likelihood of errors.

Precautions

D-9. Observe the following precautions when operating a cone penetrometer:

- Keep the instrument vertical.
- Do not attempt to take readings higher than the capacity of the dial (300) to avoid overstressing the proving ring.
- Make another penetration nearby if the dial capacity is exceeded at less than 18 inches of penetration. (The cone could be striking an isolated rock fragment or other object.)
- Withdraw the instrument by pulling on the shaft instead of the handle when difficulty is encountered extracting the cone penetrometer from the ground.

Note. Never grab the proving ring to push or pull the penetrometer. Pulling with extreme force on the handle may stretch the proving ring.

- Read the CI only at the proper depth. (If readings are made as little as 1/4 inch from the proper depth and are recorded as being at the proper depth, the readings will not accurately reflect the average soil strength. Carelessness in making proper depth determinations is perhaps the greatest source of error in using the penetrometer.)

PENETROMETER OPERATOR TRAINING

D-10. Train operators in areas that have uniform soil conditions. The instructor should take approximately 50 sets of readings that are equally spaced over the area. The average CI for 6-inch layers should be computed and used as the standard. The trainee should be instructed in proper operation techniques. They should

practice penetration while being observed by a qualified instructor until they become familiar with operation techniques. The trainee should then take 50 sets of readings, using an assistant to record them. The average CI values obtained by the trainee should be compared to the standard. If trainee readings widely deviate, the causes for the deviations should be sought and corrected.

D-11. In a uniform area, a 5-percent deviation is wide. The most probable cause of error is carelessness in determining the proper depth. Another potential source of error is the rate of penetration into the soil. Penetration rates that are too slow or too fast will produce lower or higher CI values, respectively, but the discrepancies will not be large. The CI is also insignificantly affected by the variation in the rate of penetration for the same operator or between experienced operators. However, if deviations persist, check the possibility of cone-penetrometer mechanical imperfections. Inspect the dial face to ensure that its position has not shifted around the dial shaft and that the needle is not sticking or has not slipped on its shaft. Any of these conditions could cause an improper zero setting. Next, inspect the proving ring. A damaged or overstressed ring might require recalibration. Finally, check to ensure that the instrument was properly zeroed. The contact tip on the dial indicator plunger may not have been in good contact with the lower proving ring mounting block when the instrument was zeroed.

CARE AND ADJUSTMENT OF THE PENETROMETER

D-12. Keep the penetrometer free from dirt and rust, and ensure that all of the parts are tight. Frequently check the instrument, and rezero it if necessary. Ensure that no grit is caught between the contact tip on the dial indicator plunger and the lower mounting block.

Dial Care

D-13. The dial indicator is a sensitive instrument that should be protected against water and rough use. Never immerse it in water, and wipe it dry as soon as possible after use in rainy weather. When the cone penetrometer is transported from one measurement site to another outside of the canvas carrying case, wrap the dial indicator in protective paper or cloth.

Mounting Block Adjustment

D-14. If the mounting blocks become loose and movable, adjust them so that they lie on the same diameter of the proving ring. Retighten them, and recalibrate the proving ring. Do not calibrate while on reconnaissance. Note readings made in the field after the mounting blocks have been adjusted, and correct them according to the calibration made afterward.

Cone Replacement

D-15. Considerable use of the same cone may result in a rounding of its point, but will not adversely affect the accuracy of the instrument. However, if the base of the cone has had excessive wear or is deformed by hard use, replace the cone.

Proving Ring Recalibration

D-16. The calibration will remain true for the life of the instrument unless the mounting blocks are moved or the proving ring is overstressed (deformed by a hard knock or subjected to extreme changes in temperature or other unusual strains). If the proving ring needs recalibration, complete the following steps:

- Remove the handle and shaft.
- Place the lower mounting block of the proving ring assembly on a smooth, horizontal surface.
- Use a drafting triangle or a carpenter’s square to check the alignment and tightness of the mounting blocks. (Both blocks should be on the same diameter of the proving ring, and the bolts should be snug.)
- Ensure that the contact tip for the dial indicator plunger bears firmly on the lower mounting block. Ensure that the dial plunger has sufficient travel available for the full range of deflection for the proving ring (approximately 1/10-inch). (The dial indicator can be moved up or down by adjusting

the two nuts on the threaded stud that holds it in position. Both nuts should be tight when in final position.)

- Zero the dial indicator by rotating its face so that 0 is under the needle.
- Incrementally add controlled loads on the proving ring assembly in 10-pound increments up to 150 pounds. Mark or note the needle position on the dial after the addition of each load increment. Any of the following loading methods may be used:
  - Add deadweights to the top of the proving ring assembly. (If a plate is used to hold the weights, its weight should be considered in the first 10-pound load.)
  - Use the load machines commonly used in laboratory work to apply the load.
  - Place the proving ring assembly on a set of platform scales. Apply the load increments with a jack, and measure them with platform scales.
- Remove the load in 10-pound increments, noting the position of the needle after the removal of each increment.
- Make the load run at least twice, using the average of the needle position for each increment as the final point.
- Expect some variation in needle position. (It will not be significant.)
- Establish 10-pound intervals on the dial face, and mark them. (The arcs for various 10-pound intervals are not necessarily the same, so each interval should be subdivided separately.)

Note. If the instrument cannot be calibrated or the proving ring is severely damaged, the instrument will need to be turned in for repair.

SOIL SAMPLER

D-17. The soil sampler is a piston soil sampler that is very effective for collecting samples in soft soils (See figure D-4.) It is primarily used to extract soil samples for remolding tests, but it can also be used to collect samples for moisture content and density measurements.

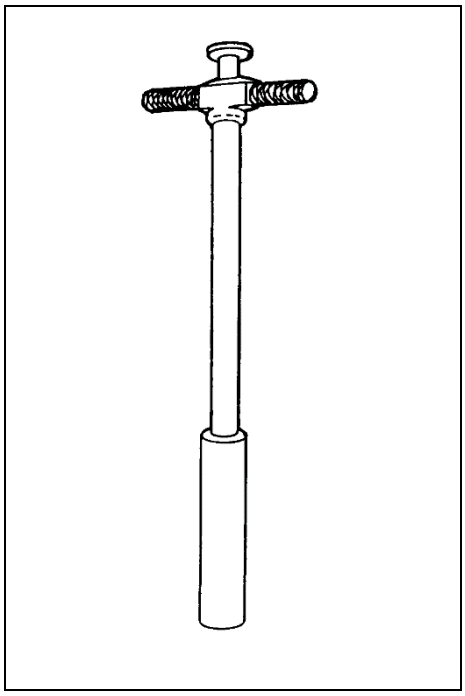


Figure D-4. Trafficability soil sampler

OPERATION

D-18. To use the soil sampler, complete the following steps:

- Loosen the knurled handle of the soil sampler to enable the piston rod to move freely. Hold the sampler firmly in both hands, and force it into the soil vertically. (See figure D-5.) Do not twist the sampler while pushing it into the soil. (If the soil is firm, two people may be required.)
- Turn the knurled handle to lock the piston rod, twist the sampler slightly, and withdraw it. (The sample will be deposited directly into the remolding cylinder.)



Figure D-5. Operating the sampler in the upright position

D-19. Figure D-6 shows the technique for using the sampler in a prone position.

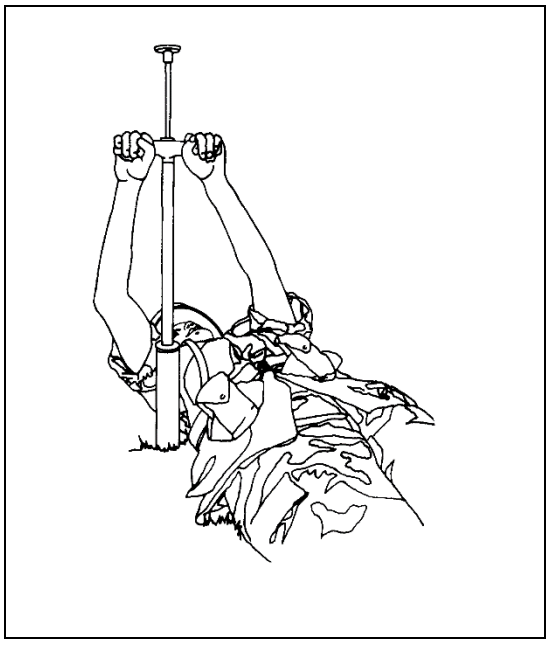


Figure D-6. Using the sampler in a prone position

CARE

D-20. It is essential to keep the inside of the sampler tube, the piston ring, and the leather washer clean. After 5 to 25 samplings, depending upon the type of soil, complete the following cleaning procedures:

- Immerse the tube first in water and then in fuel oil. Work the piston up and down five or six times in each liquid.
- Wipe off the excess fuel oil, and squirt light machine oil into the tube.
- Remove the tube, disassemble and thoroughly clean the piston, and oil the leather washer if the sampler becomes stiff and hard to work. (Tube walls and cutting edges are soft and should be handled with care. Also, cutting edges require sharpening from time to time.)

ADJUSTMENT

D-21. Adjust the piston rod length to keep the face of the piston flush with the cutting edge of the tube when the piston rod handle (disk) is fully depressed. Loosen the setscrew on the handle, screw the handle up or down to the correct position, and retighten the setscrew.

REMOLDING EQUIPMENT

D-22. The remolding equipment is shown in figure D-7. It consists of—

- A steel remolding cylinder approximately 2 inches in diameter and 8 inches long that will be mounted on an aluminum base and secured in place with a locking pin.
- A 2 1/2-pound steel drop hammer that slides freely on an 18-inch long, 5/8-inch diameter steel shaft with foot and handle.

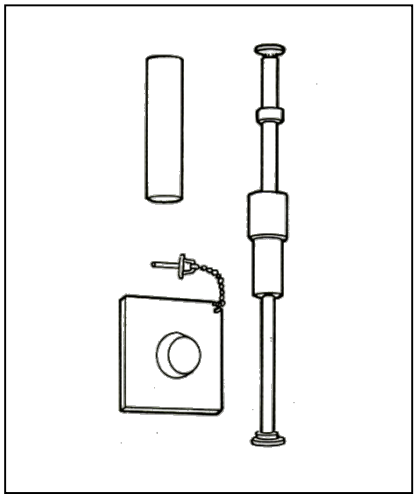


Figure D-7. Remolding equipment

D-23. The remolding equipment is used with the cone penetrometer and the soil sampler to conduct remolding tests. The cone penetrometer is used to determine the remolding index by measuring the soil strength in the remolding cylinder before and after applying blows with the drop hammer. The soil sampler is used to obtain samples for the remolding tests.

TEST PROCEDURE FOR FINE-GRAINED SOILS

D-24. The remolding test should be conducted as follows for fine-grained soils:

- Use the soil sampler to take a sample from the critical layer. Eject it directly into the remolding cylinder (see figure D-8, page D-8), and push it to the bottom of the cylinder with the foot of the drop hammer.



Figure D-8. Placing a soil sample in the remolding cylinder

- Measure the soil strength in the remolding cylinder with the cone penetrometer. Take CI readings as the cone base enters the soil sample surface and at each successive inch, to a depth of 4 inches (see figure D-9). The cone penetrometer should be equipped with the 3/8-inch or 5/8-inch penetrometer shaft and the 0.5-square-inch cone for fine-grained soils.

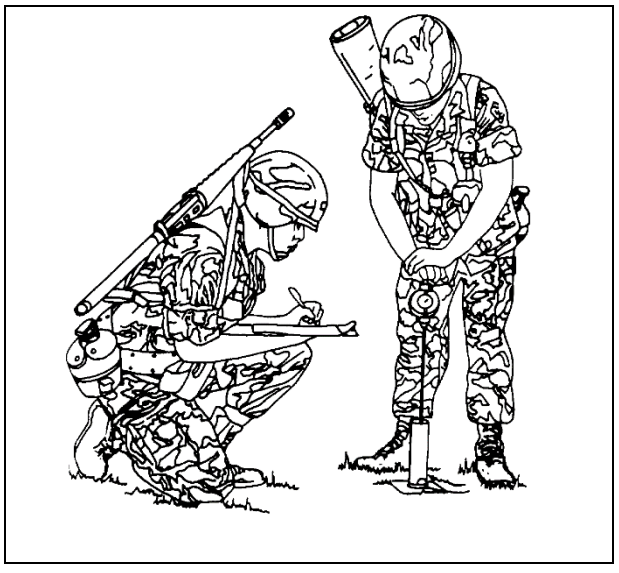


Figure D-9. Measuring CI in a remolding cylinder

- Apply 100 blows with the drop hammer (falling the full range [12 inches]) (see figure D-10).



Figure D-10. Applying hammer blows with remolding equipment

- Measure the remolded soil strength in the cylinder (after the hammer blows) with the cone penetrometer by taking CI readings from the surface to the 4-inch depth at 1-inch increments, as done before remolding.

Note. Some samples are so hard that they cannot be penetrated the full 4 inches. In such cases, the full dial capacity (300) is recorded for each inch below the last reading obtained.

D-25. To find the remolding index, take the sum of the five CI readings after remolding and divide by the sum of the five readings before remolding.

TEST PROCEDURE FOR REMOLDABLE SANDS

D-26. The test procedure for remoldable sands is usually the same as that for fine-grained soils. However, the drop hammer is not used for remolding the sample. Instead, the sample is remolded by dropping it (along with the cylinder and base) 25 times from a height of 6 inches onto a firm surface, such as a piece of timber. It may be necessary to place a stopper, such as a cloth rag or paper towel, in the top of the remolding cylinder above the sample to keep the sample constrained in the cylinder. Also, the cone penetrometer should be equipped with the 3/8-inch penetrometer shaft and the 0.2-square-inch cone for remoldable sands.

D-27. Some remoldable sands with a large amount of fines (more than 12, but less than 50 percent) react very much like fine-grained soil. When testing remoldable sand with a large amount of fines, use both remolding test procedures (one for fine-grained soils and one for remoldable sands), and use the lower remolding index resulting from the two procedures. Continue to use the more critical test procedure for similar remoldable sands throughout the area.

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Appendix E

Curve Tables

Curves are as gentle as possible. Long, gentle curves increase the capacity of the roadway by permitting higher speeds. They also provide a safer path of travel for the vehicle. Making gentle, horizontal curves will increase the curve length, thereby decreasing the tangent length. However, this reduction in tangent length is minor compared to the benefits gained by reducing the total number of curves. This appendix provides tables to cross reference for a 1-degree curve.

FUNCTIONS OF A ONE-DEGREE CURVE

E-1. The long chords, middle ordinates, externals, and tangent distances in table E-1 are for a 1-degree curve, based on the arc definition (5,729.578-foot radius). To find the corresponding functions of any other curve, divide the tabular values by the degree of curvature.

CORRECTIONS FOR TANGENTS AND DISTANCES

E-2. Complete the following steps to determine the degree of curvature for all curves other than the 1-degree curve:

- **Step 1.** Determine the value corresponding to the given intersection angle from table E-1.
- **Step 2.** Divide this value by the given degree of curvature.
- **Step 3.** Add the correction derived from table E-2, page E-22.

Table E-1. Functions of a 1-degree curve

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
0	0	0.000	0.0000	0.0000	0.0000
	10	16.666	0.0060	0.0060	8.3333
	20	33.333	0.0242	0.0242	16.6667
	30	49.999	0.0545	0.0545	25.0001
	40	66.666	0.0969	0.0969	33.3337
	50	83.332	0.1515	0.1515	41.6674
1	0	99.998	0.2181	0.2181	50.0012
	10	116.664	0.2969	0.2969	58.3353
	20	133.330	0.3878	0.3878	66.6696
	30	149.995	0.4908	0.4908	75.0042
	40	166.660	0.6060	0.6060	83.3392
	50	183.325	0.7332	0.7333	91.6744
2	0	199.989	0.8726	0.8727	100.0101
	10	216.653	1.0241	1.0243	108.3462
	20	233.317	1.1877	1.1879	116.6827
	30	249.980	1.3634	1.3638	125.0198
	40	266.642	1.5513	1.5517	133.3574
	50	283.304	1.7513	1.7518	141.6955

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
3	0	299.965	1.9633	1.9640	150.0342
	10	316.626	2.1875	2.1884	158.3736
	20	333.286	2.4238	2.4249	166.7136
	30	349.945	2.6723	2.6735	175.0544
	40	366.604	2.9328	2.9343	183.3959
	50	383.261	3.2055	3.2073	191.7381
4	0	399.918	3.4903	3.4924	200.0812
	10	416.574	3.7871	3.7896	208.4251
	20	433.230	4.0961	4.0991	216.7700
	30	449.884	4.4172	4.4207	225.1157
	40	466.537	4.7505	4.7544	233.4624
	50	483.190	5.0958	5.1003	241.8100
5	0	499.841	5.4532	5.4584	250.1587
	10	516.491	5.8228	5.8287	258.5085
	20	533.140	6.2044	6.2112	266.8593
	30	549.788	6.5982	6.6058	275.2113
	40	566.435	7.0041	7.0127	283.5645
	50	583.081	7.4221	7.4317	291.9188
6	0	599.725	7.8521	7.8629	300.2744
	10	616.369	8.2943	8.3063	308.6313
	20	633.010	8.7486	8.7620	316.9894
	30	649.651	9.2150	9.2298	325.3490
	40	666.290	9.6935	9.7099	333.7099
	50	682.928	10.1841	10.2022	342.0722
7	0	699.564	10.6868	10.7067	350.4360
	10	716.199	11.2016	11.2235	358.8012
	20	732.832	11.7284	11.7525	367.1680
	30	749.464	12.2674	12.2937	375.5363
	40	766.094	12.8185	12.8472	383.9063
	50	782.723	13.3817	13.4130	392.2778
8	0	799.350	13.9569	13.9910	400.6511
	10	815.975	14.5443	14.5813	409.0260
	20	832.599	15.1437	15.1838	417.4027
	30	849.220	15.7552	15.7987	425.7811
	40	865.840	16.3788	16.4258	434.1614
	50	882.458	17.0145	17.0652	442.5435
9	0	899.075	17.6623	17.7169	450.9275
	10	915.689	18.3222	18.3810	459.3134
	20	932.301	18.9941	19.0573	467.7013
	30	948.912	19.6782	19.7460	476.0912
	40	965.520	20.3743	20.4470	484.4831
	50	982.126	21.0825	21.1603	492.8770

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
10	0	998.731	21.8027	21.8860	501.2731
	10	1,015.333	22.5351	22.6240	509.6713
	20	1,031.933	23.2795	23.3744	518.0716
	30	1,048.531	24.0359	24.1372	526.4742
	40	1,065.126	24.8045	24.9123	534.8790
	50	1,081.720	25.5851	25.6999	543.2861
11	0	1,098.311	26.3778	26.4998	551.6956
	10	1,114.900	27.1825	27.3121	560.1073
	20	1,131.486	27.9993	28.1368	568.5215
	30	1,148.070	28.8282	28.9740	576.9381
	40	1,164.652	29.6691	29.8236	585.3572
	50	1,181.231	30.5221	30.6856	593.7788
12	0	1,197.807	31.3872	31.5601	602.2029
	10	1,214.382	32.2643	32.4470	610.6295
	20	1,230.953	33.1534	33.3464	619.0588
	30	1,247.522	34.0546	34.2582	627.4908
	40	1,264.088	34.9679	35.1826	635.9254
	50	1,280.652	35.8932	36.1194	644.3628
13	0	1,297.213	36.8305	37.0688	652.8029
	10	1,313.771	37.7799	38.0307	661.2458
	20	1,330.326	38.7413	39.0050	669.6916
	30	1,346.879	39.7148	39.9920	678.1402
	40	1,363.429	40.7003	40.9914	686.5917
	50	1,379.975	41.6978	42.0035	695.0462
14	0	1,396.519	42.7074	43.0281	703.5037
	10	1,413.060	43.7289	44.0653	711.9642
	20	1,429.598	44.7626	45.1150	720.4277
	30	1,446.133	45.8082	46.1774	728.8943
	40	1,462.665	46.8659	47.2524	737.3641
	50	1,479.194	47.9356	48.3400	745.8371
15	0	1,495.719	49.0173	49.4403	754.3132
	10	1,512.242	50.1110	50.5532	762.7926
	20	1,528.761	51.2168	51.6787	771.2753
	30	1,545.277	52.3345	52.8169	779.7613
	40	1,561.790	53.4643	53.9679	788.2507
	50	1,578.300	54.6060	55.1315	796.7434
16	0	1,594.806	55.7598	56.3078	805.2396
	10	1,611.309	56.9256	57.4968	813.7393
	20	1,627.808	58.1034	58.6986	822.2425
	30	1,644.304	59.2931	59.9132	830.7492
	40	1,660.796	60.4949	61.1404	839.2595
	50	1,677.285	61.7087	62.3805	847.7735

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
17	0	1,693.771	62.9344	63.6334	856.2911
	10	1,710.252	64.1722	64.8990	864.8124
	20	1,726.731	65.4219	66.1775	873.3375
	30	1,743.205	66.6836	67.4688	881.8663
	40	1,759.676	67.9573	68.7730	890.3990
	50	1,776.143	69.2429	70.0900	898.9355
18	0	1,792.606	70.5406	71.4199	907.4760
	10	1,809.066	71.8502	72.7626	916.0203
	20	1,825.522	73.1717	74.1183	924.5686
	30	1,841.974	74.5053	75.4869	933.1210
	40	1,858.422	75.8508	76.8684	941.6774
	50	1,874.866	77.2082	78.2629	950.2379
19	0	1,891.306	78.5777	79.6703	958.8025
	10	1,907.742	79.9590	81.0907	967.3713
	20	1,924.174	81.3524	82.5241	975.9443
	30	1,940.602	82.7576	83.9705	984.5215
	40	1,957.026	84.1749	85.4299	993.1030
	50	1,973.445	85.6040	86.9024	1,001.6889
20	0	1,989.861	87.0451	88.3879	1,010.2791
	10	2,006.272	88.4981	89.8865	1,018.8738
	20	2,022.680	89.9631	91.3982	1,027.4729
	30	2,039.082	91.4400	92.9230	1,036.0764
	40	2,055.481	92.9288	94.4609	1,044.6845
	50	2,071.875	94.4296	96.0120	1,053.2972
21	0	2,088.265	95.9423	97.5762	1,061.9145
	10	2,104.650	97.4669	99.1536	1,070.5364
	20	2,121.031	99.0034	100.7441	1,079.1630
	30	2,137.408	100.5518	102.3479	1,087.7943
	40	2,153.779	102.1121	103.9649	1,096.4304
	50	2,170.147	103.6843	105.5952	1,105.0713
22	0	2,186.510	105.2684	107.2387	1,113.7171
	10	2,202.868	106.8645	108.8955	1,122.3677
	20	2,219.221	108.4724	110.5656	1,131.0233
	30	2,235.570	110.0922	112.2490	1,139.6839
	40	2,251.914	111.7239	113.9458	1,148.3494
	50	2,268.253	113.3675	115.6559	1,157.0201
23	0	2,284.588	115.0229	117.3793	1,165.6958
	10	2,300.917	116.6903	119.1162	1,174.3766
	20	2,317.242	118.3695	120.8665	1,183.0626
	30	2,333.562	120.0605	122.6302	1,191.7539
	40	2,349.877	121.7635	124.4074	1,200.4504
	50	2,366.187	123.4783	126.1980	1,209.1522

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
24	0	2,382.492	125.2050	128.0021	1,217.8593
	10	2,398.792	126.9435	129.8198	1,226.5719
	20	2,415.087	128.6939	131.6509	1,235.2898
	30	2,431.377	130.4561	133.4957	1,244.0133
	40	2,447.661	132.2302	135.3539	1,252.7422
	50	2,463.941	134.0161	137.2258	1,261.4767
25	0	2,480.215	135.8138	139.1113	1,270.2168
	10	2,496.484	137.6234	141.0105	1,278.9625
	20	2,512.747	139.4448	142.9232	1,287.7140
	30	2,529.006	141.2780	144.8497	1,296.4711
	40	2,545.259	143.1231	146.7899	1,305.2340
	50	2,561.507	144.9800	148.7438	1,314.0027
26	0	2,577.749	146.8487	150.7114	1,322.7773
	10	2,593.985	148.7292	152.6928	1,331.5577
	20	2,610.217	150.6215	154.6880	1,340.3441
	30	2,626.443	152.5256	156.6970	1,349.1365
	40	2,642.663	154.4415	158.7198	1,357.9349
	50	2,658.877	156.3692	160.7565	1,366.7393
27	0	2,675.086	158.3086	162.8070	1,375.5499
	10	2,691.290	160.2599	164.8715	1,384.3667
	20	2,707.487	162.2230	166.9499	1,393.1896
	30	2,723.679	164.1978	169.0422	1,402.0188
	40	2,739.865	166.1844	171.1485	1,410.8542
	50	2,756.046	168.1828	173.2688	1,419.6960
28	0	2,772.220	170.1929	175.4031	1,428.5442
	10	2,788.389	172.2148	177.5515	1,437.3988
	20	2,804.552	174.2484	179.7139	1,446.2598
	30	2,820.708	176.2939	181.8905	1,455.1274
	40	2,836.859	178.3510	184.0811	1,464.0015
	50	2,853.004	180.4199	186.2859	1,472.8822
29	0	2,869.143	182.5005	188.5049	1,481.7696
	10	2,885.276	184.5929	190.7380	1,490.6636
	20	2,901.402	186.6970	192.9854	1,499.5644
	30	2,917.523	188.8128	195.2470	1,508.4719
	40	2,933.637	190.9404	197.5229	1,517.3863
	50	2,949.745	193.0796	199.8131	1,526.3076
30	0	2,965.847	195.2306	202.1176	1,535.2357
	10	2,981.943	197.3933	204.4364	1,544.1709
	20	2,998.032	199.5676	206.7697	1,553.1130
	30	3,014.115	201.7537	209.1173	1,562.0622
	40	3,030.192	203.9515	211.4794	1,571.0185
	50	3,046.262	206.1610	213.8559	1,579.9819

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1◦ Long chord*	*M_1◦ Middle ordinate*	*E_1◦ External distance*	*T_1◦ Tangent distance*
31	0	3,062.326	208.3821	216.2469	1,588.9526
	10	3,078.383	210.6149	218.6524	1,597.9304
	20	3,094.434	212.8594	221.0725	1,606.9156
	30	3,110.478	215.1156	223.5071	1,615.9081
	40	3,126.516	217.3834	225.9564	1,624.9079
	50	3,142.547	219.6629	228.4202	1,633.9152
32	0	3,158.571	221.9541	230.8987	1,642.9300
	10	3,174.589	224.2569	233.3919	1,651.9523
	20	3,190.600	226.5713	235.8998	1,660.9822
	30	3,206.604	228.8974	238.4224	1,670.0196
	40	3,222.601	231.2352	240.9598	1,679.0648
	50	3,238.592	233.5845	243.5121	1,688.1177
33	0	3,254.576	235.9455	246.0791	1,697.1783
	10	3,270.553	238.3181	248.6610	1,706.2467
	20	3,286.522	240.7023	251.2578	1,715.3230
	30	3,302.485	243.0981	253.8695	1,724.4072
	40	3,318.442	245.5056	256.4961	1,733.4994
	50	3,334.391	247.9246	259.1378	1,742.5995
34	0	3,350.332	250.3553	261.7944	1,751.7077
	10	3,366.267	252.7975	264.4661	1,760.8241
	20	3,382.195	255.2513	267.1529	1,769.9485
	30	3,398.116	257.7167	269.8548	1,779.0812
	40	3,414.029	260.1937	272.5718	1,788.2221
	50	3,429.935	262.6822	275.3040	1,797.3714
35	0	3,445.834	265.1823	278.0514	1,806.5290
	10	3,461.726	267.6940	280.8140	1,815.6949
	20	3,477.610	270.2172	283.5919	1,824.8694
	30	3,493.487	272.7519	286.3851	1,834.0523
	40	3,509.357	275.2982	289.1936	1,843.2438
	50	3,525.219	277.8561	292.0175	1,852.4439
36	0	3,541.073	280.4255	294.8568	1,861.6527
	10	3,556.921	283.0064	297.7115	1,870.8702
	20	3,572.760	285.5988	300.5817	1,880.0964
	30	3,588.592	288.2027	303.4674	1,889.3314
	40	3,604.417	290.8182	306.3686	1,898.5753
	50	3,620.234	293.4451	309.2855	1,907.8281
37	0	3,636.043	296.0836	312.2179	1,917.0899
	10	3,651.845	298.7335	315.1659	1,926.3607
	20	3,667.638	301.3950	318.1297	1,935.6406
	30	3,683.424	304.0679	321.1091	1,944.9296
	40	3,699.203	306.7523	324.1043	1,954.2278
	50	3,714.973	309.4482	327.1153	1,963.5352

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*$C_{1°}$ Long chord*	*$M_{1°}$ Middle ordinate*	*$E_{1°}$ External distance*	*$T_{1°}$ Tangent distance*
38	0	3,730.736	312.1555	330.1421	1,972.8519
	10	3,746.490	314.8743	333.1848	1,982.1779
	20	3,762.237	317.6046	336.2434	1,991.5133
	30	3,777.976	320.3463	339.3179	2,000.8582
	40	3,793.707	323.0994	342.4083	2,010.2125
	50	3,809.430	325.8640	345.5148	2,019.5764
39	0	3,825.144	328.6400	348.6373	2,028.9499
	10	3,840.851	331.4274	351.7759	2,038.3331
	20	3,856.550	334.2263	354.9306	2,047.7260
	30	3,872.240	337.0366	358.1015	2,057.1287
	40	3,887.922	339.8582	361.2886	2,066.5411
	50	3,903.596	342.6913	364.4919	2,075.9635
40	0	3,919.262	345.5358	367.7115	2,085.3958
	10	3,934.919	348.3916	370.9474	2,094.8381
	20	3,950.568	351.2589	374.1997	2,104.2904
	30	3,966.209	354.1375	377.4683	2,113.7529
	40	3,981.841	357.0275	380.7534	2,123.2255
	50	3,997.465	359.9289	384.0550	2,132.7083
41	0	4,013.081	362.8416	387.3731	2,142.2014
	10	4,028.687	365.7657	390.7077	2,151.7048
	20	4,044.286	368.7011	394.0590	2,161.2186
	30	4,059.876	371.6478	397.4268	2,170.7429
	40	4,075.457	374.6059	400.8114	2,180.2776
	50	4,091.030	377.5753	404.2127	2,189.8229
42	0	4,106.594	380.5561	407.6307	2,199.3789
	10	4,122.149	383.5481	411.0656	2,208.9455
	20	4,137.696	386.5515	414.5173	2,218.5228
	30	4,153.234	389.5662	417.9859	2,228.1110
	40	4,168.763	392.5921	421.4715	2,237.7100
	50	4,184.283	395.6294	424.9740	2,247.3199
43	0	4,199.794	398.6779	428.4935	2,256.9407
	10	4,215.297	401.7377	432.0302	2,266.5726
	20	4,230.790	404.8088	435.5839	2,276.2156
	30	4,246.275	407.8912	439.1548	2,285.8698
	40	4,261.751	410.9848	442.7429	2,295.5351
	50	4,277.217	414.0896	446.3482	2,305.2118
44	0	4,292.675	417.2057	449.9709	2,314.8997
	10	4,308.123	420.3331	453.6109	2,324.5991
	20	4,323.563	423.4716	457.2682	2,334.3099
	30	4,338.993	426.6214	460.9430	2,344.0322
	40	4,354.414	429.7825	464.6353	2,553.7661
	50	4,369.826	432.9547	468.3451	2,363.5116

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
45	0	4,385.229	436.1381	472.0725	2,373.2689
	10	4,400.622	439.3327	475.8175	2,383.0379
	20	4,416.006	442.5385	479.5802	2,392.8187
	30	4,431.381	445.7556	483.3605	2,402.6114
	40	4,446.746	448.9837	487.1587	2,412.4161
	50	4,462.102	452.2231	490.9746	2,422.2328
46	0	4,477.448	455.4736	494.8085	2,432.0615
	10	4,492.785	458.7353	498.6602	2,441.9024
	20	4,508.113	462.0081	502.5299	2,451.7555
	30	4,523.431	465.2920	506.4176	2,461.6209
	40	4,538.739	468.5871	510.3234	2,471.4986
	50	4,554.038	471.8934	514.2473	2,481.3888
47	0	4,569.327	475.2107	518.1893	2,491.2914
	10	4,584.607	478.5392	522.1496	2,501.2065
	20	4,599.877	481.8786	526.1281	2,511.1342
	30	4,615.137	485.2294	530.1249	2,521.0746
	40	4,630.387	488.5912	534.1401	2,531.0277
	50	4,645.627	491.9641	538.1738	2,540.9936
48	0	4,660.858	495.3480	542.2259	2,550.9724
	10	4,676.079	498.7430	546.2965	2,560.9641
	20	4,691.290	502.1491	550.3857	2,570.9689
	30	4,706.491	505.5662	554.4936	2,580.9866
	40	4,721.682	508.9944	558.6201	2,591.0176
	50	4,736.863	512.4336	562.7654	2,601.0617
49	0	4,752.034	515.8839	566.9295	2,611.1191
	10	4,767.195	519.3452	571.1124	2,621.1898
	20	4,782.346	522.8175	575.3143	2,631.2740
	30	4,797.487	526.3008	579.5351	2,641.3716
	40	4,812.617	529.7951	583.7749	2,651.4828
	50	4,827.738	533.3005	588.0338	2,661.6076
50	0	4,842.848	536.8168	592.3118	2,671.7460
	10	4,857.948	540.3441	596.6090	2,681.8983
	20	4,873.038	543.8824	600.9255	2,692.0644
	30	4,888.117	547.4316	605.2612	2,702.2444
	40	4,903.186	550.9919	609.6164	2,712.4383
	50	4,918.245	554.5630	613.9909	2,722.6463
51	0	4,933.293	558.1452	618.3850	2,732.8685
	10	4,948.331	561.7382	622.7985	2,743.1048
	20	4,963.359	565.3422	627.2317	2,753.3554
	30	4,978.375	568.9571	631.6845	2,763.6203
	40	4,993.382	572.5830	636.1571	2,773.8996
	50	5,008.378	576.2197	640.6494	2,784.1935

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
52	0	5,023.363	579.8674	645.1616	2,794.5019
	10	5,038.337	583.5259	649.6936	2,804.8249
	20	5,053.301	587.1953	654.2456	2,815.1626
	30	5,068.255	590.8756	658.8177	2,825.5151
	40	5,083.197	594.5668	663.4098	2,835.8825
	50	5,098.129	598.2688	668.0221	2,846.2648
53	0	5,113.050	601.9817	672.6546	2,856.6622
	10	5,127.960	605.7055	677.3074	2,867.0746
	20	5,142.859	609.4400	681.9805	2,877.5022
	30	5,157.748	613.1854	686.6740	2,887.9450
	40	5,172.625	616.9417	691.3880	2,898.4032
	50	5,187.492	620.7087	696.1225	2,908.8767
54	0	5,202.347	624.4866	700.8777	2,919.3658
	10	5,217.192	628.2752	705.6535	2,929.8703
	20	5,232.026	632.0747	710.4500	2,940.3906
	30	5,246.848	635.8849	715.2673	2,950.9265
	40	5,261.660	639.7059	720.1055	2,961.4783
	50	5,276.460	643.5377	724.9646	2,972.0459
55	0	5,291.249	647.3802	729.8448	2,982.6295
	10	5,306.027	651.2335	734.7459	2,993.2291
	20	5,320.793	655.0975	739.6683	3,003.8448
	30	5,335.549	658.9723	744.6118	3,014.4768
	40	5,350.293	662.8577	749.5766	3,025.1250
	50	5,365.026	666.7539	754.5628	3,035.7896
56	0	5,379.747	670.6608	759.5704	3,046.4706
	10	5,394.457	674.5785	764.5995	3,057.1682
	20	5,409.156	678.5068	769.6501	3,067.8824
	30	5,423.843	682.4458	774.7224	3,078.6133
	40	5,438.519	686.3954	779.8163	3,089.3609
	50	5,453.183	690.3558	784.9321	3,100.1255
57	0	5,467.836	694.3268	790.0697	3,110.9070
	10	5,482.477	698.3084	795.2292	3,121.7055
	20	5,497.107	702.3007	800.4107	3,132.5212
	30	5,511.725	706.3036	805.6143	3,143.3541
	40	5,526.331	710.3172	810.8401	3,154.2043
	50	5,540.926	714.3413	816.0880	3,165.0718
58	0	5,555.509	718.3761	821.3583	3,175.9569
	10	5,570.080	722.4215	826.6509	3,186.8595
	20	5,584.639	726.4775	831.9660	3,197.7798
	30	5,599.187	730.5440	837.3036	3,208.7178
	40	5,613.722	734.6212	842.6638	3,219.6737
	50	5,628.246	738.7088	848.0467	3,230.6474

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
59	0	5,642.758	742.8071	853.4523	3,241.6392
	10	5,657.258	746.9159	858.8808	3,252.6491
	20	5,671.746	751.0352	864.3323	3,263.6772
	30	5,686.222	755.1651	869.8067	3,274.7236
	40	5,700.686	759.3055	875.3042	3,285.7883
	50	5,715.138	763.4564	880.8248	3,296.8716
60	0	5,729.578	767.6178	886.3688	3,307.9734
	10	5,744.005	771.7898	891.9360	3,319.0938
	20	5,758.421	775.9722	897.5266	3,330.2330
	30	5,772.824	780.1650	903.1408	3,341.3911
	40	5,787.215	784.3684	908.7785	3,352.5681
	50	5,801.594	788.5822	914.4398	3,363.7641
61	0	5,815.961	792.8065	920.1249	3,374.9793
	10	5,830.315	797.0412	925.8339	3,386.2137
	20	5,844.657	801.2863	931.5667	3,397.4675
	30	5,858.987	805.5419	937.3236	3,408.7407
	40	5,873.304	809.8079	943.1045	3,420.0334
	50	5,887.609	814.0843	948.9096	3,431.3457
62	0	5,901.901	818.3710	954.7390	3,442.6777
	10	5,916.181	822.6682	960.5927	3,454.0296
	20	5,930.448	826.9758	966.4709	3,465.4014
	30	5,944.703	831.2937	972.3736	3,476.7932
	40	5,958.945	835.6220	978.3009	3,488.2052
	50	5,973.175	839.9606	984.2529	3,499.6374
63	0	5,987.392	844.3096	990.2297	3,511.0899
	10	6,001.596	848.6689	996.2314	3,522.5628
	20	6,015.788	853.0386	1,002.2581	3,534.0563
	30	6,029.967	857.4185	1,008.3099	3,545.5704
	40	6,044.133	861.8088	1,014.3868	3,557.1053
	50	6,058.286	866.2094	1,020.4890	3,568.6610
64	0	6,072.427	870.6202	1,026.6166	3,580.2376
	10	6,086.555	875.0414	1,032.7696	3,581.8354
	20	6,100.670	879.4728	1,038.9482	3,603.4543
	30	6,114.771	883.9144	1,045.1524	3,615.0944
	40	6,128.860	888.3663	1,051.3823	3,626.7560
	50	6,142.936	892.8285	1,057.6381	3,638.4391
65	0	6,157.000	897.3009	1,063.9198	3,650.1437
	10	6,171.050	901.7835	1,070.2276	3,661.8701
	20	6,185.086	906.2763	1,076.5615	3,673.6182
	30	6,199.110	910.7793	1,082.9216	3,685.3884
	40	6,213.121	915.2925	1,089.3081	3,697.1805
	50	6,227.119	919.8159	1,095.7210	3,708.9948

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
66	0	6,241.103	924.3495	1,102.1604	3,720.8314
	10	6,255.074	928.8933	1,108.6265	3,732.6904
	20	6,269.032	933.4471	1,115.1194	3,744.5718
	30	6,282.977	938.0112	1,121.6390	3,756.4759
	40	6,296.909	942.5854	1,128.1857	3,768.4027
	50	6,310.827	947.1697	1,134.7594	3,780.3523
67	0	6,324.732	951.7641	1,141.3602	3,792.3249
	10	6,338.623	956.3686	1,147.9883	3,804.3206
	20	6,352.501	960.9832	1,154.6438	3,816.3394
	30	6,366.365	965.6080	1,161.3268	3,828.3816
	40	6,380.217	970.2427	1,168.0374	3,840.4472
	50	6,394.054	974.8876	1,174.7757	3,852.5363
68	0	6,407.878	979.5425	1,181.5418	3,864.6491
	10	6,421.689	984.2075	1,188.3358	3,876.7857
	20	6,435.486	988.8825	1,195.1578	3,888.9462
	30	6,449.269	993.5675	1,202.0080	3,901.1308
	40	6,463.039	998.2626	1,208.8865	3,913.3395
	50	6,476.795	1,002.9676	1,215.7933	3,925.5724
69	0	6,490.537	1,007.6827	1,222.7286	3,937.8298
	10	6,504.265	1,012.4077	1,229.6925	3,950.1117
	20	6,517.980	1,017.1427	1,236.6852	3,962.4183
	30	6,531.681	1,021.8877	1,243.7066	3,974.7496
	40	6,545.369	1,026.6427	1,250.7570	3,987.1059
	50	6,559.042	1,031.4076	1,257.8365	3,999.4872
70	0	6,572.701	1,036.1824	1,264.9452	4,011.8937
	10	6,586.347	1,040.9672	1,272.0831	4,024.3254
	20	6,599.979	1,045.7619	1,279.2505	4,036.7826
	30	6,613.596	1,050.5665	1,286.4475	4,049.2653
	40	6,627.200	1,055.3810	1,293.6741	4,061.7738
	50	6,640.790	1,060.2053	1,300.9305	4,074.3080
71	0	6,654.365	1,065.0396	1,308.2168	4,086.8682
	10	6,667.927	1,069.8837	1,315.5331	4,099.4545
	20	6,681.474	1,074.7377	1,322.8797	4,112.0670
	30	6,695.008	1,079.6015	1,330.2565	4,124.7059
	40	6,708.527	1,084.4752	1,337.6637	4,137.3713
	50	6,722.032	1,089.3587	1,345.1014	4,150.0633
72	0	6,735.522	1,094.2520	1,352.5698	4,162.7820
	10	6,748.999	1,099.1551	1,360.0691	4,175.5277
	20	6,762.461	1,104.0680	1,367.5992	4,188.3004
	30	6,775.909	1,108.9907	1,375.1604	4,201.1004
	40	6,789.343	1,113.9232	1,382.7528	4,213.9276
	50	6,802.762	1,118.8654	1,390.3765	4,226.7823

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1◦ Long chord*	*M_1◦ Middle ordinate*	*E_1◦ External distance*	*T_1◦ Tangent distance*
73	0	6,816.167	1,123.8174	1,398.0317	4,239.6646
	10	6,829.557	1,128.7791	1,405.7185	4,252.5747
	20	6,842.933	1,133.7506	1,413.4370	4,265.5127
	30	6,856.294	1,138.7317	1,421.1873	4,278.4788
	40	6,869.641	1,143.7226	1,428.9696	4,291.4730
	50	6,882.974	1,148.7232	1,436.7841	4,304.4956
74	0	6,896.292	1,153.7335	1,444.6309	4,317.5467
	10	6,906.595	1,158.7535	1,452.5100	4,330.6264
	20	6,922.884	1,163.7831	1,460.4217	4,343.7349
	30	6,936.158	1,168.8224	1,468.3662	4,356.8723
	40	6,949.417	1,173.8713	1,476.3434	4,370.0388
	50	6,962.662	1,178.9299	1,484.3536	4,383.2346
75	0	6,975.892	1,183.9981	1,492.3970	4,396.4598
	10	6,989.107	1,189.0759	1,500.4736	4,409.7145
	20	7,002.307	1,194.1633	1,508.5836	4,422.9989
	30	7,015.493	1,199.2604	1,516.7272	4,436.3132
	40	7,028.664	1,204.3670	1,524.9045	4,449.6576
	50	7,041.819	1,209.4831	1,533.1156	4,463.0321
76	0	7,054.960	1,214.6089	1,541.3608	4,476.4369
	10	7,068.086	1,219.7442	1,549.6401	4,489.8722
	20	7,081.198	1,224.8890	1,557.9537	4,503.3382
	30	7,094.294	1,230.0433	1,566.3018	4,516.8350
	40	7,107.375	1,235.2072	1,574.6845	4,530.3628
	50	7,120.441	1,240.3806	1,583.1020	4,543.9218
77	0	7,133.492	1,245.5635	1,591.5544	4,557.5121
	10	7,146.528	1,250.7558	1,600.0419	4,571.1338
	20	7,159.549	1,255.9577	1,608.5647	4,584.7872
	30	7,172.554	1,261.1690	1,617.1228	4,598.4725
	40	7,185.545	1,266.3897	1,625.7165	4,612.1897
	50	7,198.520	1,271.6199	1,634.3459	4,625.9390
78	0	7,211.480	1,276.8595	1,643.0113	4,639.7207
	10	7,224.425	1,282.1086	1,651.7126	4,653.5349
	20	7,237.354	1,287.3670	1,660.4502	4,667.3818
	30	7,250.269	1,292.6349	1,669.2242	4,681.2615
	40	7,263.167	1,297.9121	1,678.0347	4,695.1743
	50	7,276.051	1,303.1987	1,686.8819	4,709.1202
79	0	7,288.919	1,308.4947	1,695.7660	4,723.0996
	10	7,301.772	1,313.8000	1,704.6072	4,737.1125
	20	7,314.609	1,319.1147	1,713.6455	4,751.1591
	30	7,327.431	1,324.4387	1,722.6413	4,765.2397
	40	7,340.237	1,329.7720	1,731.6747	4,779.3543
	50	7,353.028	1,335.1146	1,740.7458	4,793.5033

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
80	0	7,365.803	1,340.4666	1,749.8548	4,807.6867
	10	7,378.563	1,345.8278	1,759.0020	4,821.9048
	20	7,391.307	1,351.1982	1,768.1874	4,836.1578
	30	7,404.035	1,356.5780	1,777.4113	4,850.4458
	40	7,416.748	1,361.9670	1,786.6738	4,864.7690
	50	7,429.445	1,367.3652	1,795.9751	4,879.1276
81	0	7,442.126	1,372.7727	1,805.3155	4,893.5219
	10	7,454.792	1,378.1893	1,814.6950	4,907.9519
	20	7,467.441	1,383.6152	1,824.1140	4,922.4180
	30	7,480.075	1,389.0503	1,833.5725	4,936.9202
	40	7,492.694	1,394.4945	1,843.0707	4,951.4589
	50	7,505.296	1,399.9480	1,852.6089	4,966.0341
82	0	7,517.882	1,402.4105	1,862.1872	4,980.6461
	10	7,530.453	1,410.8823	1,871.8059	4,995.2951
	20	7,543.007	1,416.3631	1,881.4651	5,009.9814
	30	7,555.546	1,421.8531	1,891.1650	5,024.7050
	40	7,568.069	1,427.3522	1,900.9058	5,039.4662
	50	7,580.575	1,432.8604	1,910.6878	5,054.2653
83	0	7,593.066	1,438.3777	1,920.5111	5,069.1024
	10	7,605.541	1,443.9041	1,930.3758	5,083.9777
	20	7,617.999	1,449.4395	1,940.2823	5,098.8914
	30	7,630.441	1,454.9840	1,950.2308	5,113.8438
	40	7,642.868	1,460.5376	1,960.2213	5,128.8351
	50	7,655.278	1,466.1001	1,970.2542	5,143.8655
84	0	7,667.672	1,471.6717	1,980.3296	5,158.9352
	10	7,680.049	1,477.2523	1,990.4478	5,174.0443
	20	7,692.441	1,481.8419	2,000.6090	5,189.1933
	30	7,704.756	1,488.4405	2,010.8133	5,204.3822
	40	7,717.084	1,494.0480	2,021.0610	5,219.6113
	50	7,729.397	1,499.6645	2,031.3524	5,234.8808
85	0	7,741.693	1,505.2899	2,041.6875	5,250.1909
	10	7,753.973	1,510.9243	2,052.0668	5,265.5419
	20	7,766.236	1,516.5676	2,062.4902	5,280.9340
	30	7,778.483	1,522.2199	2,072.9582	5,296.3674
	40	7,790.714	1,527.8810	2,083.4709	5,311.8423
	50	7,802.928	1,533.5510	2,094.0285	5,327.3591
86	0	7,815.125	1,539.2299	2,104.6313	5,342.9179
	10	7,827.306	1,544.9176	2,115.2795	5,358.5189
	20	7,839.470	1,550.6142	2,125.9733	5,374.1625
	30	7,851.618	1,556.3197	2,136.7129	5,389.8487
	40	7,863.749	1,562.0339	2,147.4987	5,405.5780
	50	7,875.864	1,567.7570	2,158.3308	5,421.3505

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
87	0	7,887.962	1,573.4889	2,169.2094	5,437.1665
	10	7,900.043	1,579.2296	2,180.1349	5,453.0261
	20	7,912.108	1,584.9791	2,191.1074	5,468.9298
	30	7,924.155	1,590.7373	2,202.1272	5,484.8777
	40	7,936.186	1,596.5043	2,213.1945	5,500.8700
	50	7,948.201	1,602.2800	2,224.3096	5,516.9071
88	0	7,960.198	1,608.0645	2,235.4727	5,532.9891
	10	7,972.179	1,613.8576	2,246.6841	5,549.1164
	20	7,984.142	1,619.6595	2,257.9440	5,565.2892
	30	7,996.089	1,625.4701	2,269.2527	5,581.5077
	40	8,008.019	1,631.2894	2,280.6104	5,597.7723
	50	8,019.932	1,637.1173	2,292.0174	5,614.0832
89	0	8,031.828	1,642.9539	2,303.4740	5,630.4406
	10	8,043.707	1,648.7991	2,314.9804	5,646.8448
	20	8,055.569	1,654.6530	2,326.5369	5,663.2961
	30	8,067.414	1,660.5154	2,338.1437	5,679.7949
	40	8,079.242	1,666.3865	2,349.8011	5,696.3412
	50	8,091.053	1,672.2662	2,361.5094	5,712.9355
90	0	8,102.846	1,678.1545	2,373.2689	5,729.5780
	10	8,114.623	1,684.0513	2,385.0797	5,746.2689
	20	8,126.382	1,689.9567	2,396.9423	5,763.0086
	30	8,138.125	1,695.8707	2,408.8568	5,779.7974
	40	8,149.849	1,701.7931	2,420.8236	5,796.6355
	50	8,161.557	1,707.7241	2,432.8430	5,813.5232
91	0	8,173.248	1,713.6636	2,444.9151	5,830.4609
	10	8,184.921	1,719.6116	2,457.0404	5,847.4487
	20	8,196.577	1,725.5681	2,469.2190	5,864.4871
	30	8,208.215	1,731.5331	2,481.4514	5,881.5763
	40	8,219.836	1,737.5065	2,493.7377	5,898.7166
	50	8,231.440	1,743.4883	2,506.0783	5,915.9083
92	0	8,243.026	1,749.4786	2,518.4734	5,933.1517
	10	8,254.595	1,755.4773	2,530.9235	5,950.4471
	20	8,266.147	1,761.4845	2,543.4286	5,967.7948
	30	8,277.681	1,767.5000	2,555.9893	5,985.1952
	40	8,289.197	1,773.5238	2,568.6057	6,002.6486
	50	8,300.696	1,779.5561	2,581.2783	6,020.1552
93	0	8,312.178	1,785.5967	2,594.0072	6,037.7154
	10	8,323.641	1,791.6457	2,606.7929	6,055.3295
	20	8,335.088	1,797.7030	2,619.6355	6,072.9978
	30	8,346.516	1,803.7686	2,632.5355	6,090.7207
	40	8,357.927	1,809.8425	2,645.4932	6,108.4985
	50	8,369.320	1,815.9247	2,658.5089	6,126.3316

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1◦ Long chord*	*M_1◦ Middle ordinate*	*E_1◦ External distance*	*T_1◦ Tangent distance*
94	0	8,380.696	1,822.0152	2,671.5829	6,144.2201
	10	8,392.053	1,828.1139	2,684.7156	6,162.1646
	20	8,403.393	1,834.2209	2,697.9072	6,180.1653
	30	8,414.716	1,840.3361	2,711.1581	6,198.2225
	40	8,426.020	1,846.4596	2,724.4687	6,216.3367
	50	8,437.307	1,852.5913	2,737.8393	6,234.5081
95	0	8,448.576	1,858.7312	2,751.2702	6,252.7371
	10	8,459.826	1,864.8792	2,764.7617	6,271.0241
	20	8,471.059	1,871.0355	2,778.3143	6,289.3694
	30	8,482.274	1,877.1999	2,791.9283	6,307.7734
	40	8,493.472	1,883.3724	2,805.6040	6,326.2364
	50	8,504.651	1,889.5531	2,819.3417	6,344.7588
96	0	8,515.812	1,895.7419	2,833.1419	6,363.3410
	10	8,526.955	1,901.9389	2,847.0049	6,381.9833
	20	8,538.080	1,908.1439	2,860.9311	6,400.6861
	30	8,549.187	1,914.3570	2,874.9208	6,419.4497
	40	8,560.276	1,920.5782	2,888.9743	6,438.2747
	50	8,571.347	1,926.8074	2,903.0922	6,457.1612
97	0	8,582.400	1,933.0447	2,917.2747	6,476.1098
	10	8,593.435	1,939.2900	2,931.5223	6,495.1208
	20	8,604.451	1,945.5433	2,945.8352	6,514.1945
	30	8,615.449	1,951.8047	2,960.2140	6,433.3315
	40	8,626.429	1,958.0740	2,974.6589	6,552.5320
	50	8,637.391	1,964.3513	2,989.1704	6,571.7966
98	0	8,648.334	1,970.6366	3,003.7489	6,591.1255
	10	8,659.259	1,976.9298	3,018.3948	6,610.5192
	20	8,670.166	1,983.2309	3,033.1084	6,629.9780
	30	8,681.055	1,989.5400	3,047.8902	6,649.5025
	40	8,691.925	1,995.8570	3,062.7406	6,669.0931
	50	8,702.777	2,002.1819	3,077.6600	6,688.7500
99	0	8,713.610	2,008.5147	3,092.6488	6,708.4739
	10	8,724.425	2,014.8554	3,107.7074	6,728.2650
	20	8,735.221	2,021.2039	3,122.8363	6,748.1238
	30	8,745.999	2,027.5602	3,138.0359	6,768.0508
	40	8,756.759	2,033.9244	3,153.3066	6,788.0464
	50	8,767.500	2,040.2964	3,168.6488	6,808.1110
100	0	8,778.222	2,046.6762	3,184.0630	6,828.2451
	10	8,788.926	2,053.0638	3,199.5496	6,848.4491
	20	8,799.611	2,059.4592	3,215.1090	6,868.7235
	30	8,810.278	2,065.8623	3,230.7418	6,889.0687
	40	8,820.926	2,072.2732	3,246.4484	6,909.4852
	50	8,831.555	2,078.6918	3,262.2291	6,929.9734

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
101	0	8,842.166	2,085.1182	3,278.0846	6,950.5339
	10	8,852.758	2,091.5522	3,294.0151	6,971.1670
	20	8,863.331	2,097.9940	3,310.0213	6,991.8733
	30	8,873.886	2,104.4434	3,326.1035	7,012.6532
	40	8,884.421	2,110.9005	3,342.2623	7,033.5072
	50	8,894.938	2,117.3653	3,358.4982	7,054.4358
102	0	8,905.436	2,123.8377	3,374.8115	7,075.4395
	10	8,915.916	2,130.3177	3,391.2029	7,096.5188
	20	8,926.376	2,136.8054	3,407.6727	7,117.6742
	30	8,936.817	2,143.3006	3,424.2215	7,138.9062
	40	8,947.240	2,149.8034	3,440.8498	7,160.2152
	50	8,957.644	2,156.3138	3,457.5581	7,181.6019
103	0	8,968.028	2,162.8318	3,474.3469	7,203.0667
	10	8,978.394	2,169.3573	3,491.2167	7,224.6101
	20	8,988.741	2,175.8903	3,508.1681	7,246.2327
	30	8,999.069	2,182.4309	3,525.2015	7,267.9350
	40	9,009.377	2,188.9789	3,542.3174	7,289.7175
	50	9,019.667	2,195.5345	3,559.5165	7,311.5808
104	0	9,029.938	2,202.0975	3,576.7993	7,333.5254
	10	9,040.189	2,208.6680	3,594.1662	7,355.5518
	20	9,050.421	2,215.2459	3,611.6179	7,377.6607
	30	9,060.635	2,221.8313	3,629.1548	7,399.8525
	40	9,070.829	2,228.4241	3,646.7777	7,422.1278
	50	9,081.004	2,235.0243	3,664.4869	7,444.4873
105	0	9,091.159	2,241.6319	3,682.2830	7,466.9314
	10	9,101.296	2,248.2468	3,700.1667	7,489.4607
	20	9,111.413	2,254.8692	3,718.1386	7,512.0759
	30	9,121.511	2,261.4988	3,736.1991	7,534.7775
	40	9,131.589	2,268.1358	3,754.3489	7,557.5661
	50	9,141.648	2,274.7802	3,772.5886	7,580.4423
106	0	9,151.688	2,281.4318	3,790.9187	7,603.4068
	10	9,161.709	2,288.0908	3,809.3400	7,626.4600
	20	9,171.710	2,294.7570	3,827.8529	7,649.6027
	30	9,181.692	2,301.4305	3,846.4581	7,672.8354
	40	9,191.654	2,308.1112	3,865.1562	7,696.1588
	50	9,201.597	2,314.7992	3,883.9479	7,719.5736
107	0	9,211.521	2,321.4944	3,902.8337	7,743.0802
	10	9,221.425	2,328.1968	3,921.8143	7,766.6795
	20	9,231.309	2,334.9064	3,940.8904	7,790.3720
	30	9,241.174	2,341.6232	3,960.0626	7,814.1584
	40	9,251.019	2,348.3472	3,979.3315	7,838.0393
	50	9,260.845	2,355.0783	3,998.6979	7,862.0155

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1◦ Long chord*	*M_1◦ Middle ordinate*	*E_1◦ External distance*	*T_1◦ Tangent distance*
108	0	9,270.651	2,361.8165	4,018.1623	7,886.0875
	10	9,280.438	2,368.5619	4,037.7254	7,910.2561
	20	9,290.205	2,375.3143	4,057.3880	7,934.5220
	30	9,299.952	2,382.0739	4,077.1507	7,958.8859
	40	9,309.680	2,388.8406	4,097.0142	7,983.3483
	50	9,319.388	2,395.6143	4,116.9792	8,007.9102
109	0	9,329.076	2,402.3951	4,137.0464	8,032.5721
	10	9,338.745	2,409.1829	4,157.2166	8,057.3347
	20	9,348.393	2,415.9777	4,177.4903	8,082.1989
	30	9,358.022	2,422.7796	4,197.8685	8,107.1653
	40	9,367.632	2,429.5884	4,218.3517	8,132.2347
	50	9,377.221	2,436.4042	4,238.9407	8,157.4078
110	0	9,386.791	2,443.2270	4,259.6364	8,182.6854
	10	9,396.340	2,450.0568	4,280.4393	8,208.0681
	20	9,405.870	2,456.8934	4,301.3504	8,233.5569
	30	9,415.380	2,463.7370	4,322.3703	8,259.1525
	40	9,424.870	2,470.5875	4,343.4998	8,284.8556
	50	9,434.340	2,477.4450	4,364.7398	8,310.6671
111	0	9,443.790	2,484.3092	4,386.0909	8,336.5877
	10	9,453.220	2,491.1804	4,407.5541	8,362.6182
	20	9,462.630	2,498.0584	4,429.1301	8,388.7595
	30	9,472.020	2,504.9432	4,450.8197	8,415.0123
	40	9,481.390	2,511.8349	4,472.6237	8,441.3776
	50	9,490.740	2,518.7333	4,494.5430	8,467.8561
112	0	9,500.070	2,525.6386	4,516.5784	8,494.4487
	10	9,509.380	2,532.5506	4,538.7308	8,521.1562
	20	9,518.670	2,539.4694	4,561.0010	8,547.9795
	30	9,527.939	2,546.3950	4,583.3899	8,574.9194
	40	9,537.189	2,553.3272	4,605.8983	8,601.9769
	50	9,546.418	2,560.2662	4,628.5271	8,629.1528
113	0	9,555.627	2,567.2119	4,651.2773	8,656.4480
	10	9,564.816	2,574.1643	4,674.1497	8,683.8635
	20	9,573.985	2,581.1234	4,697.1451	8,711.4001
	30	9,583.133	2,588.0891	4,720.2646	8,739.0587
	40	9,592.261	2,595.0615	4,743.5091	8,766.8404
	50	9,601.369	2,602.0405	4,766.8795	8,794.7459
114	0	9,610.456	2,609.0261	4,790.3767	8,822.7764
	10	9,619.524	2,616.0183	4,814.0017	8,850.9327
	20	9,628.570	2,623.0171	4,837.7554	8,879.2157
	30	9,637.597	2,630.0225	4,861.6389	8,907.6266
	40	9,646.603	2,637.0345	4,885.6531	8,936.1663
	50	9,655.588	2,644.0529	4,909.7990	8,964.8357

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
115	0	9,664.554	2,651.0779	4,934.0776	8,993.6359
	10	9,673.498	2,658.1095	4,958.4899	9,022.5679
	20	9,682.423	2,665.1475	4,983.0370	9,051.6328
	30	9,691.327	2,672.1920	5,007.7198	9,080.8315
	40	9,700.210	2,679.2429	5,032.5395	9,110.1651
	50	9,709.073	2,686.3003	5,057.4970	9,139.6348
116	0	9,717.915	2,693.3642	5,082.5935	9,169.2415
	10	9,726.737	2,700.4345	5,107.8300	9,198.9863
	20	9,735.538	2,707.5112	5,133.2077	9,228.8704
	30	9,744.318	2,714.5942	5,158.7275	9,258.8948
	40	9,753.078	2,721.6837	5,184.3907	9,289.0607
	50	9,761.818	2,728.7795	5,210.1984	9,319.3692
117	0	9,770.536	2,735.8817	5,236.1516	9,349.8215
	10	9,779.234	2,742.9902	5,262.2516	9,380.4186
	20	9,787.911	2,750.1050	5,288.4995	9,411.1618
	30	9,796.568	2,757.2261	5,314.8964	9,442.0523
	40	9,805.204	2,764.3535	5,341.4436	9,473.0912
	50	9,813.819	2,771.4872	5,368.1423	9,504.2797
118	0	9,822.413	2,778.6271	5,394.9937	9,535.6191
	10	9,830.987	2,785.7733	5,421.9989	9,567.1105
	20	9,839.540	2,792.9257	5,449.1593	9,598.7553
	30	9,848.072	2,800.0843	5,476.4761	9,630.5547
	40	9,856.583	2,807.2491	5,503.9505	9,662.5100
	50	9,865.073	2,814.4201	5,531.5839	9,694.6224
119	0	9,873.542	2,821.5973	5,559.3775	9,726.8932
	10	9,881.991	2,828.7806	5,587.3326	9,759.3238
	20	9,890.419	2,835.9701	5,615.4506	9,791.9155
	30	9,898.825	2,843.1657	5,643.7327	9,824.6696
	40	9,907.211	2,850.3673	5,672.1804	9,857.5875
	50	9,915.576	2,857.5751	5,700.7950	9,890.6706
120	0	9,923.920	2,864.7890	5,729.5780	9,923.9202
	10	9,932.243	2,872.0089	5,758.5305	9,957.3377
	20	9,940.544	2,879.2348	5,787.6542	9,990.9246
	30	9,948.825	2,886.4668	5,816.9504	10,024.6823
	40	9,957.085	2,893.7048	5,846.4206	10,058.6123
	50	9,965.324	2,900.9488	5,876.0663	10,092.7159
121	0	9,973.541	2,908.1988	5,905.8888	10,126.9948
	10	9,981.738	2,915.4547	5,935.8897	10,161.4503
	20	9,989.913	2,922.7166	5,966.0706	10,196.0841
	30	9,998.067	2,929.9844	5,996.4328	10,230.8976
	40	10,006.200	2,937.2582	6,026.9781	10,265.8925
	50	10,014.312	2,944.5379	6,057.7079	10,301.0701

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1◦ Long chord*	*M_1◦ Middle ordinate*	*E_1◦ External distance*	*T_1◦ Tangent distance*
122	0	10,022.403	2,951.8234	6,088.6239	10,336.4323
	10	10,030.473	2,959.1148	6,119.7276	10,371.9805
	20	10,038.521	2,966.4121	6,151.0206	10,407.7164
	30	10,046.548	2,973.7153	6,182.5047	10,443.6416
	40	10,054.554	2,981.0243	6,214.1813	10,479.7578
	50	10,062.539	2,988.3390	6,246.0523	10,516.0667
123	0	10,070.502	2,995.6596	6,278.1193	10,552.5699
	10	10,078.444	3,002.9860	6,310.3841	10,589.2692
	20	10,086.365	3,010.3181	6,342.8483	10,626.1664
	30	10,094.264	3,017.6560	6,375.5137	10,663.2632
	40	10,102.142	3,024.9996	6,408.3821	10,700.5613
	50	10,109.998	3,032.3490	6,441.4553	10,738.0626
124	0	10,117.834	3,039.7040	6,474.7352	10,775.7689
	10	10,125.648	3,047.0648	6,508.2235	10,813.6821
	20	10,133.440	3,054.4312	6,541.9221	10,851.8040
	30	10,141.211	3,061.8032	6,575.8329	10,890.1365
	40	10,148.960	3,069.1810	6,609.9578	10,928.6815
	50	10,156.688	3,076.5643	6,644.2987	10,967.4410
125	0	10,164.395	3,083.9533	6,678.8577	11,006.4169
	10	10,172.080	3,091.3478	6,713.6366	11,045.6112
	20	10,179.744	3,098.7479	6,748.6375	11,085.0259
	30	10,187.386	3,106.1536	6,783.8625	11,124.6631
	40	10,195.006	3,113.5649	6,819.3134	11,164.5247
	50	10,202.605	3,120.9817	6,854.9926	11,204.6130
126	0	10,210.182	3,128.4040	6,890.9019	11,244.9299
	10	10,217.738	3,135.8318	6,927.0436	11,285.4777
	20	10,225.272	3,143.2651	6,963.4199	11,326.2585
	30	10,232.785	3,150.7038	7,000.0328	11,367.2744
	40	10,240.275	3,158.1480	7,036.8847	11,408.5277
	50	10,247.744	3,165.5977	7,073.9777	11,450.0207
127	0	10,255.192	3,173.0528	7,111.3141	11,491.7556
	10	10,262.618	3,180.5133	7,148.8963	11,533.7347
	20	10,270.022	3,187.9791	7,186.7264	11,575.9603
	30	10,277.404	3,195.4504	7,224.8070	11,618.4348
	40	10,284.765	3,202.9270	7,263.1404	11,661.1606
	50	10,292.104	3,210.4090	7,301.7289	11,704.1401
128	0	10,299.421	3,217.8963	7,340.5750	11,747.3757
	10	10,306.716	3,225.3889	7,379.6813	11,790.8700
	20	10,313.989	3,232.8868	7,419.0502	11,834.6254
	30	10,321.241	3,240.3900	7,458.6842	11,878.6446
	40	10,328.471	3,247.8984	7,498.5860	11,922.9300
	50	10,335.679	3,255.4121	7,538.7581	11,967.4842

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1° Long chord*	*M_1° Middle ordinate*	*E_1° External distance*	*T_1° Tangent distance*
129	0	10,342.865	3,262.9310	7,579.2032	12,012.3100
	10	10,350.029	3,270.4552	7,619.9239	12,057.4100
	20	10,357.172	3,277.9845	7,660.9230	12,102.7870
	30	10,364.292	3,285.5191	7,702.2032	12,148.4436
	40	10,371.391	3,293.0588	7,743.7673	12,194.3827
	50	10,378.467	3,300.6037	7,785.6181	12,240.6071
130	0	10,385.522	3,308.1537	7,827.7585	12,287.1196
	10	10,392.554	3,315.7088	7,870.1913	12,333.9232
	20	10,399.565	3,323.2690	7,912.9196	12,381.0208
	30	10,406.554	3,330.8343	7,955.9462	12,428.4154
	40	10,413.520	3,338.4047	7,999.2743	12,476.1100
	50	10,420.465	3,345.9802	8,042.9067	12,524.1076
131	0	10,427.388	3,353.5607	8,086.8467	12,572.4114
	10	10,434.288	3,361.1462	8,131.0975	12,621.0245
	20	10,441.167	3,368.7367	8,175.6620	12,669.9501
	30	10,448.023	3,376.3322	8,220.5437	12,719.1915
	40	10,454.857	3,383.9328	8,265.7457	12,768.7518
	50	10,461.669	3,391.5382	8,311.2715	12,818.6345
132	0	10,468.459	3,399.1486	8,357.1242	12,868.8428
	10	10,475.227	3,406.7640	8,403.3075	12,919.3803
	20	10,481.973	3,414.3842	8,449.8246	12,970.2504
	30	10,488.697	3,422.0094	8,496.6792	13,021.4565
	40	10,495.398	3,429.6394	8,543.8747	13,073.0023
	50	10,502.077	3,437.2743	8,591.4148	13,124.8913
133	0	10,508.734	3,444.9141	8,639.3032	13,177.1272
	10	10,515.369	3,452.5586	8,687.5434	13,229.7138
	20	10,521.981	3,460.2080	8,736.1394	13,282.6548
	30	10,528.571	3,467.8622	8,785.0950	13,335.9539
	40	10,535.139	3,475.5212	8,834.4139	13,389.6152
	50	10,541.685	3,483.1850	8,884.1001	13,443.6425
134	0	10,548.208	3,490.8535	8,934.1577	13,498.0398
	10	10,554.709	3,498.5267	8,984.5905	13,552.8112
	20	10,561.188	3,506.2047	9,035.4029	13,607.9608
	30	10,567.644	3,513.8873	9,086.5988	13,663.4926
	40	10,574.078	3,521.5747	9,138.1826	13,719.4111
	50	10,580.490	3,529.2667	9,190.1585	13,775.7204
135	0	10,586.879	3,536.9634	9,242.5308	13,832.4249
	10	10,593.246	3,544.6647	9,295.3040	13,889.5290
	20	10,599.590	3,552.3706	9,348.4826	13,947.0372
	30	10,605.913	3,560.0812	9,402.0710	14,004.9541
	40	10,612.212	3,567.7963	9,456.0740	14,063.2842
	50	10,618.489	3,575.5160	9,510.4962	14,122.0323

Table E-1. Functions of a 1-degree curve (continued)

Degrees	*Minutes*	*C_1 ◦ Long chord*	*M_1 ◦ Middle ordinate*	*E_1 ◦ External distance*	*T_1 ◦ Tangent distance*
136	0	10,624.744	3,583.2403	9,565.3423	14,181.2031
	10	10,630.976	3,590.9691	9,620.6172	14,240.8015
	20	10,637.186	3,598.7024	9,676.3257	14,300.8324
	30	10,643.373	3,606.4402	9,732.4730	14,361.3006
	40	10,649.538	3,614.1825	9,789.0639	14,422.2114
	50	10,655.680	3,621.9293	9,846.1036	14,483.5698
137	0	10,661.800	3,629.6806	9,903.5975	14,545.3811
	10	10,667.897	3,637.4363	9,961.5506	14,607.6505
	20	10,673.971	3,645.1964	10,019.9685	14,670.3834
	30	10,680.023	3,652.9609	10,078.8565	14,733.5853
	40	10,686.052	3,660.7299	10,138.2202	14,797.2618
	50	10,692.059	3,668.5032	10,198.0653	14,861.4184
138	0	10,698.043	3,676.2808	10,258.3975	14,926.0609
	10	10,704.005	3,684.0628	10,319.2225	14,991.1952
	20	10,709.944	3,691.8492	10,380.5463	15,056.8271
	30	10,715.860	3,699.6398	10,442.3749	15,122.9626
	40	10,721.753	3,707.4348	10,504.7144	15,189.6078
	50	10,727.624	3,715.2340	10,567.5710	15,256.7690
139	0	10,733.472	3,723.0374	10,630.9509	15,324.4524
	10	10,739.298	3,730.8452	10,694.8606	15,392.6645
	20	10,745.100	3,738.6571	10,759.3066	15,461.4117
	30	10,750.880	3,746.4733	10,824.2955	15,530.7007
	40	10,756.638	3,754.2936	10,889.8340	15,600.5382
	50	10,762.372	3,762.1182	10,955.9290	15,670.9310
140	0	10,768.084	3,769.9469	11,022.5873	15,741.8861
	10	10,773.773	3,777.7797	11,089.8161	15,813.4106
	20	10,779.439	3,785.6167	11,157.6226	15,885.5116
	30	10,785.082	3,793.4578	11,226.0140	15,958.1965
	40	10,790.703	3,801.3029	11,294.9977	16,031.4726
	50	10,796.301	3,809.1522	11,364.5814	16,105.3476
141	0	10,801.875	3,817.0055	11,434.7727	16,179.8291

Table E-2. Corrections for tangents and externals

For tangents, add—						
Angle in degrees	***5° curve***	***10° curve***	***15° curve***	***20° curve***	***25° curve***	***30° curve***
10	0.03	0.06	0.09	0.13	0.16	0.19
20	0.06	0.13	0.19	0.26	0.32	0.39
30	0.10	0.19	0.29	0.39	0.49	0.59
40	0.13	0.26	0.40	0.53	0.67	0.80
50	0.17	0.34	0.51	0.68	0.85	1.02
60	0.21	0.42	0.63	0.84	1.05	1.27
70	0.25	0.51	0.76	1.02	1.28	1.54
80	0.30	0.61	0.91	1.22	1.53	1.84
90	0.36	0.72	1.09	1.45	1.83	2.20
100	0.43	0.86	1.30	1.74	2.18	2.62
110	0.51	1.03	1.56	2.08	2.61	3.14
120	0.62	1.25	1.93	2.52	3.16	3.81
For externals, add—						
Angle in degrees	***5° curve***	***10° curve***	***15° curve***	***20° curve***	***25° curve***	***30° curve***
10	0.001	0.003	0.004	0.006	0.007	0.008
20	0.006	0.011	0.017	0.022	0.028	0.034
30	0.013	0.025	0.038	0.051	0.065	0.078
40	0.023	0.046	0.070	0.093	0.117	0.141
50	0.037	0.075	0.116	0.151	0.189	0.227
60	0.056	0.112	0.168	0.225	0.283	0.340
70	0.080	0.159	0.240	0.321	0.403	0.485
80	0.110	0.220	0.332	0.445	0.558	0.671
90	0.149	0.299	0.450	0.603	0.756	0.910
100	0.200	0.401	0.604	0.809	1.015	1.221
110	0.268	0.536	0.806	1.082	1.355	1.633
120	0.380	0.721	1.086	1.456	1.825	2.197

Appendix F

Frost Design for Roads

In areas where frost effects have an impact on the design of roads, additional considerations concerning thickness and required layers in the road structure must be addressed. Specific areas where frost has an impact on the design are discussed in the following paragraphs. A more detailed discussion of frost effects is presented in TM 5-852-2/AFR 88-19, Volume 2, and in CRREL Special Report 83-27.

DETERMINING FROST POTENTIAL

F-1. Frost action is a general term describing the freezing and thawing of moisture in materials and the resulting effects on these materials and on the structures of which they are a part. The term cold region applies to areas where the mean monthly temperature of at least one month per year is less than 34 degrees Fahrenheit. This determination may be made using local climatological data summary from a first order weather station. Worldwide climate data may be obtained from the climatic database World Index (version 99.1), available from PCASE, a computer software program developed and distributed by the Corps of Engineers containing criteria for the design and evaluation of transportation systems.

F-2. Summary temperature data may be acquired from the Air Force Combat Climatology Center, operated by the 14th Weather Squadron, which compiles and provides meteorological data in support of Department of Defense applications. Air Force Combat Climatology Center compiles data on thousands of worldwide stations, including Operational Climatic Data Summaries containing average monthly temperatures.

F-3. For frost-design purposes, soils have been divided into eight groups as shown in table F-1, page F-2. Soils in the first four groups (NFS, PFS, S1, and S2) are generally suitable for base course and subbase course materials. Any of the eight soil groups may be encountered as subgrade soil. Soils are listed in the approximate order of decreasing bearing capability during periods of thaw.

REQUIRED THICKNESS

F-4. Where frost-susceptible subgrades are encountered, the section thickness required will be determined according to the reduced-subgrade-strength method. The reduced-subgrade-strength method requires the use of frost-area soil-support indexes listed in table F-2, page F-3, and strength curves shown in figure F-1, page F-3. The required thickness is determined by comparing the natural subgrade CBR to the frost-area soil-support index associated to the relevant frost group. If the natural subgrade CBR is less than the frost-area soil-support index, then the CBR value governs the design and the thickness is determined from figure F-2, page F-4. If the natural subgrade CBR is greater than the soil-support index, then figure F-1 is used. The required thickness is determined by entering figure F-1 at the correct design index, moving horizontally to intersect the relevant frost-group curve, and then moving vertically downward to determine the design thickness in inches.

REQUIRED LAYERS IN A ROAD SECTION

F-5. When frost is a consideration, the road section should consist of a series of layers that will ensure the stability of the system, particularly during thaw periods. The layered system in the aggregate fill may consist of a wearing surface of fine-crushed stone, overlying a base coarse of coarse-graded crushed rock, overlying a subbase of well-graded sand composed of soils from frost groups S1 and S2, or a geotextile.

F-6. To ensure the stability of the wearing surface, the width of the base course and subbase should exceed the final desired surface width by a minimum of 1 foot on each side.

Table F-1. Frost-design soil classification

Frost group	*Type of soil*	*% by weight < 0.02 mm*	*Typical soil types under the USCS*	*Material suitability*
NFS**	(a) Gravels Crushed stone Crushed rock (b) Sands	0 – 1.5 0-3	GW, GP SW, SP	
PFS‡	(a) Gravels Crushed stone Crushed rock (b) Sands	1.5 – 3 3 – 10	GW, GP SW, SP	
S1	Gravelly soils	3 – 6	GW, GP, GW-GM, GP-GM	
S2	Sandy soils	3 – 6	SW, SP, SW-SM, SP-SM	
F1	Gravelly soils	6 – 10	GM, GW-GM, GP-GM	
F2	(a) Gravelly soils (b) Sands	10 – 20 6 – 15	GM, GW-GM, GP-GM SM, SW-SM, SP-SM	
F3	(a) Gravelly soils (b) Sands, except very fine, silty sands (c) Clays (PI > 12)	> 20 > 15 ----	GM, GC SM, SC CL, CH	
F4	(a) All silts (b) Very fine, silty sands (c) Clays (PI < 12) (d) Varved clays and other fine-grained, banded sediments	---- > 15 ---- ----	ML, MH SM CL, CL – ML CL, ML CL, ML, SM CL, CH, ML CL, CH, ML, SM	

** Nonfrost susceptible

‡ Possibly frost-susceptible; laboratory testing required to determine frost design soil classification

Legend:

CH	clay high plasticity	mm	millimeter
CL	clay low plasticity	NFS	nonfrost susceptible
GC	clayey gravels, gravel-sand-clay mixture	PFS	partially frost susceptible
GM	silty gravels, gravel-sand-silt mixtures	PI	plasticity index
GP	gravel poorly graded, gravel-sand-mixtures, little or no fines	SC	clayey sand, sand-clay mixture
		SM	silty sands, sand-silt mixture
		SP	poorly graded sands, gravelly sands, little or no fines
GW	gravel well-graded, gravel-sand mixtures, little or no fines	SW	well-graded sand, gravelly sands, little or no fines
MH	silt high plasticity		
ML	silt low plasticity	USCS	United Soil Classification System

Table F-2. Frost-area soil-support indexes of subgrade soils

Frost group of subgrade soils	*Frost-area soil-support index*
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

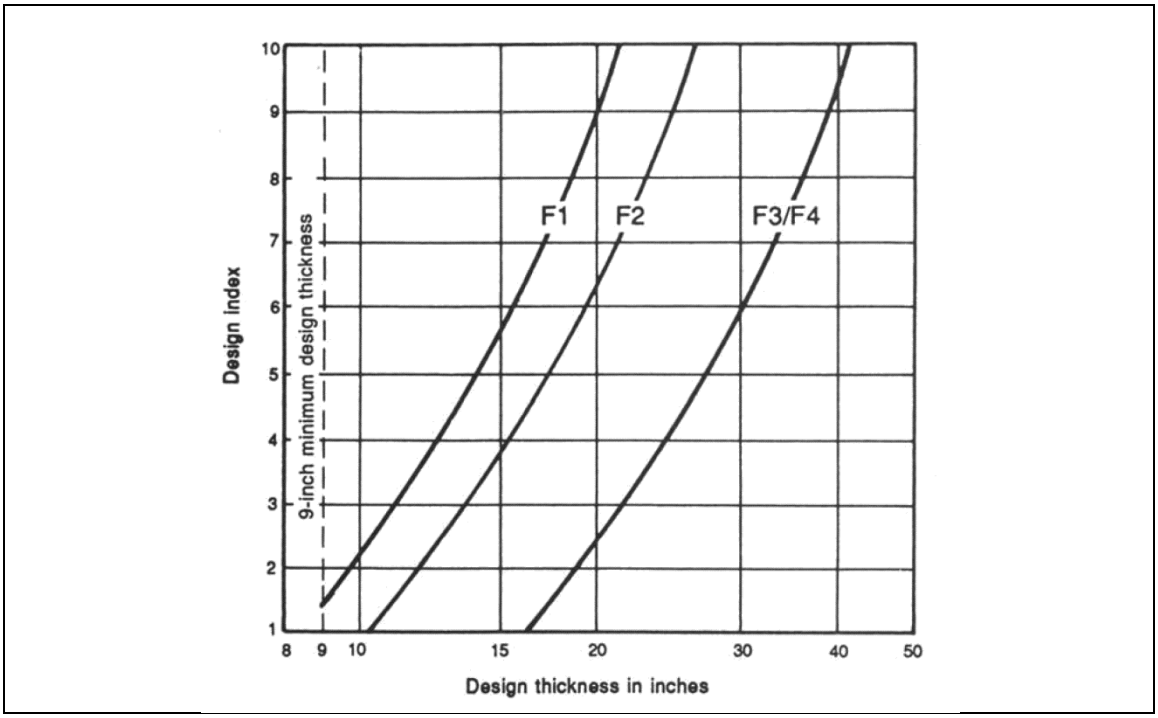
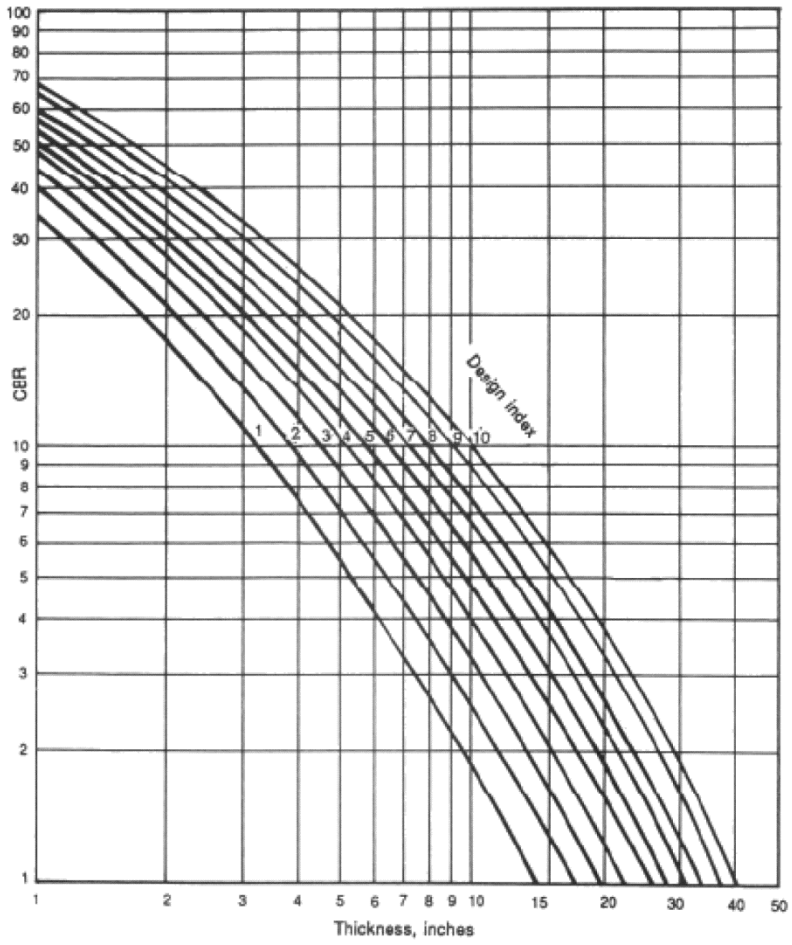


Figure F-1. Frost-design reduced-subgrade-strength curves



Legend:
CBR California Bearing Ratio

Figure F-2. Design curves for aggregate-surfaced roads

WEARING SURFACE

F-7. The wearing surface contains fines to provide stability in the aggregate surface. The presence of fines helps with layer compaction characteristics and helps to provide a relatively smooth riding surface. Its thickness will vary between 4 and 6 inches.

BASE COURSE

F-8. The coarse-graded base course is important in providing drainage of the granular fill. It is also important that this material be NFS so that it retains its strength during spring thaw.

SUBBASE

F-9. The well-graded sand subbase is used for additional bearing capacity over the frost-susceptible subgrade and as a filter layer between the coarse-graded base course and the subgrade. This process prevents the migration of the subgrade into the voids in the coarser material during periods of reduced subgrade strength. The material must therefore meet standard filter criteria.

F-10. The sand subbase must be NFS, S1, or S2. The filter layer may or may not be necessary depending on the type of subgrade material. If the subgrade consists principally of gravel or sand, the filter layer may not

be necessary and may be replaced by additional base course material, if the gradation of the base course is such that it meets filter criteria. However, for finer-grained soils, the filter layer will be necessary. If a geotextile is used, the sand subbase or filter layer may be omitted because the fabric will be placed directly on the subgrade and will act as a filter. If select materials are used, they must be NFS, S1, S2, F1, or F2 from table F-1, page F-2.

COMPACTION

F-11. The subgrade should be compacted to provide uniformity of conditions and a firm working platform for placement and compaction of the subbase. However, compaction of the subgrade will not change its frost-area soil-support index (FASSI) designation, because frost action will cause the subgrade to revert to a weaker state. Determine the compaction requirements based on the material CBR for each layer. The required depth of compaction for the subgrade is determined for cohesionless and cohesive soils.

THICKNESS OF BASE COURSE AND FILTER LAYER

F-12. The relative thicknesses of the base course and filter layer are variable and should be based on the required cover (minimum of 4 inches) and economic considerations.

FROST-AREA DESIGN STEPS

F-13. Frost-area design steps closely resemble aggregated-surfaced road design with a few differences. The steps below provide the information needed for a frost area aggregate road.

- **Steps 1 through 5.** Steps 1 through 5 are the same as for regular aggregate-surfaced roads. (Refer to TM 3-34.48-1).
- **Step 6.** Determine the applicable frost group for the subgrade type from table F-1.
- **Step 7.** Determine the frost-area soil-support index from table F-2, page F-3, based on the applicable frost group.
- **Step 8.** Determine the required road structure thickness. First, compare the natural subgrade CBR to the FASSI value.
  - If the natural subgrade CBR is less than the FASSI value, then the CBR value governs the design, and the thickness is determined from figure F-2, page F-4, as in nonfrost design.
  - If the natural subgrade CBR is greater than the FASSI, then figure F-1, page F-3, is used. Using the design index value, enter figure F-1, move horizontally to intersect the frost-group curve, and then move vertically downward to determine the required thickness in inches.
- **Step 9.** Determine the required compaction densities.
- **Step 10.** Draw the section of the aggregate road structure.

Notes.

1. All layer depths should be rounded up to the next full inch for construction purposes.

2. The material should meet gradation requirements.

3. After all possible design sections are analyzed, the final section used should be determined on the basis of economic analysis.

Example (Frost-Area Design)

An aggregate-surfaced road in a frost area is to be used for one year. The road will be subject to—

Vehicles	Average Daily Traffic
M998 HMMWV	1,800
M929 5-ton dump (2 average trucks)	600

Available material CBR:

Natural subgrade = 4 (clay PI – 14)
Compacted subgrade = 8
Fine-graded, crushed rock = 80
Coarse-graded, crushed rock = 80
Clean sand subbase = 15

Solution

1. Number of daily passes = 2,400 (given).
2. Select road class D based on average daily traffic of 2,400 (see TM 3-34.48-1).
3. Select traffic Category IV (see TM 3-34.48-1), based upon the presence of the 25-percent truck traffic.
4. Select design index of 4.
5. Natural subgrade CBR = 4.

   Compacted subgrade CBR = 8
6. From table F-1, page F-2, the subgrade frost group is F3 based on it being a clay (CL) material.
7. Select FASSI of 3.5 from table F-1 based on frost group F3.
8. Determine the acquired road-structure thickness.

   a. First, look at the required road thickness as though it was not designed for frost. In this case, the compact subgrade CBR = 8 is used in figure F-2, page F-4. This results in a required total thickness of 6.25 inches, rounding up to 7 inches as shown below.

7 inches crushed rock CBR = 80
6 inches compacted subgrade CBR = 8
Natural subgrade CBR = 4

   b. Now, design the road for frost. In this case, the natural subgrade CBR = 4, and the FASSI = 3.5. Since the natural subgrade CBR is greater than the FASSI, figure F-1 is used. A design index of 4 is entered into figure F-1 resulting in a design thickness of 24.5 inches, rounding up to 25 inches. Notice the rather large difference in design thickness between frost design and nonfrost design.
9. Determine compaction densities for each layer.

   Wearing course: at least 100 percent.
   Base course: at least 100 percent.
   Subbase course: 100 to 105 percent.
   Subgrade: 90 to 95 percent for cohesion soil (PI 5).
10. Draw the section of the frost-area, aggregate road structure.

Notes.

1. The function of the subbase as a filter layer is not always required, depending upon the subgrade material. In this case, the subgrade is a CL; therefore, it is required.

2. For economy, the thickness of the base and subbase courses can be adjusted, so long as the minimum thickness above the CBR = 15 subbase is maintained at 4 inches, as determined from Figure F-2, page F-4.

3. An overall minimal thickness layer of 4 inches should be maintained.

F-14. When using a geotextile as a filter layer, the design could be reduced by deducting 6 inches of the clean sand subbase and replacing it with a geotextile. The total thickness above the geotextile must be a minimum of 25 inches. Two alternate designs using geotextile are shown in figure F-3.

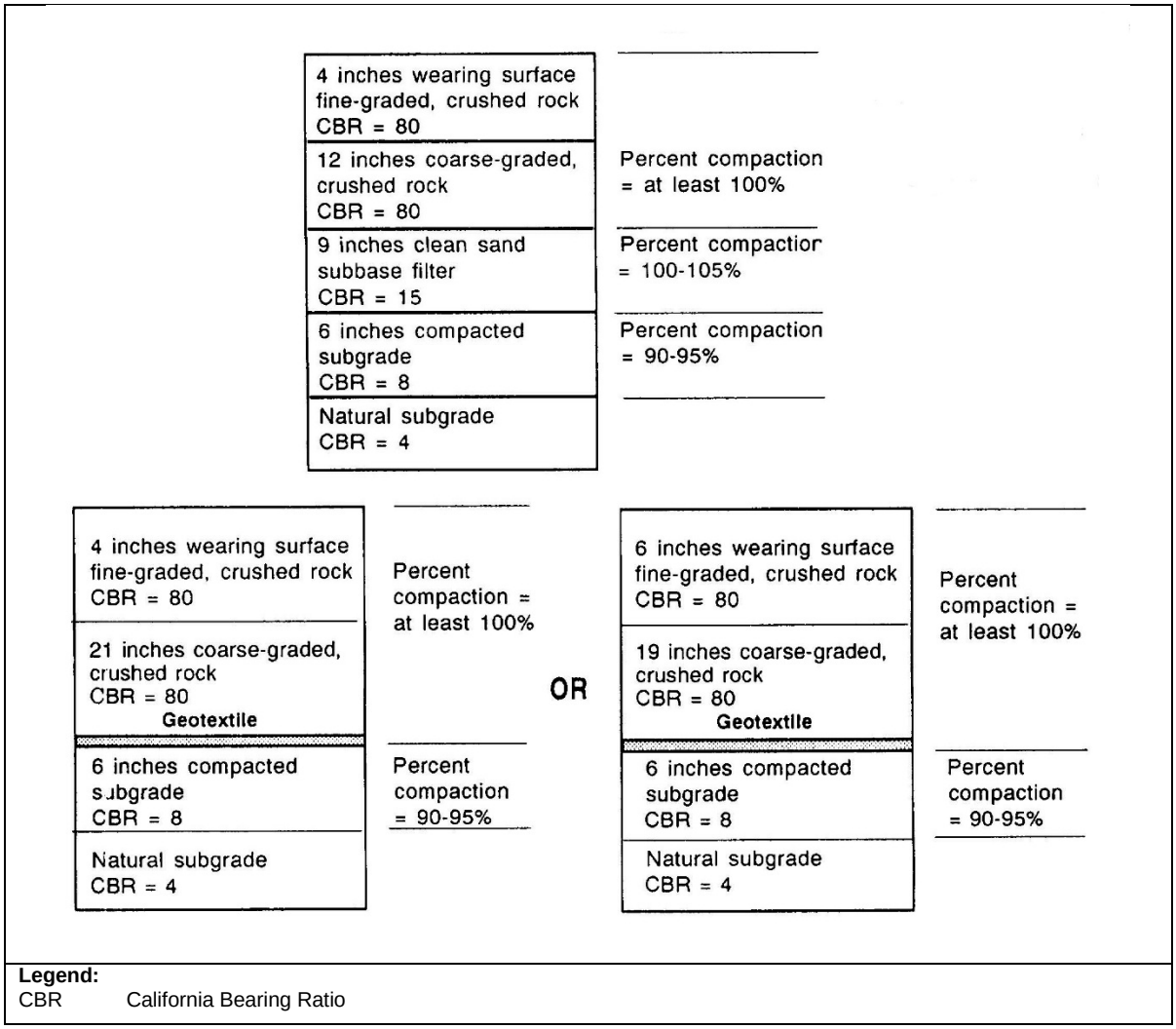


Figure F-3. Geotextile alternate designs

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Appendix G

Airfield Cone Penetrometer and Dual-Mass Dynamic Cone Penetrometer

Two 12 5/8-inch extensions are graduated every 2 inches, and two 11/32-inch wrenches are used to tighten the set in during assembly.

AIRFIELD CONE PENETROMETER

G-1. 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 pin for the handle are also included.

G-2. 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 0 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.

G-3. 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.

G-4. The airfield cone penetrometer does well when used in silt or clay. The readings are meaningless in gravel, so the AI is determined for the soil beneath the gravel layer.

G-5. Sands require special treatment. Many sands occur in a loose state. When very dry sands show increasing AIs with depth, the 2-inch depth index is often low (about AI 3 or AI 4). Sands can usually support aircraft with requirements much higher than AI 3 or AI 4 because the strength of the sand increases under the confining action of 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). The evaluation of moist sands should be determined by the same method as the one used for fine soils.

G-6. 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.

ASSEMBLY AND OPERATION OF THE AIRFIELD PENETROMETER

G-7. 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. Do not over-tighten the extension. Excessive force can bend or break shafts.

G-8. To operate the airfield penetrometer, inspect the device for tightness. Ensure that the handle, cone, and extension are properly attached. Next, position your hands vertically on the handle, and place the penetrometer vertically on the soil surface. 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. Readings should be recorded in tabular fashion, similar to the sample format shown in figure G-1, page G-2. If you suspect that the cone is encountering stone or other foreign body at the depth at which a reading is desired, make another penetration nearby.

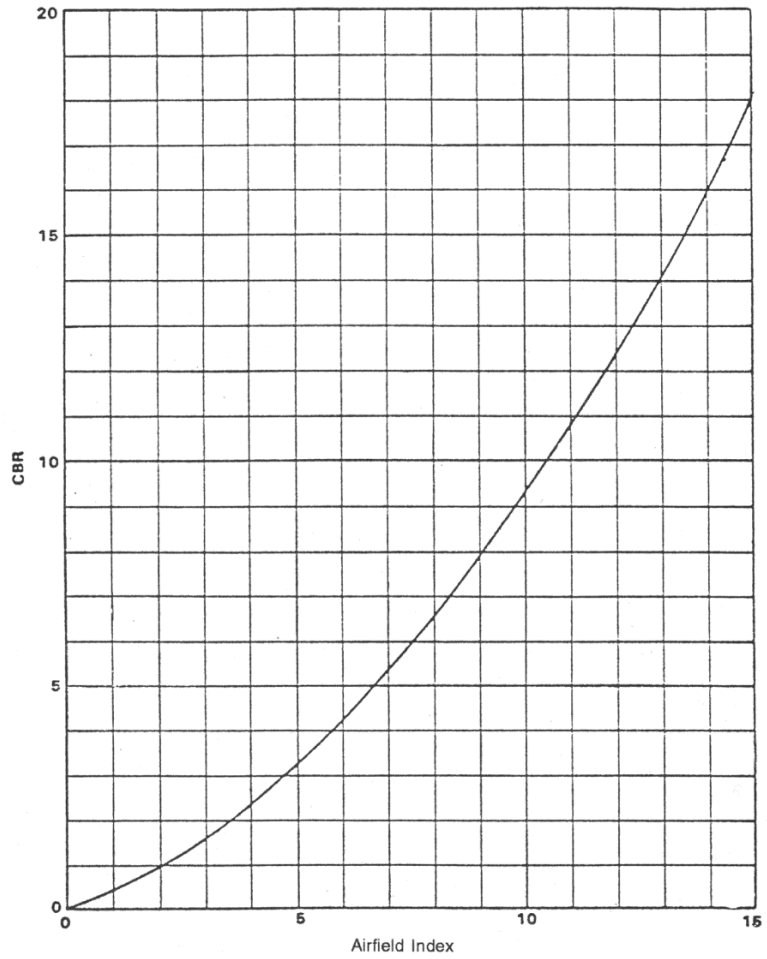
Soil Strength Evaluation Airfield Index			
Airfield location:		**Date:**	
Depth	**Airfield Index**	**Sum**	**Average**
	SAMPLE		
Critical depth:			
Critical airfield index:			
Comments:			

Figure G-1. Sample format for AI data sheet

G-9. Use an X configuration in a 12-inch radius circle to take five penetrations at each location. Note the readings at each 2-inch increment. When an AI (15) has been reached, lower depths can be assigned an AI (15), provided that a minimum of three sites have been tested to ensure that the lower depth has an AI (15) or higher. Tests should be taken at least every 6 inches down to the 24-inch depth or lower for the heaviest C-17 landing and highest pass levels. If very low AI (4) values appear to exist below the 24-inch depths, an auger may be used to penetrate to the desired depth.

G-10. If a low strength layer is present, enough readings must be taken at full depth (24 inches) to verify the extent of the area containing the layer. Since this is the most critical area, the entire airfield must be evaluated based on the abnormal layer.

G-11. 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 critical AIs are determined for the sites, the lowest critical AI is assigned for the entire airfield. The AI can then be used to estimate the CBR using figure G-2. Surface thickness requirements should be determined as described in chapter 4.



Legend:

CBR California Bearing Ratio

Figure G-2. Correlation between AI and CBR

DETERMINATION OF CRITICAL AIRFIELD INDEX

G-12. A minimum of one reading at the parking apron, runway, and hammerhead must be taken to the 24-inch depth to ensure that 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.

RUNWAYS AND TAXIWAYS

G-13. The first reading should be taken 50 feet from one end of the runway or taxiway on the centerline. Additional readings should be obtained every 200 feet, 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. This pattern should be repeated until the midpoint is reached. After the midpoint, the survey team should go to the other end of the runway or taxiway, start the readings 50 feet from that end, and repeat the survey pattern back to the midpoint (see figure G-3, page G-4).

PARKING APRONS

G-14. The first set of readings will be obtained at the center of the apron. Additional readings should be taken every 200 feet in both directions as shown in figure G-3. This should be repeated until the extent of the area has been covered.

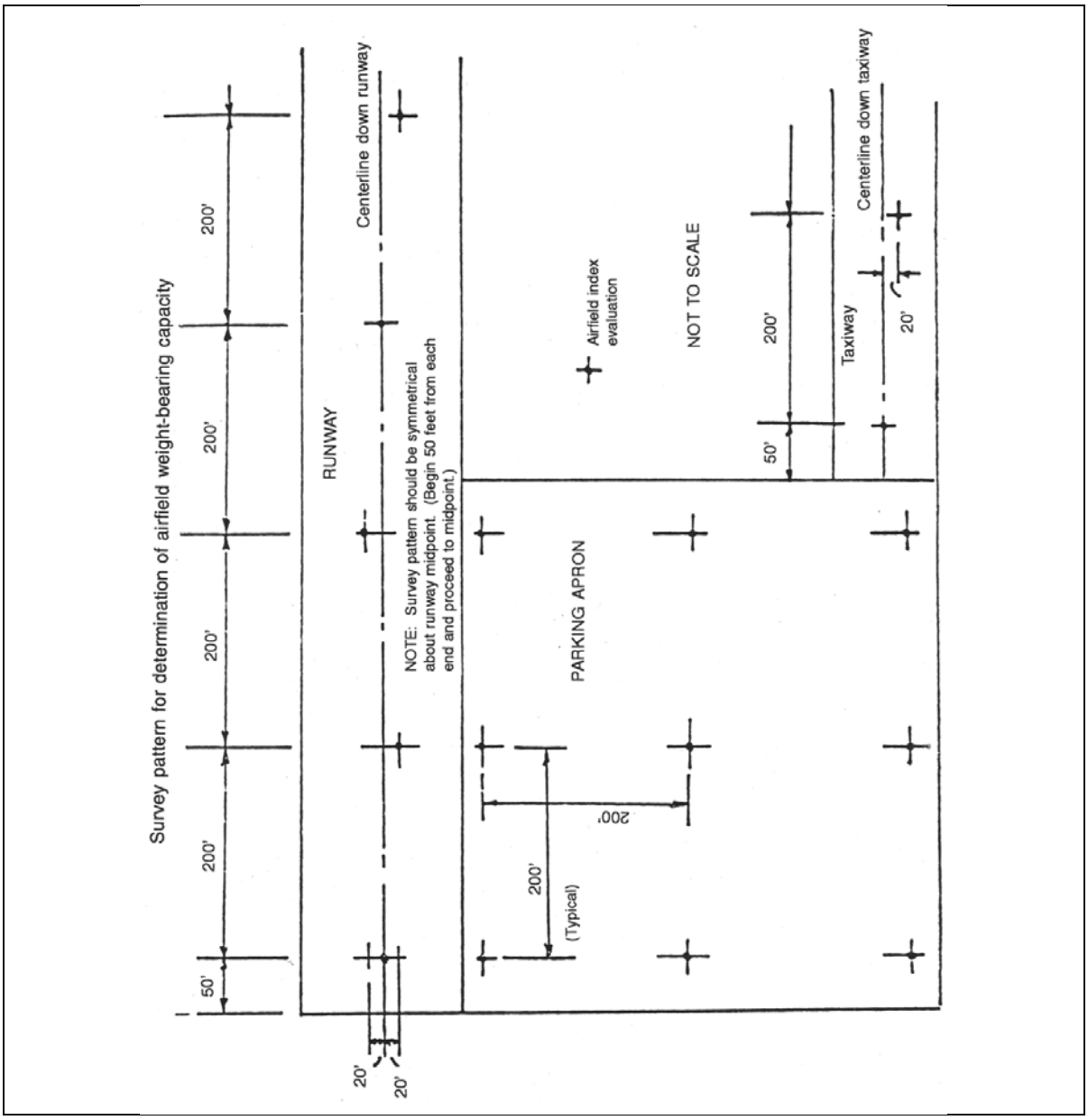


Figure G-3. Survey pattern for runways, taxiways, and parking aprons

HAMMERHEAD TURNAROUNDS

G-15. The initial set of readings should be obtained at the center of the turnaround. Additional readings should be taken 40 feet in both directions until the extent of the area has been covered (see figure G-4).

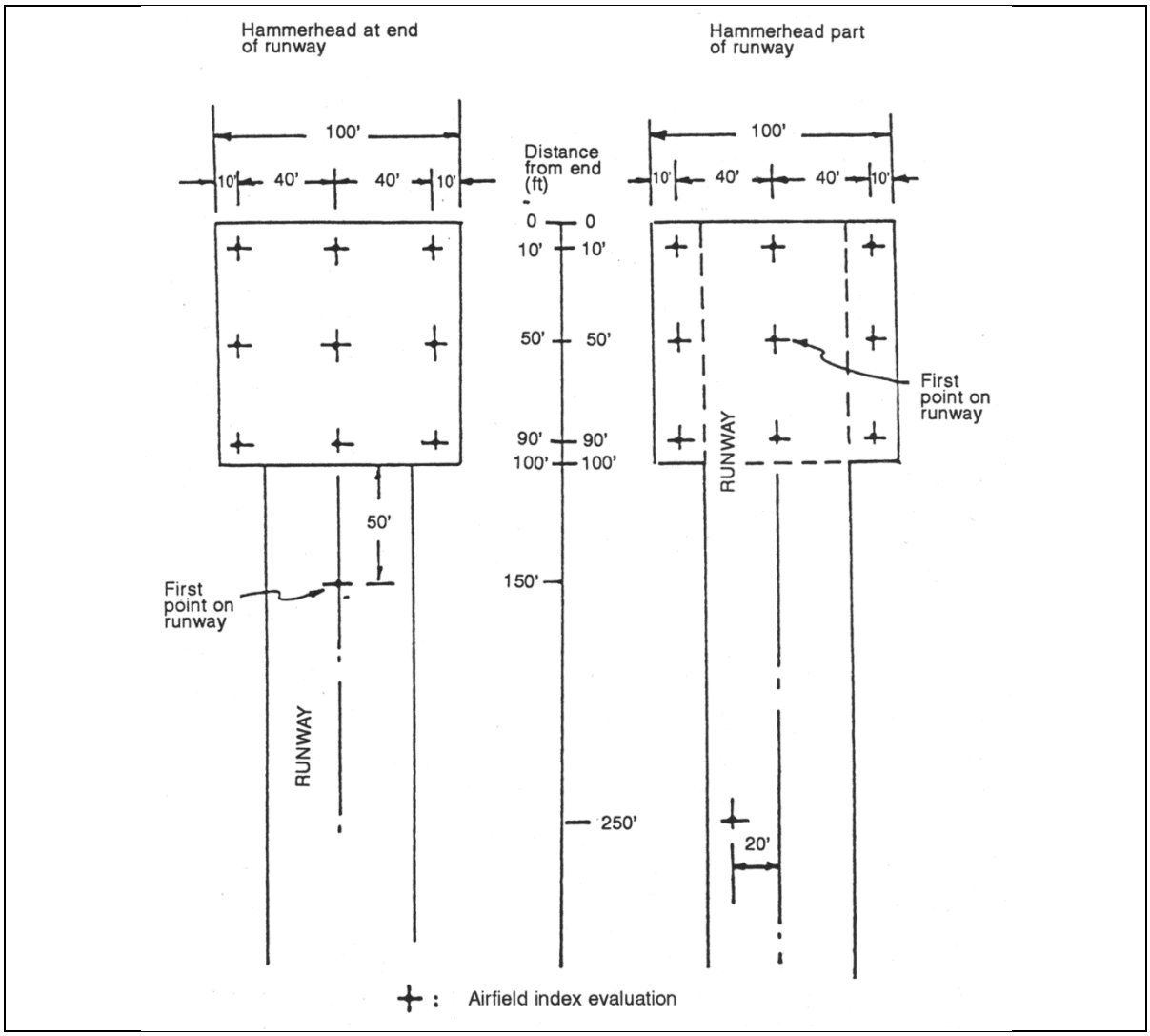
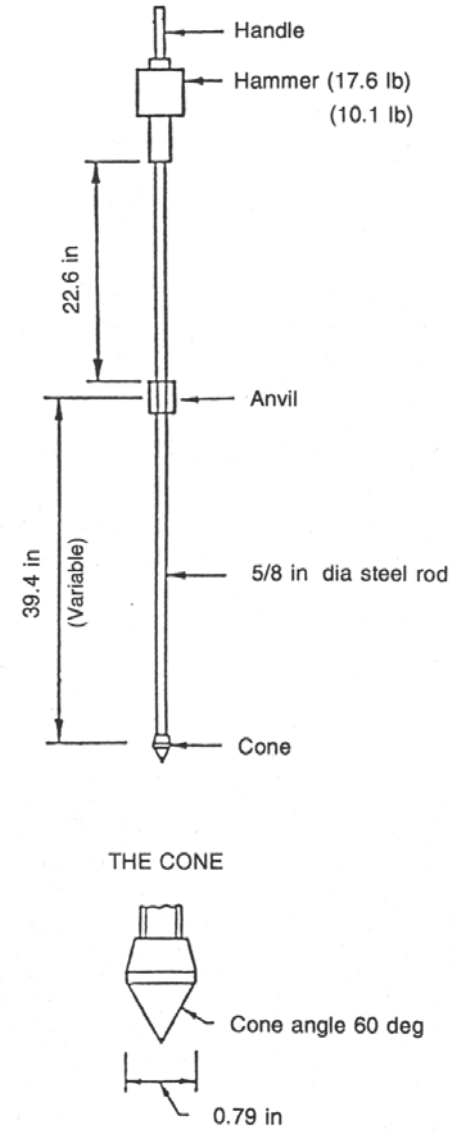


Figure G-4. Survey pattern for hammerhead turnarounds

DUAL-MASS DYNAMIC CONE PENETROMETER DEVICE

G-16. 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 a sliding dual-mass hammer (see figure G-5, page G-6). 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 penetration resistance is exerted on the cone. Figure G-6, page G-7, shows an assembled DCP with a vertical scale for measuring cone penetration depth. The DCP is driven into the soil by dropping 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 setscrew and the outer steel sleeve (see figure G-7, page G-7). This procedure can be accomplished during a test because 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 twice the blow 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 soils are encountered. 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.



Legend:

deg	degree
in	inch
lb	pound

Figure G-5. Dual mass DCP

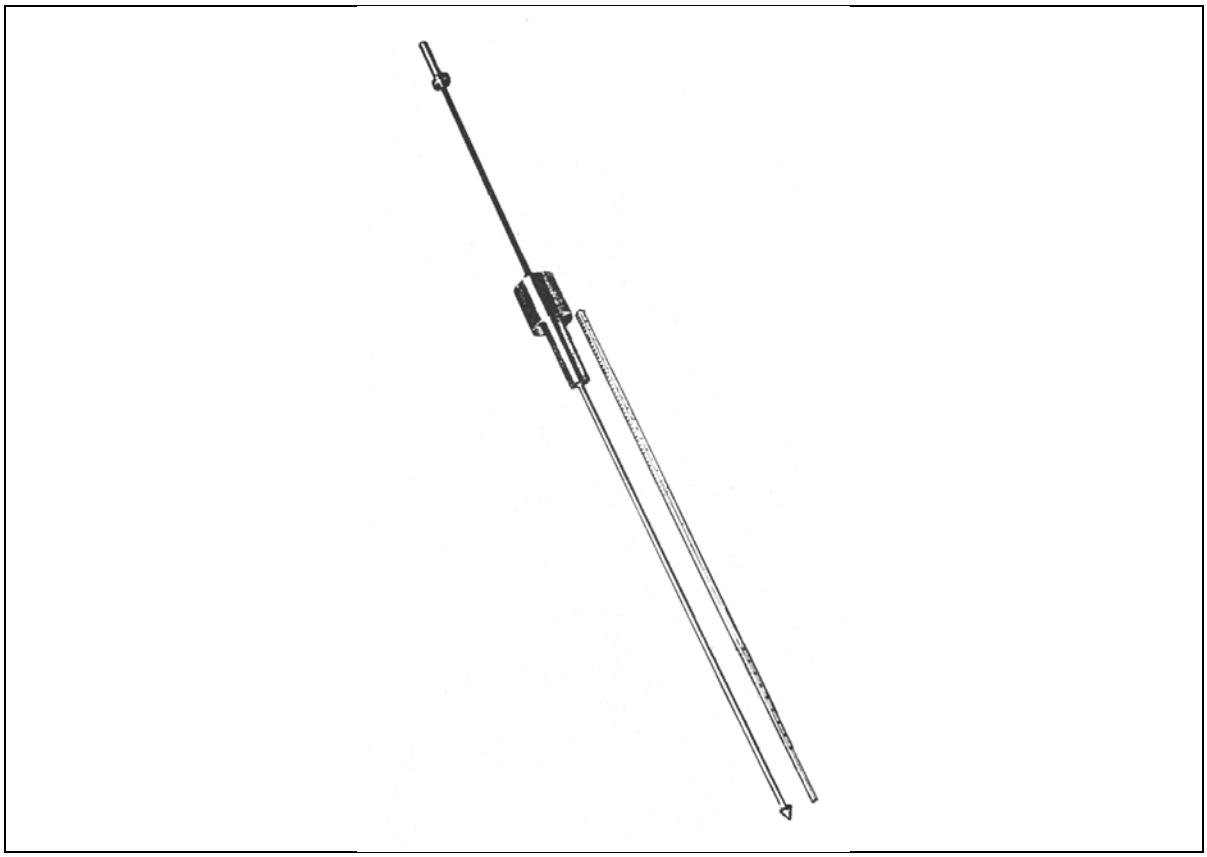


Figure G-6. Assembled DCP with vertical scale

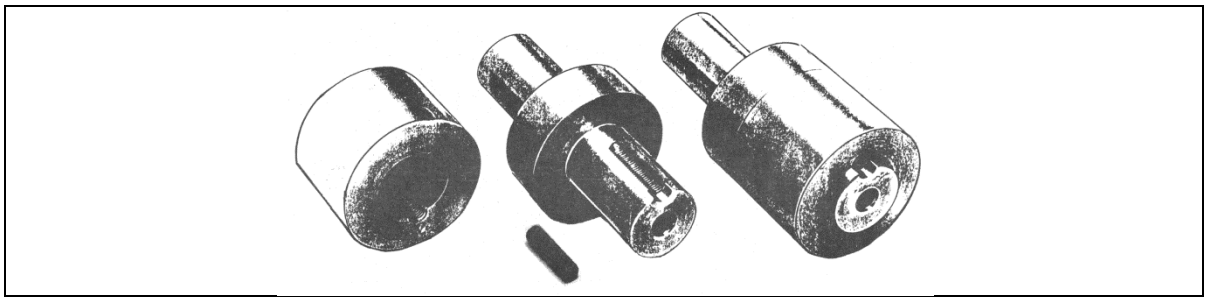


Figure G-7. Dual-mass hammer showing the removable steel sleeve, set screw, 10.1 pound hammer, and 17.6 pound hammer configuration

DUAL-MASS DYNAMIC CONE PENETROMETER KIT

G-17. Figure G-8, page G-8, shows a dual-mass DCP kit (NSN 6635-01-450-9778) designed for military engineer use. The kit includes—

- One case assembly.
- One top rod threaded and welded to the handle.
- One bottom rod threaded and welded to the anvil.
- One dual-mass hammer.
- One vertical scale in centimeters and inches.
- One 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.
- One thread-locking compound.
- One hexagonal wrench set (5/64 to 1/4 inch).

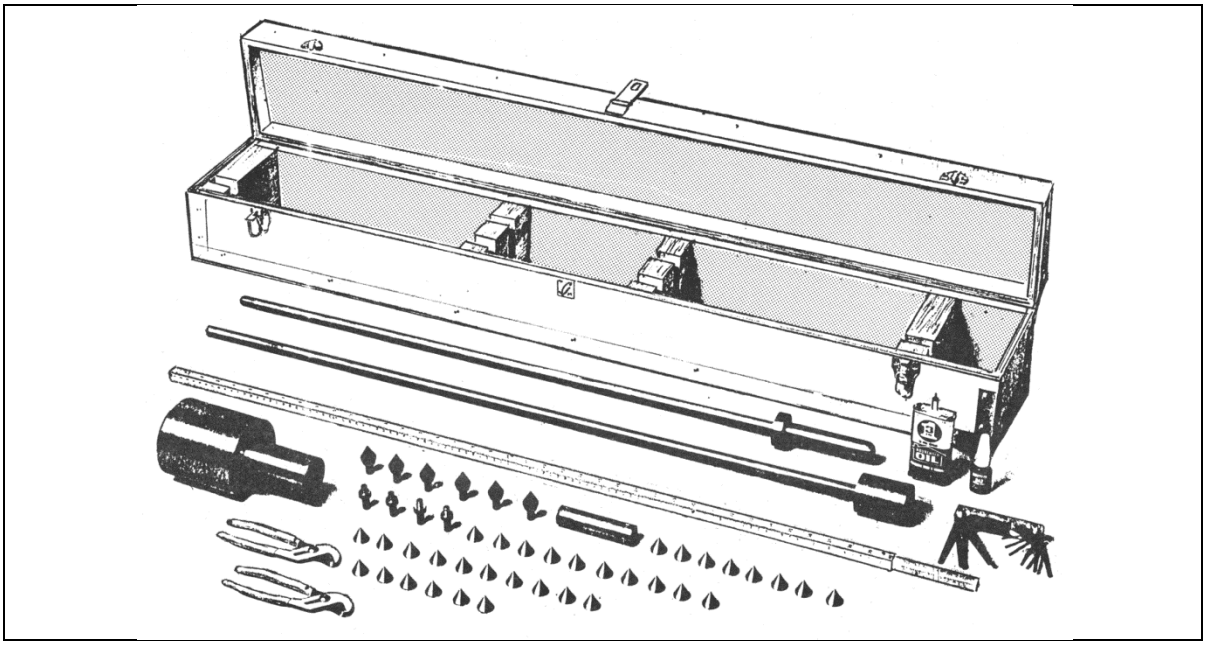


Figure G-8. Dual-mass DCP test kit

DISPOSABLE CONE

G-18. 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 G-9. 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

G-19. The go/no go gauge is used to ensure that the base diameter of the cone is within proper tolerance. Each new fixed cone should be checked before use and at selected usage intervals to ensure that the base diameter of the cone 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.

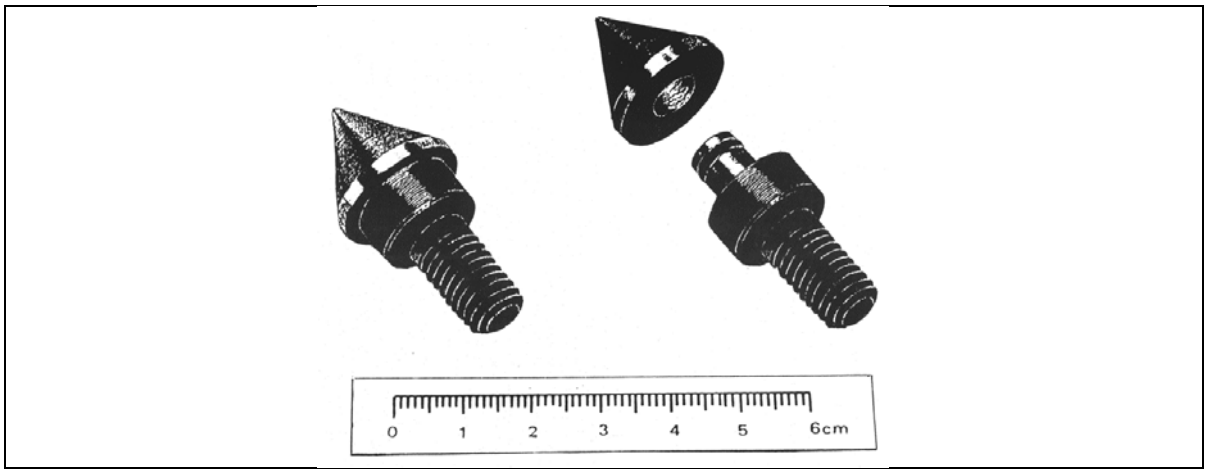


Figure G-9. Disposable cone and adaptor

USE OF THE DYNAMIC CONE PENETROMETER

G-20. 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 that the joints are tight. A thread-locking compound should be used on loose joints. Also, the base diameter of the cone should be checked to ensure that it is within tolerance. If the cone point becomes bent or too blunt to penetrate around aggregate, it must be replaced.

G-21. Two people (an operator and a recorder) are required to operate the DCP. The operator 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 recorder then checks the device for a zero reading by holding the vertical scale between the soil surface and the bottom of the hammer. The bottom of the 4-inch-diameter portion of the hammer should read 0 millimeters on the vertical scale. If the hammer is above the vertical scale, the hammer should be tapped until it is flush with 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 that 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 hand movements. The operator should also be careful not to exert a downward force on the handle after dropping the hammer. 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 G-10, page G-10, shows a penetration depth of 150 millimeters.

G-22. 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 typically be 20, 10, 5, 3, 2, or 1, depending on the soil strength and the cone penetration rate. This should be selected so that average penetrations of 25 to 35 millimeters are achieved for recording. The operator and recorder should be alert to sudden increases in the cone-penetration rates during the test. A 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.

G-23. 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 at the connection 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 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.

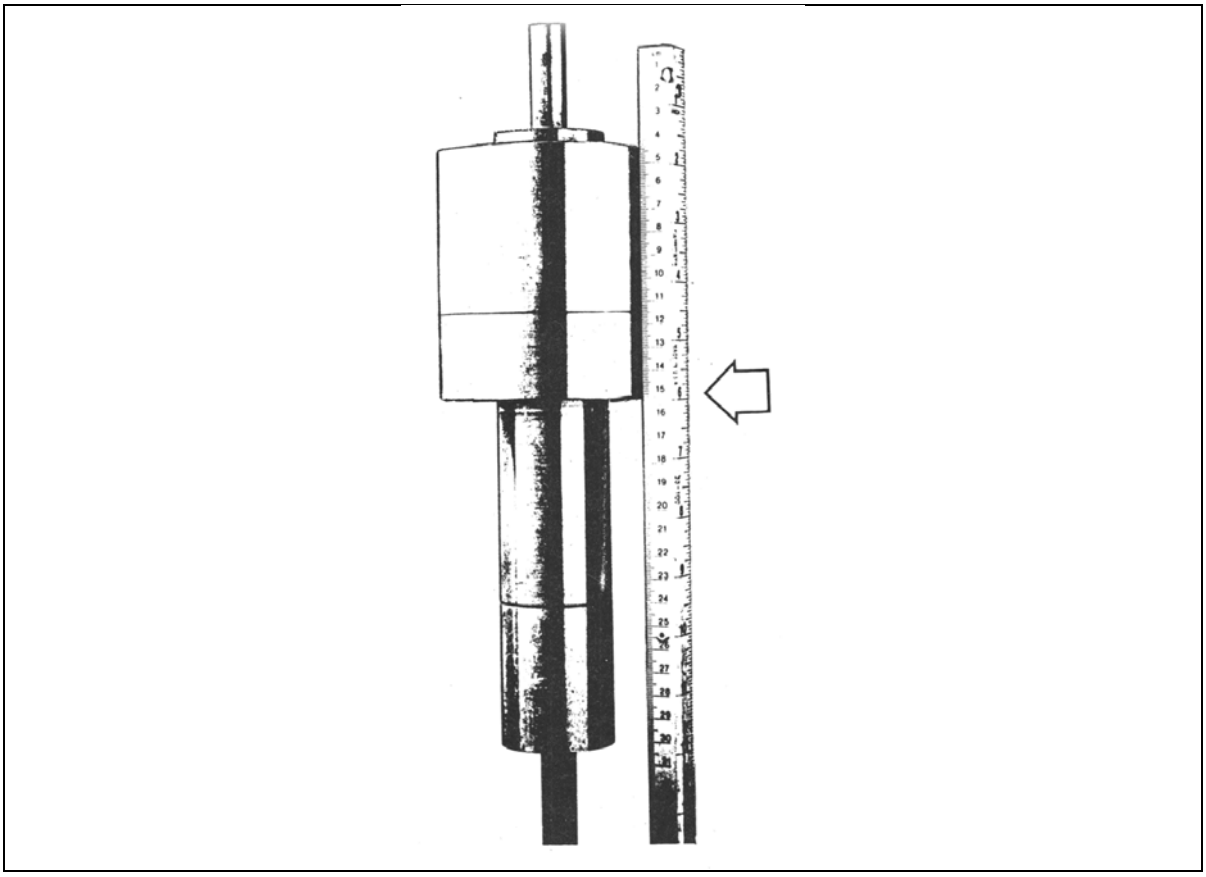


Figure G-10. Example penetration measurement showing 150-millimeter penetration

DYNAMIC CONE PENETROMETER MAINTENANCE

G-24. The DCP should be kept clean, and soil should be removed from the penetration rod and cone after each test. A light application of spray lubricant or oil should be applied to the hammer slide rod before each daily use. Loose joints will lead to equipment failure, so joints should be constantly monitored and kept tight. 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 USING THE DYNAMIC CONE PENETROMETER

G-25. Using the DCP requires a variety of measurements at different locations and depths depending on the project. This provides data to correlate with the CBR and tabulate for further analysis.

NUMBER OF MEASUREMENTS

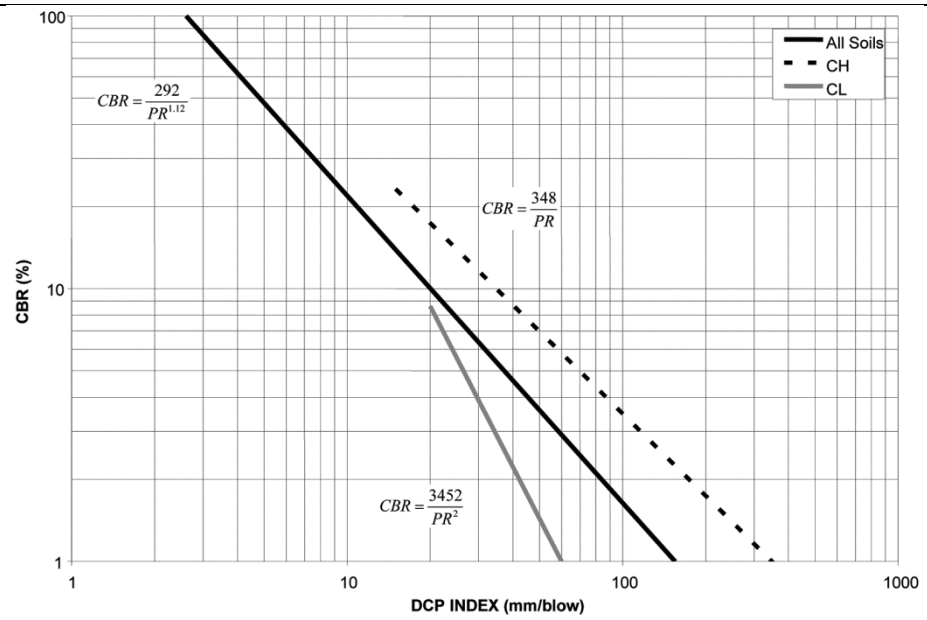
G-26. The number of measurements to be made, the location of the measurements, the depth of the measurements required, and the frequency of recording data with depth vary with the type of road or airfield pavement operation and with the time available for conducting the tests. For this reason, hard-and-fast 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 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 the 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 soil conditions.

READING DEPTHS IN SOIL

G-27. 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 affect the soil to depths of 36 inches or more, it is recommended that each penetration be made to 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 DYNAMIC CONE PENETROMETER INDEX WITH CALIFORNIA BEARING RATIO

G-28. A correlation of DCP index with CBR is necessary because the CBR is the soil strength value used for designing and evaluating unsurfaced, aggregate-surfaced, and flexible pavements for military roads and airfields. A database of field CBR versus DCP index values was collected from many sites and different soil types. The data showed that a separate correlation was required for CH soils and for wet CL soils with a CBR below 10 (see figure G-11). Table G-1, page G-12, shows a tabulated correlation of DCP index with CBR for the soil conditions.



Legend:

CBR	California Bearing Ratio	PR	penetration rate
DCP	dynamic cone penetrometer		

Figure G-11. Tabulated correlation of DCP index to CBR

Table G-1. Tabulated correlation of DCP index to CBR

CH soils				*CL soils (CBR<10)*		*All other soils*	
DCP index (mm/blow)	***CBR (%)***	***DCP index (mm/blow)***	***CBR (%)***	***DCP index (mm/blow)***	***CBR (%)***	***DCP index (mm/blow)***	***CBR (%)***
17	20	19	9.6	<3	100	51	3.6
18	19	20	8.6	3	85	52	3.5
19	18	22	7.1	4	62	53	3.4
20	17	24	6.0	5	48	55	3.3
22	16	26	5.1	6	39	56	3.2
23	15	27	4.7	7	33	58	3.1
25	14	28	4.4	8	28	59	3.0
27	13	29	4.1	9	25	61	2.9
29	12	30	3.8	10	22	63	2.8
32	11	31	3.6	12	18	65	2.7
35	9.9	32	3.4	13	17	67	2.6
39	8.9	33	3.2	14	15	69	2.5
43	8.1	34	3.0	15	14	72	2.4
50	7.0	35	2.8	16	13	75	2.3
58	6.0	36	2.7	17	12	78	2.2
69	5.0	37	2.5	18	11	81	2.1
72	4.8	38	2.4	20	10	84	2.0
75	4.6	39	2.3	22	9.2	88	1.9
79	4.4	40	2.2	24	8.3	92	1.8
83	4.2	41	2.1	27	7.3	97	1.7
87	4.0	42	2.0	30	6.5	102	1.6
92	3.8	43	1.9	35	5.4	108	1.5
97	3.6	44	1.8	39	4.8	115	1.4
102	3.4	45	1.7	40	4.7	122	1.3
110	3.2	46	1.6	41	4.6	131	1.2
115	3.0	48	1.5	42	4.4	141	1.1
125	2.8	50	1.4	43	4.3	153	1.0
135	2.6	51	1.3	44	4.2	167	0.9
145	2.4	54	1.2	45	4.1	184	0.8
152	2.3	56	1.1	46	4.0	206	0.7
158	2.2	59	1.0	47	3.9	234	0.6
165	2.1	—	—	48	3.8	272	0.5
175	2.0	—	—	49	3.7	>324	<0.5

Legend:
CBR California Bearing Ratio
CH clay high plasticity
CL clay low plasticity
DCP dynamic cone penetrometer

DATA TABULATION

G-29. The data can be tabulated in spreadsheet format during testing. The number of hammer blows, the hammer weight, and the cone penetration (to the nearest 5 millimeters) need to be recorded. Figure G-12 shows a sample format for a DCP data sheet.

DYNAMIC CONE PENETROMETER DATA SHEET

Project: **Date:**
Location: **Soil Type(s):**

Hammer Type	Number of Blows	Cumulative Penetration (millimeter)	Penetration per Blow Set (millimeter)	Penetration per Blow (millimeter)	DCP Index	CBR (%)	Depth (inch)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)

SAMPLE

(1) Size of hammer, large or small

(2) Number of hammer blows between test readings.

(3) Cumulative cone penetration after each set of hammer blows (minimum penetration between test readings should be 25 millimeters).

(4) Difference in cumulative penetration (3) between start and end of hammer blow set

(5) (4) divided by (2)

(6) Enter 1 for 17.6-pound hammer and 2 for 10.1-pound hammer.

(7) (5) * (6)

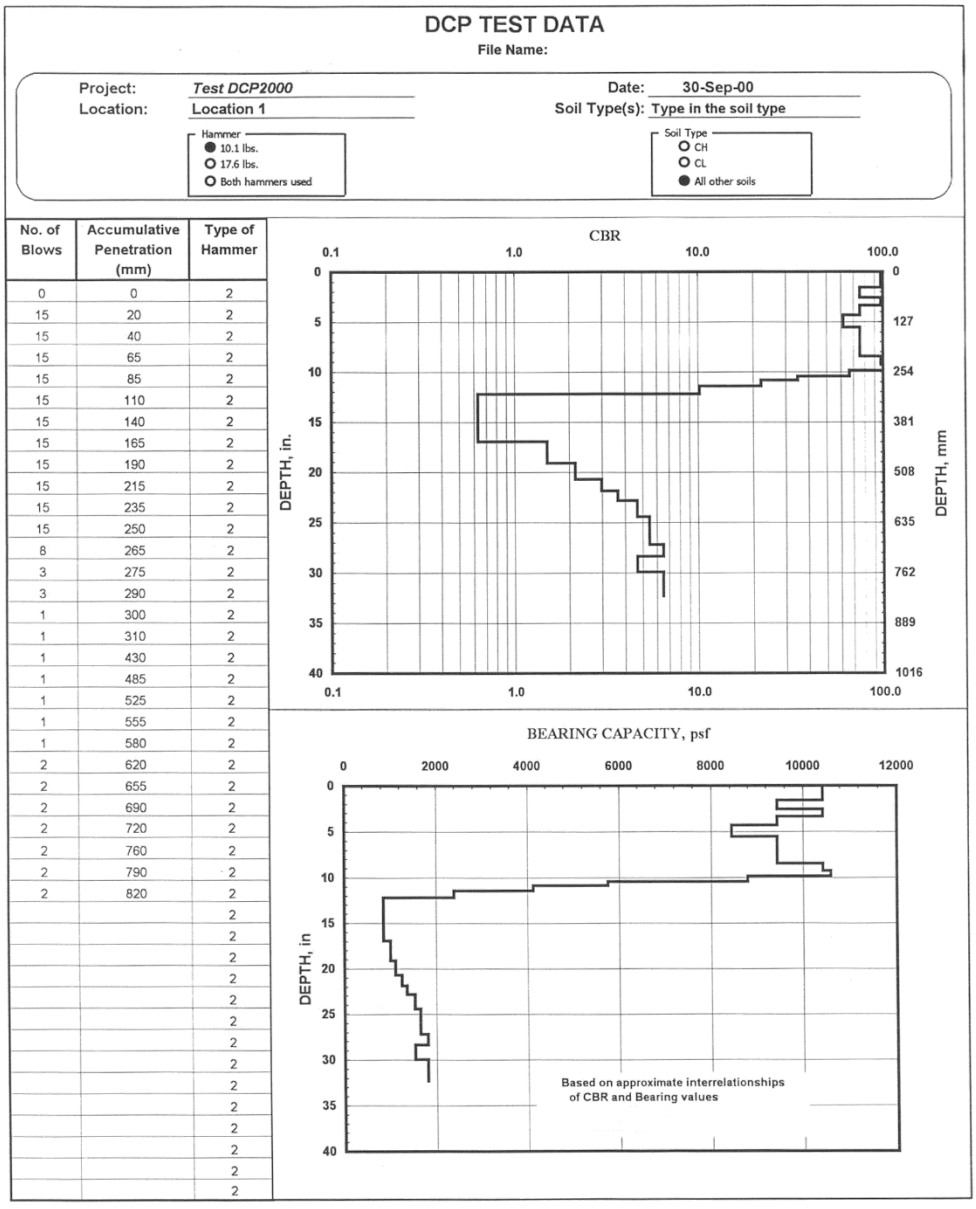
(8) From California Bearing Ratio versus dynamic cone penetrometer correlation

(9) Previous entry in (3) divided by 25.4, rounded off to 0.1 inch.

Figure G-12. Sample format for DCP data sheet

EXCEL SPREADSHEET FOR DATA ANALYSIS

G-30. Figure G-13, page G-14, shows a printout from the Microsoft Excel™ spreadsheet program developed by ERDC for use in analyzing DCP test data. The Excel DCP program is included in the DCP kit and is also available from ERDC or the DCP manufacturer. The DCP data shown was obtained on a test road consisting of 10 inches of crushed gravel over a very weak CH subgrade. A geogrid over geotextile was installed over the soft subgrade to separate and reinforce the aggregate layer. The CBR versus depth plot in figure G-13 shows a 10-inch layer of base material with an 80 to 100 CBR over a very weak subgrade soil having a CBR of 0.6 to 0.7. The stair-step increase in subgrade strength below the 15-inch depth is typical in plastic clay soils. This occurs due to the plastic clay sticking to the DCP penetration rod at test depths below 12 inches. The strength of the CH soil may not actually be increasing as indicated at the 17-inch depth. The geogrid/geotextile layer was easily located by the DCP as it took several hammer drops to penetrate the geotextile at the 10-inch depth (See figure G-12).



No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	2
15	20	2
15	40	2
15	65	2
15	85	2
15	110	2
15	140	2
15	165	2
15	190	2
15	215	2
15	235	2
15	250	2
8	265	2
3	275	2
3	290	2
1	300	2
1	310	2
1	430	2
1	485	2
1	525	2
1	555	2
1	580	2
2	620	2
2	655	2
2	690	2
2	720	2
2	760	2
2	790	2
2	820	2

Legend:

CBR	California Bearing Ratio	lb	pound
CH	clay high plasticity	mm	millimeter
CL	clay low plasticity	No.	number
DCP	dynamic cone penetrometer	psf	pounds per square foot
in	inch	Sep	September

Figure G-13. Excel spreadsheet used for DCP data analysis

APPLICATION OF DYNAMIC CONE PENETROMETER DATA

G-31. UFC 3-250-09FA 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 to determine the allowable design index for roads or the allowable gross

weight and aircraft pass configuration for airfields. The design index for roads is then used to determine the allowable road classification and number of vehicle passes per day for various traffic categories.

G-32. For unsurfaced soils in which the soil strength increases with depth, the average strength of the top layer is first used to ensure 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.

G-33. For aggregate-surfaced roads and airfields, 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

G-34. DCP operators must consider other conditions that could influence the data collected. Weather, soil type, or failure of the DCP to penetrate have different effects on the DCP index, CBR values, or trafficability of the soil.

WEATHER

G-35. 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

G-36. DCP tests in highly plastic clays are generally accurate for depths to approximately 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 and lower-rod friction problems and allow the test to accurately measure the clay soil strength for an additional 12 inches.

SANDS

G-37. Many sands occur in a loose state. When relatively dry, loose 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, dry sand or gravel will be adequate for aircraft in the C-130 class, regardless of the DCP index values. 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 above.

SOIL REMOLDING

G-38. 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

G-39. 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 a large rock or other object stopped the cone penetration, 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 H

Airfield Cone Penetrometer

The airfield cone penetrometer is a probe instrument that provides 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 can then be used to estimate a CBR value, as shown in figure H-1, page H-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

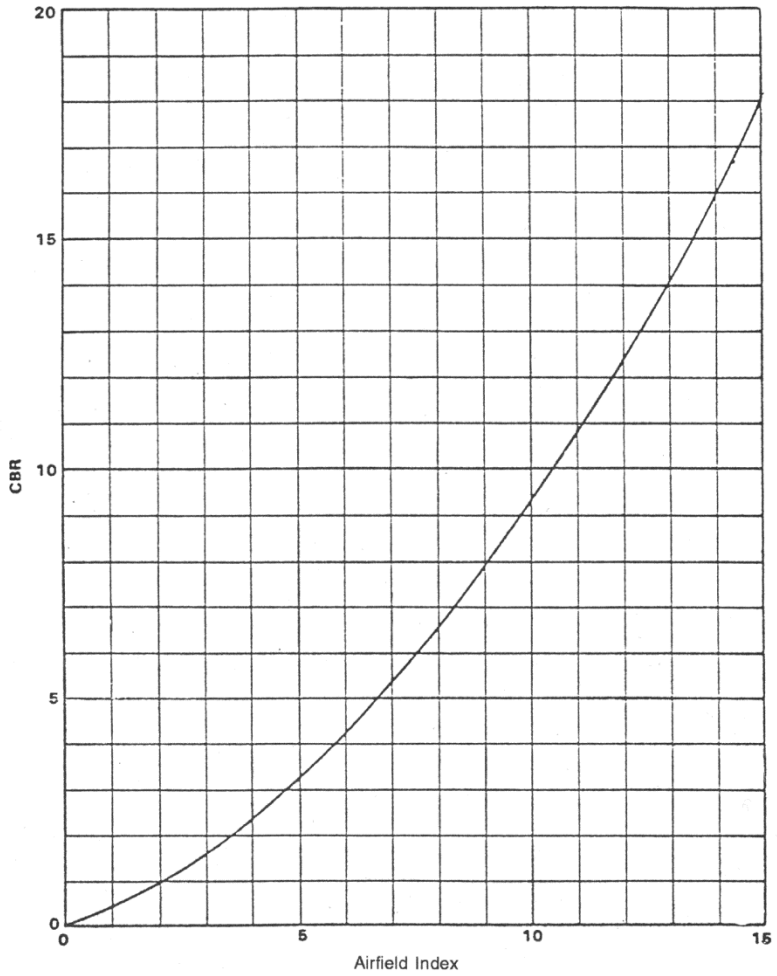
H-1. The airfield cone penetrometer must not be confused with the trafficability penetrometer, which is a standard military item included in the soil test set. If the trafficability penetrometer is used to measure the AI, the reading obtained with the 0.2-square inch cone must be divided by 20, and the readings obtained with the 0.5-square-inch cone must be divided by 50.

H-2. 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.

H-3. 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 0 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.

H-4. 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.

H-5. 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 AI 4. Sands can usually support aircraft with requirements much higher than AI 3 or AI 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.



Legend:

CBR California Bearing Ratio

Figure H-1. Correlation of CBR and AI

H-6. 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.

ASSEMBLY AND OPERATION OF AN AIRFIELD PENETROMETER

H-7. 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.

H-8. Use the following procedures to operate an airfield penetrometer:

- **Step 1.** Inspect for tightness and ensure that the handle, cone, and extension are properly attached.
- **Step 2.** Place the penetrometer in a vertical position on the soil, and place your hands in a vertical position on the handle.
- **Step 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 engineer use similar to the formats shown in appendix G.

- 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 that 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 airfield must be evaluated based on the abnormal layer.

- **Step 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 critical AIs are determined for all sites, the lowest critical AI is assigned for the entire airfield.
- **Step 5.** Determine the surface thickness requirements as described in chapter 4.

DETERMINATION OF CRITICAL AIRFIELD INDEX RUNWAYS AND TAXIWAYS

H-9. To determine the critical airfield index for runways and taxiways, use the following procedure:

- **Step 1.** The first reading will be taken 50 feet from one end of the runway or taxiway on the centerline.
- **Step 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.
- **Step 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 or taxiway, start the readings 50 feet on center from that end, and repeat the survey pattern back to the midpoint.

PARKING APRONS

H-10. To determine the critical airfield index for parking aprons, use the following procedure:

- **Step 1.** Locate the center of the area, and take the first set of readings.
- **Step 2.** Take the rest of the readings every 200 feet in both directions until the extent of the area has been covered (figure G-3, page G-4).

HAMMERHEAD TURNAROUNDS

H-11. To determine the critical airfield index for hammerhead turnarounds, use the following procedure:

- **Step 1.** Locate the ENTER area and take the set of readings.
- **Step 2.** Take the rest of the readings 40 feet in both directions until the extent of the area has been covered. A minimum of one reading at the parking apron, runway, and hammerhead must be taken to the 24-inch depth to ensure that 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.

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Appendix I

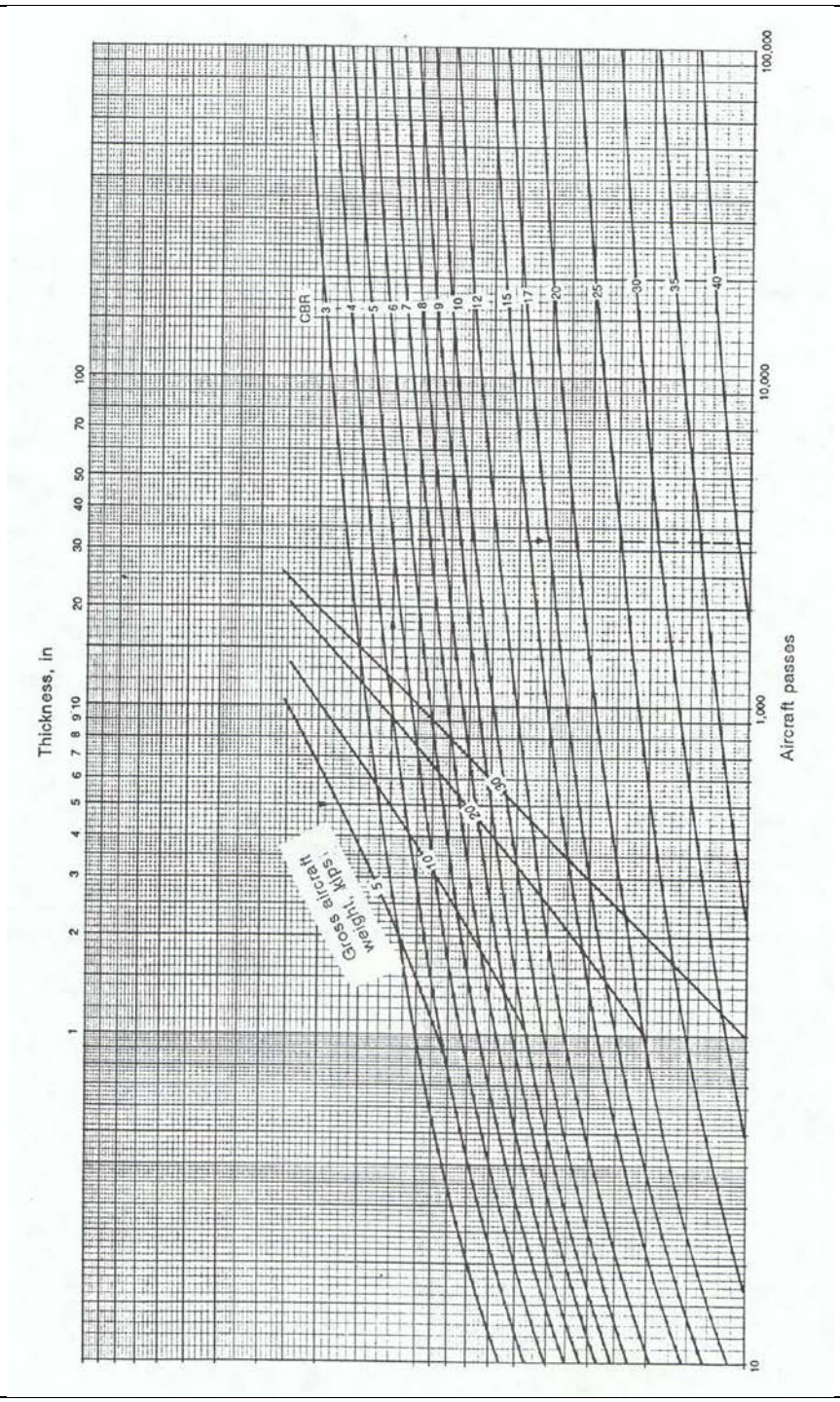
Flexible Pavement Evaluation Curves

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 I-1 through I-38, page I-2 through I-39. Table I-1 shows the different aircraft in each of the group indexes and also lists the page numbers.

Note. See UFC 3-260-03 for airfield pavement evaluation.

Table I-1. Air Force aircraft group index

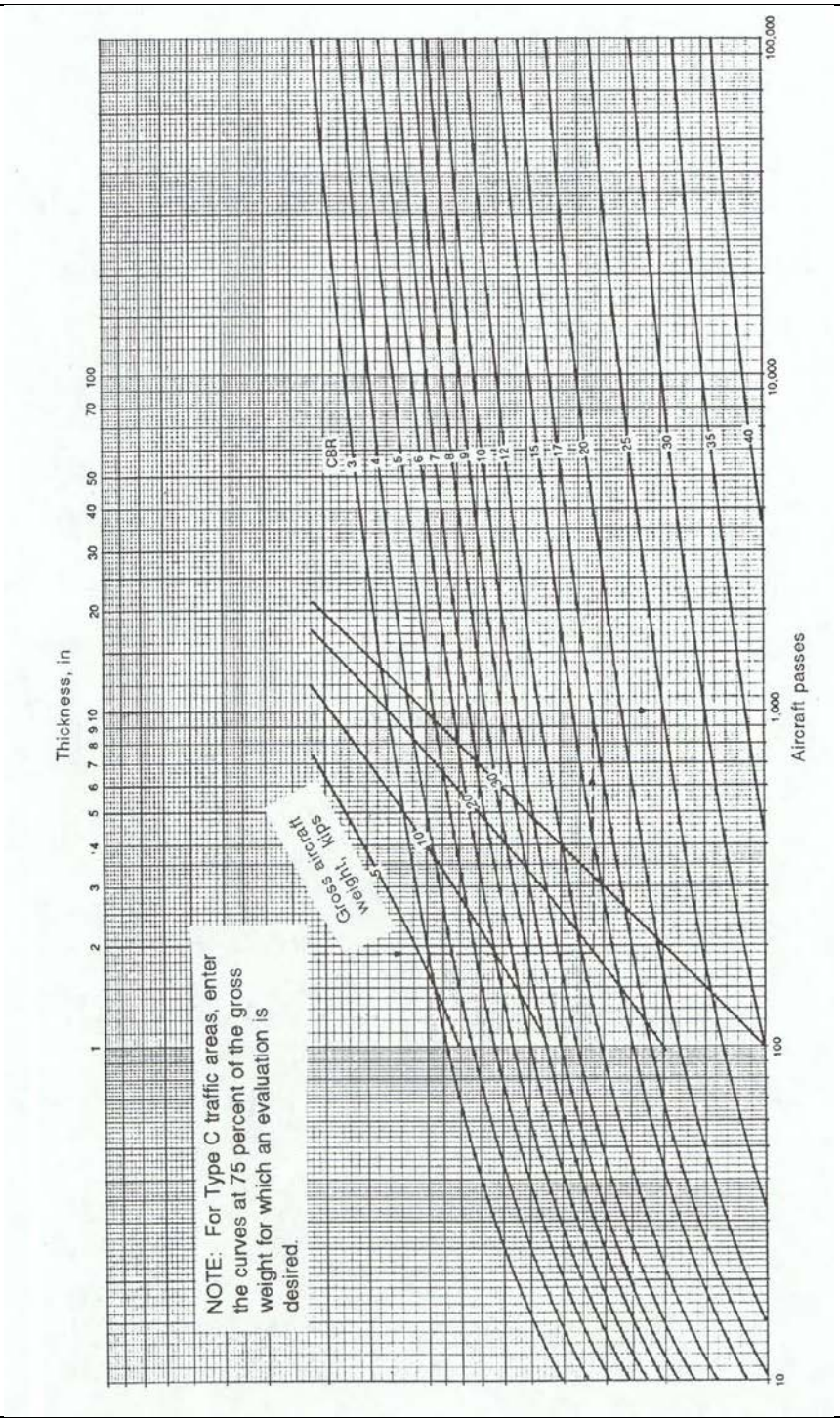
Group index and page number													
I K-2	***II K-4***	***III K-6***	***IV K-8***	***V K-10***	***VI K-12***	***VII K-14***	***VIII K-16***	***IX K-18***	***X K-20***	***XI K-22***	***XII K-24***	***XIII K-26***	***XIV K-28***
C-23*	F-15*	F-111*	C-130*	C-9*	T-43*	B-727*	E-3*	C-141*	C-17*	C-5*	KC-10*	E-4*	B-52*
C-12	A-7	F-117		C-7	737	C-22	707	B-1			DC-10	747	
C-21	A-10			DC-9		P-3	C-135	B-757			L-1011	VC-25	
C-27	C-20			C-140			KC-135	B-2					
A-37	F-4						VC-137						
	F-5						DC-8						
	F-14						EC-18						
	F-16						A-300						
	F-100						B-767						
	F-101												
	F-102												
	F-105												
	F-106												
	T-1A												
	T-33												
	T-38												
	T-39												
*Controlling aircraft.													



Legend:

CBR	California Bearing Ratio
in	inch

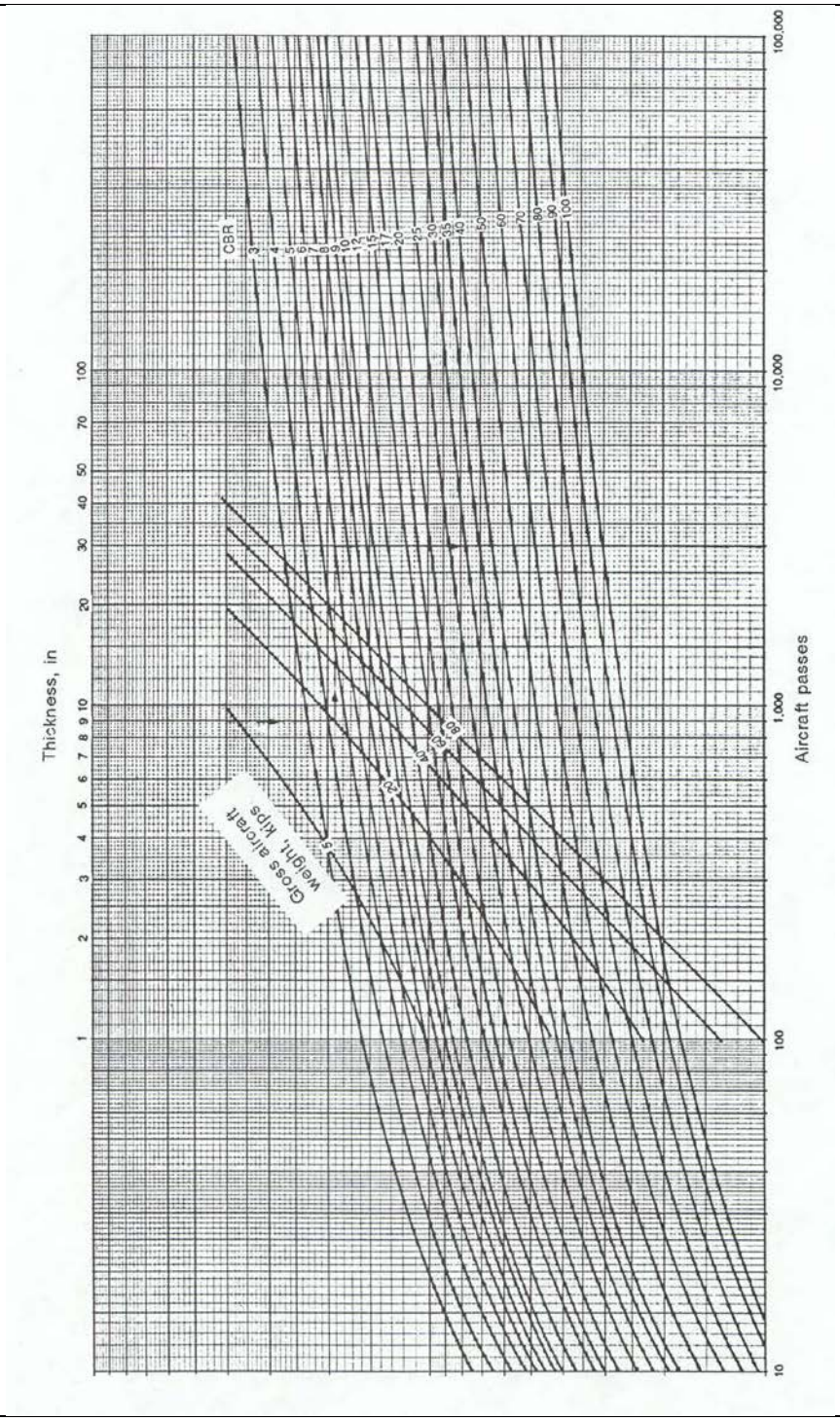
Figure I-1. Flexible-pavement evaluation curves, Group Index I, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

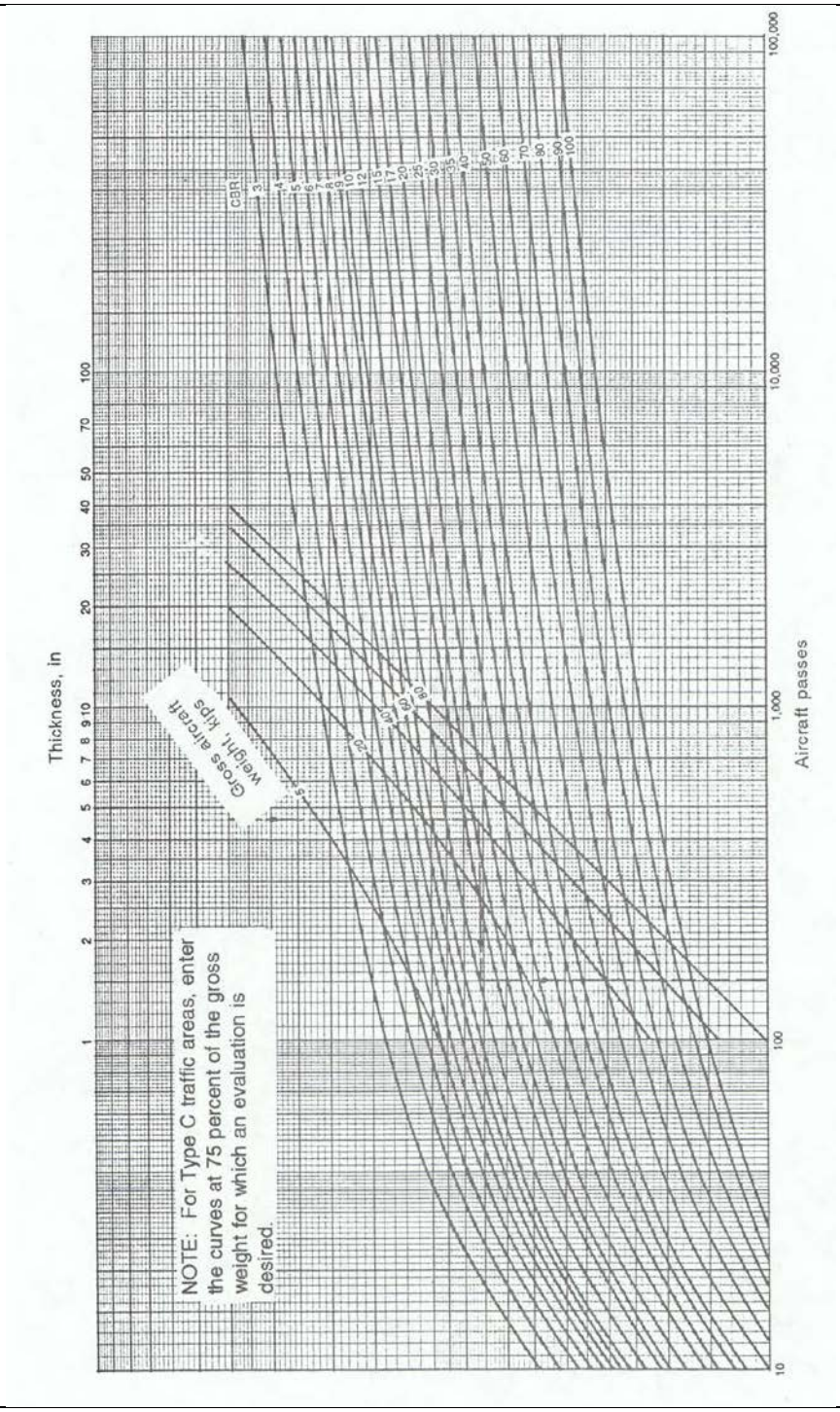
Figure I-2. Flexible-pavement evaluation curves, Group Index I, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

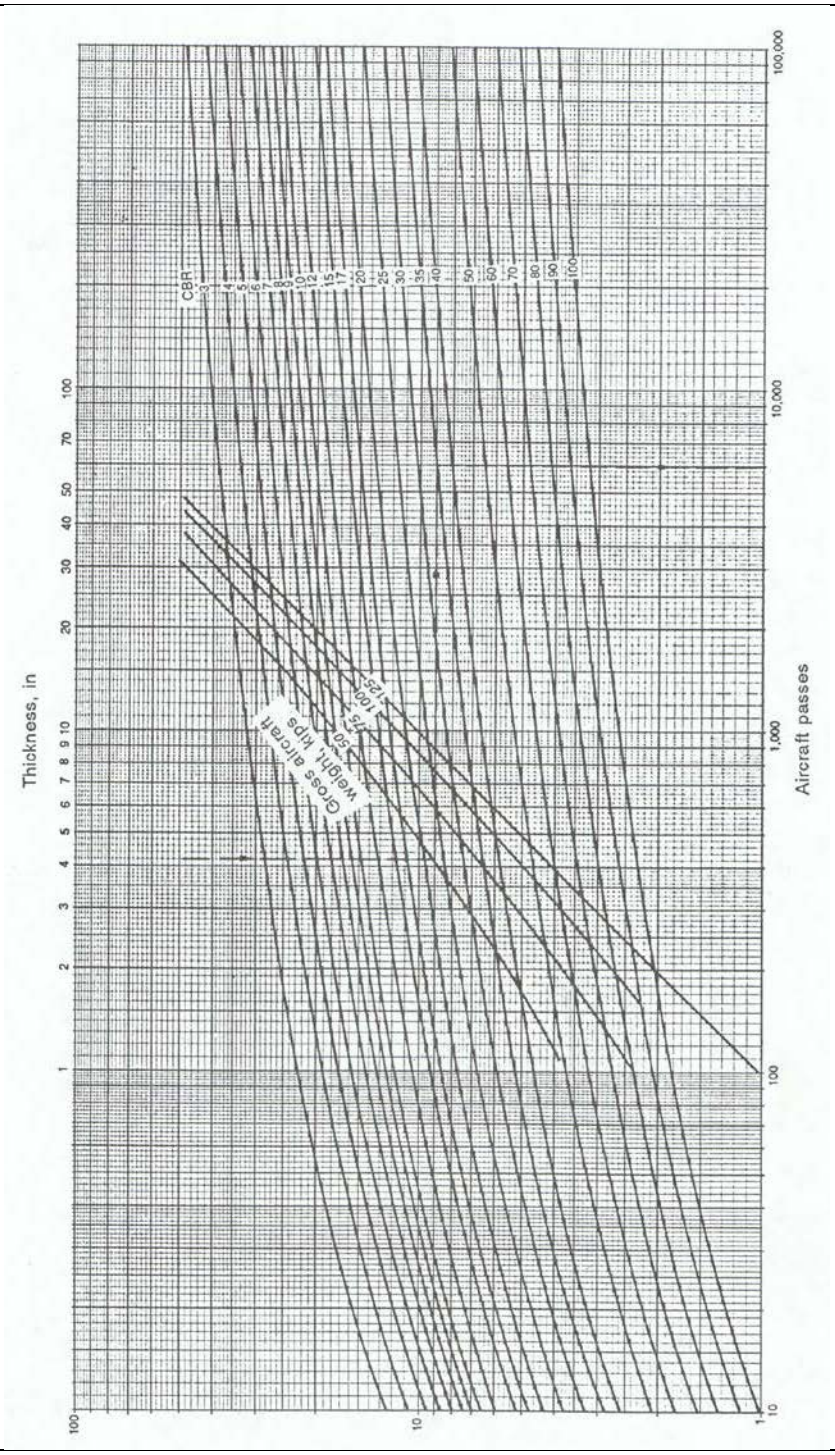
Figure I-3. Flexible-pavement evaluation curves, Group Index II, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

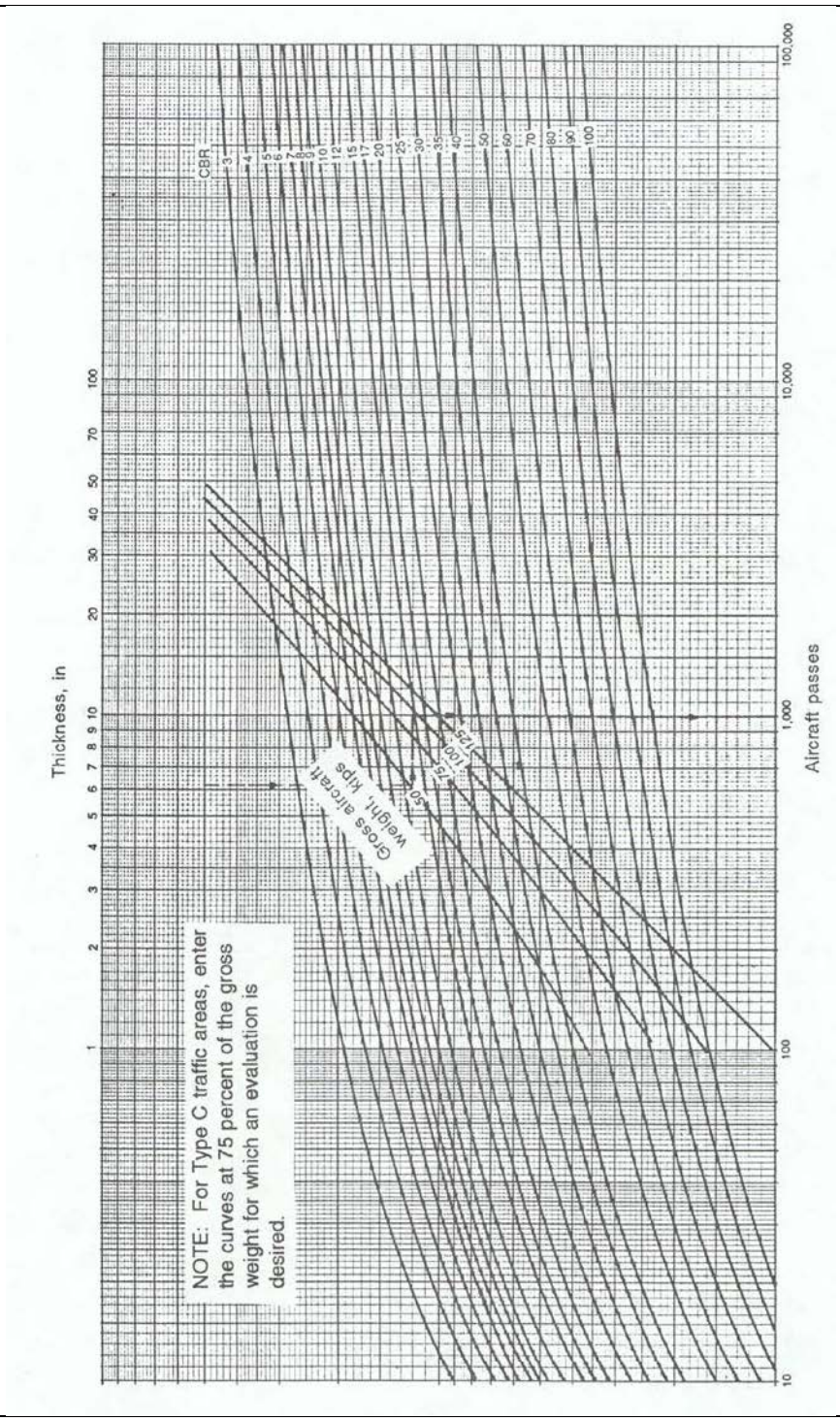
Figure I-4. Flexible-pavement evaluation curves, Group Index II, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

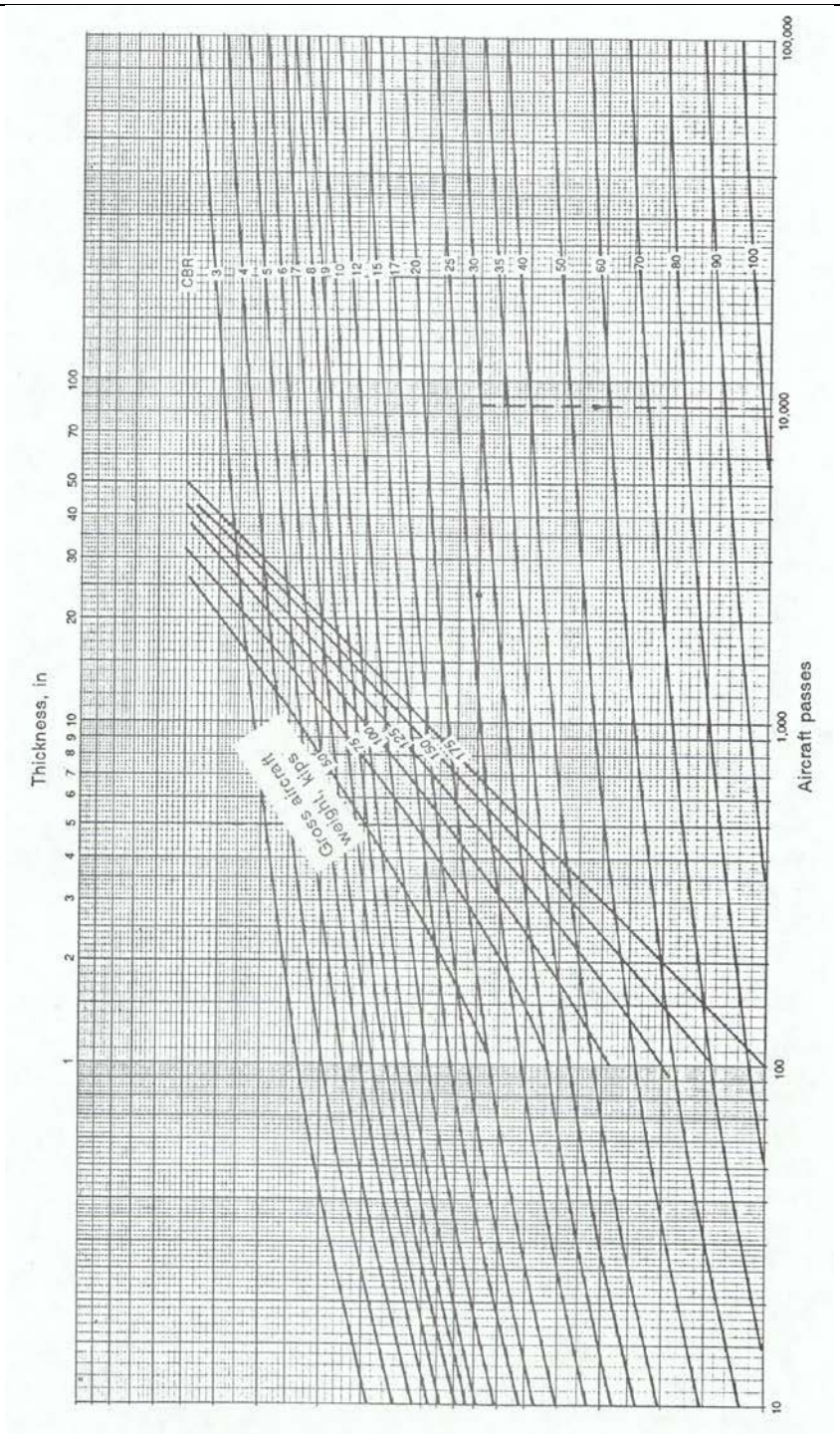
Figure I-5. Flexible-pavement evaluation curves, Group Index III, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

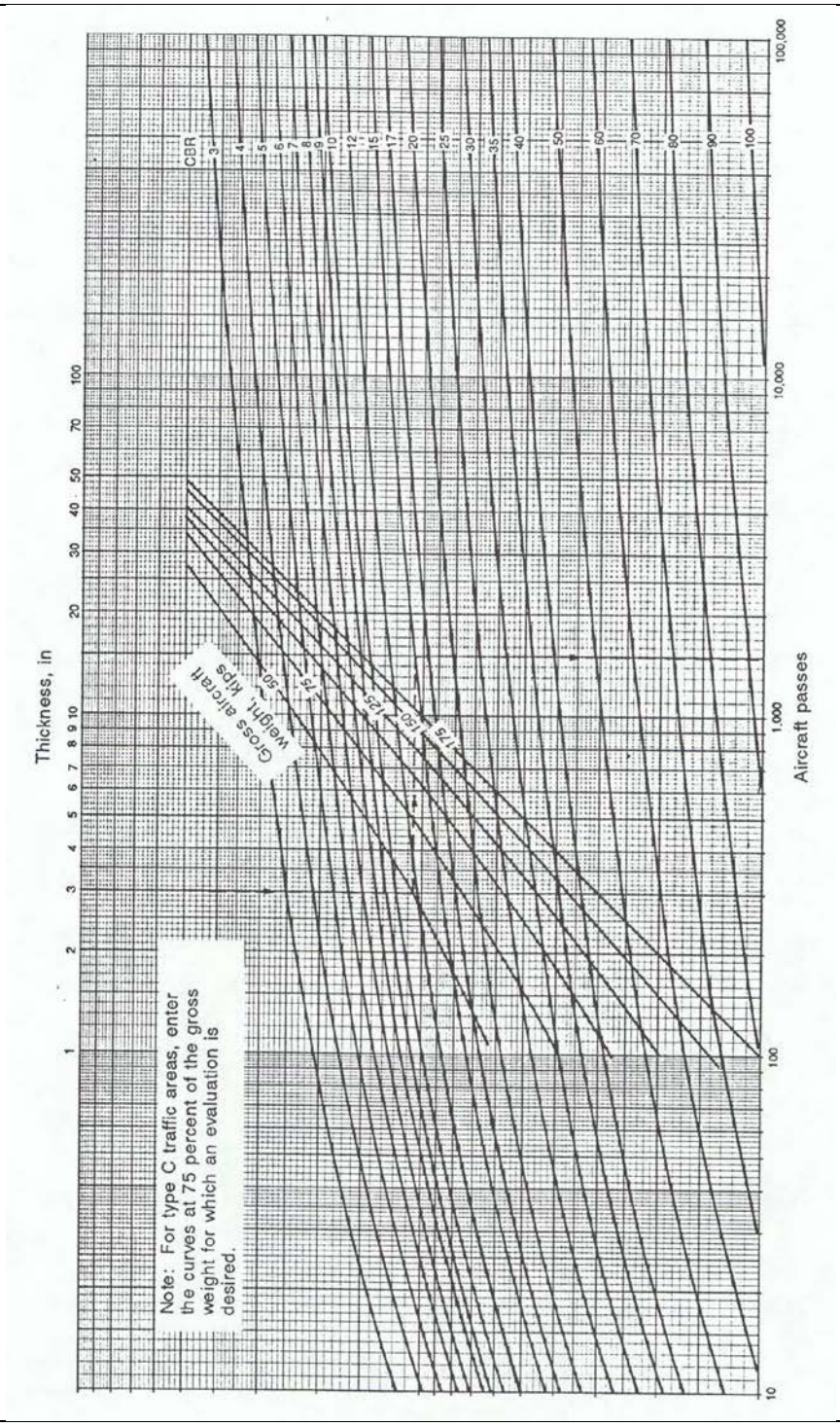
Figure I-6. Flexible-pavement evaluation curves, Group Index III, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

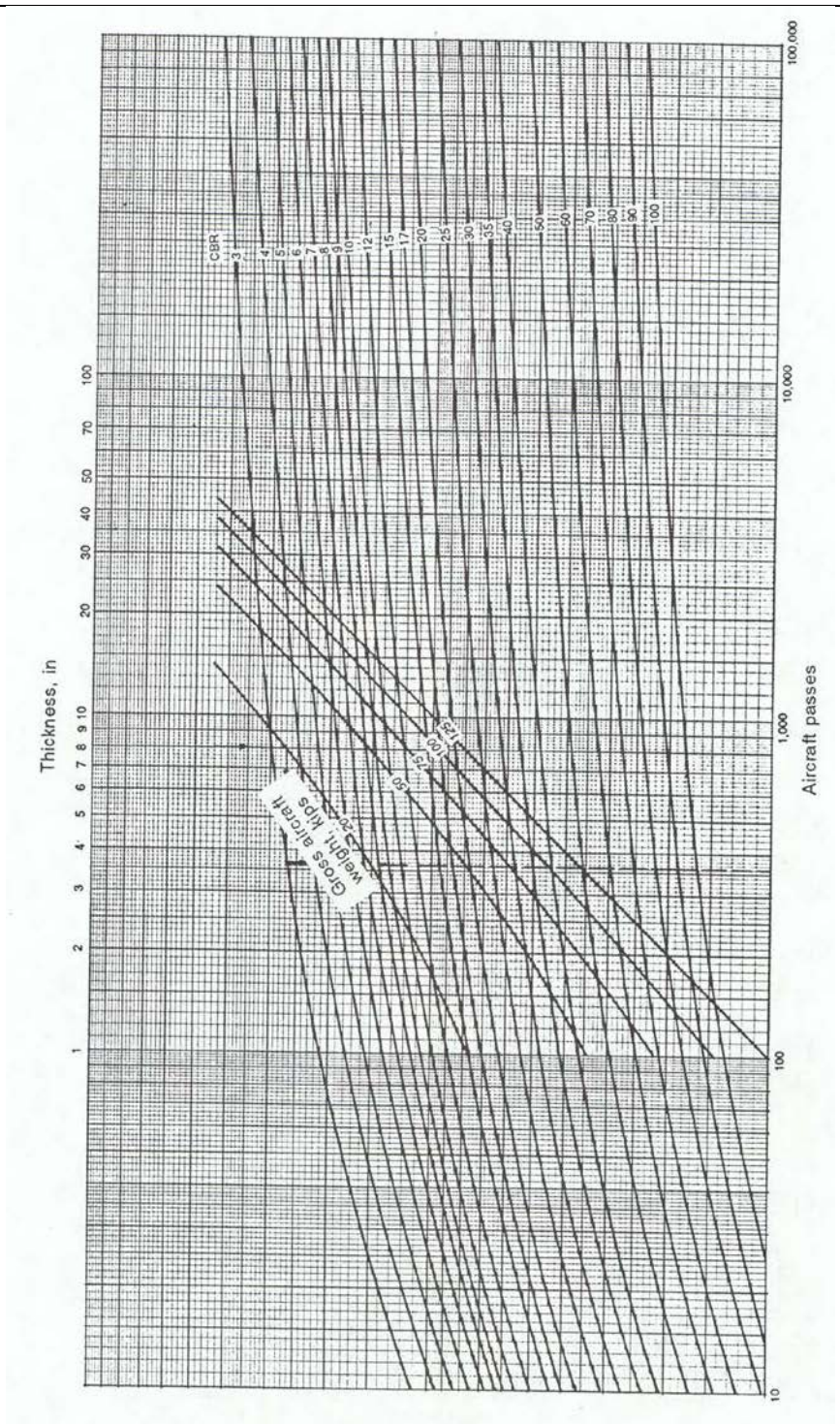
Figure I-7. Flexible-pavement evaluation curves, Group Index IV, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

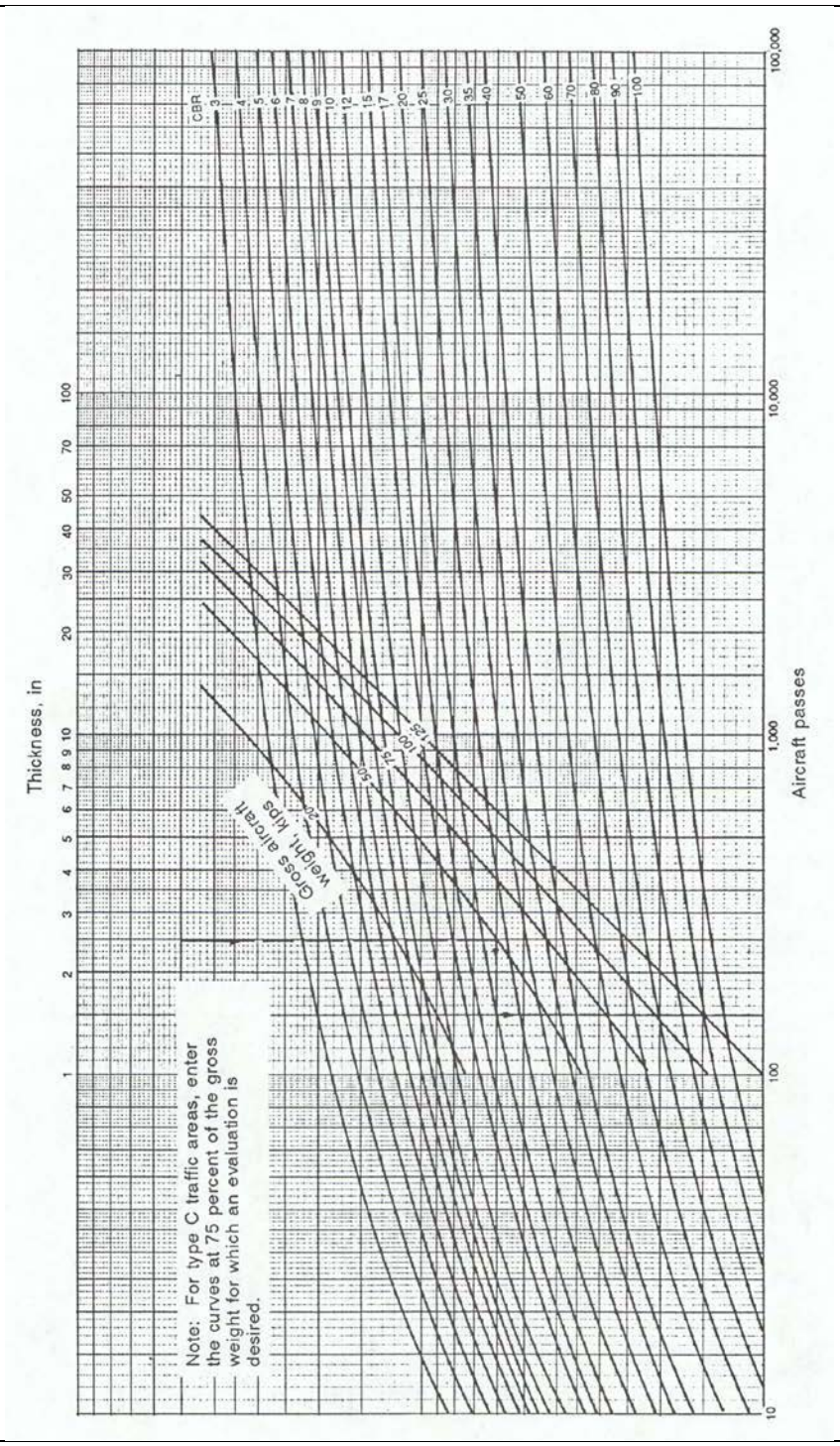
Figure I-8. Flexible-pavement evaluation curves, Group Index IV, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

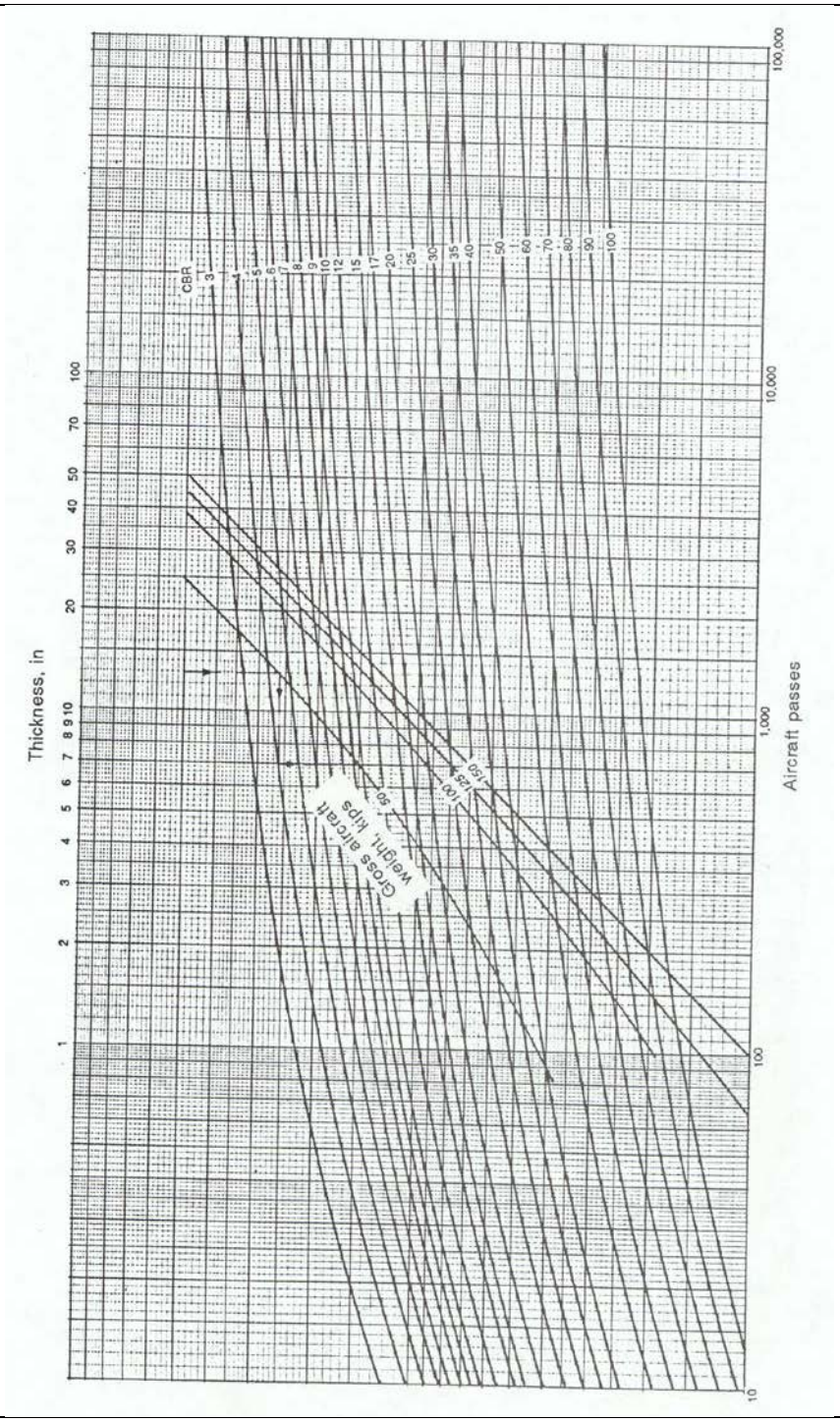
Figure I-9. Flexible-pavement evaluation curves, Group Index V, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

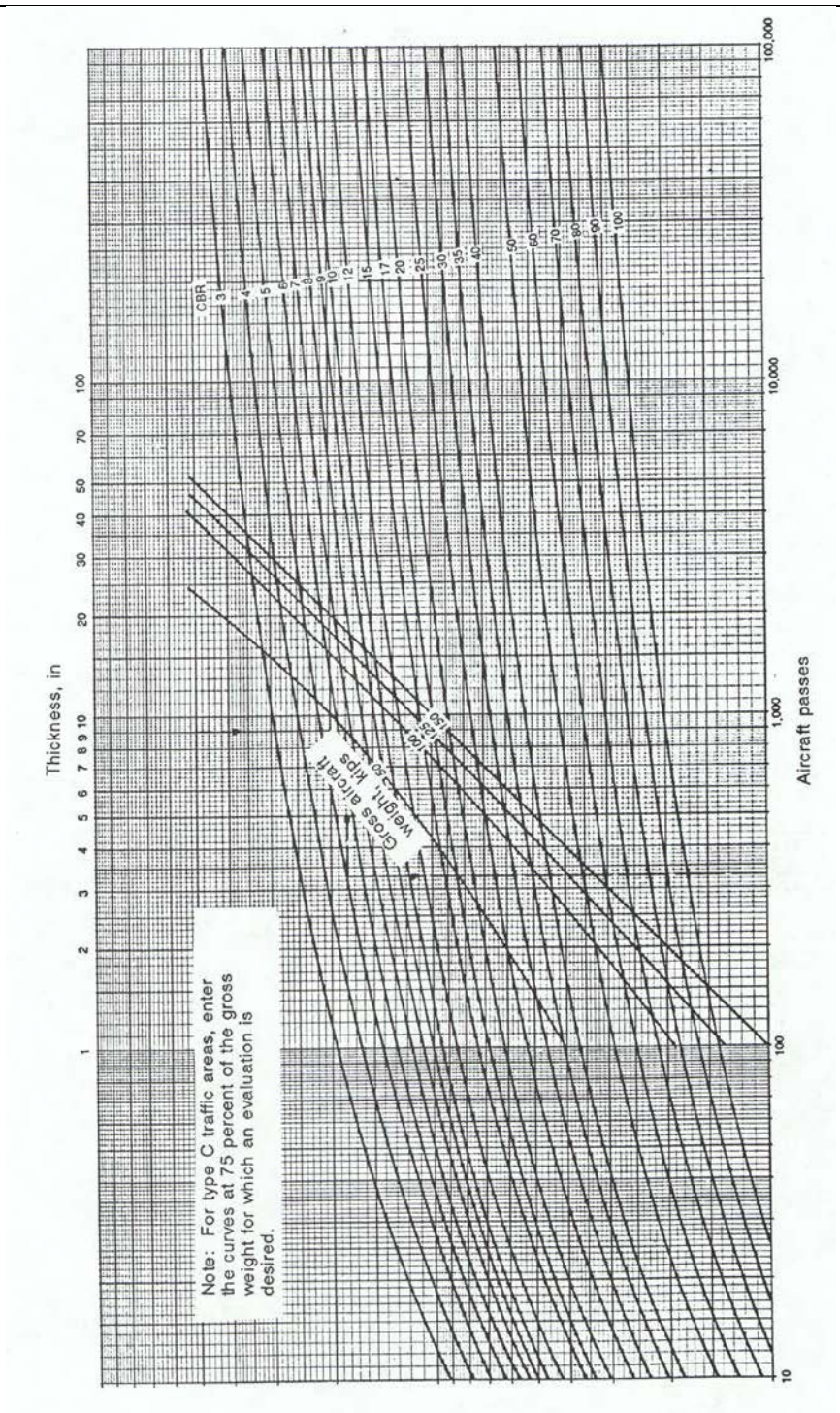
Figure I-10. Flexible-pavement evaluation curves, Group Index V, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

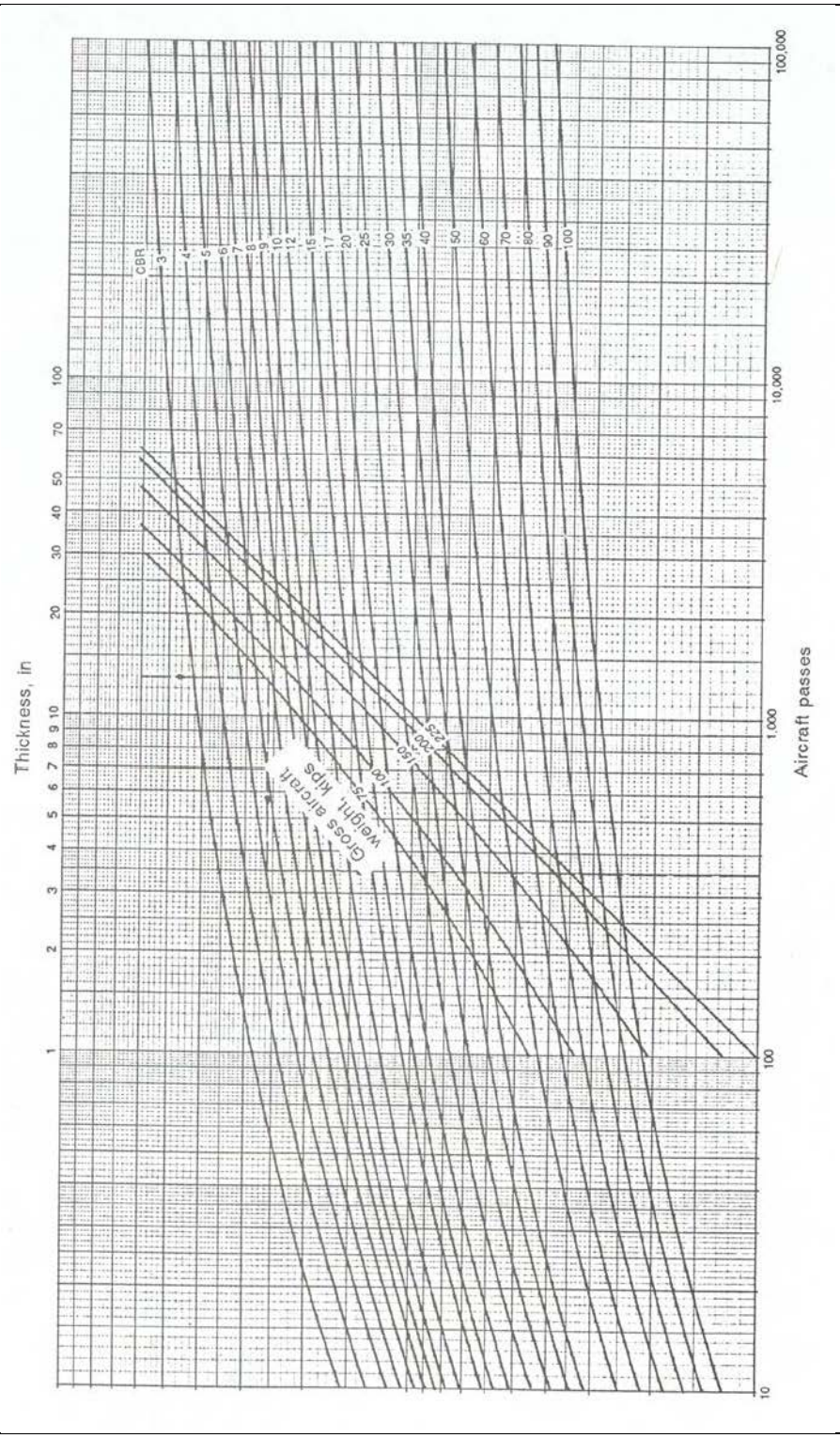
Figure I-11. Flexible-pavement evaluation curves, Group Index VI, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

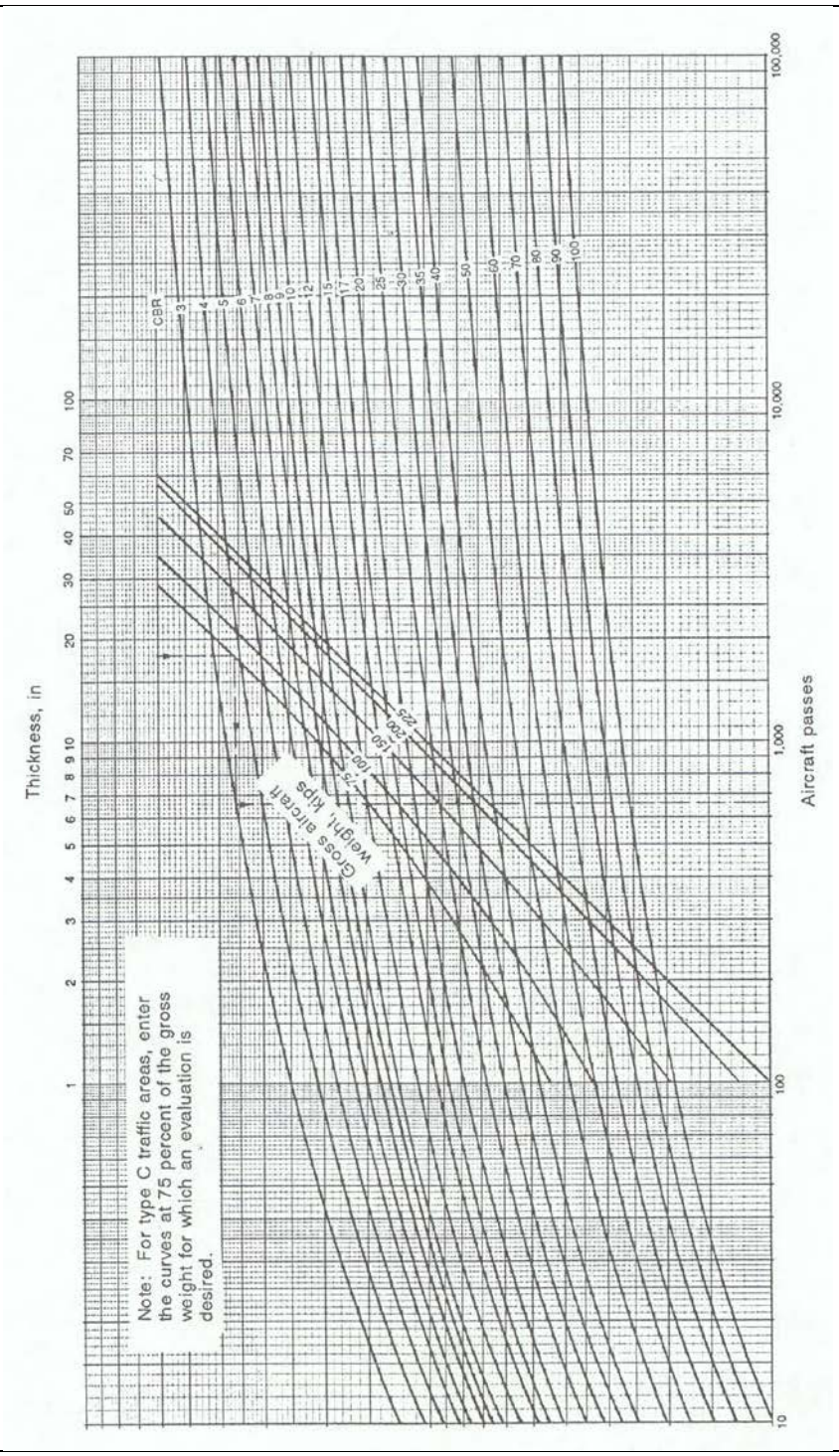
Figure I-12. Flexible-pavement evaluation curves, Group Index VI, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

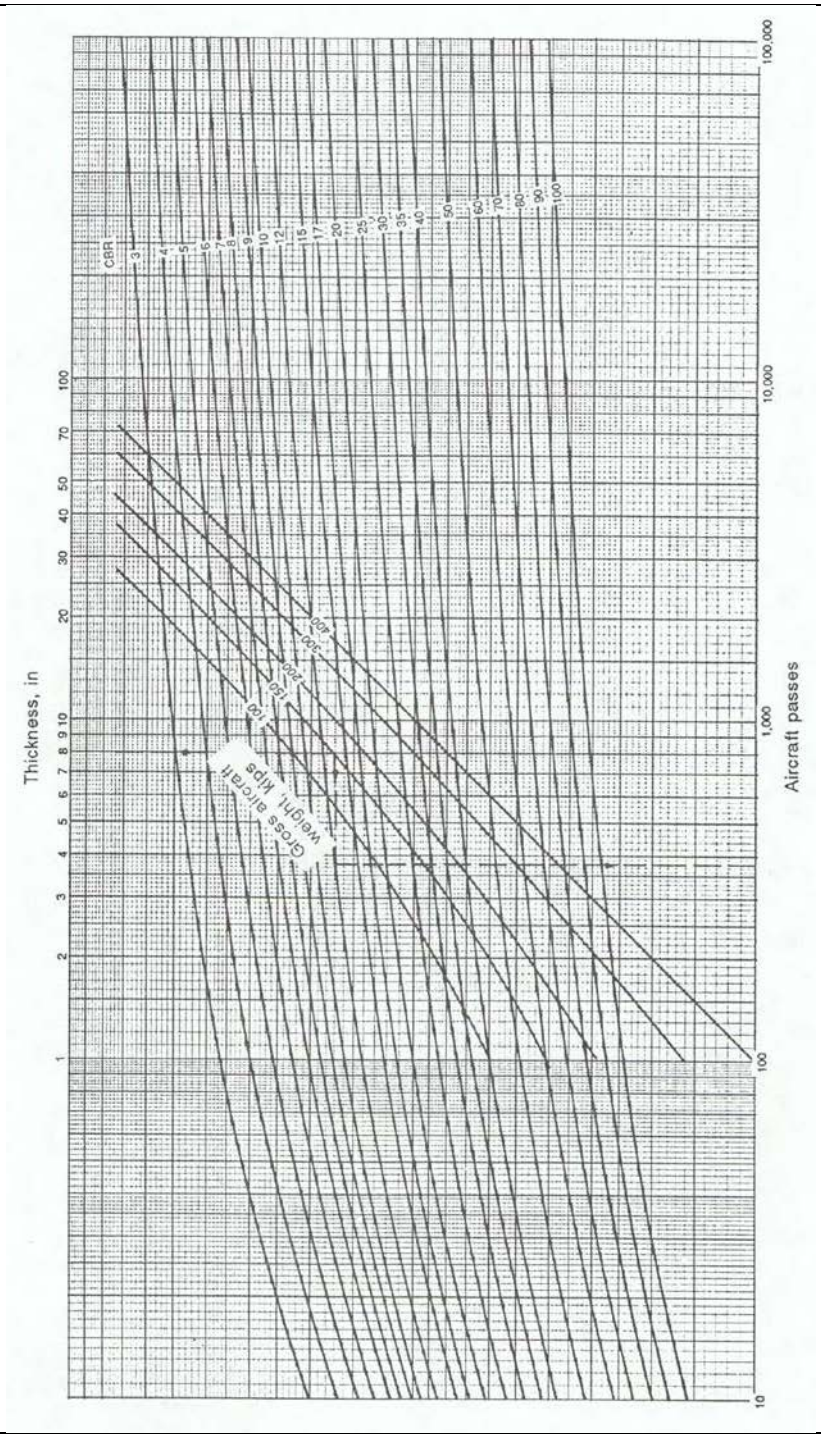
Figure I-13. Flexible-pavement evaluation curves, Group Index VII, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

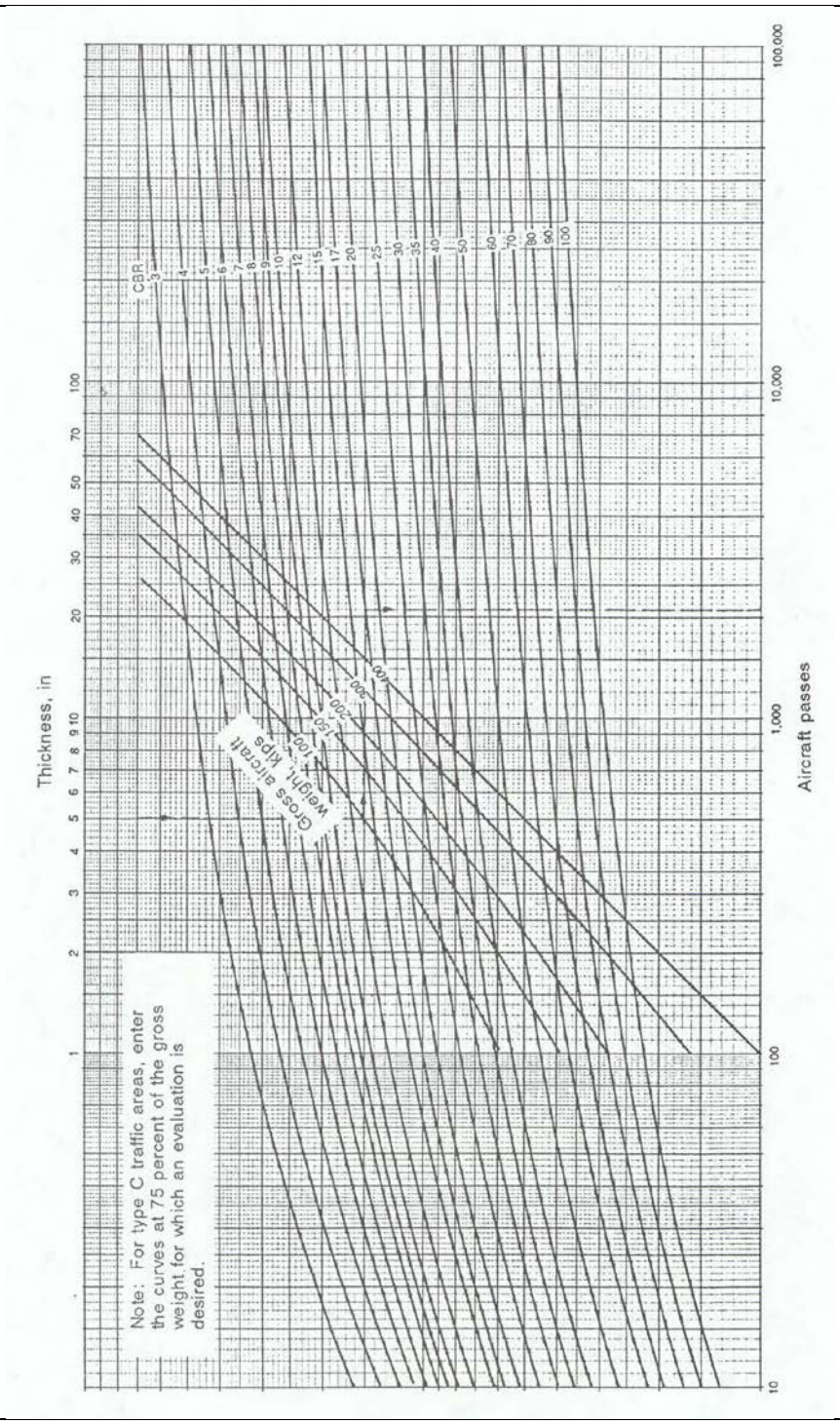
Figure I-14. Flexible-pavement evaluation curves, Group Index VII, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

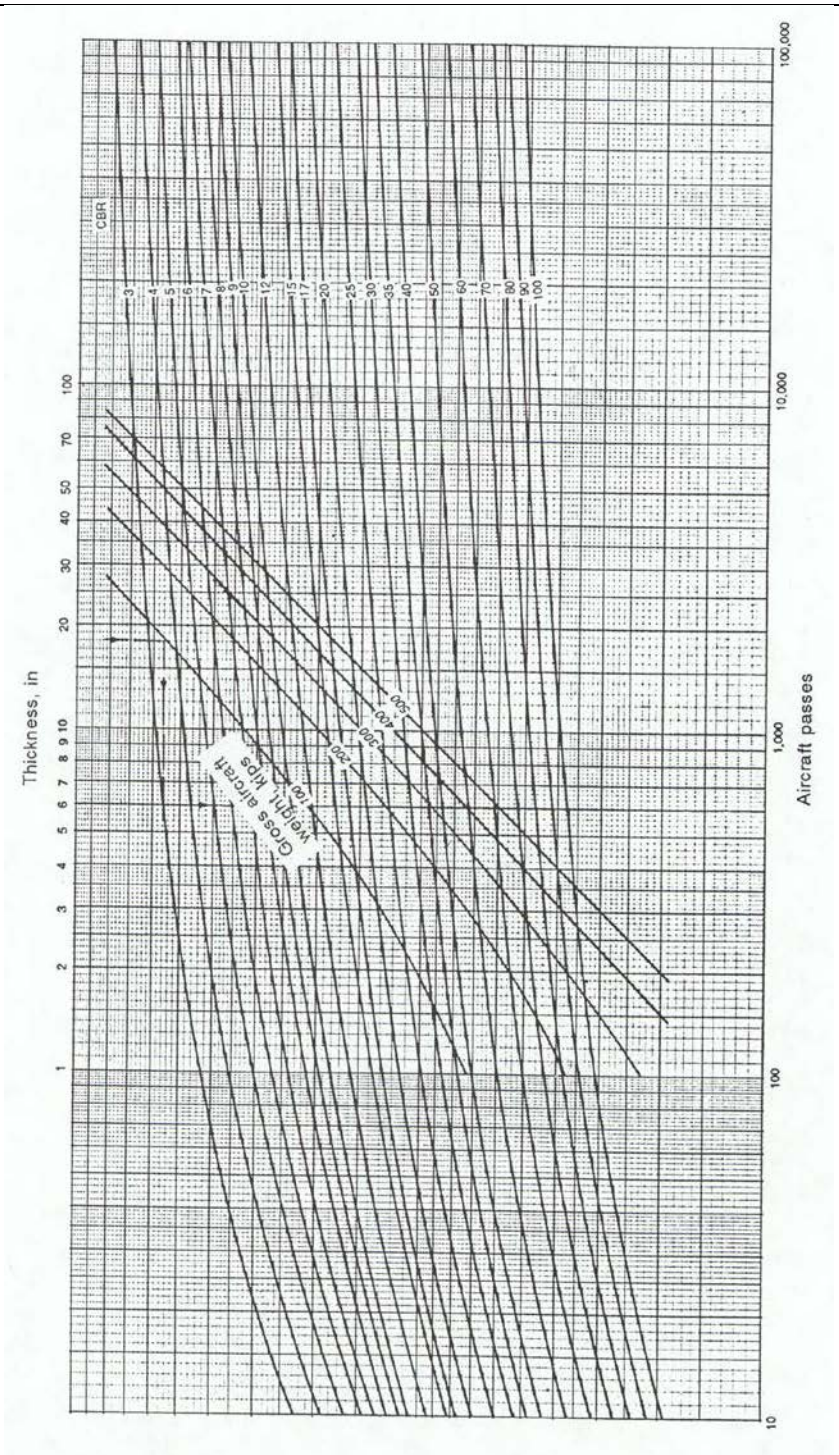
Figure I-15. Flexible-pavement evaluation curves, Group Index VIII, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

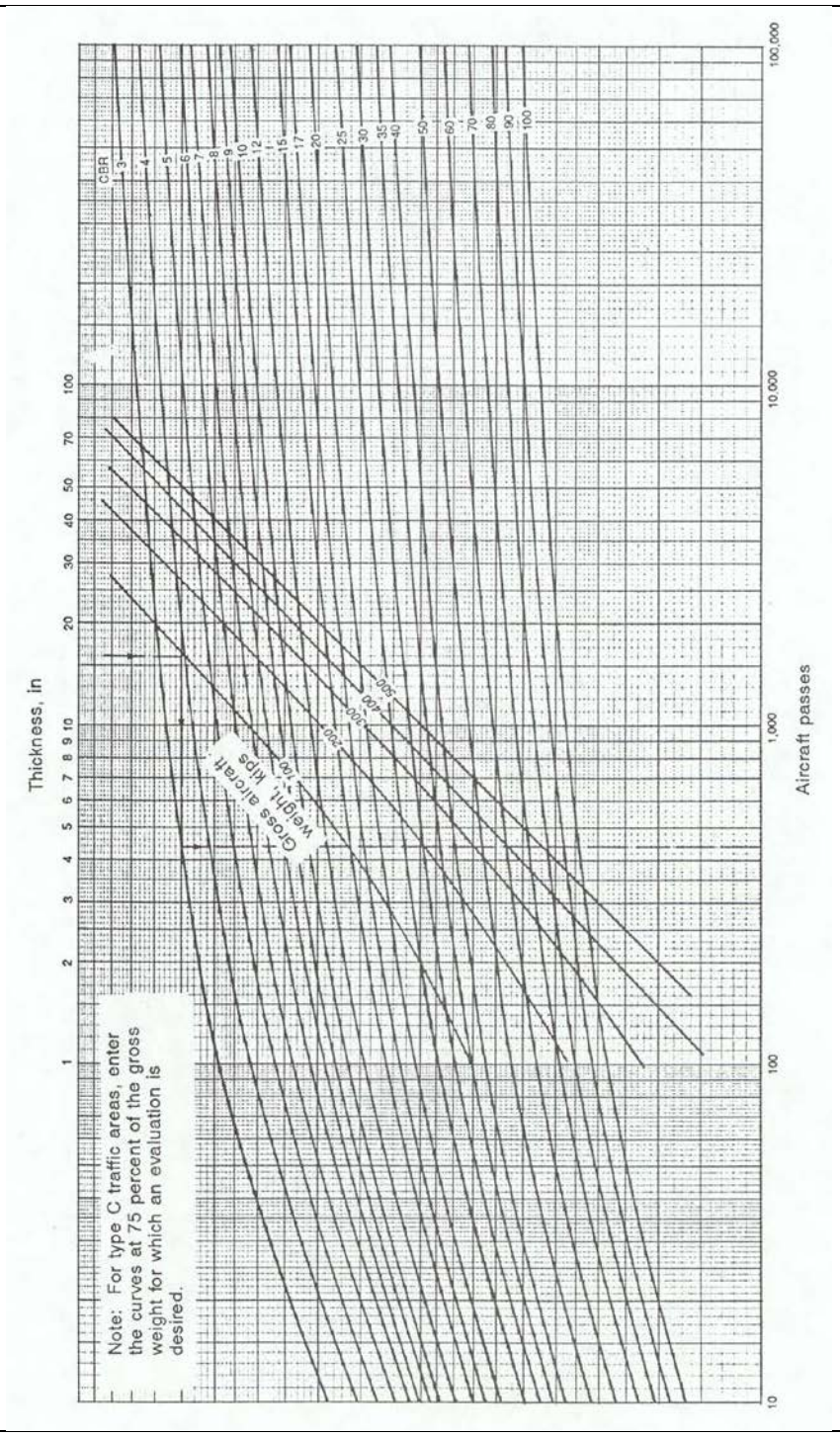
Figure I-16. Flexible-pavement evaluation curves, Group Index VIII, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

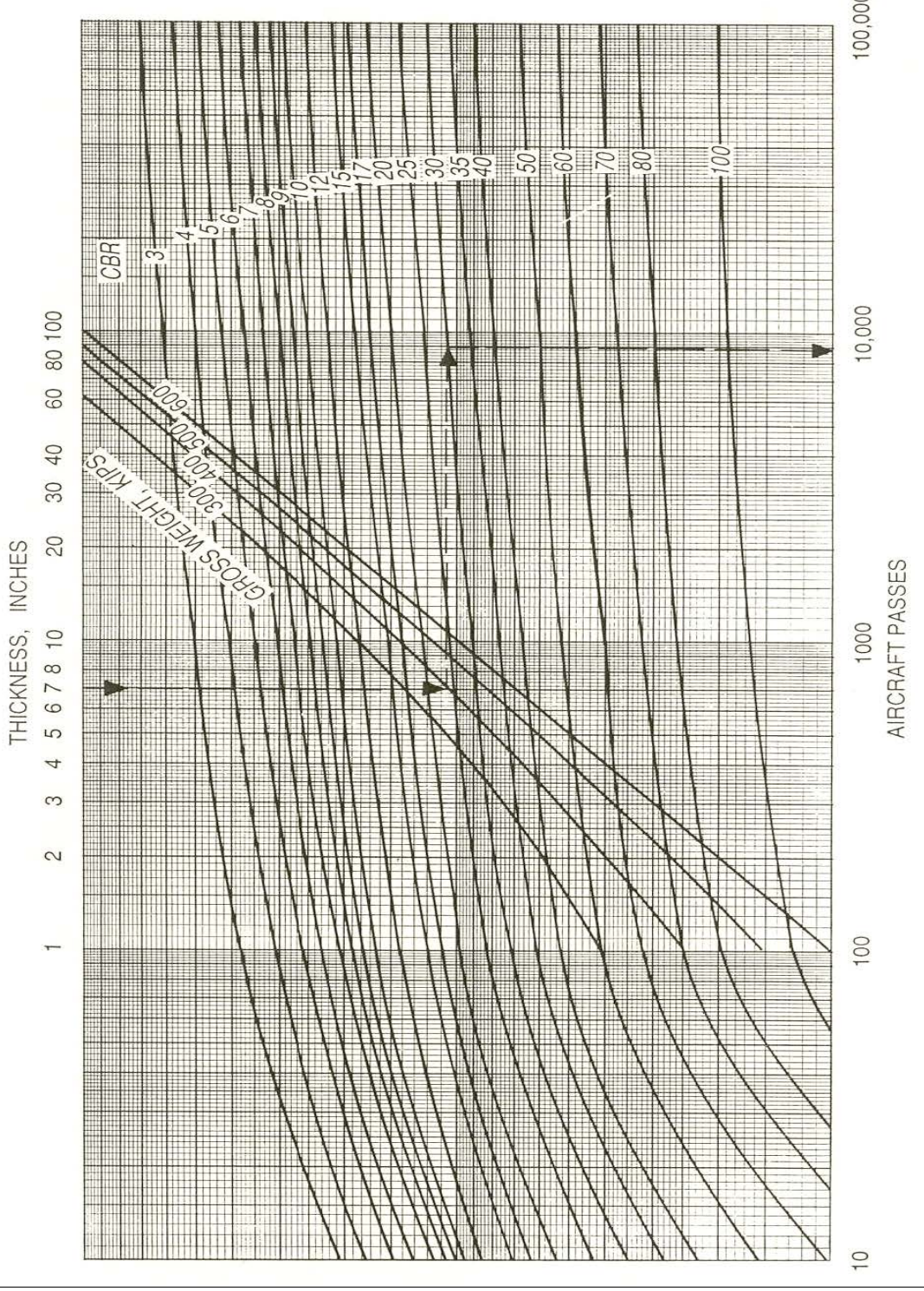
Figure I-17. Flexible-pavement evaluation curves, Group Index IX, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

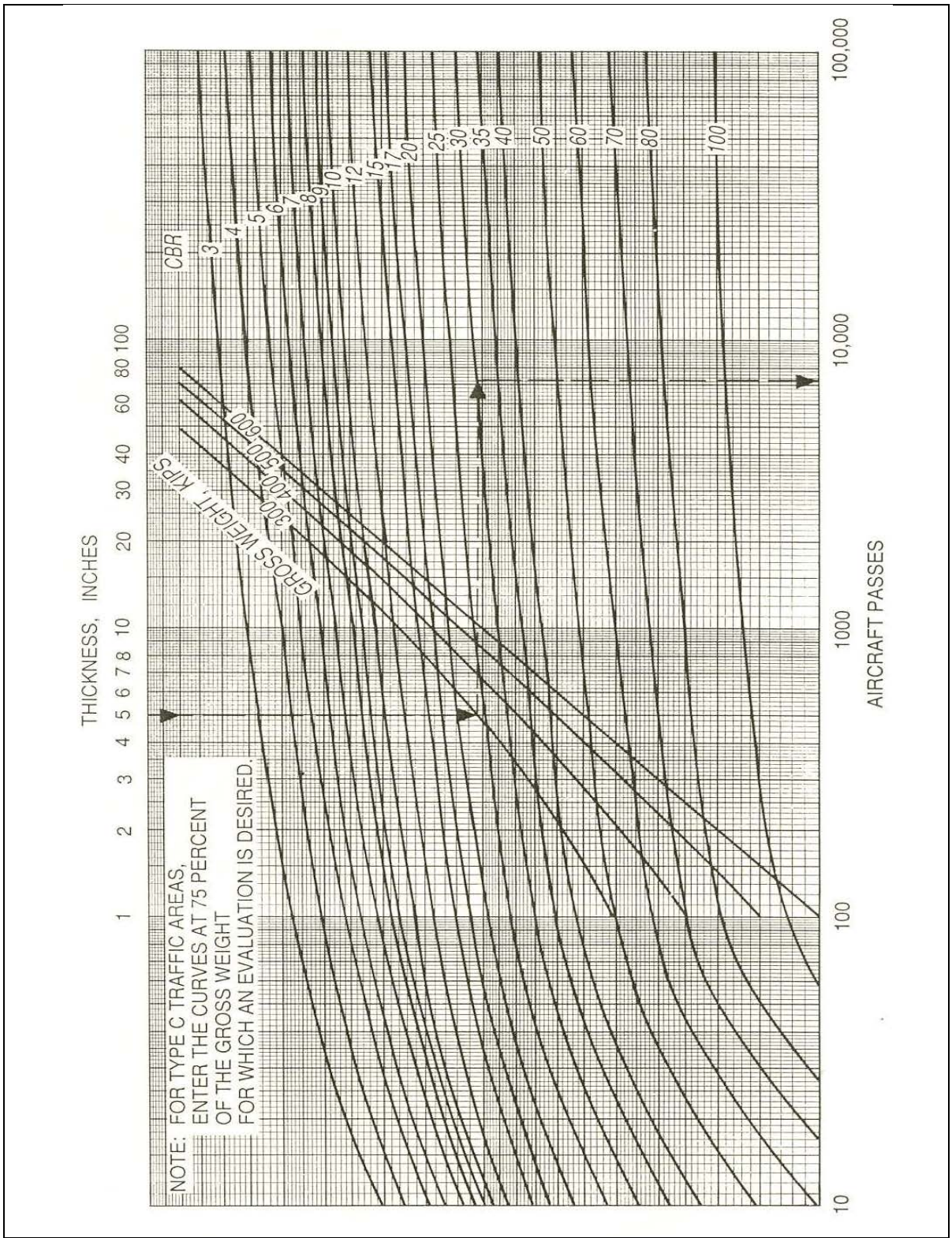
Figure I-18. Flexible-pavement evaluation curves, Group Index IX, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

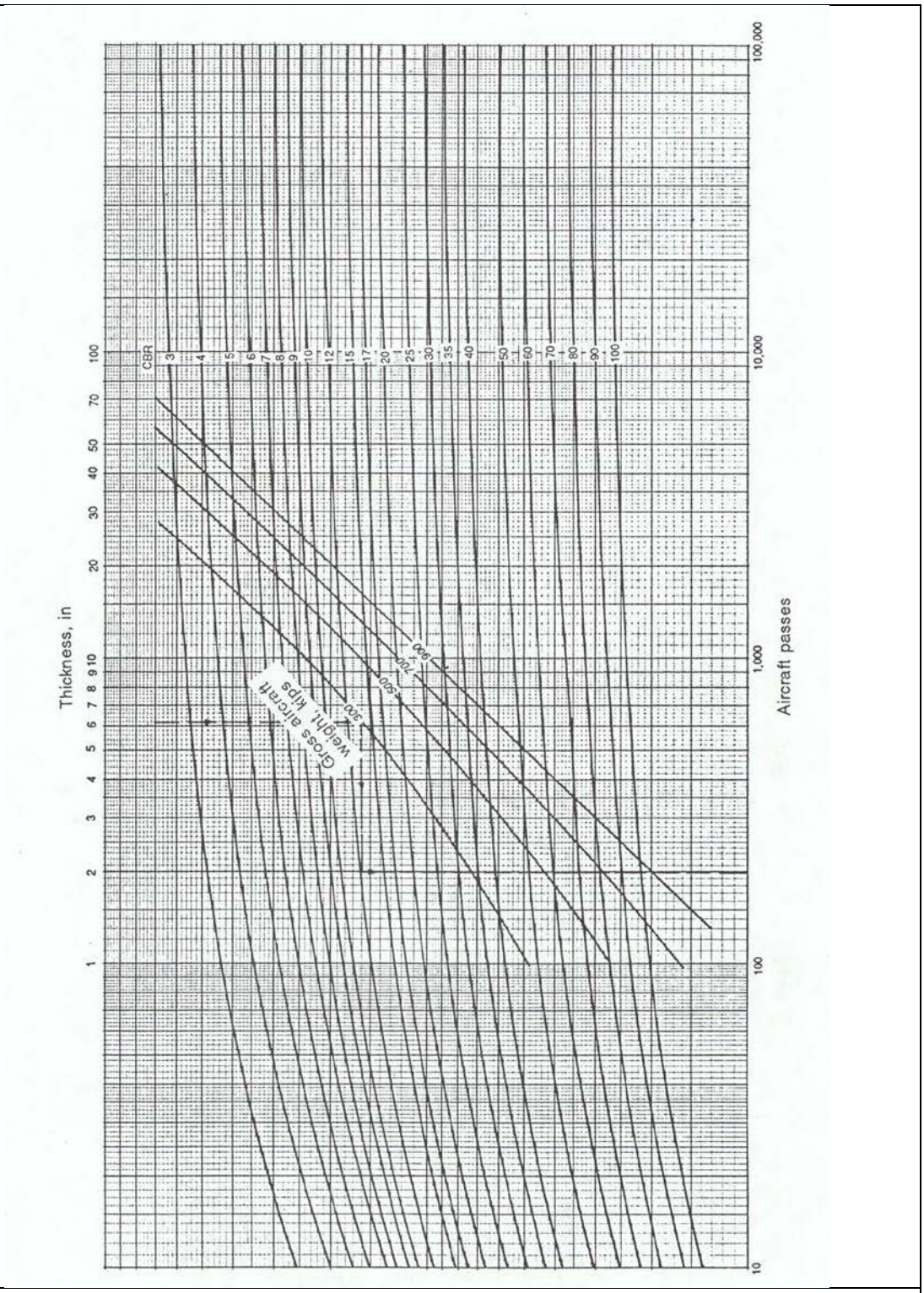
Figure I-19. Flexible-pavement evaluation curves, Group Index X, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

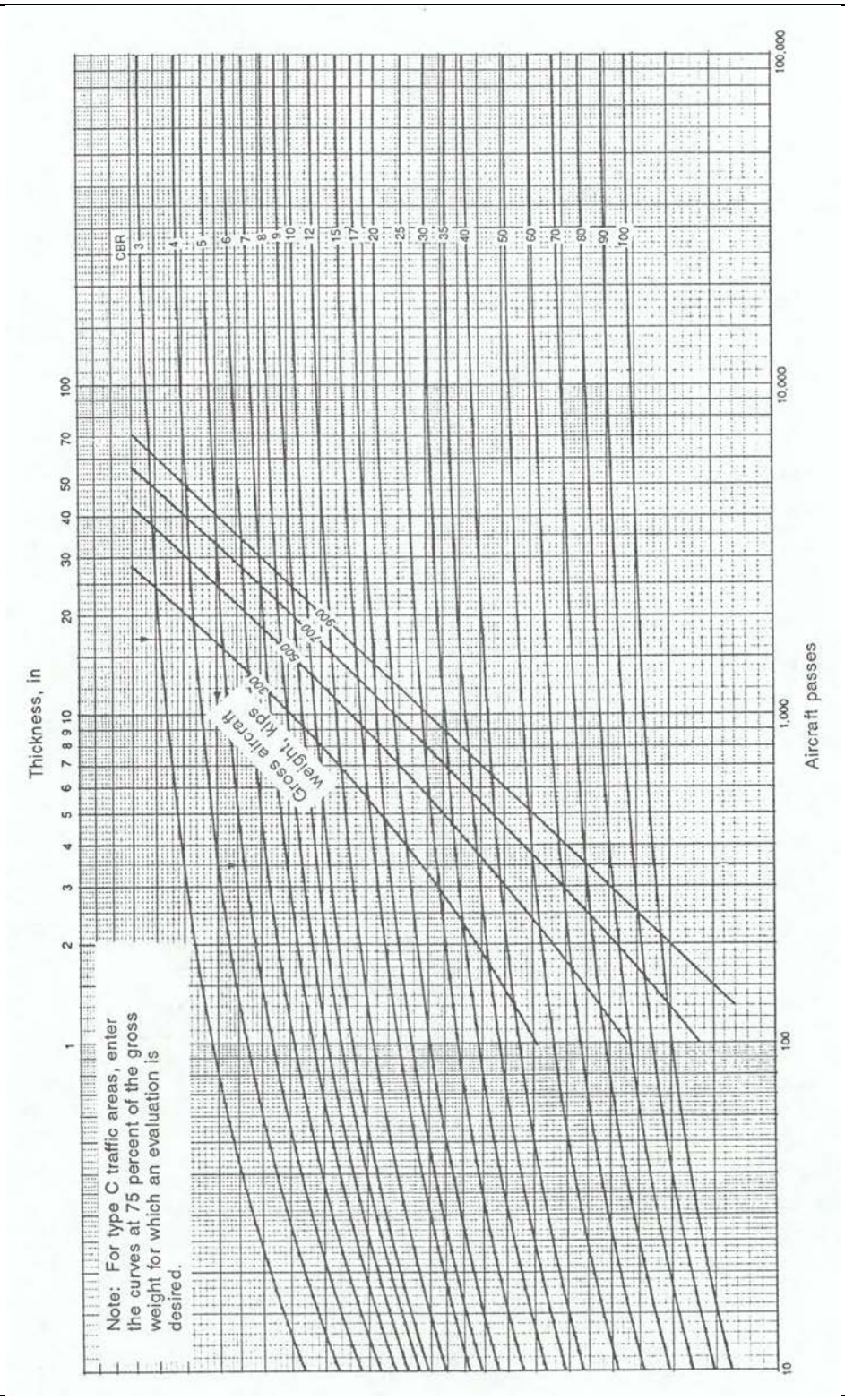
Figure I-20. Flexible-pavement evaluation curves, Group Index X, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

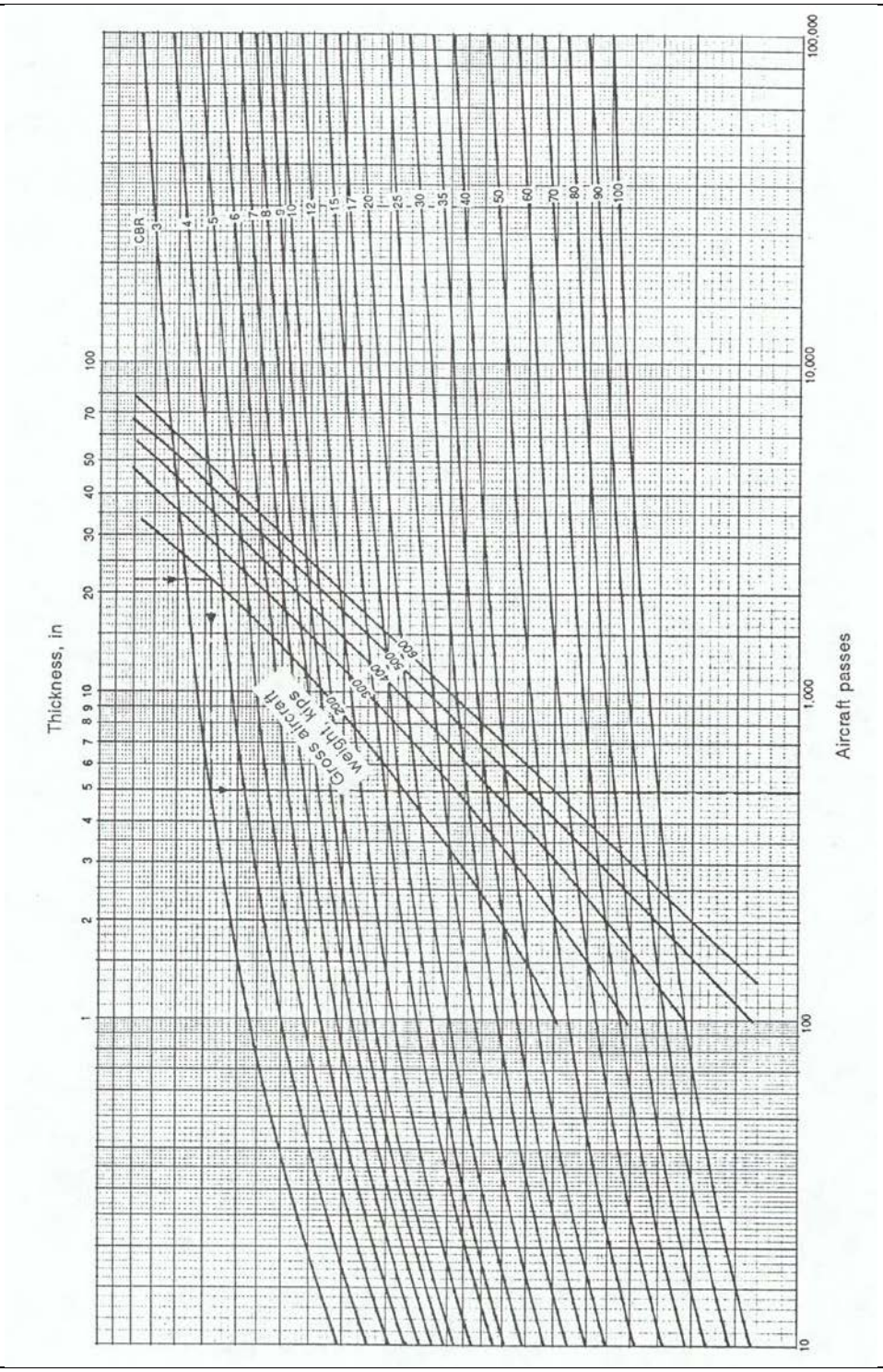
Figure I-21. Flexible-pavement evaluation curves, Group Index X, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

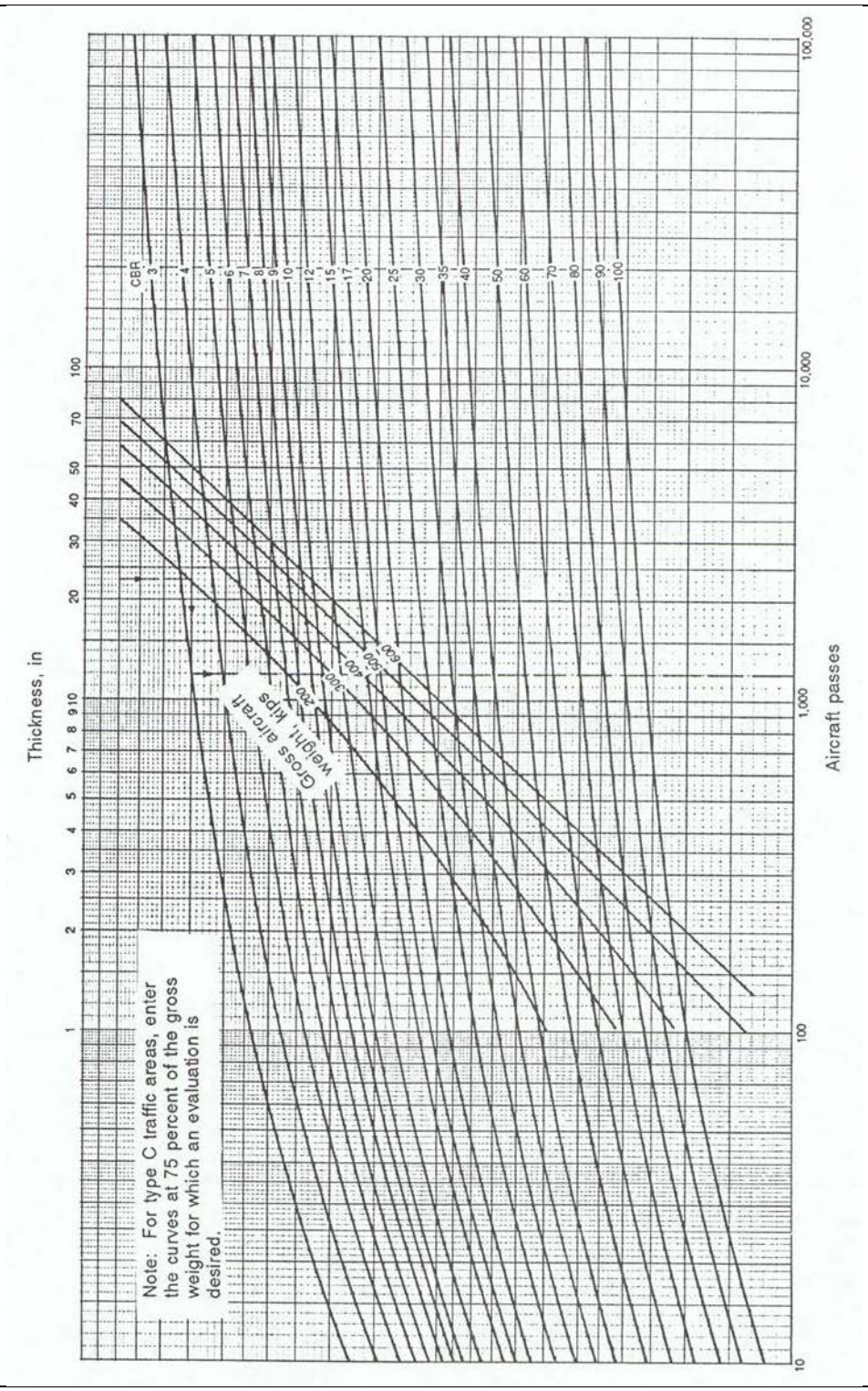
Figure I-22. Flexible-pavement evaluation curves, Group Index X, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

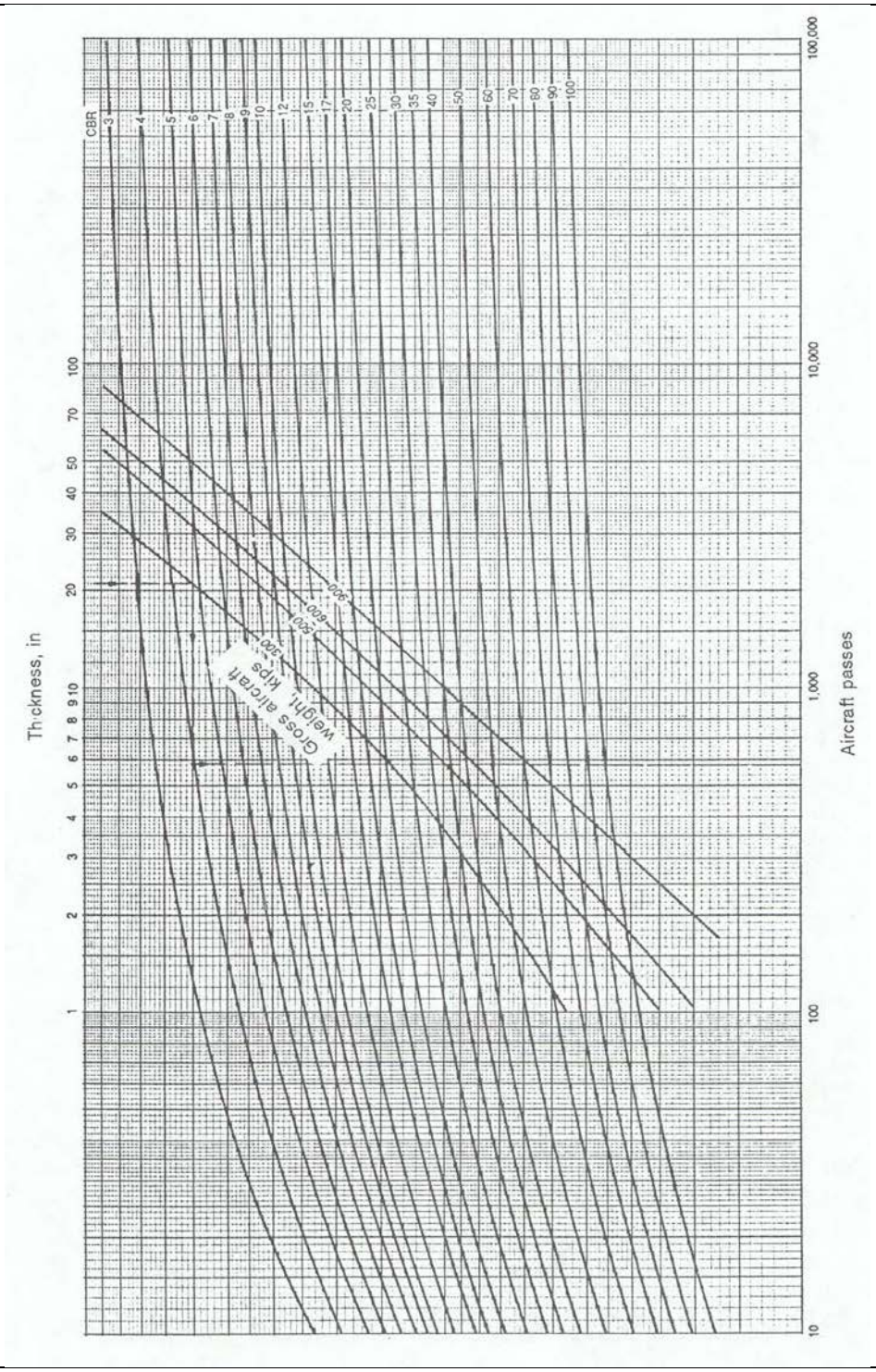
Figure I-23. Flexible-pavement evaluation curves, Group Index XI, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

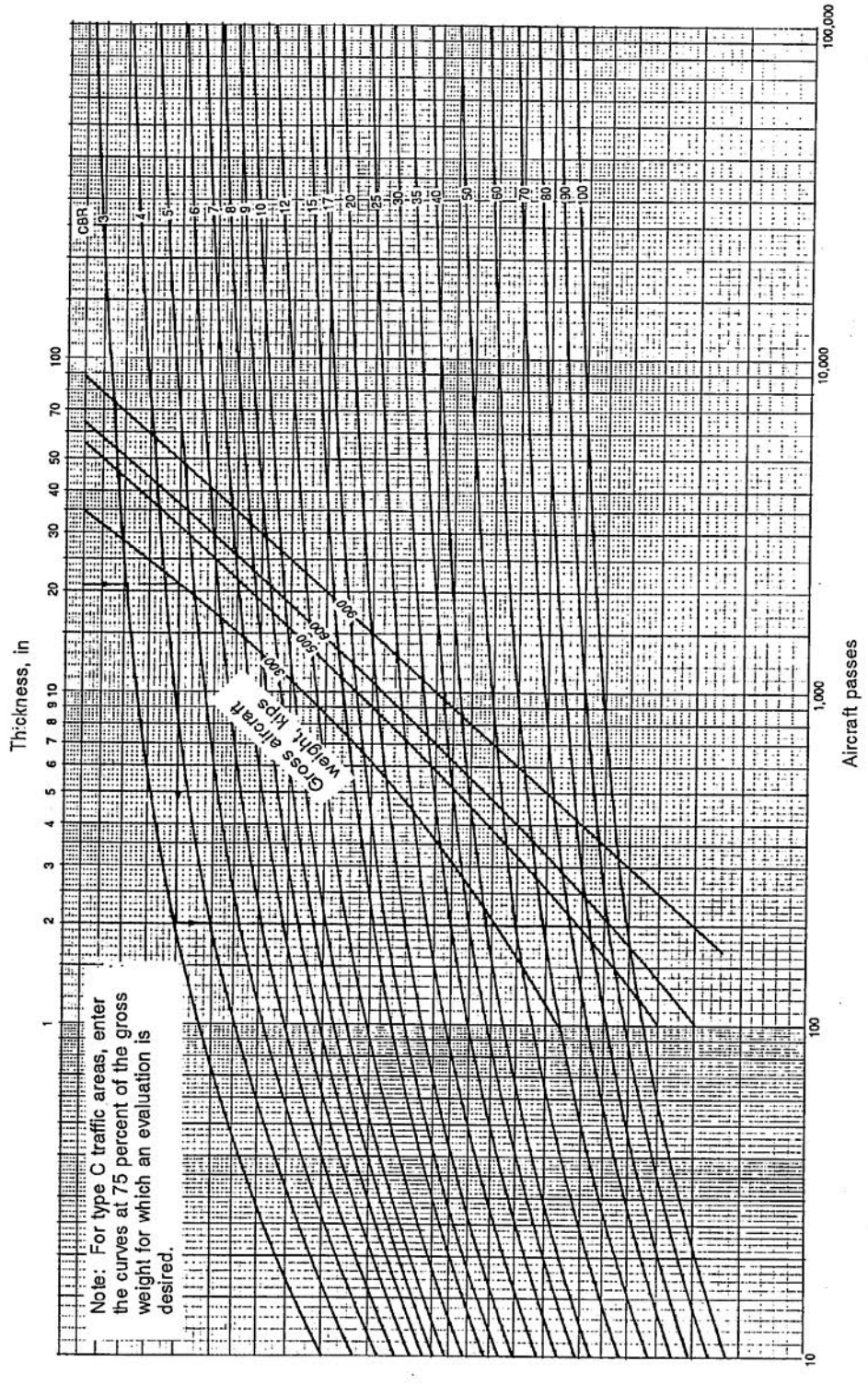
Figure I-24. Flexible-pavement evaluation curves, Group Index XII, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

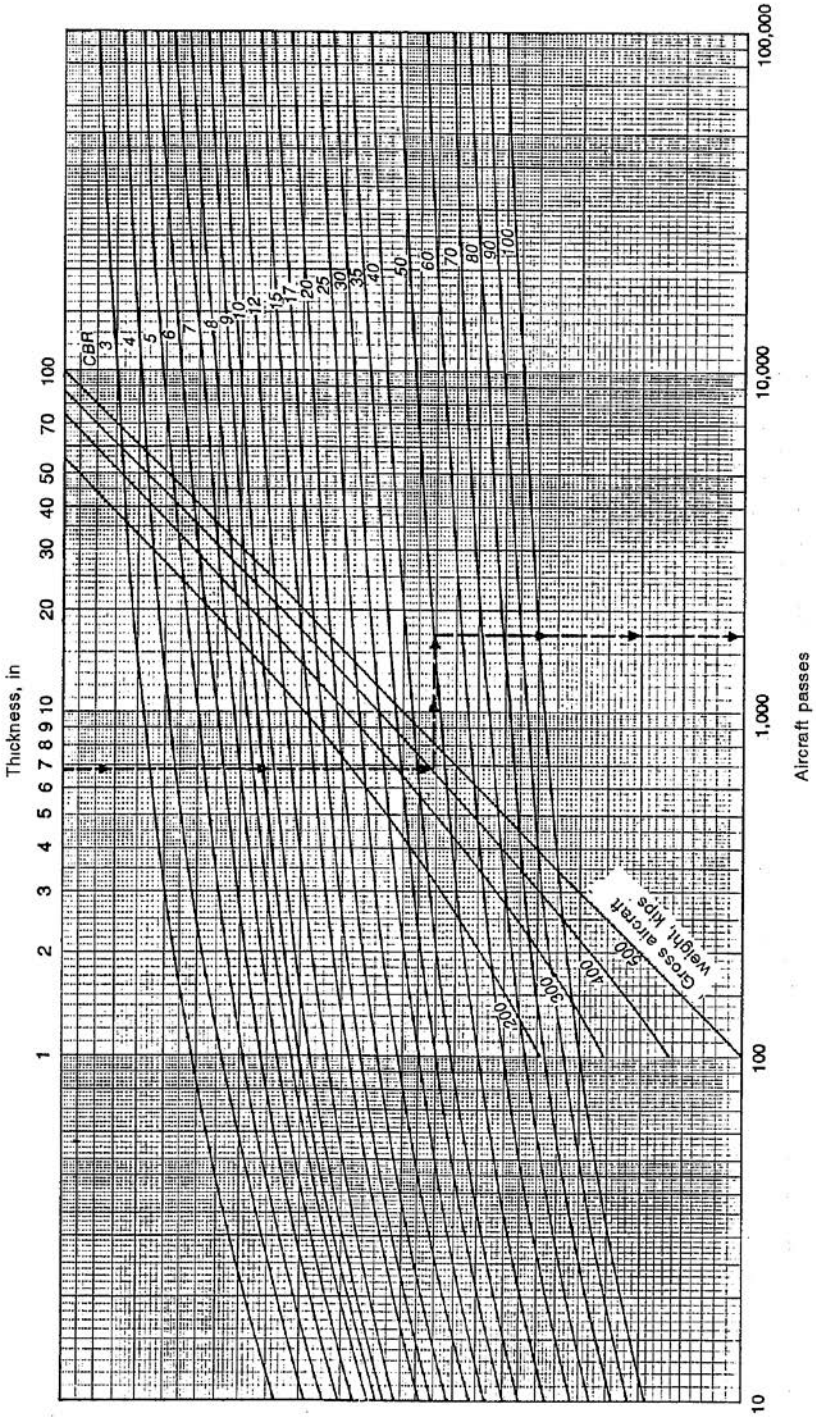
Figure I-25. Flexible-pavement evaluation curves, Group Index XIII, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

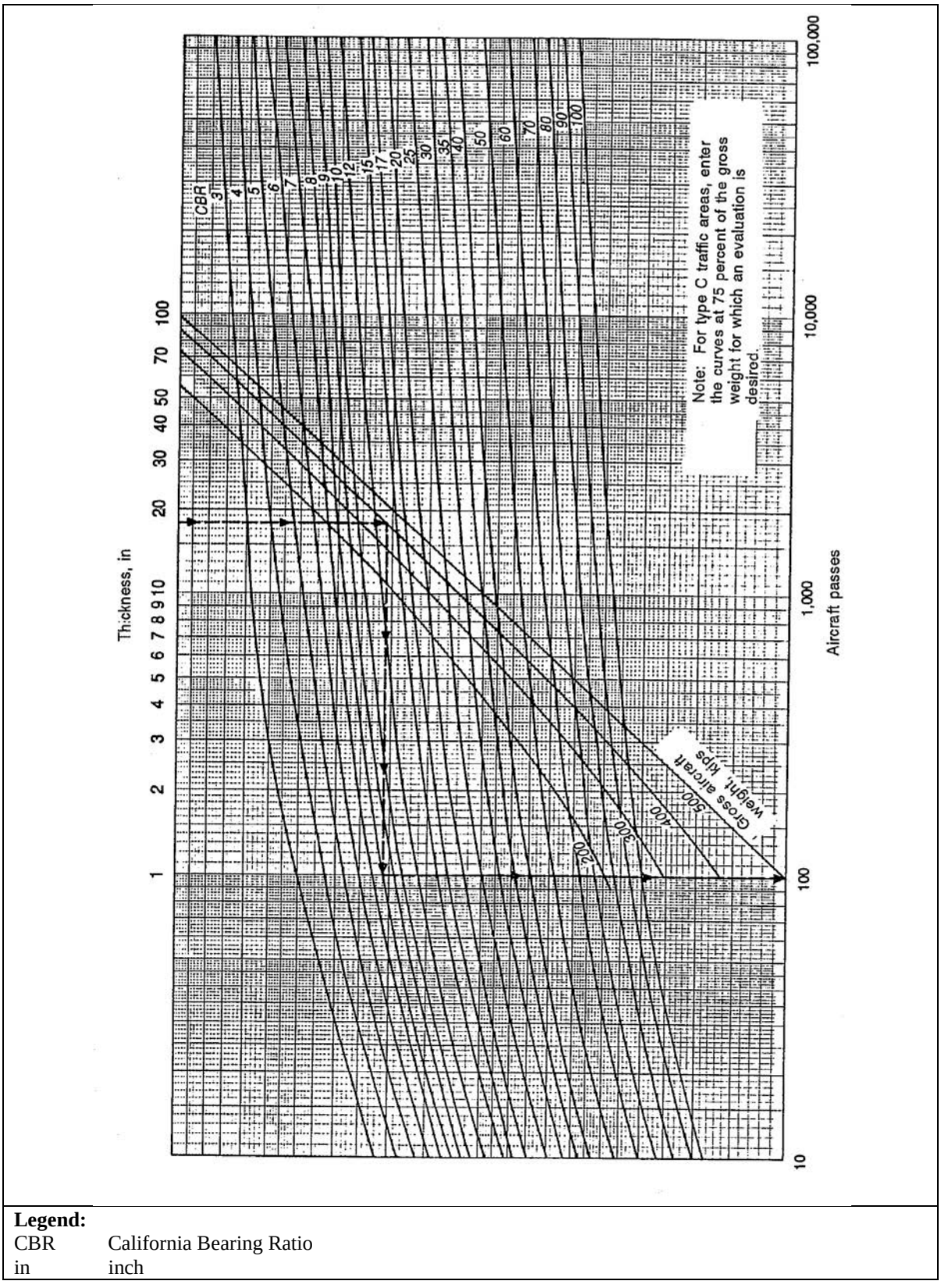
Figure I-26. Flexible-pavement evaluation curves, Group Index XIII, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

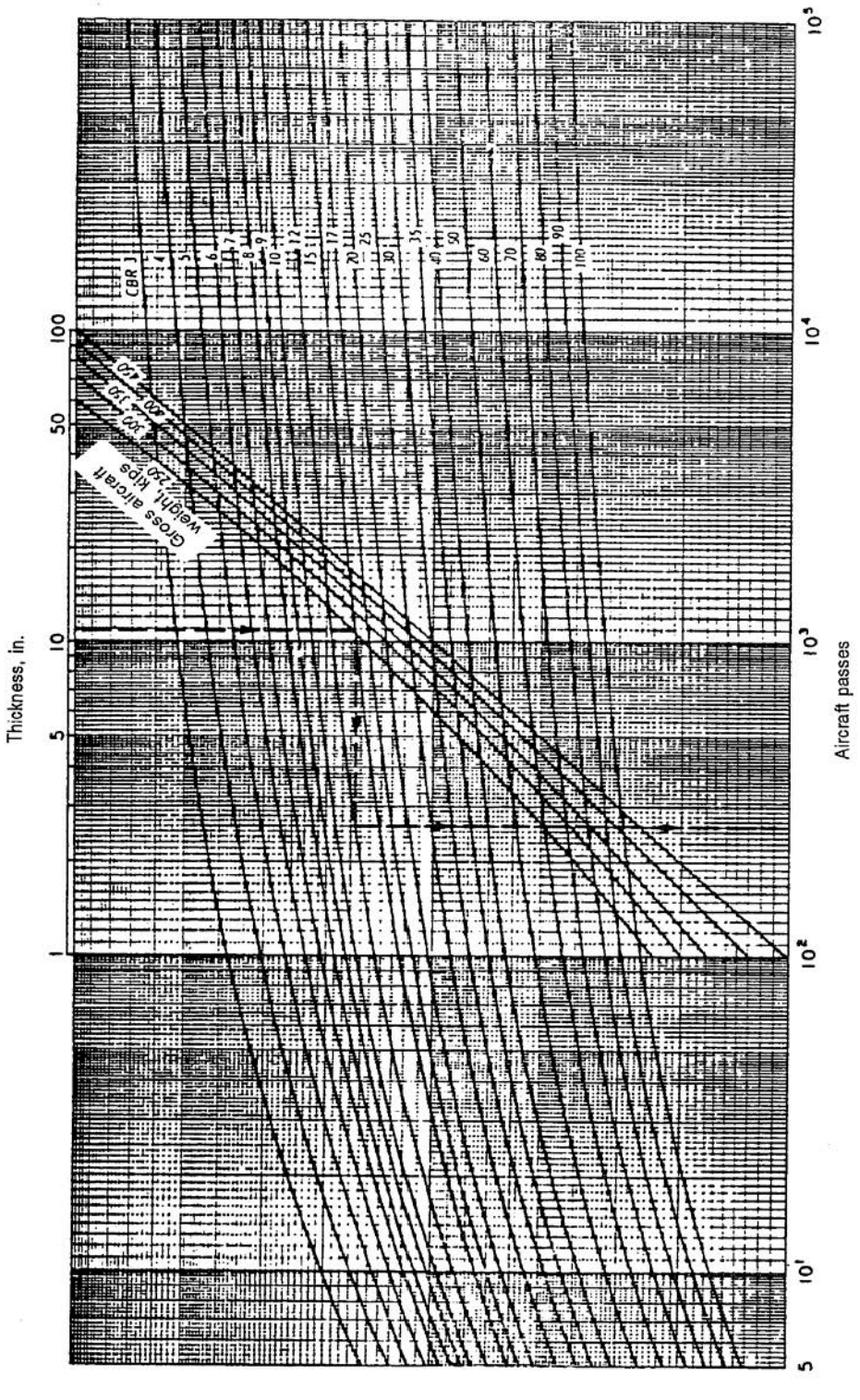
Figure I-27. Flexible-pavement evaluation curves, Group Index XIV, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

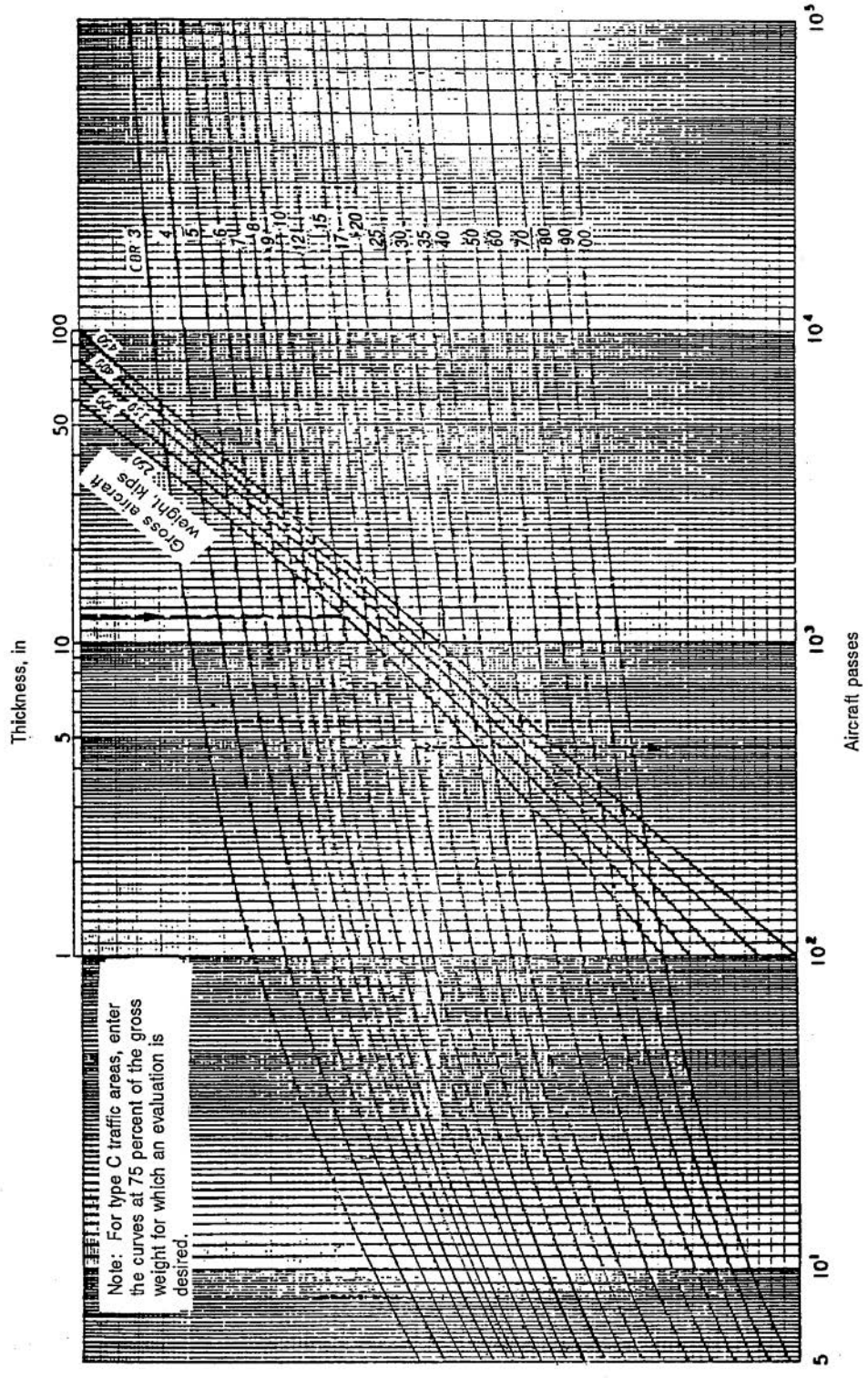
Figure I-28. Flexible-pavement evaluation curves, Group Index XIV, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

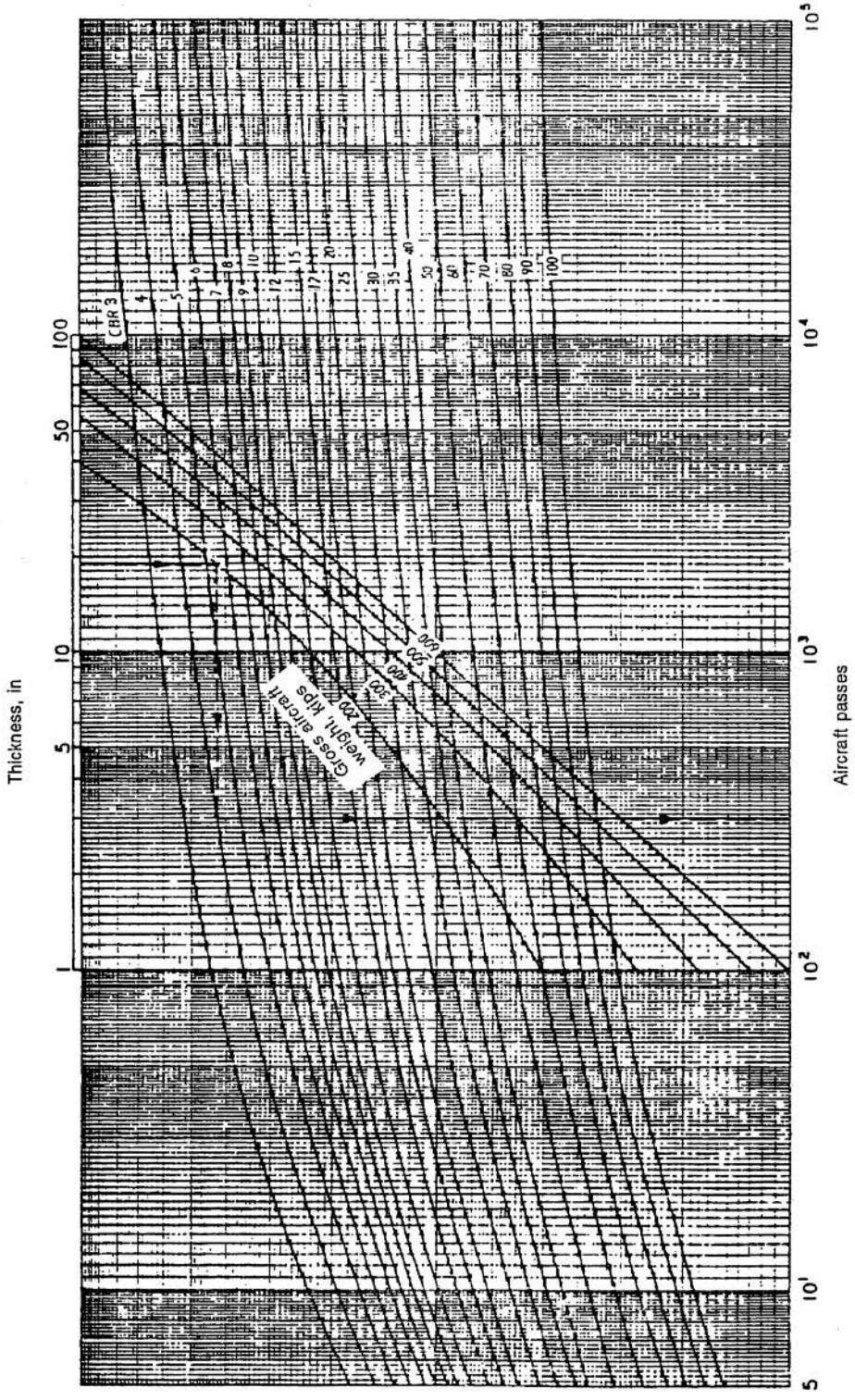
Figure I-29. Flexible-pavement evaluation curves, B-1, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

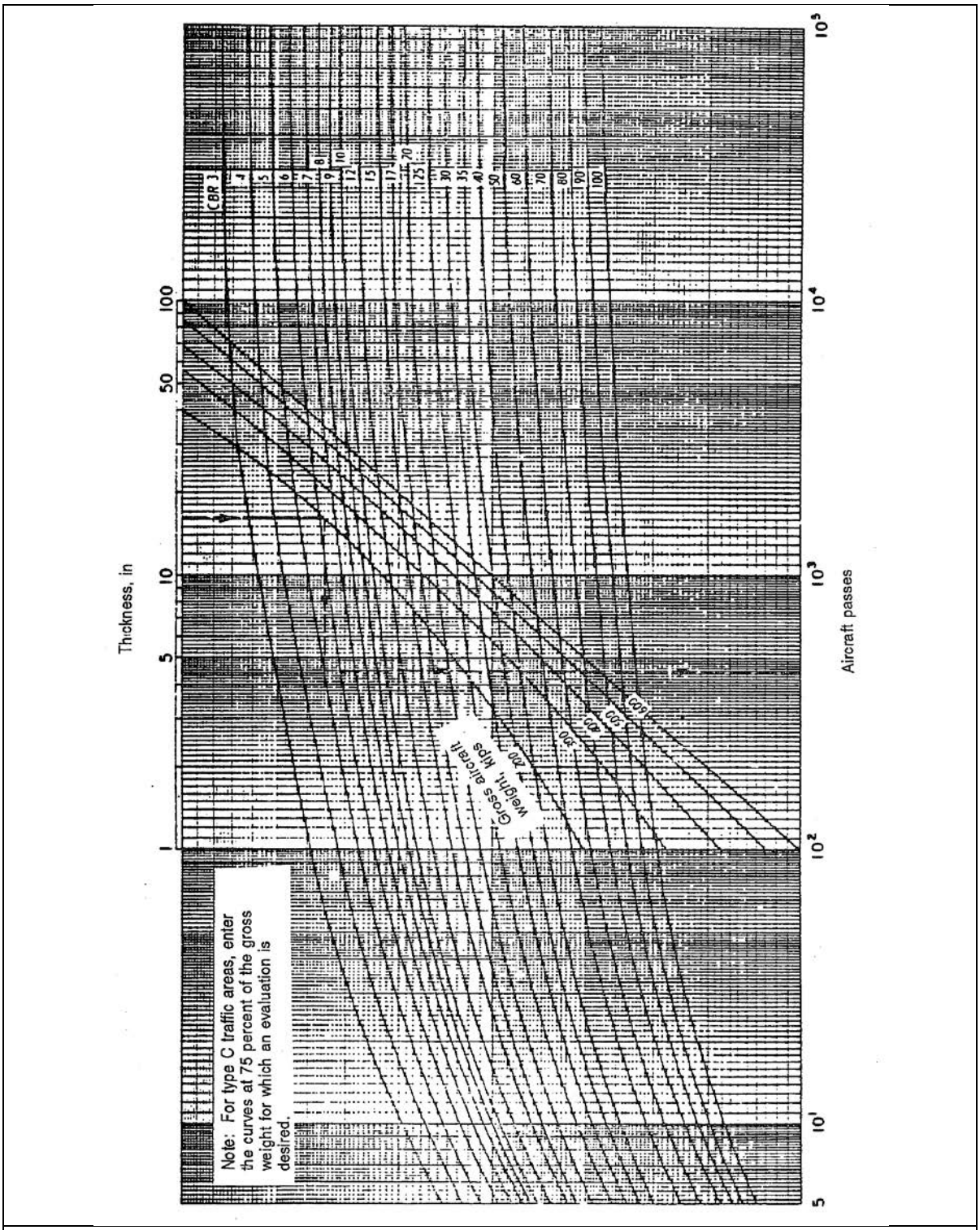
Figure I-30. Flexible-pavement evaluation curves, B-1, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

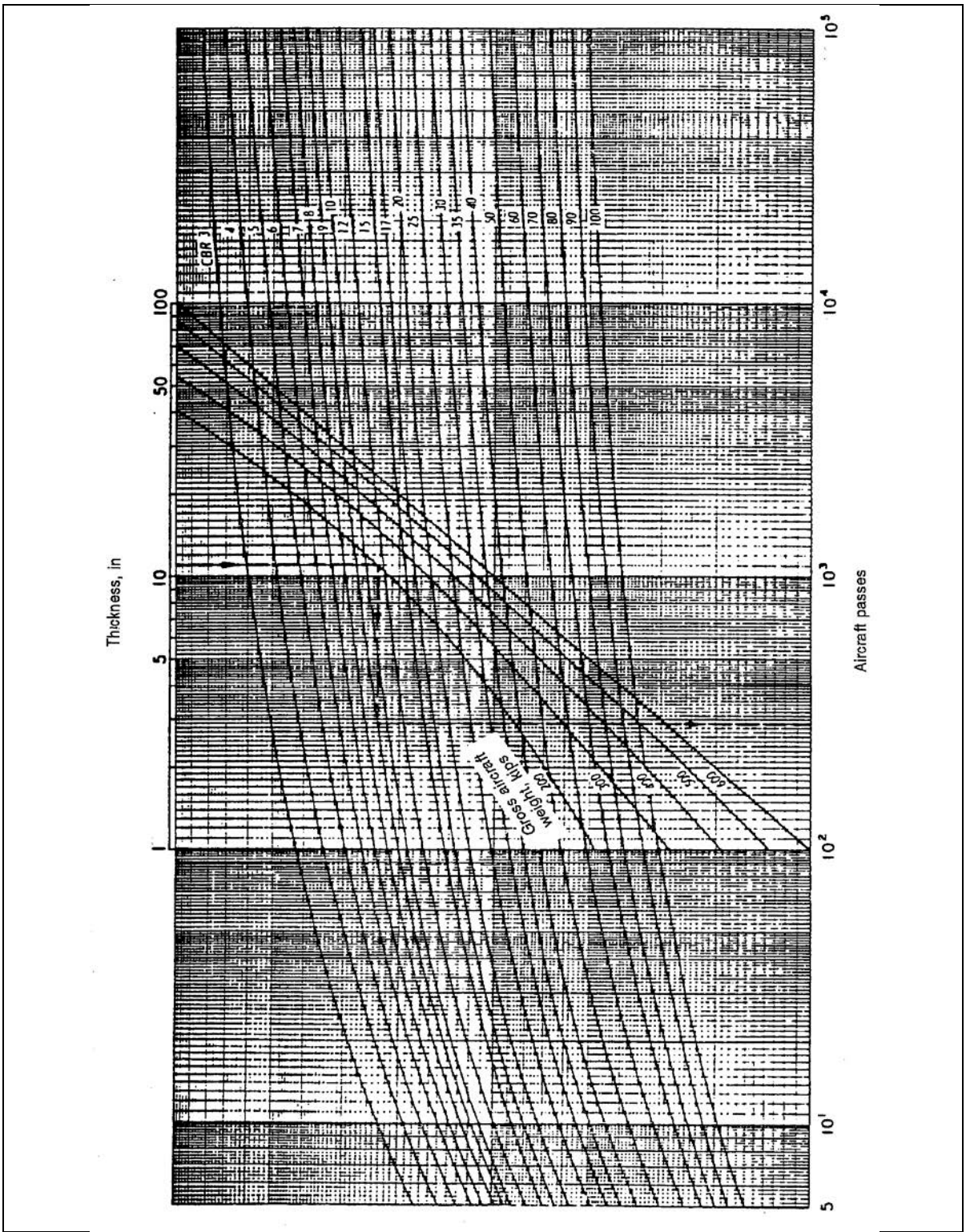
Figure I-31. Flexible-pavement evaluation curves, DC-10-10, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

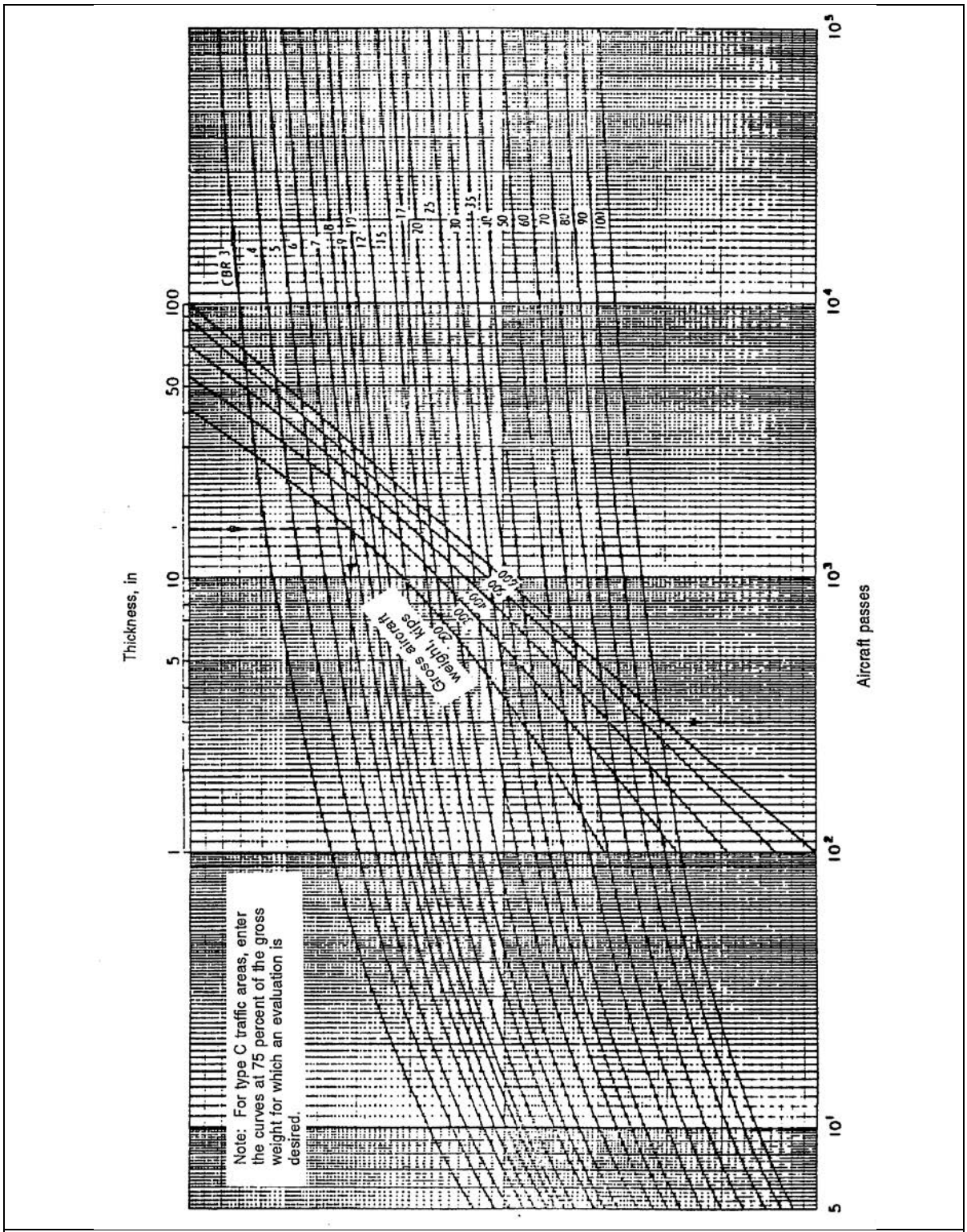
Figure I-32. Flexible-pavement evaluation curves, DC-10-10, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

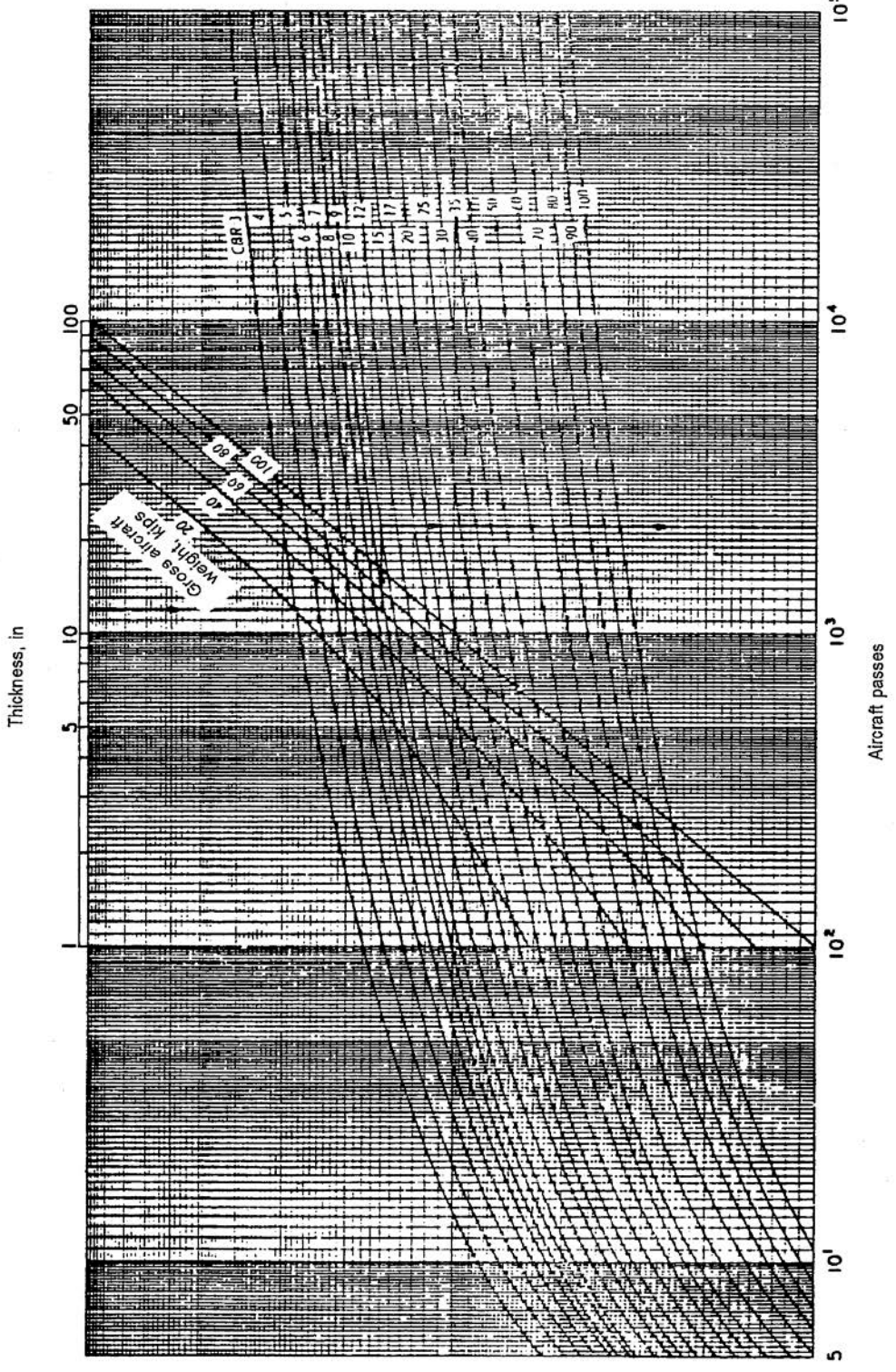
Figure I-33. Flexible-pavement evaluation curves, L-1011, Type A traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

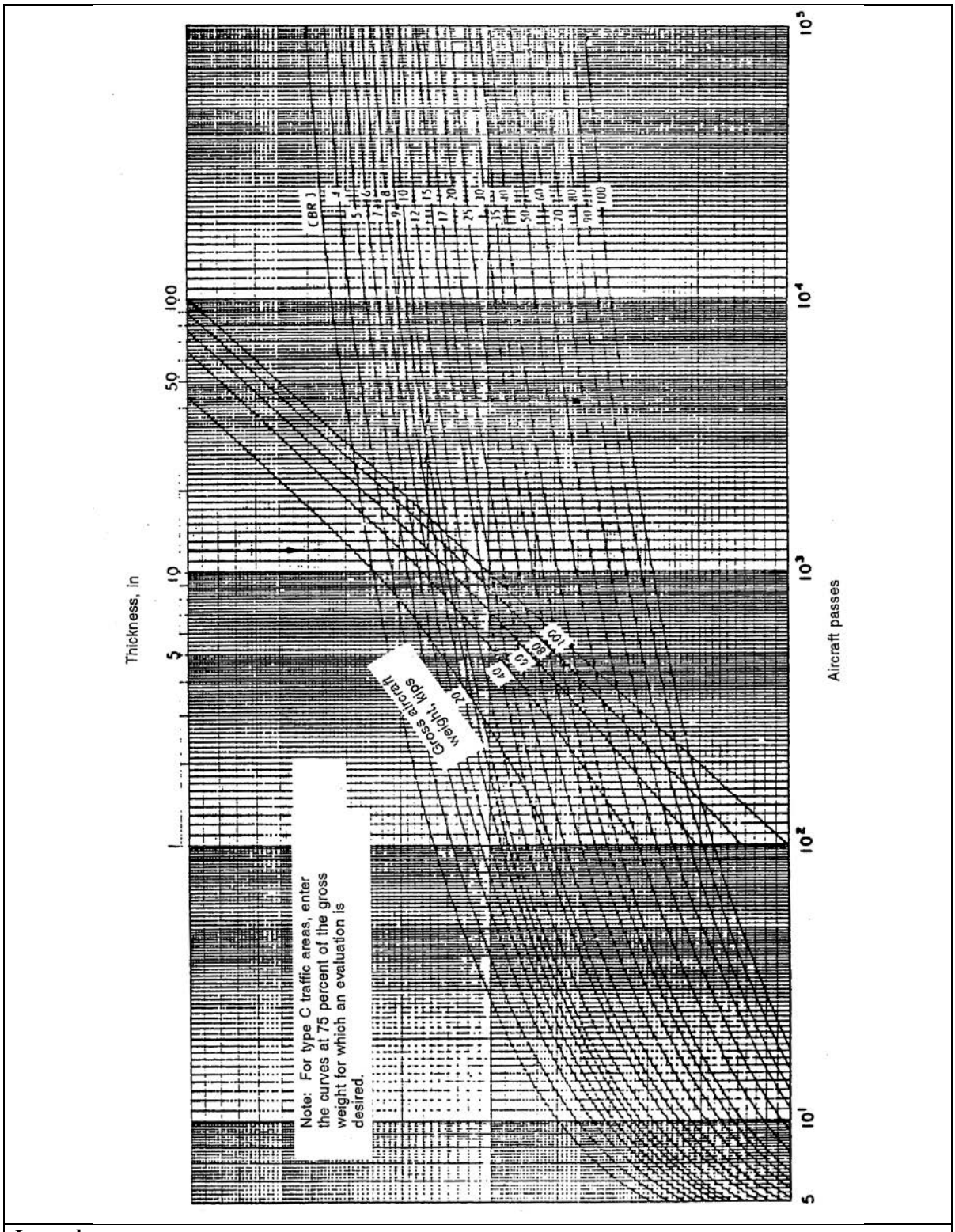
Figure I-34. Flexible-pavement evaluation curves, L-1011, Type B and C traffic areas



Legend:

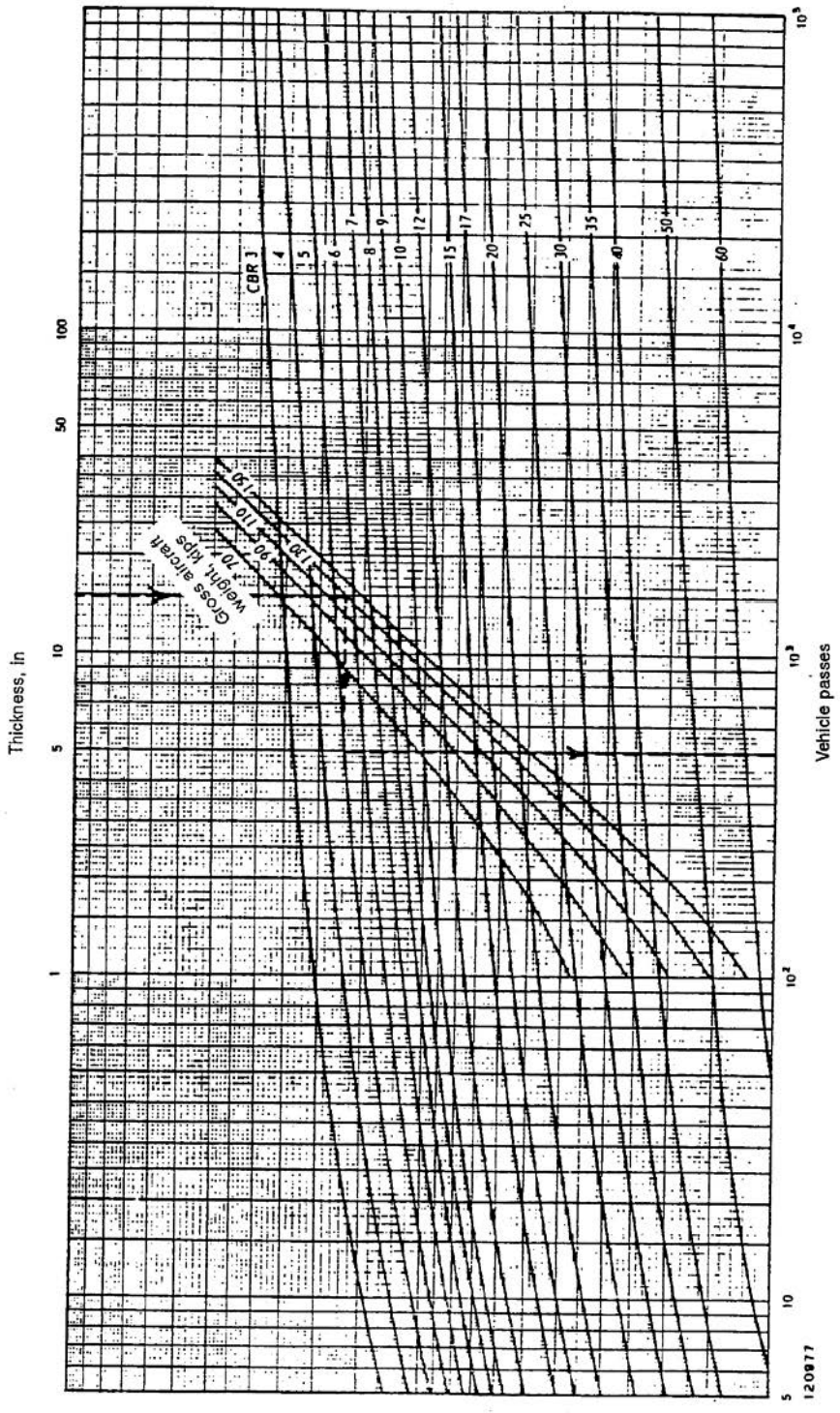
CBR	California Bearing Ratio
in	inch

Figure I-35. Flexible-pavement evaluation curves, single-wheel, 100 square inches, Type A traffic areas



Legend:
CBR California Bearing Ratio in inch

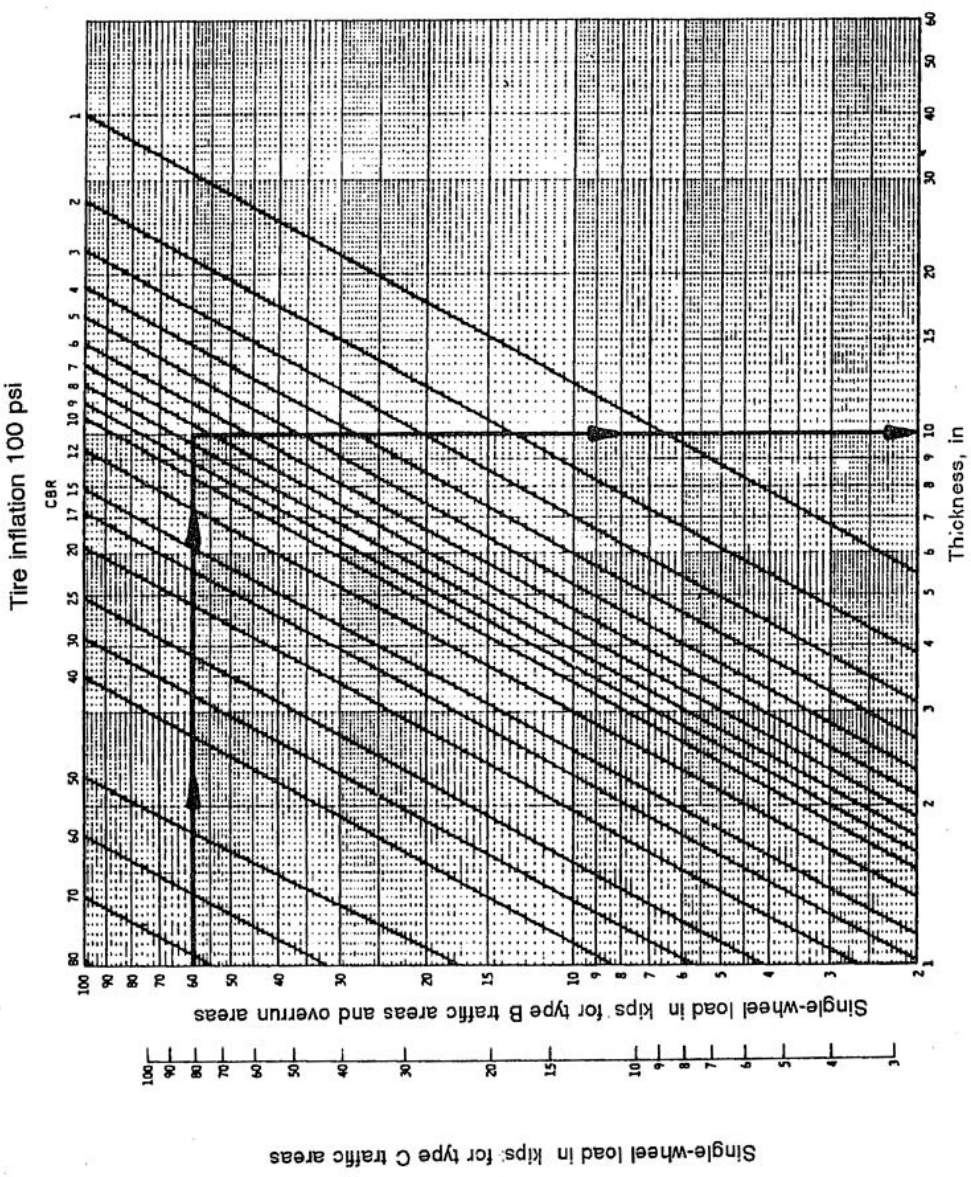
Figure I-36. Flexible-pavement evaluation curves, single-wheel, 100 square inches, Type B and C traffic areas



Legend:

CBR	California Bearing Ratio
in	inch

Figure I-37. Flexible-pavement evaluation curves, for roads and streets, crash-rescue vehicle P-15



Legend:

CBR	California Bearing Ratio
in	inch
psi	pounds per square inch

Figure I-38. Flexible-pavement evaluation curves, single-wheel (used for shoulder design)

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Appendix J

Mat Requirement Tables for Airfields

Table J-1 and table J-2, page J-2, show the number of F-44 bundles, the weight, and the volumes of landing mat required to meet the needs of a main battle area or support area airfield.

Table J-1. Mat required for main battle area airfield

Bundle Logistics	***Landing Mat Type***
	AM2
Number Required For	
Runway	521
Taxiway	306
Apron, warm-up	105
Overrun	125
Shoulder	289
Apron, parking	313
Total	1,759
Weight (tons)	
Runway	515.8
Taxiway	302.9
Apron, warm-up	104.0
Overrun	123.8
Shoulder	385.1
Apron, parking	309.9
Total	1,741.5
Cargo Space (cubic foot)	
Runway	32,302
Taxiway	18,972
Apron, warm-up	6,510
Overrun	7,750
Shoulder	24,118
Apron, parking	19,406
Total	109,058
Measurement Tons (40 cubic foot = 1 measurement ton)	
Runway	807.5
Taxiway	474.3
Apron, warm-up	162.7
Overrun	193.7
Shoulder	602.9
Apron, parking	485.2
Total	2,726.3

Table J-2. Mat required for support area airfield

Bundle Logistics	***Landing Mat Type***
	AM2
Number Required For	
Runway	730
Taxiway	494
Apron, warm-up	96
Overrun	125
Shoulder	528
Apron, parking	1,299
Total	3,272
Weight (tons)	
Runway	722.7
Taxiway	489.1
Apron, warm-up	95.0
Overrun	123.8
Shoulder	522.7
Apron, parking	1,286.0
Total	3,239.3
Cargo Space (cubic foot)	
Runway	45,260
Taxiway	30,628
Apron, warm-up	5,952
Overrun	7,750
Shoulder	32,736
Apron, parking	80,538
Total	202,864
Measurement Tons (40 cubic foot = 1 measurement ton)	
Runway	1,131.5
Taxiway	765.7
Apron, warm-up	148.8
Overrun	193.7
Shoulder	818.4
Apron, parking	2,013.4
Total	5,071.5

Appendix K

Ballistic Data

CONDITION I

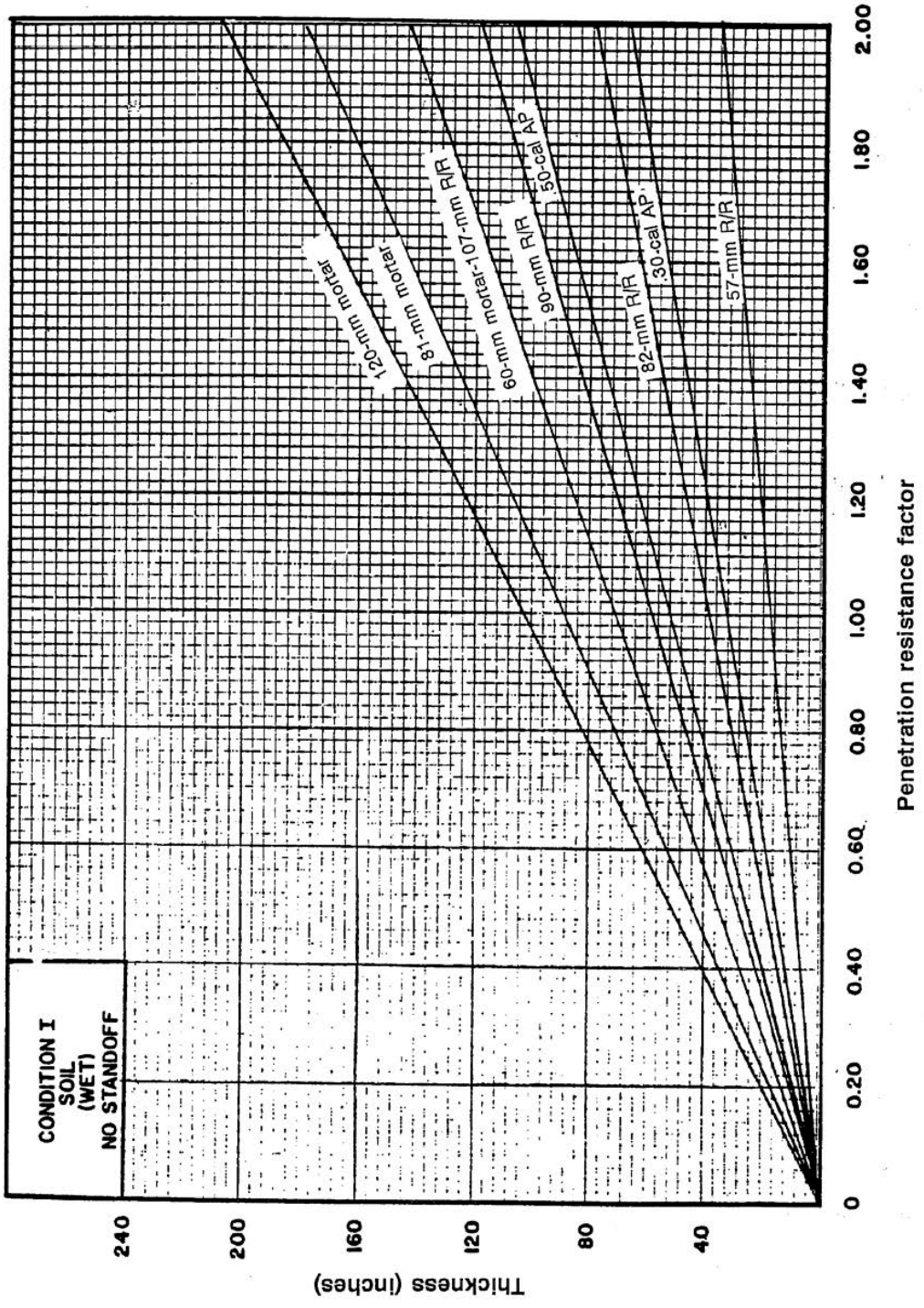
K-1. Figures K-1 through K-11, pages K-2 through K-12, provide detailed ballistic data for different types of ammunition under Condition I, when no standoff is used. Each graph pertains to one of the 11 types of the protective material discussed.

CONDITION II

K-2. Figures K-12 through K-22, pages K-13 through K-23, provide penetration data under Condition II, when a steel standoff is used.

CONDITION III

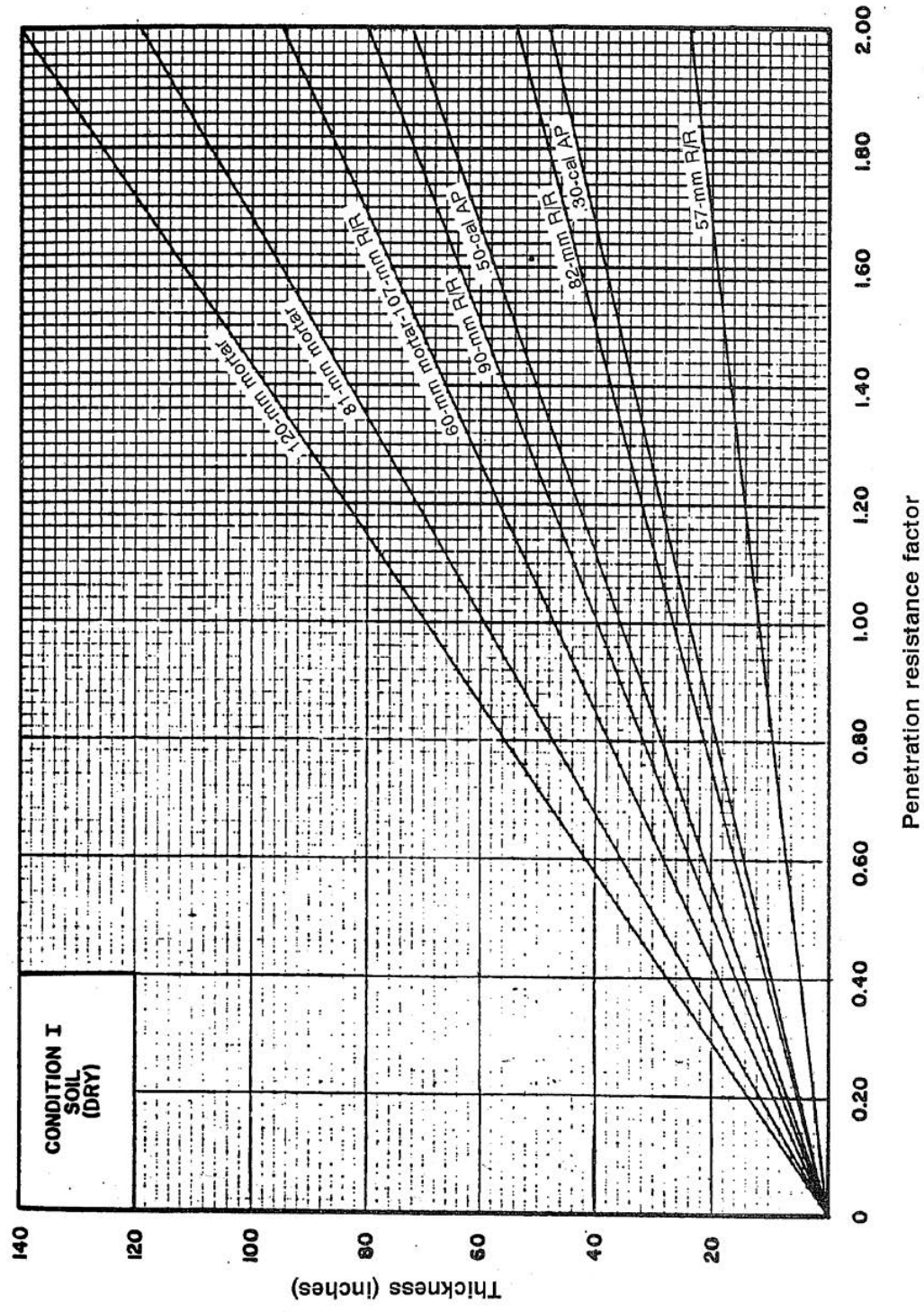
K-3. Figures K-23 through K-33, pages K-24 through K-34, provide penetration data under Condition III, when a wooden standoff is used.



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

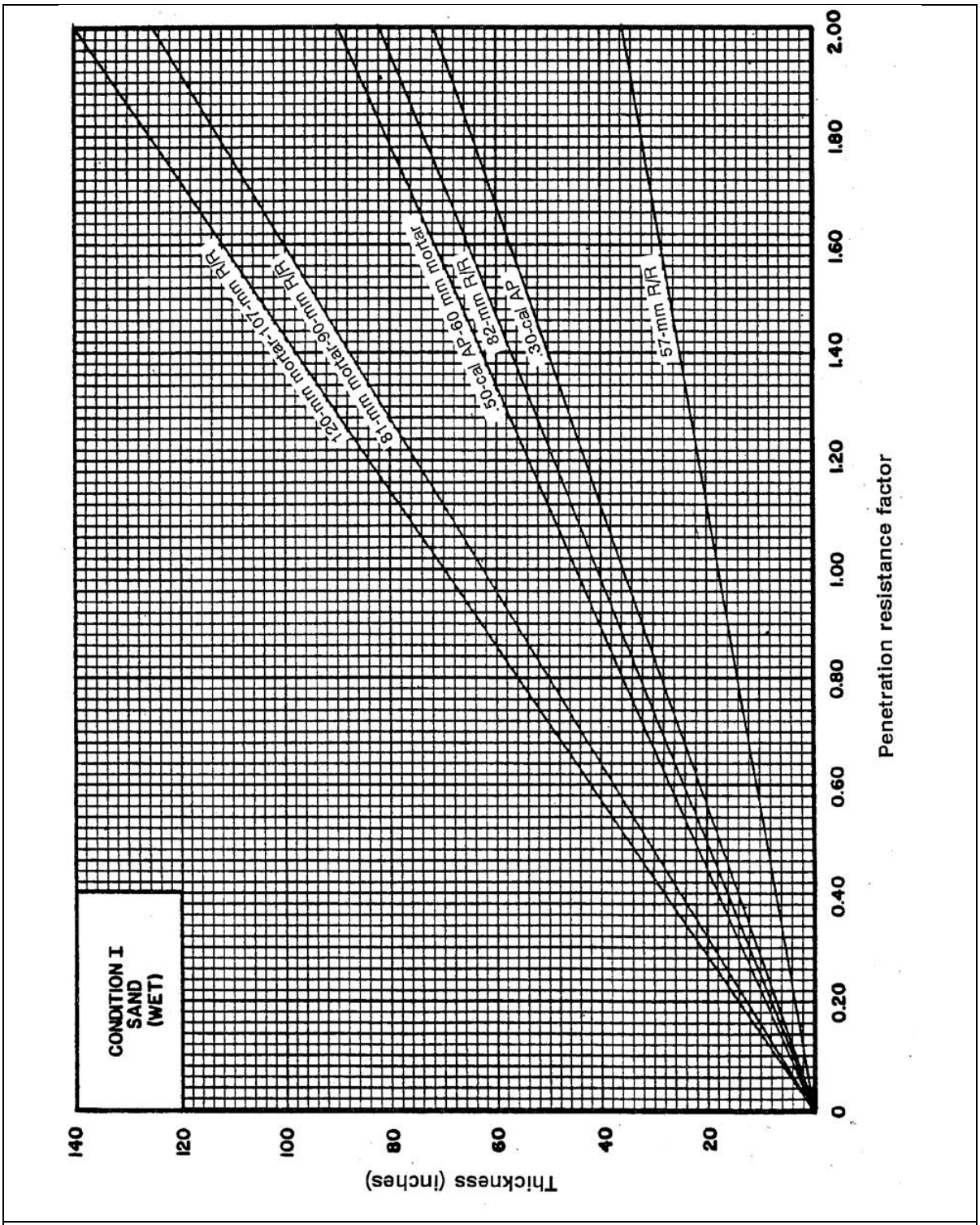
Figure K-1. Ballistic graphs for Condition I for wet soils



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

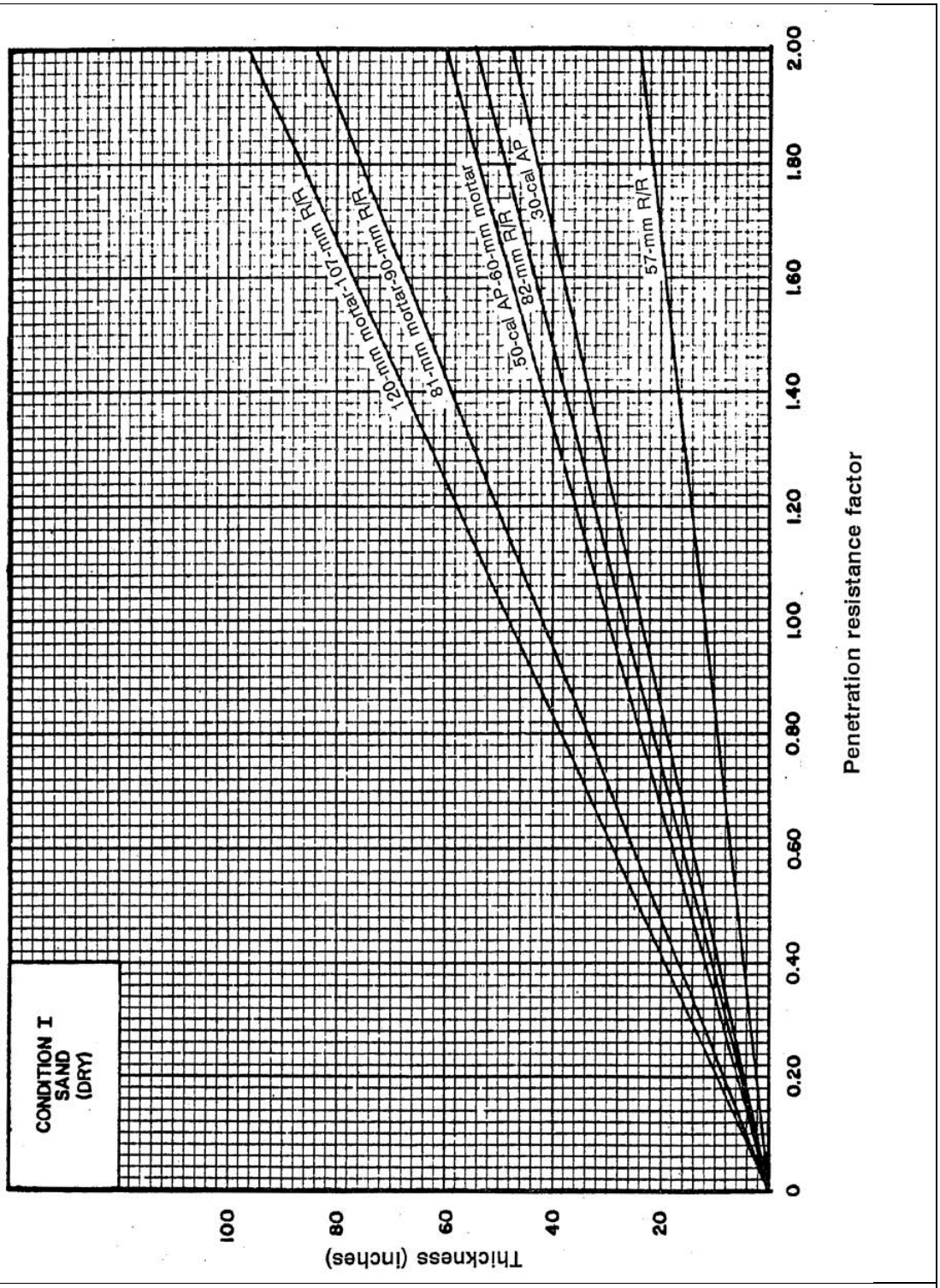
Figure K-2. Ballistic graphs for Condition I for dry soils



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

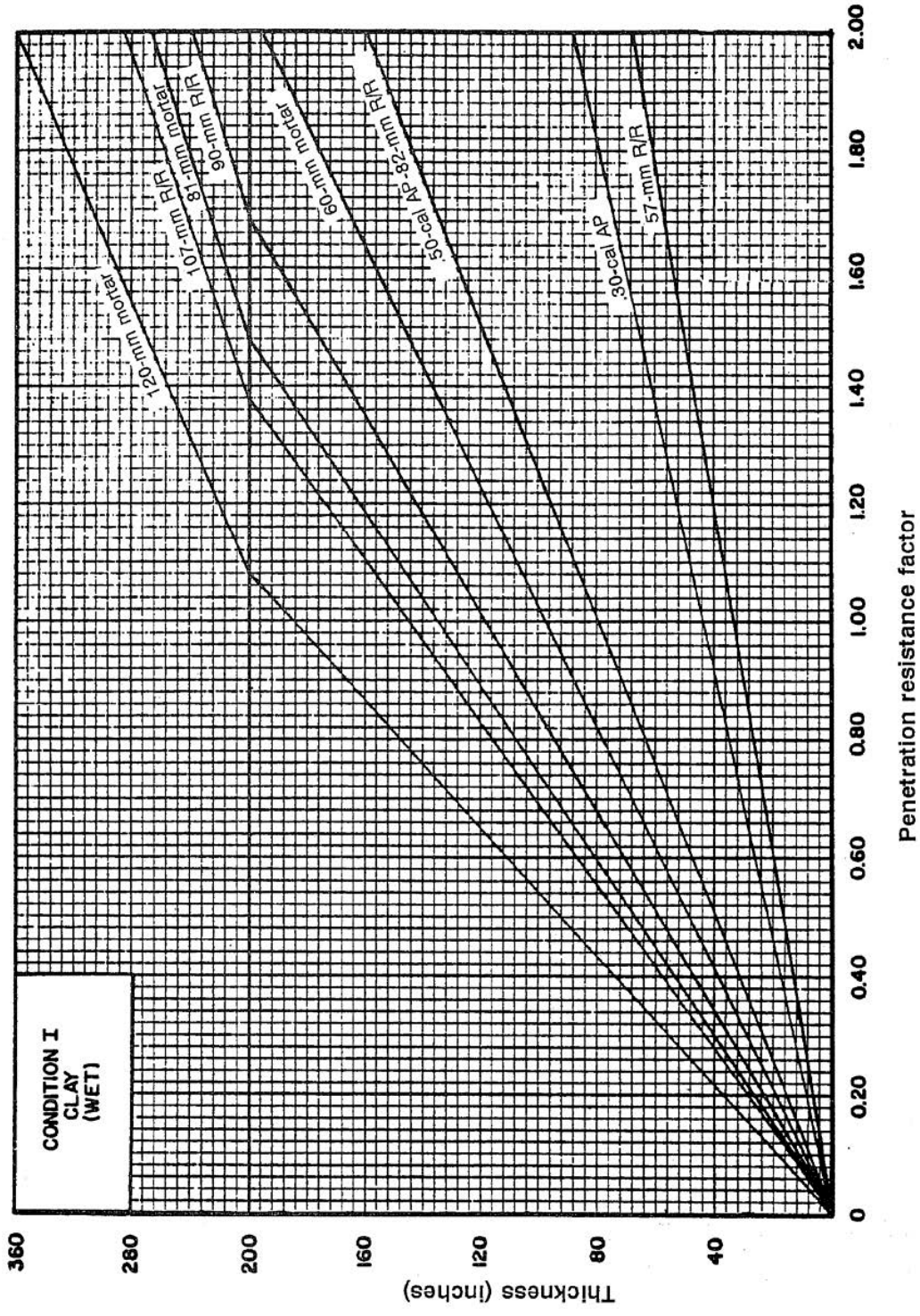
Figure K-3. Ballistic graphs for Condition I for wet sand



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

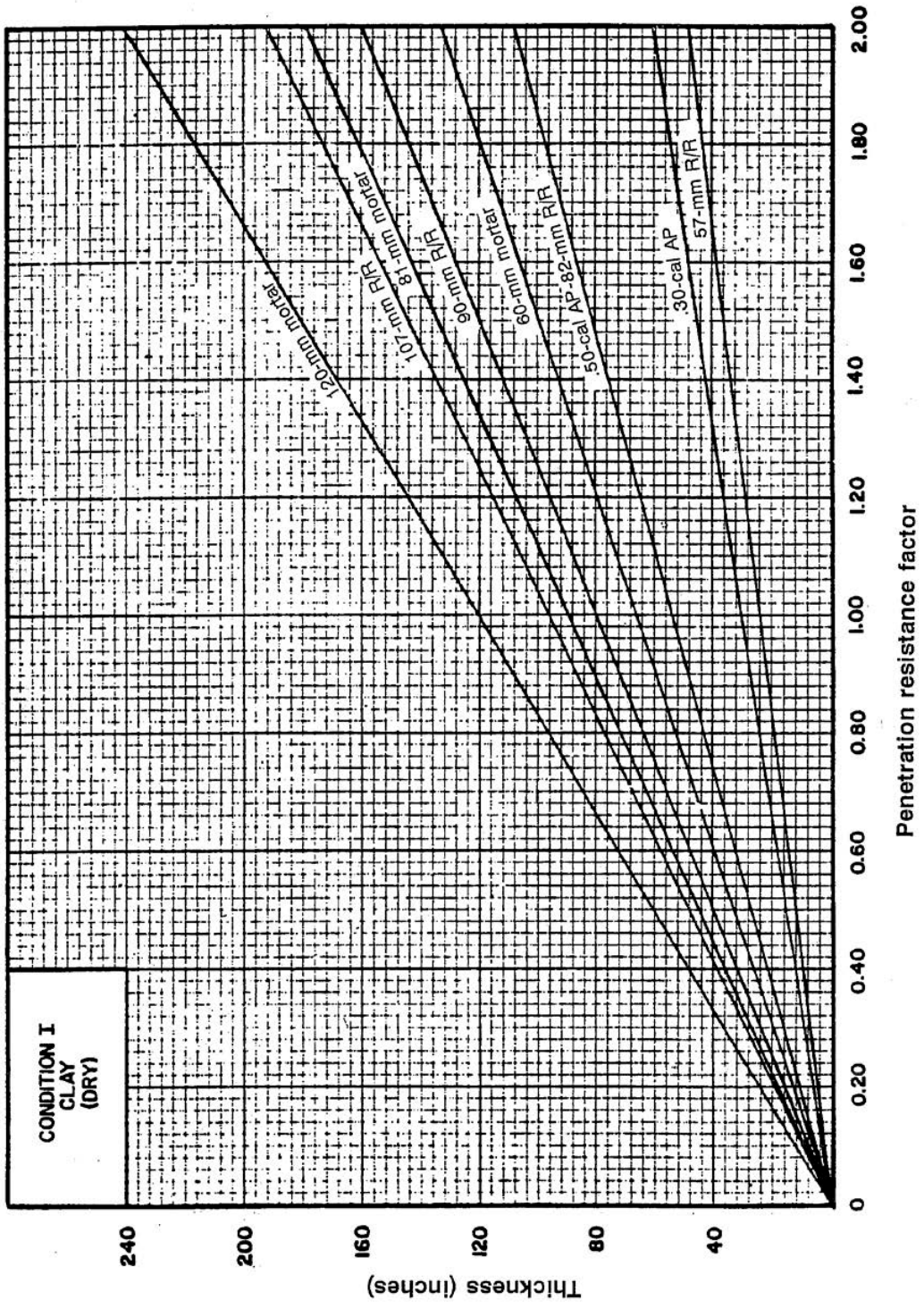
Figure K-4. Ballistic graphs for Condition I for dry sand



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

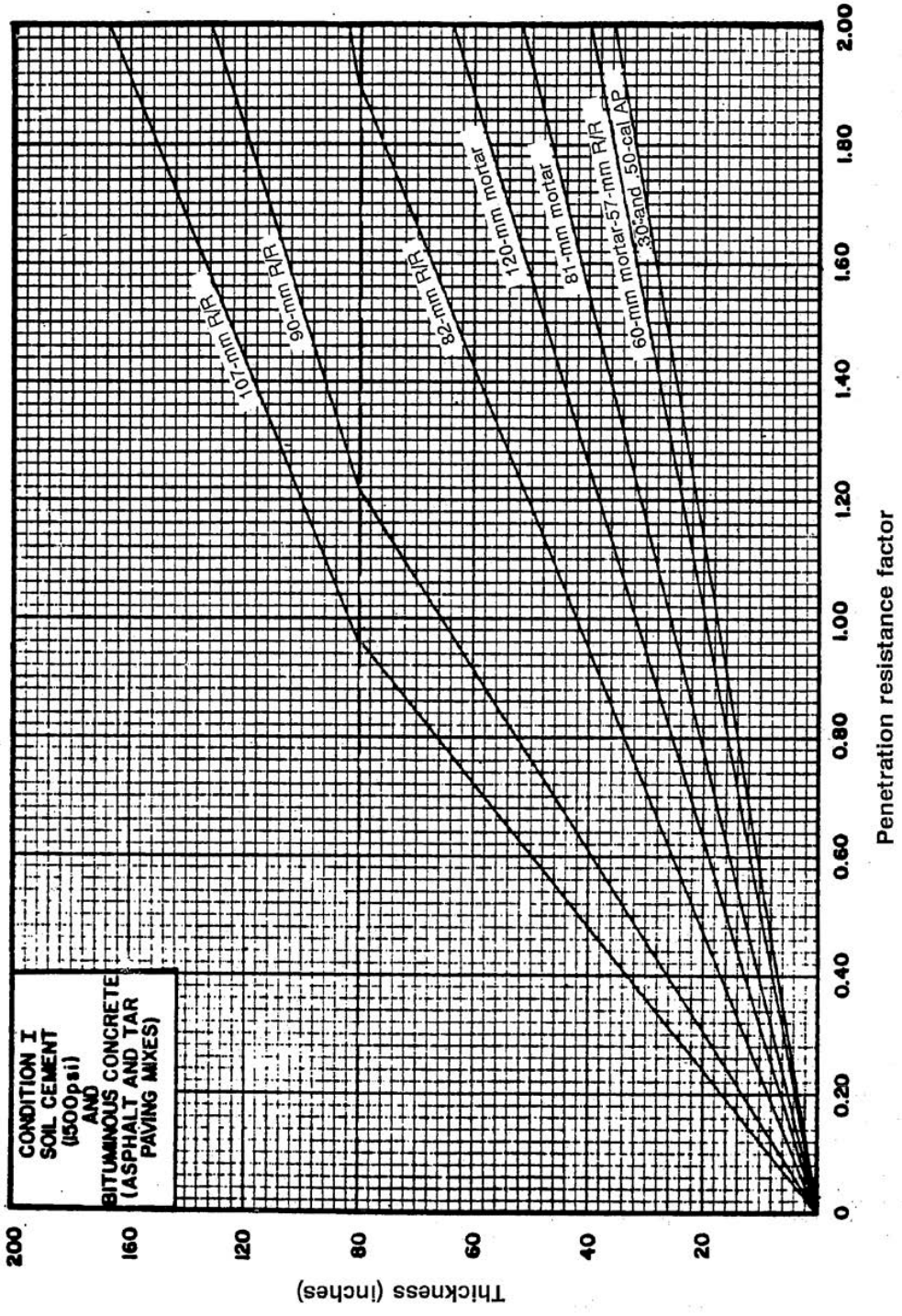
Figure K-5. Ballistic graphs for Condition I for wet clay



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

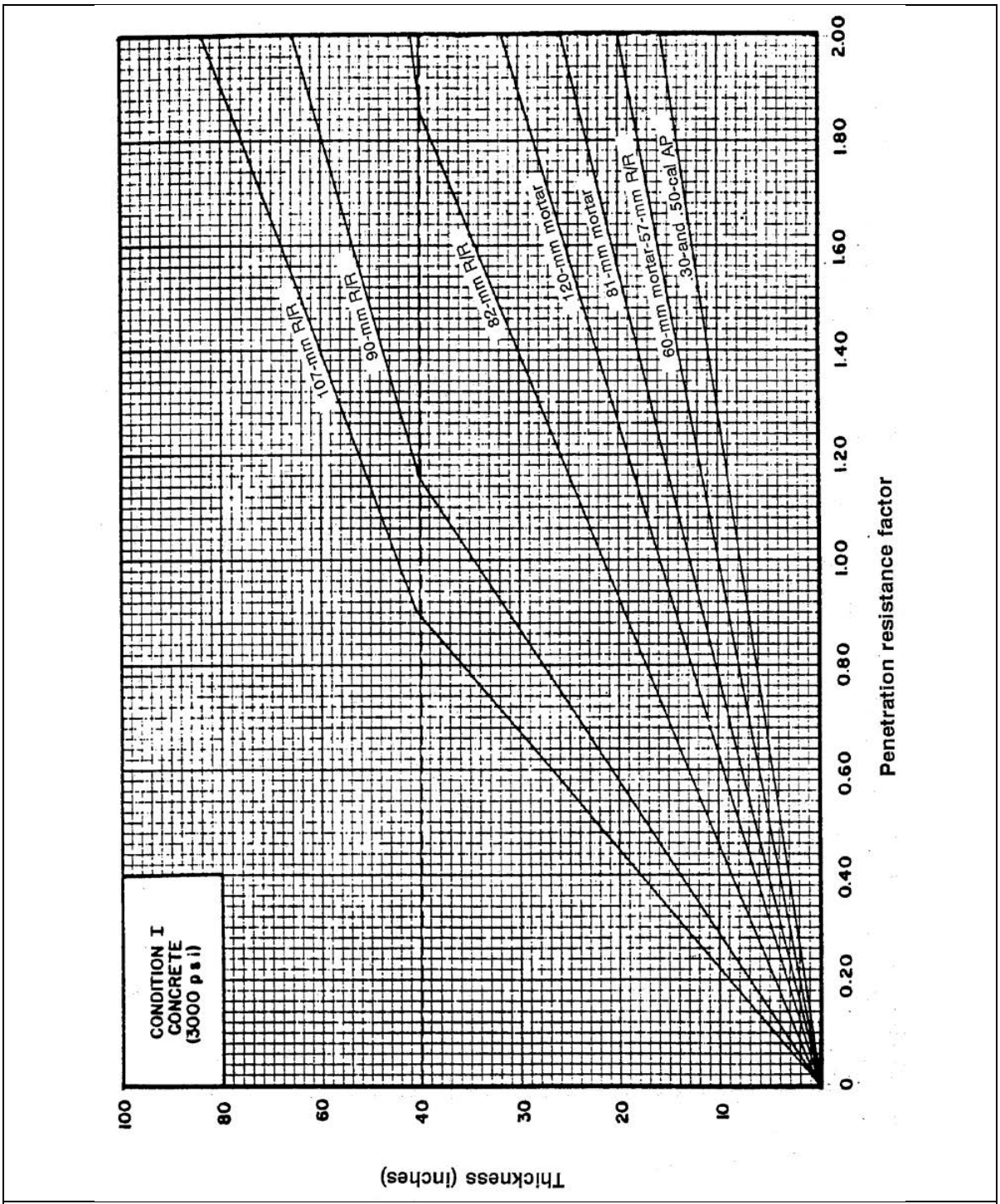
Figure K-6. Ballistic graphs for Condition I for dry clay



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
psi	pounds per square inch
R/R	recoiless rifle

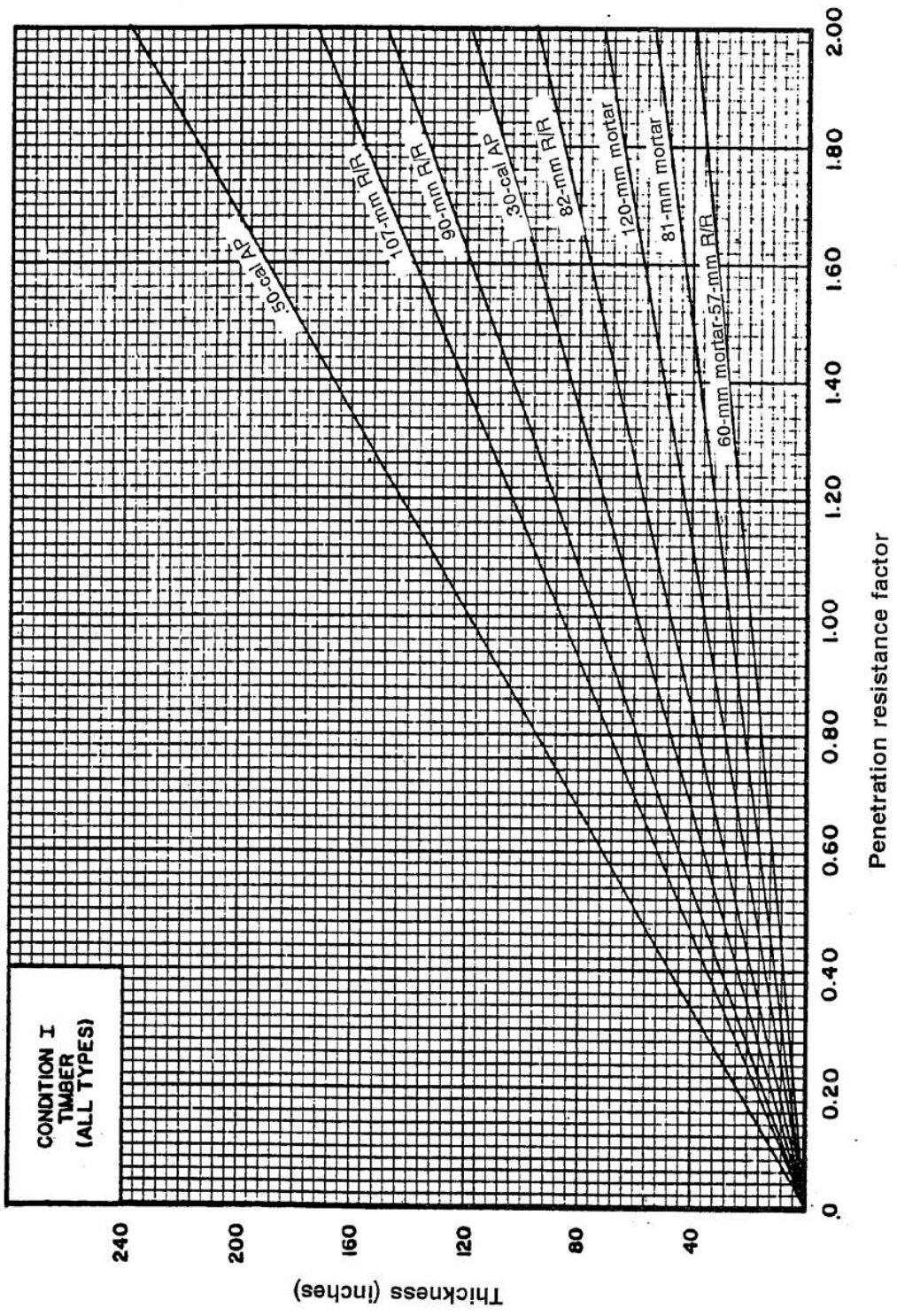
Figure K-7. Ballistic graphs for Condition I for soil cement and bituminous concrete



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
psi	pounds per square inch
R/R	recoiless rifle

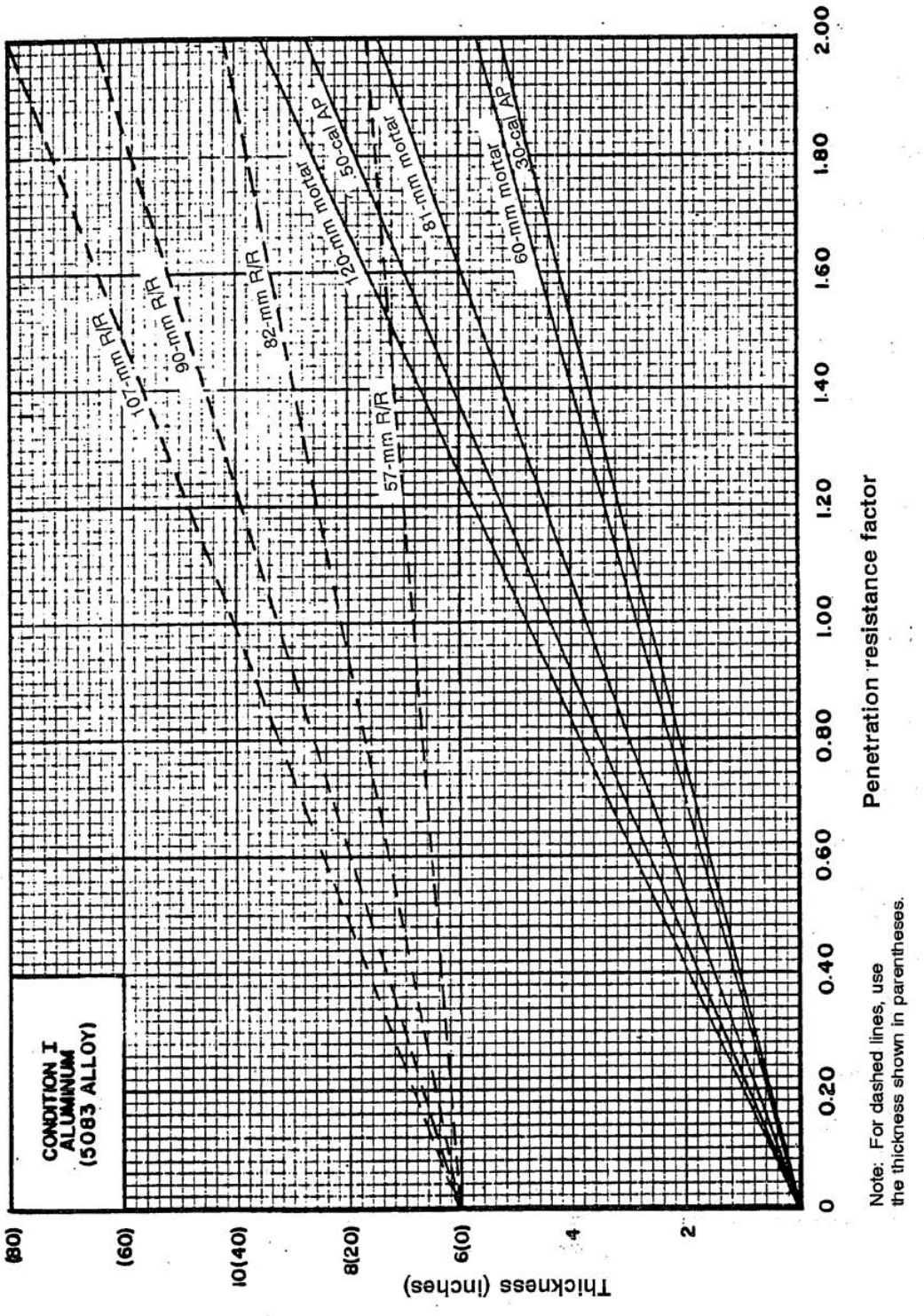
Figure K-8. Ballistic graphs for Condition I for concrete



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

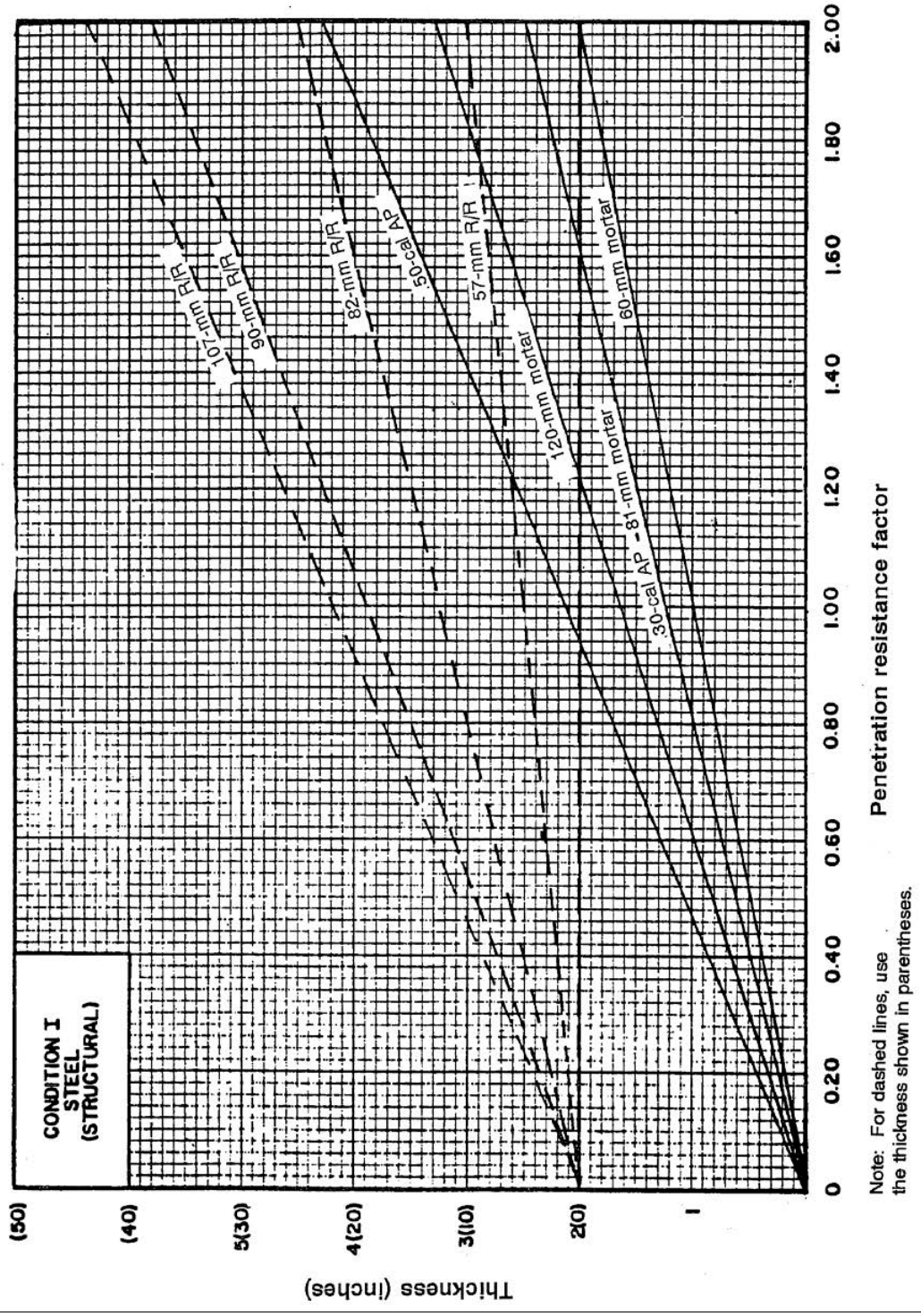
Figure K-9. Ballistic graphs for Condition I for timber



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

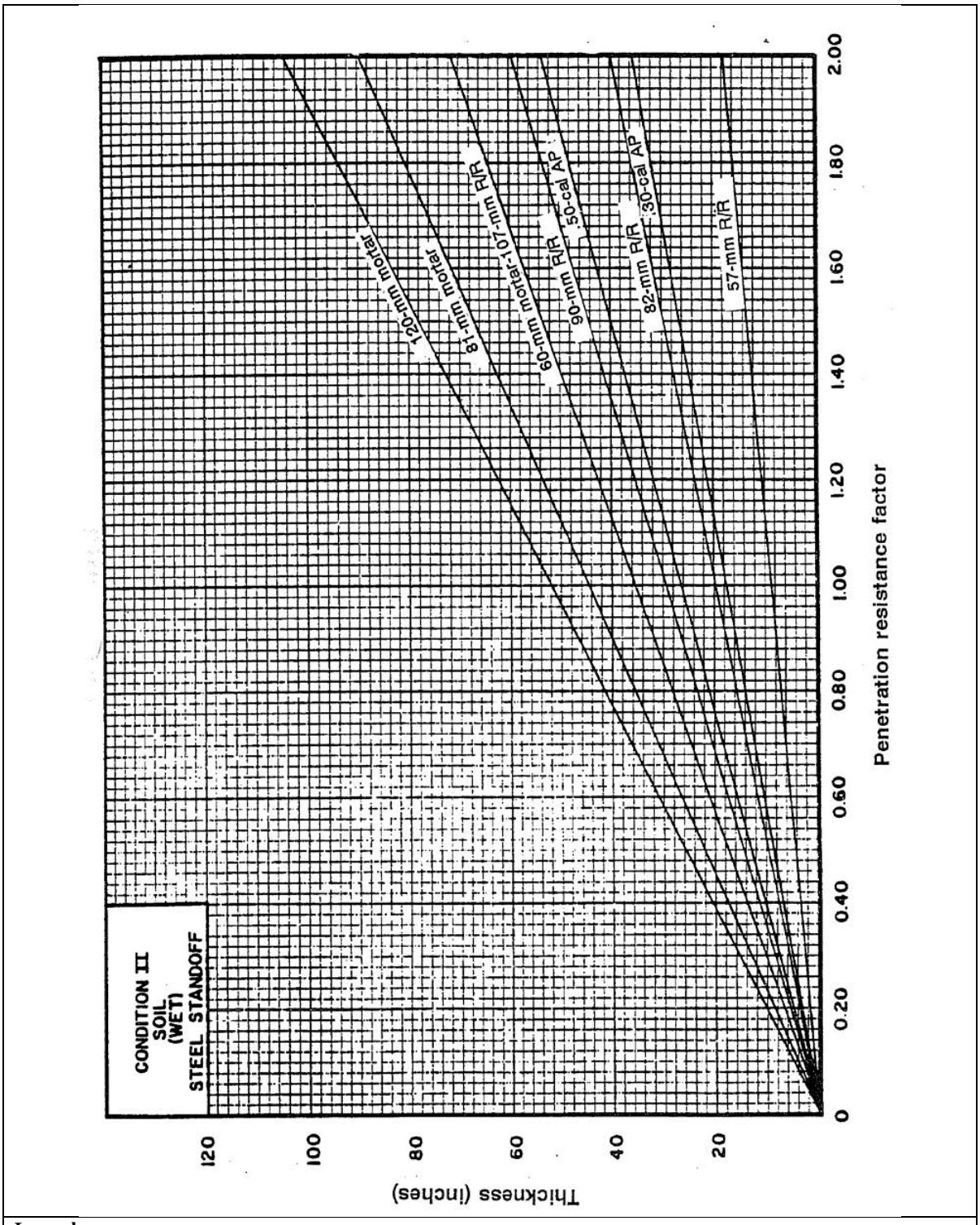
Figure K-10. Ballistic graphs for Condition I for aluminum



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

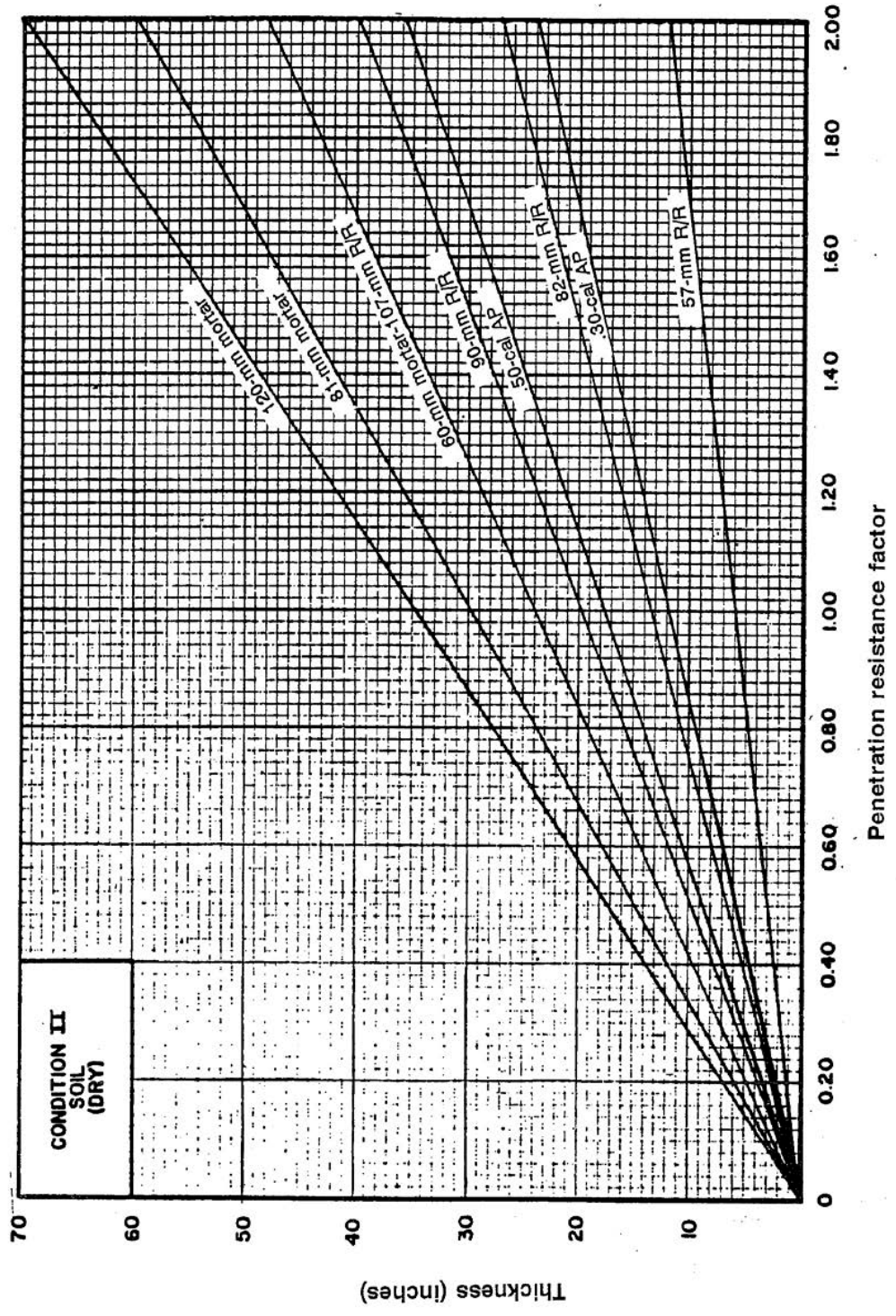
Figure K-11. Ballistic graphs for Condition I for steel



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

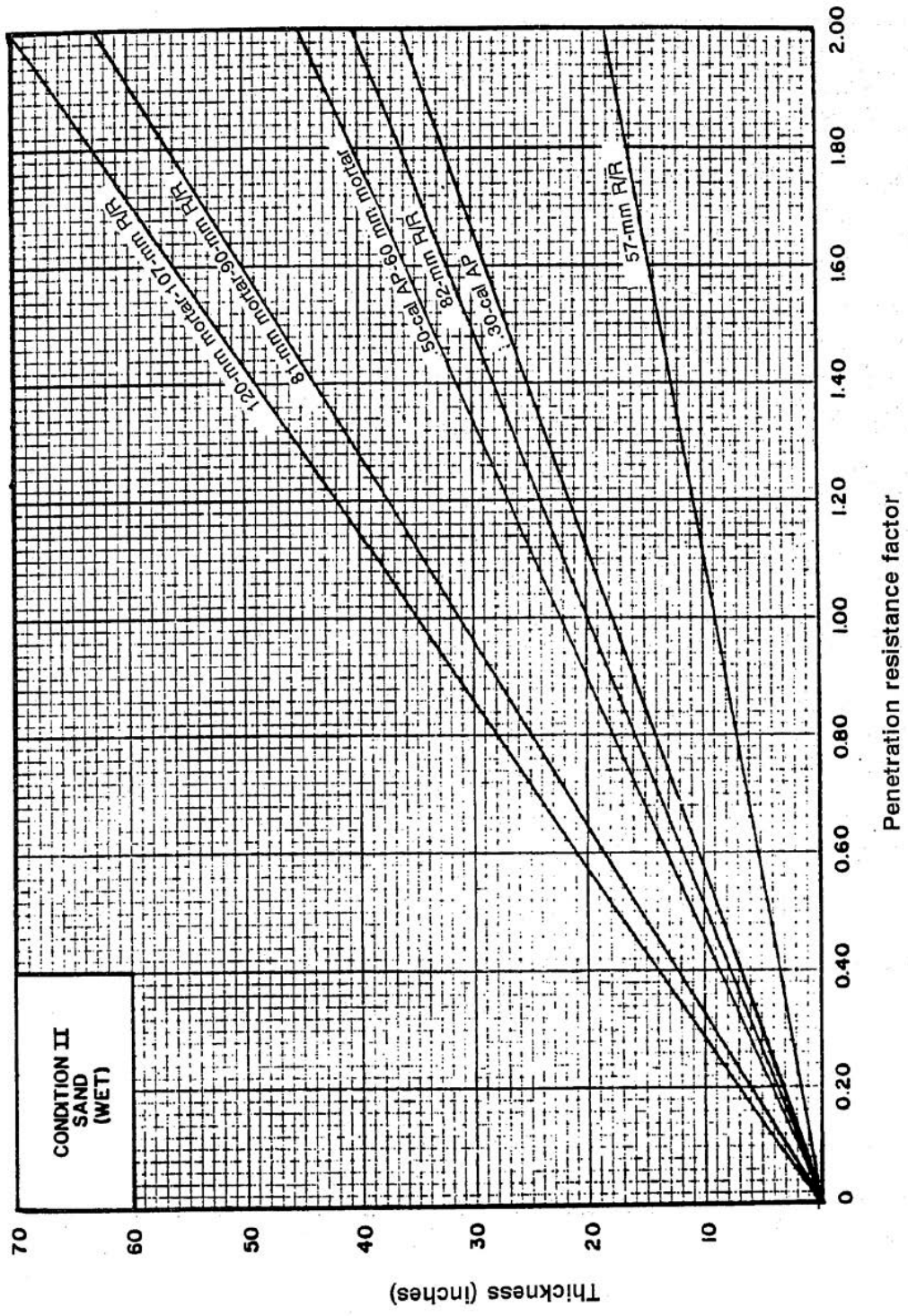
Figure K-12. Ballistic graphs for Condition II for wet soil



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

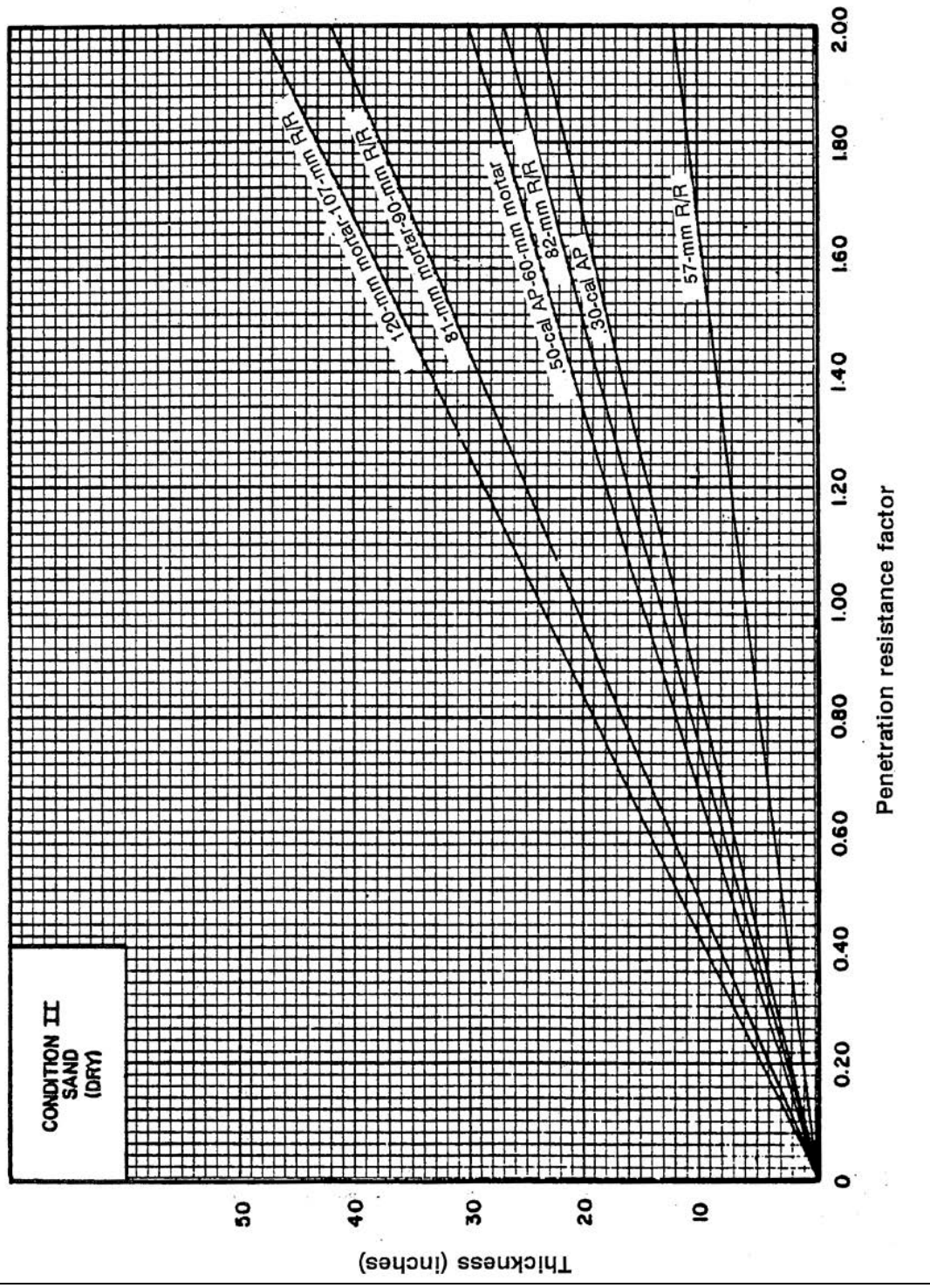
Figure K-13. Ballistic graphs for Condition II for dry soil



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

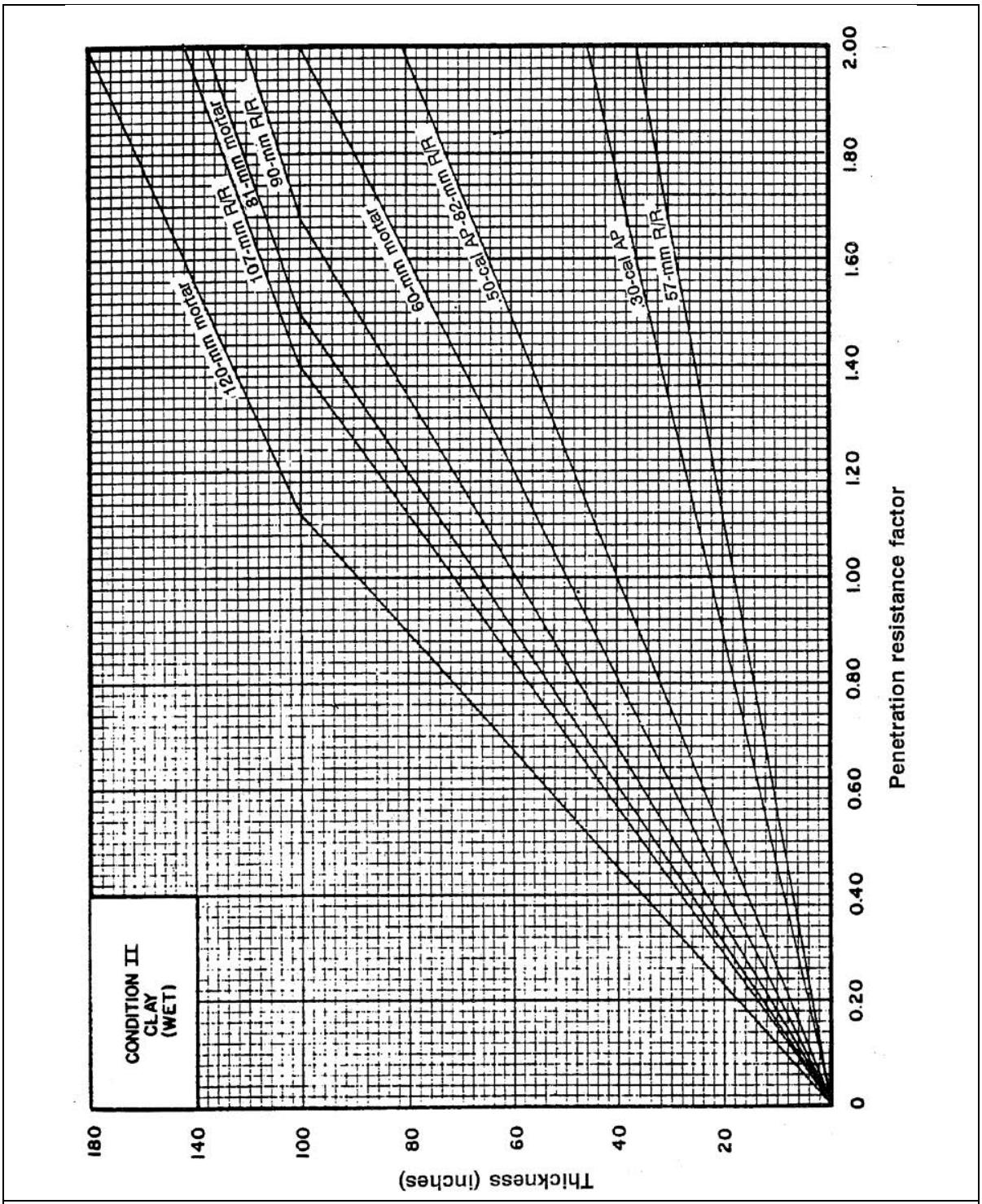
Figure K-14. Ballistic graphs for Condition II for wet sand



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

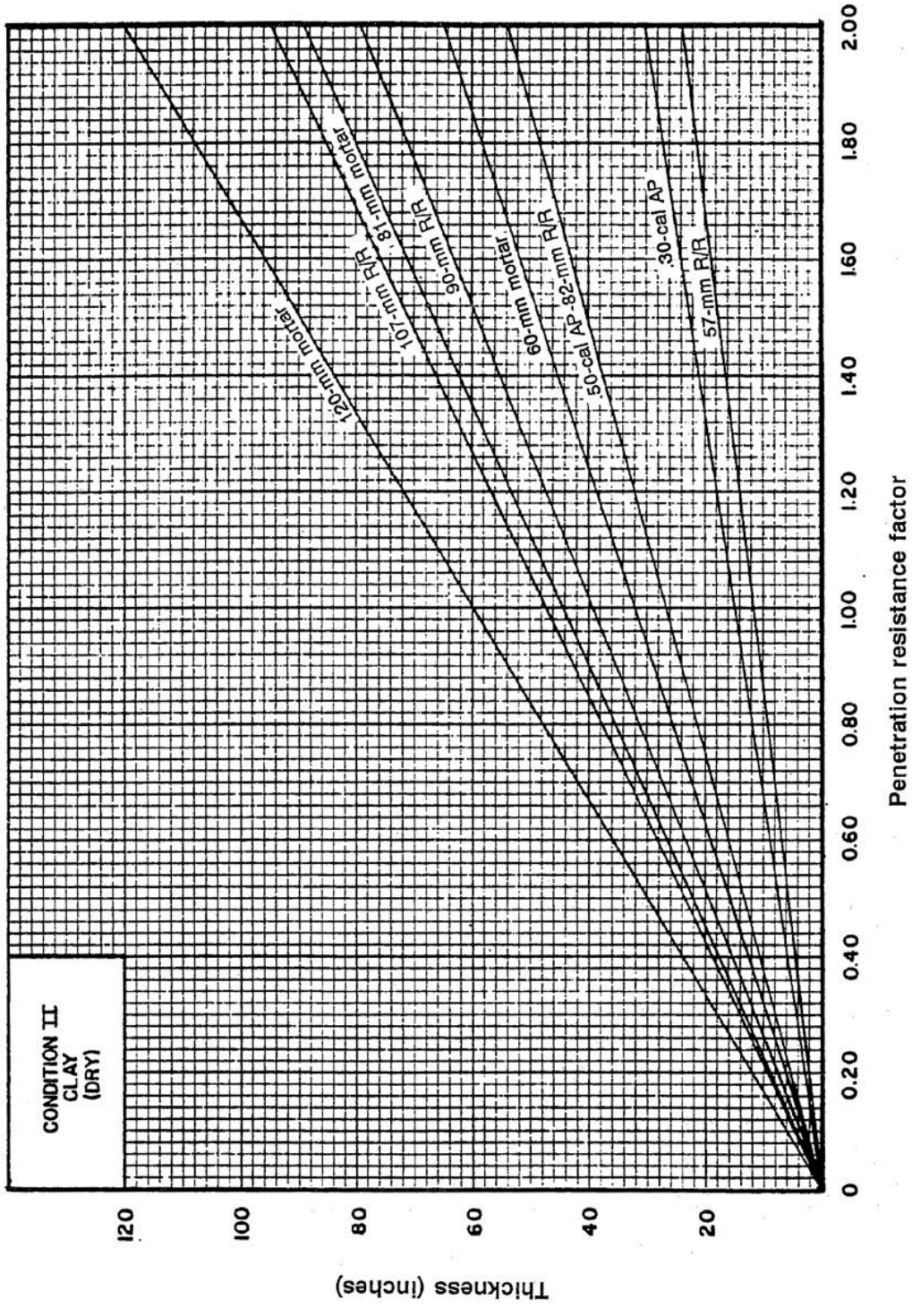
Figure K-15. Ballistic graphs for Condition II for dry sand



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

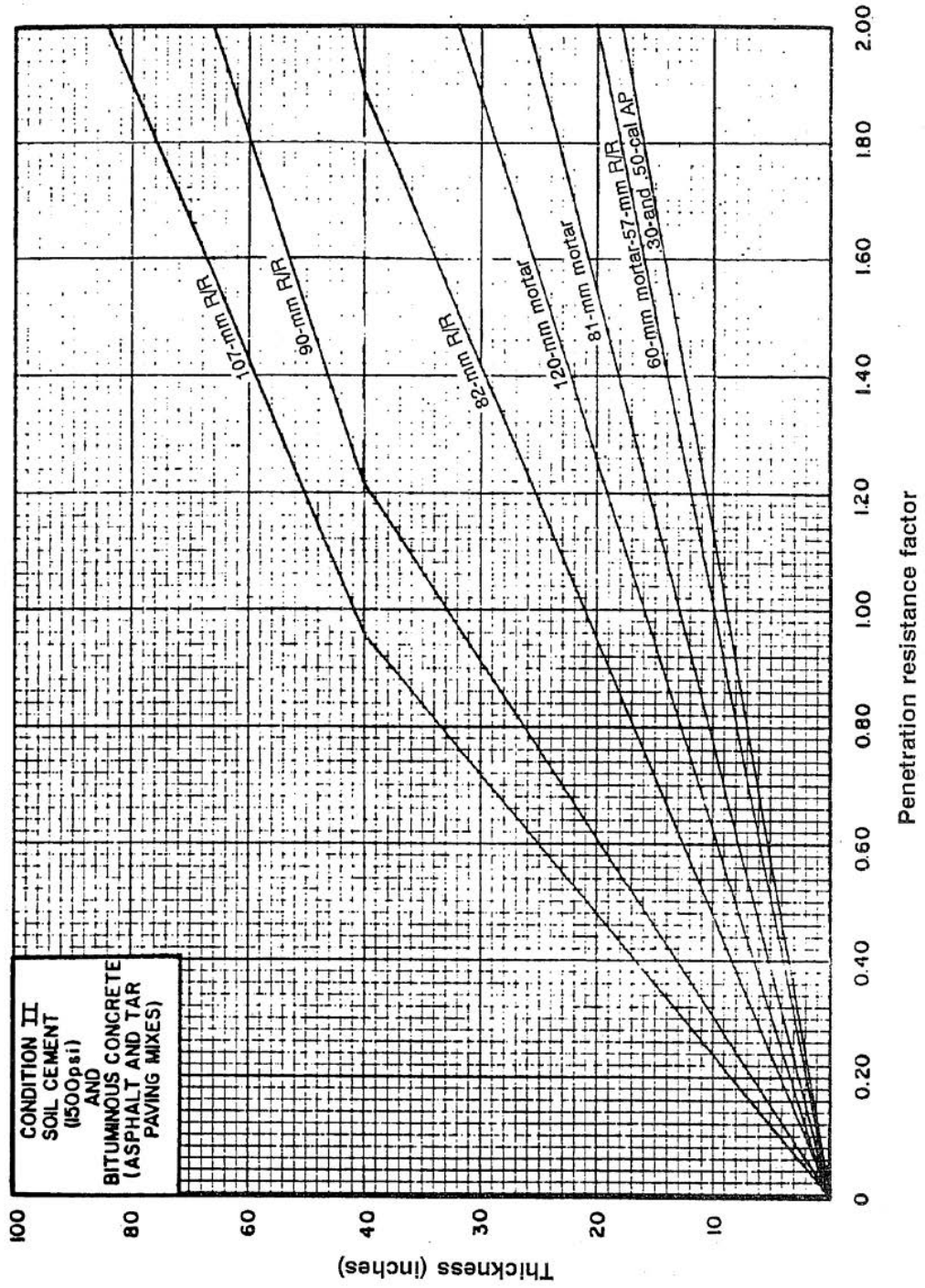
Figure K-16. Ballistic graphs for Condition II for wet clay



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

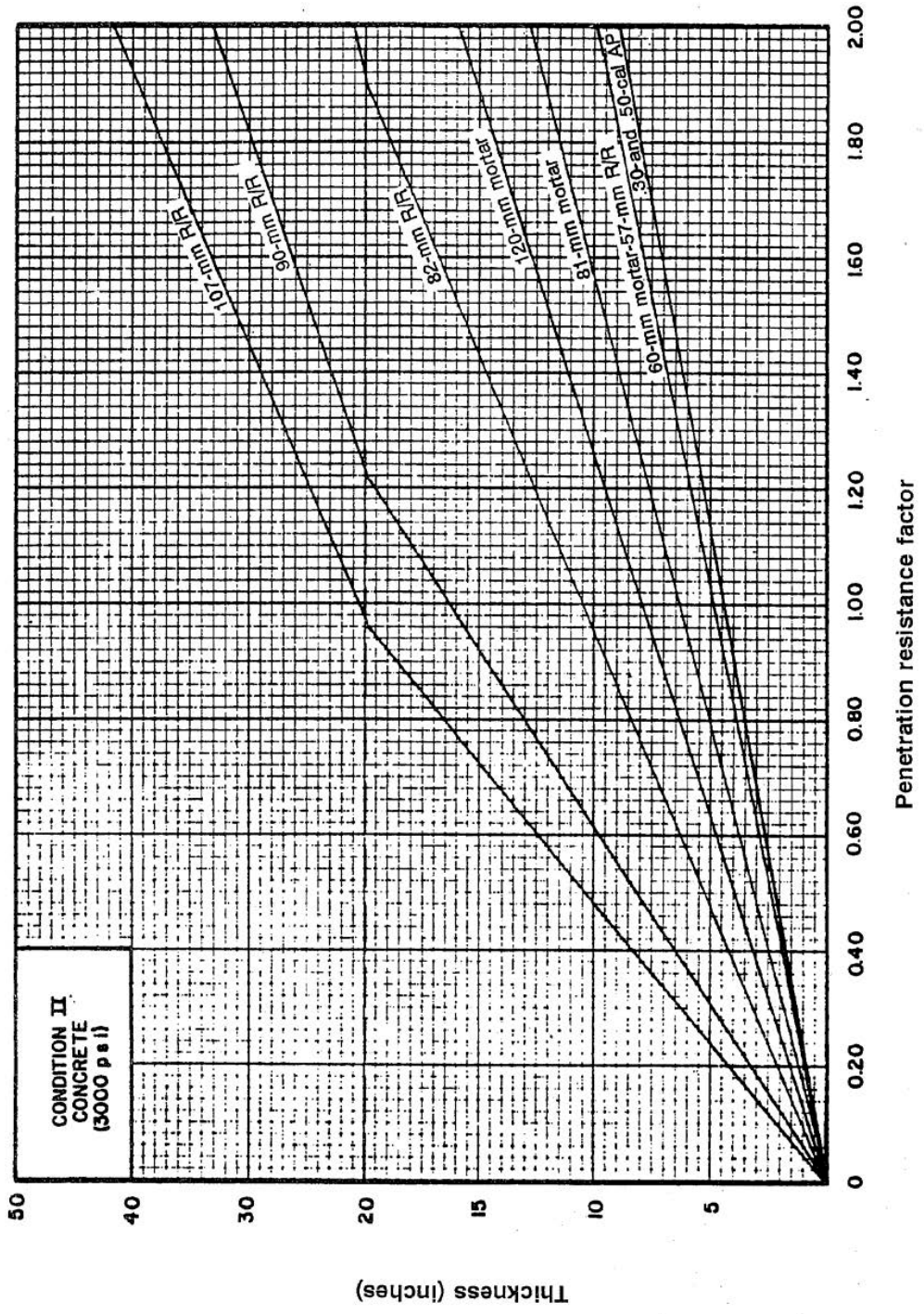
Figure K-17. Ballistic graphs for Condition II for dry clay



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
psi	pounds per square inch
R/R	recoiless rifle

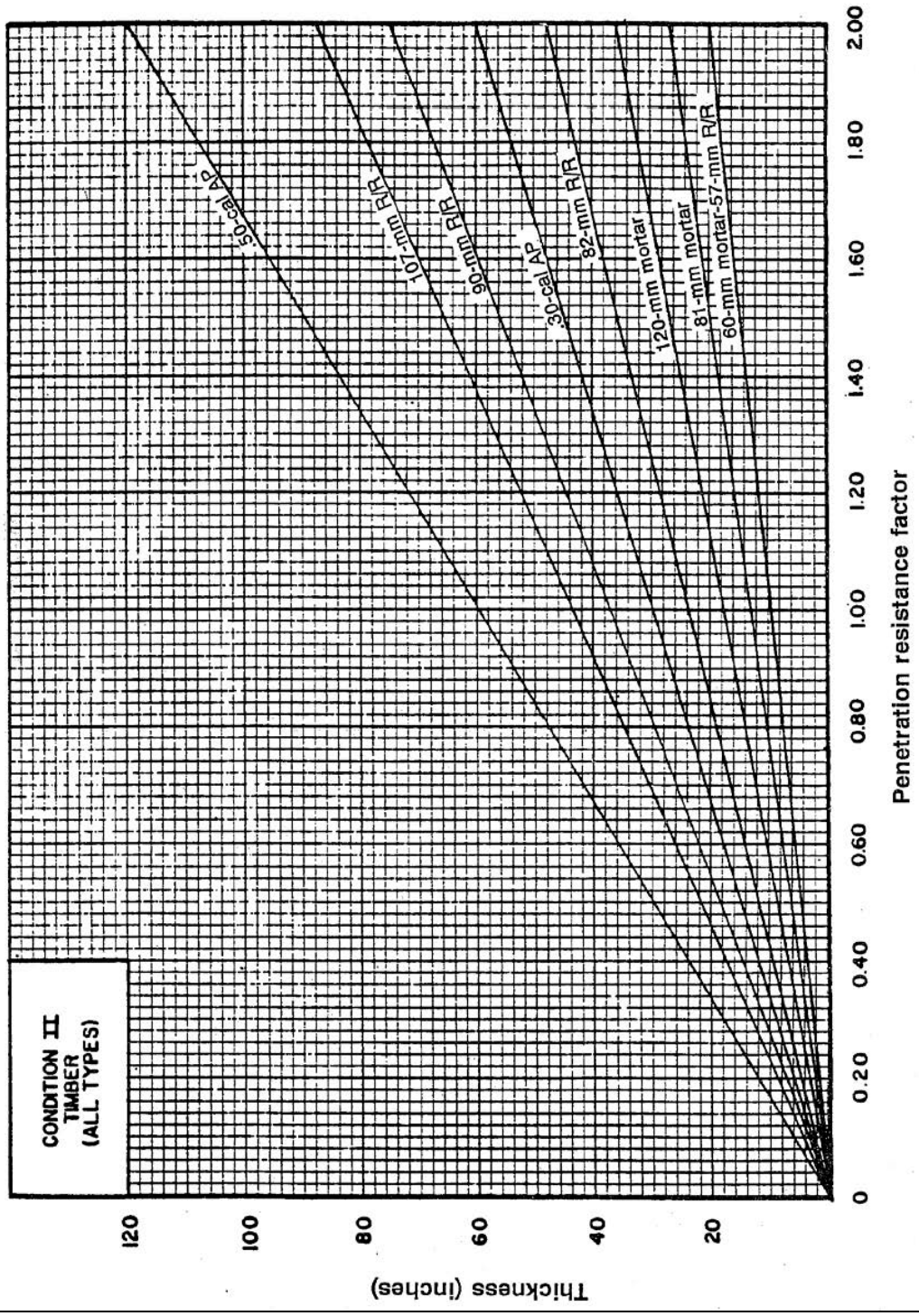
Figure K-18. Ballistic graphs for Condition II for soil cement and bituminous concrete



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
psi	pounds per square inch
R/R	recoiless rifle

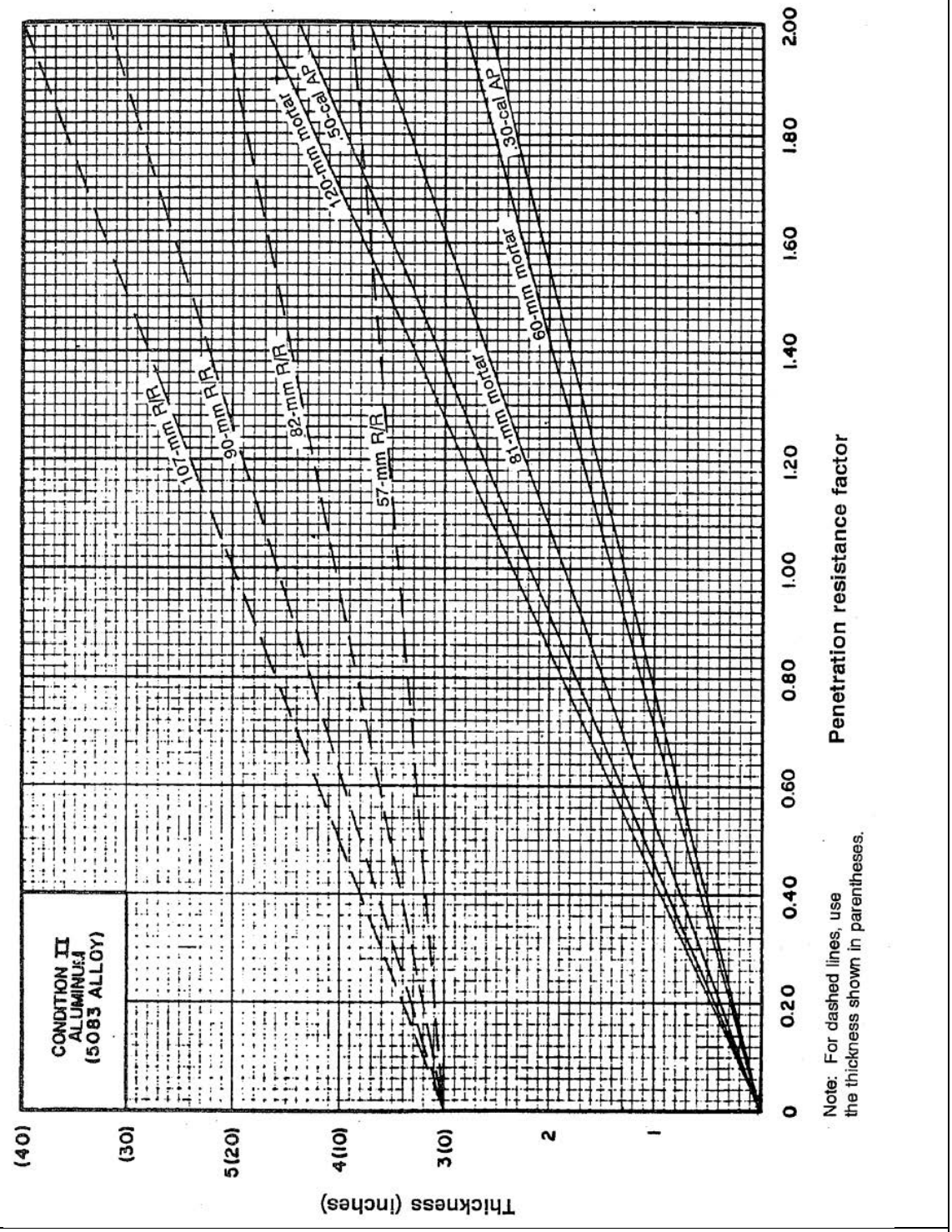
Figure K-19. Ballistic graphs for Condition II for concrete



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

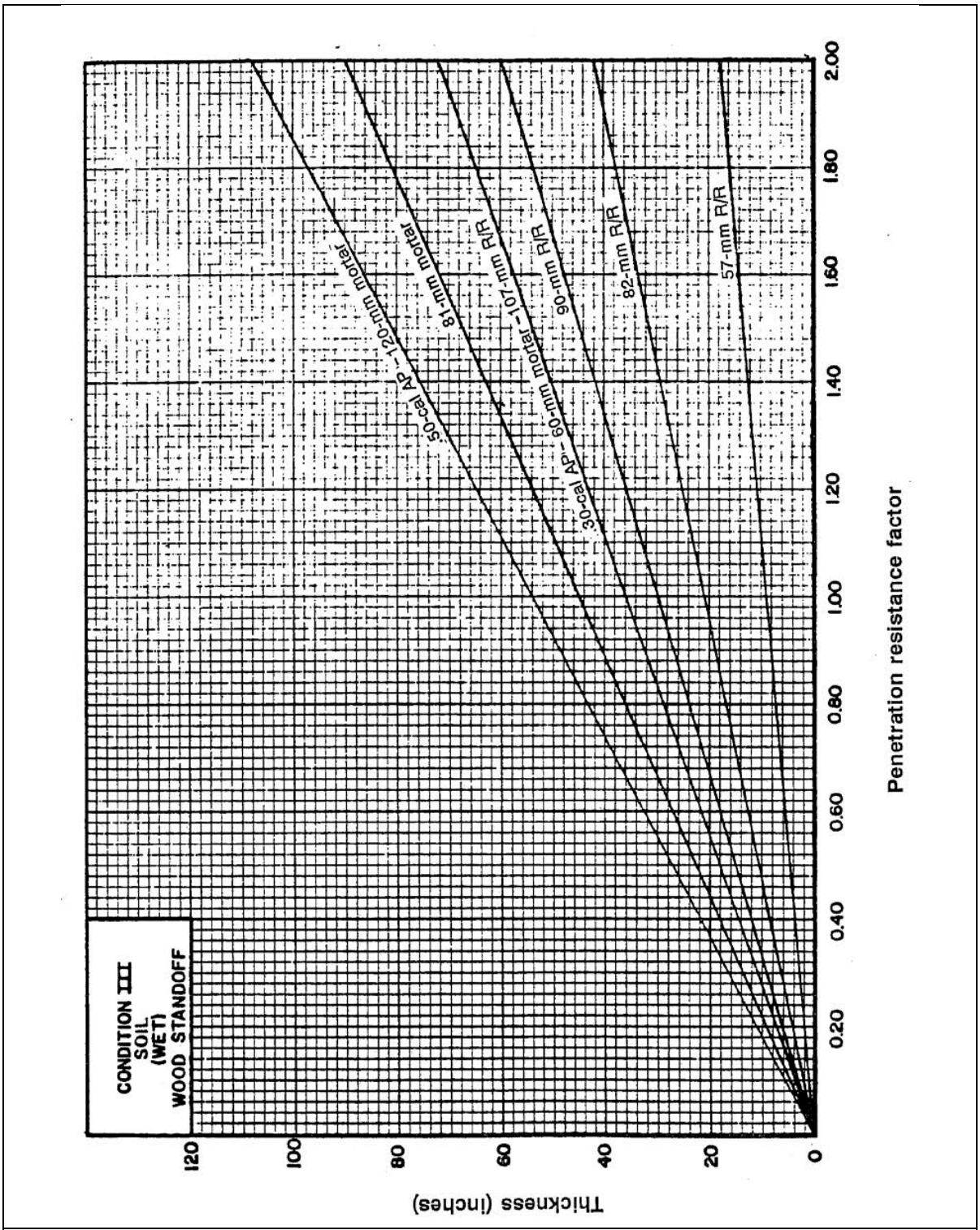
Figure K-20. Ballistic graphs for Condition II for timber



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

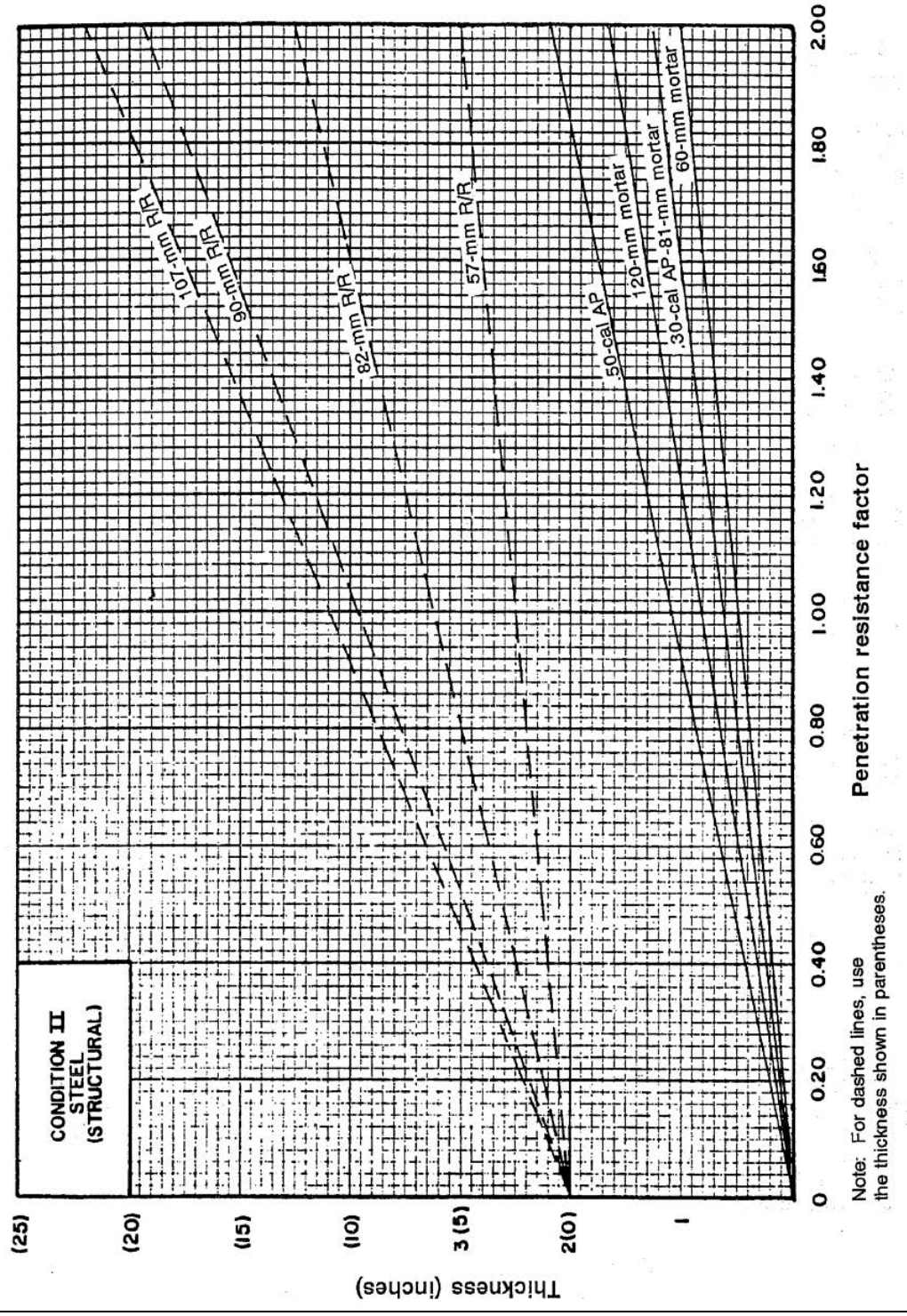
Figure K-21. Ballistic graphs for Condition II for aluminum



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

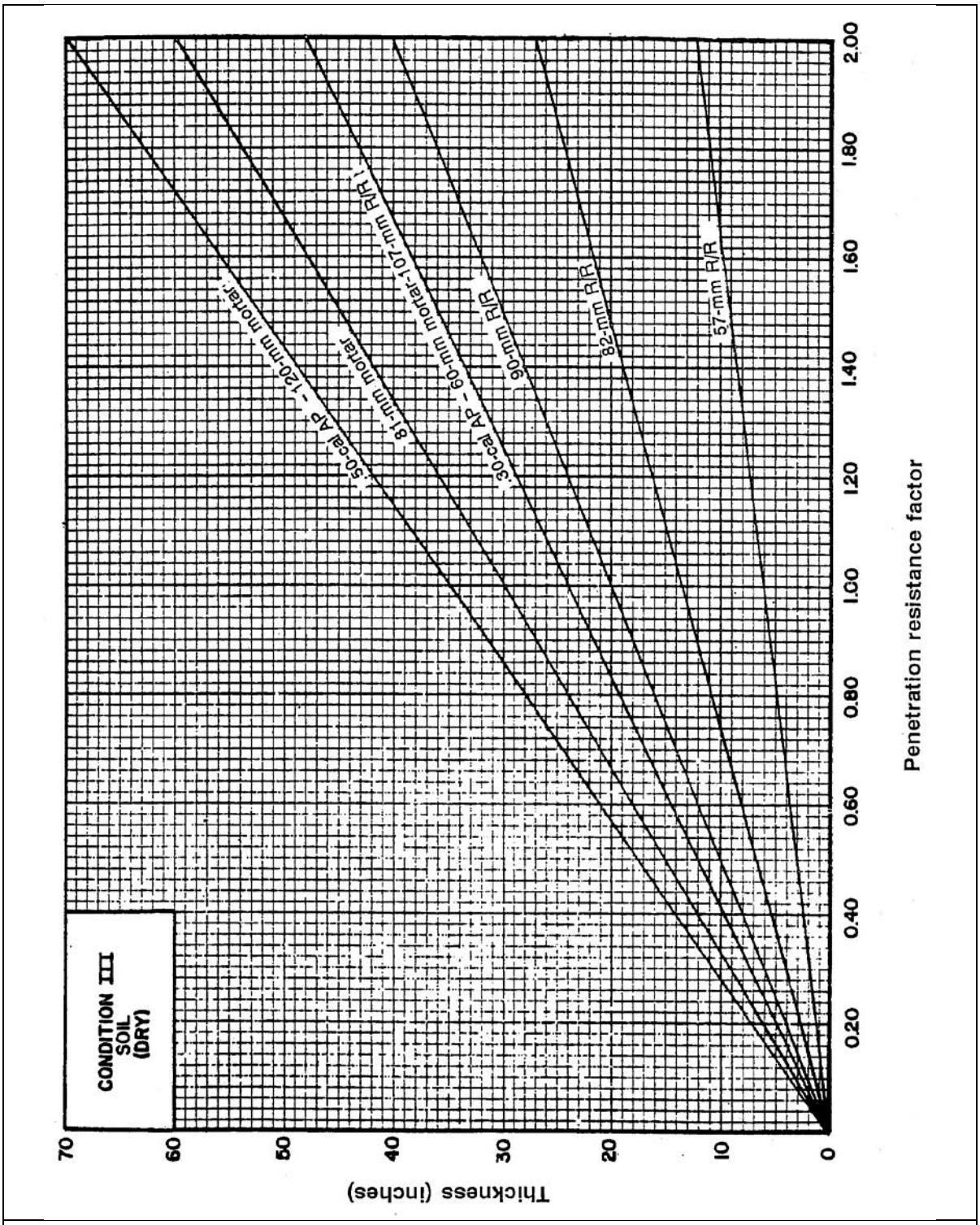
Figure K-22. Ballistic graphs for Condition II for steel



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

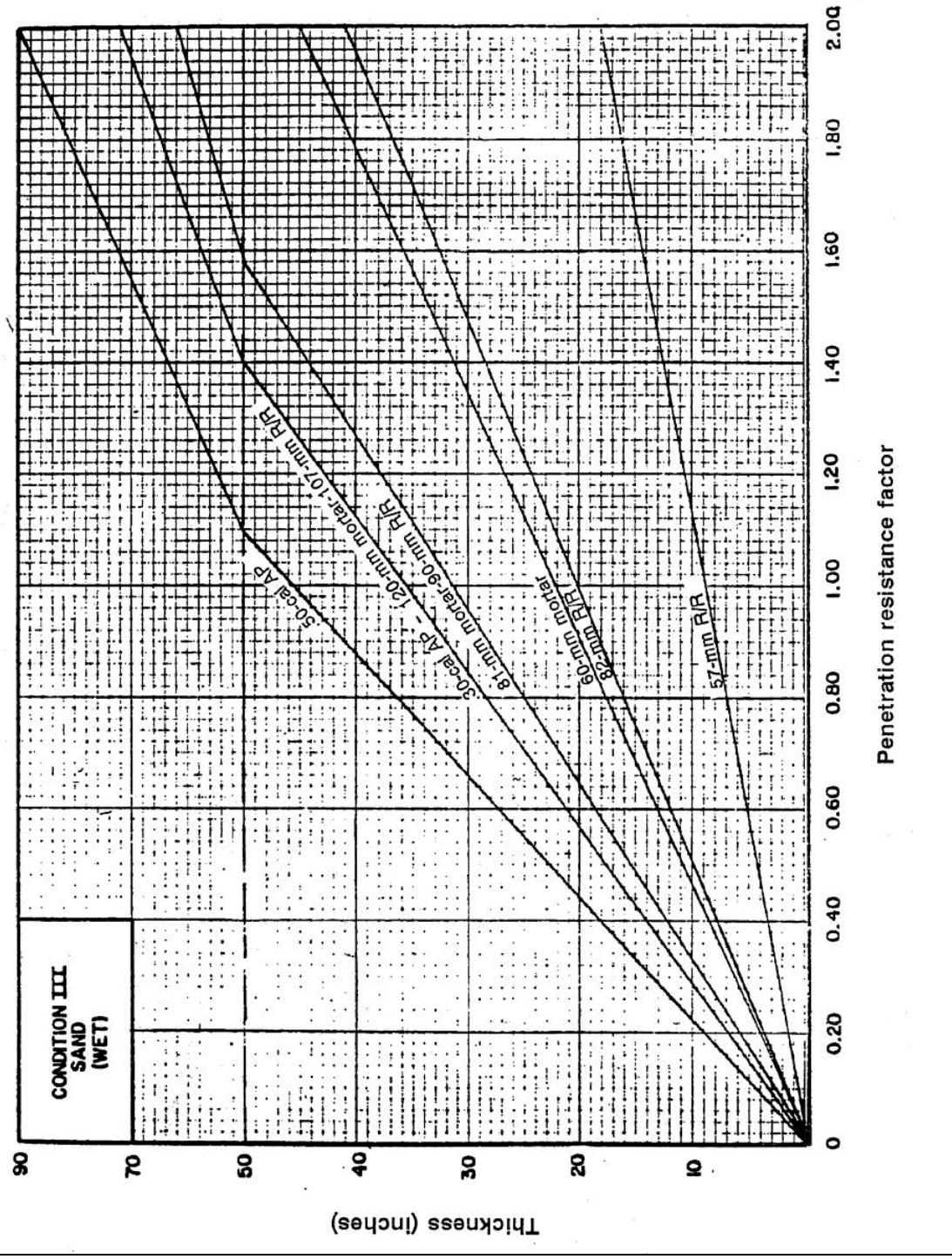
Figure K-23. Ballistic graphs for Condition III for wet soil



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

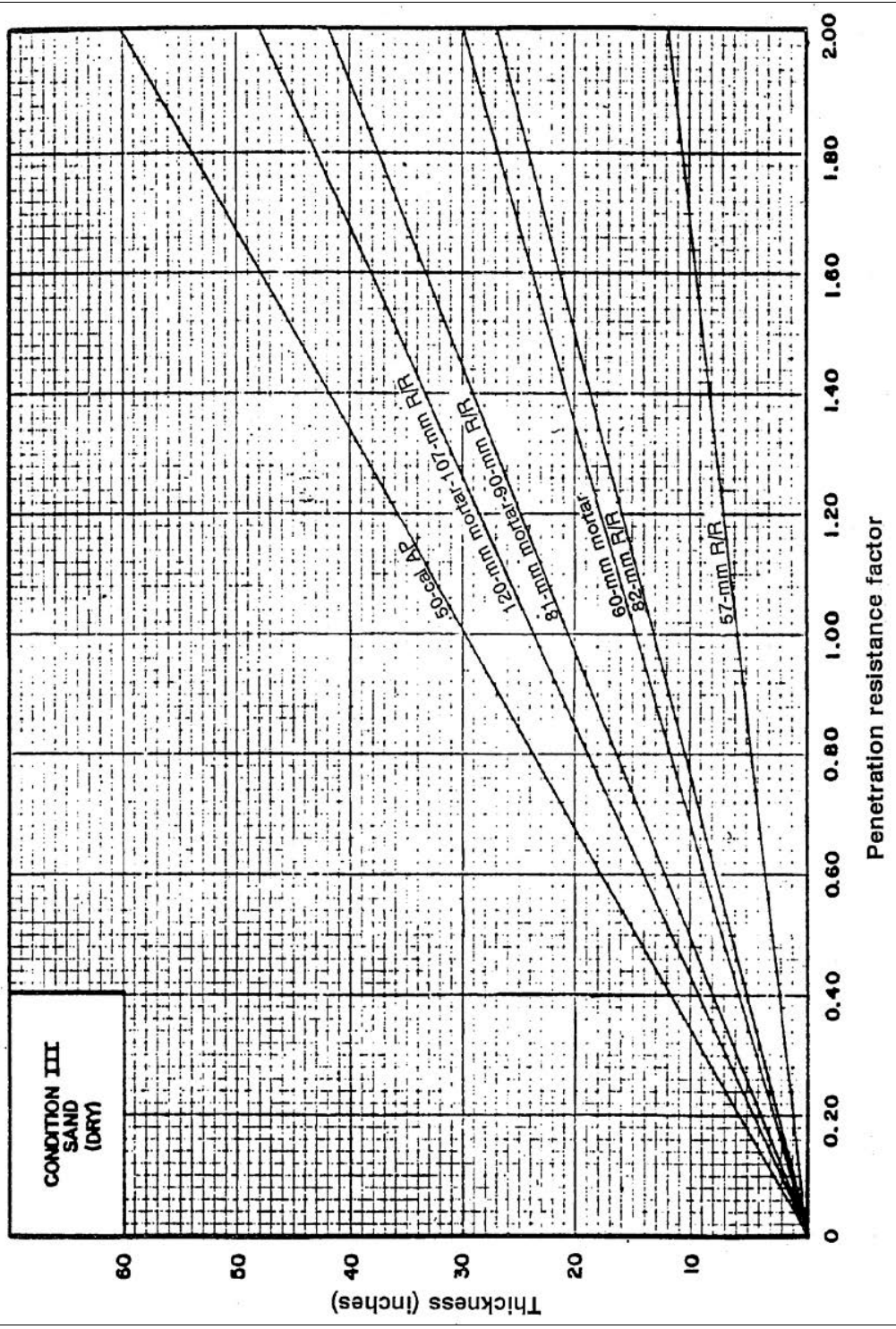
Figure K-24. Ballistic graphs for Condition III for dry soil



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

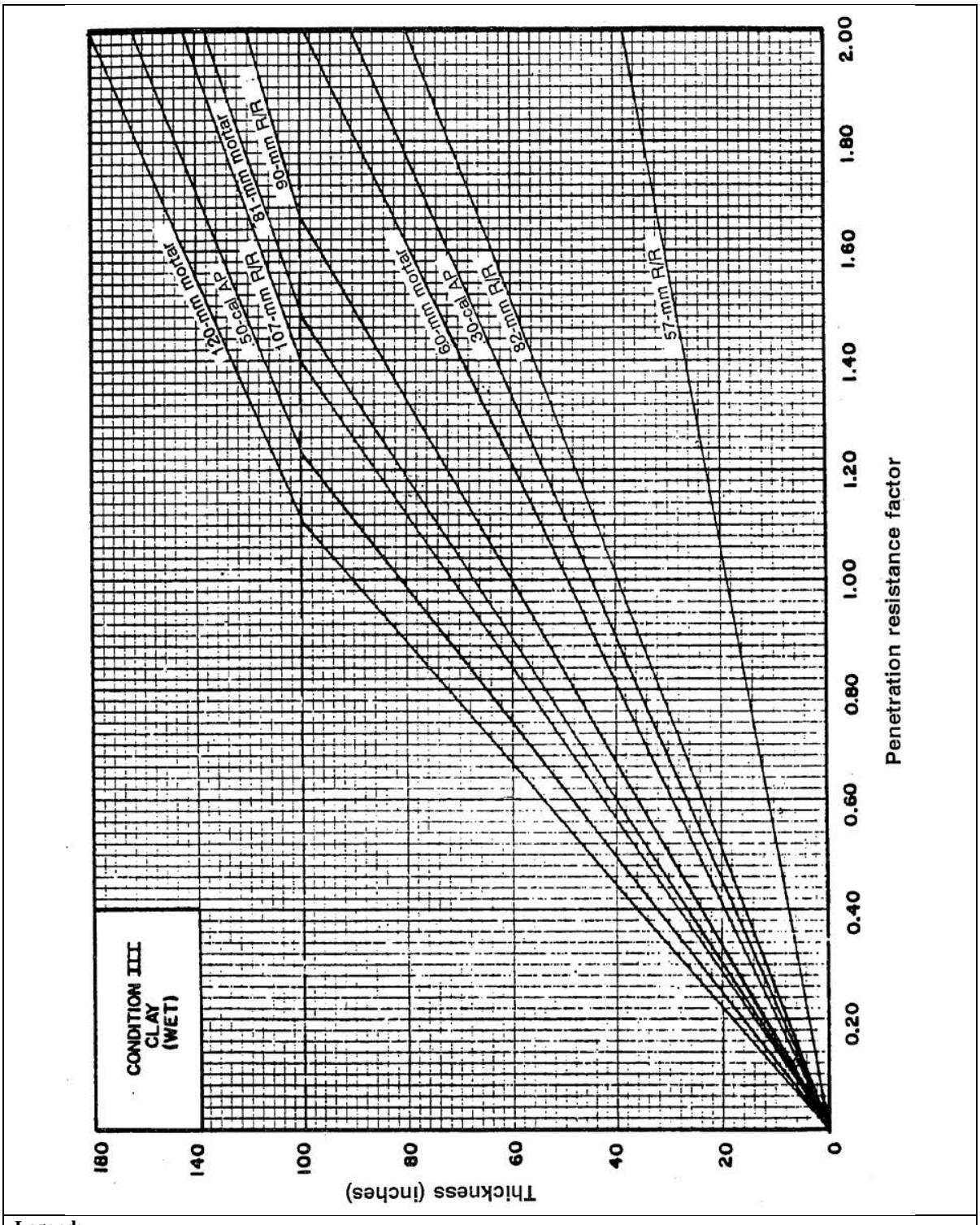
Figure K-25. Ballistic graphs for Condition III for wet sand



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

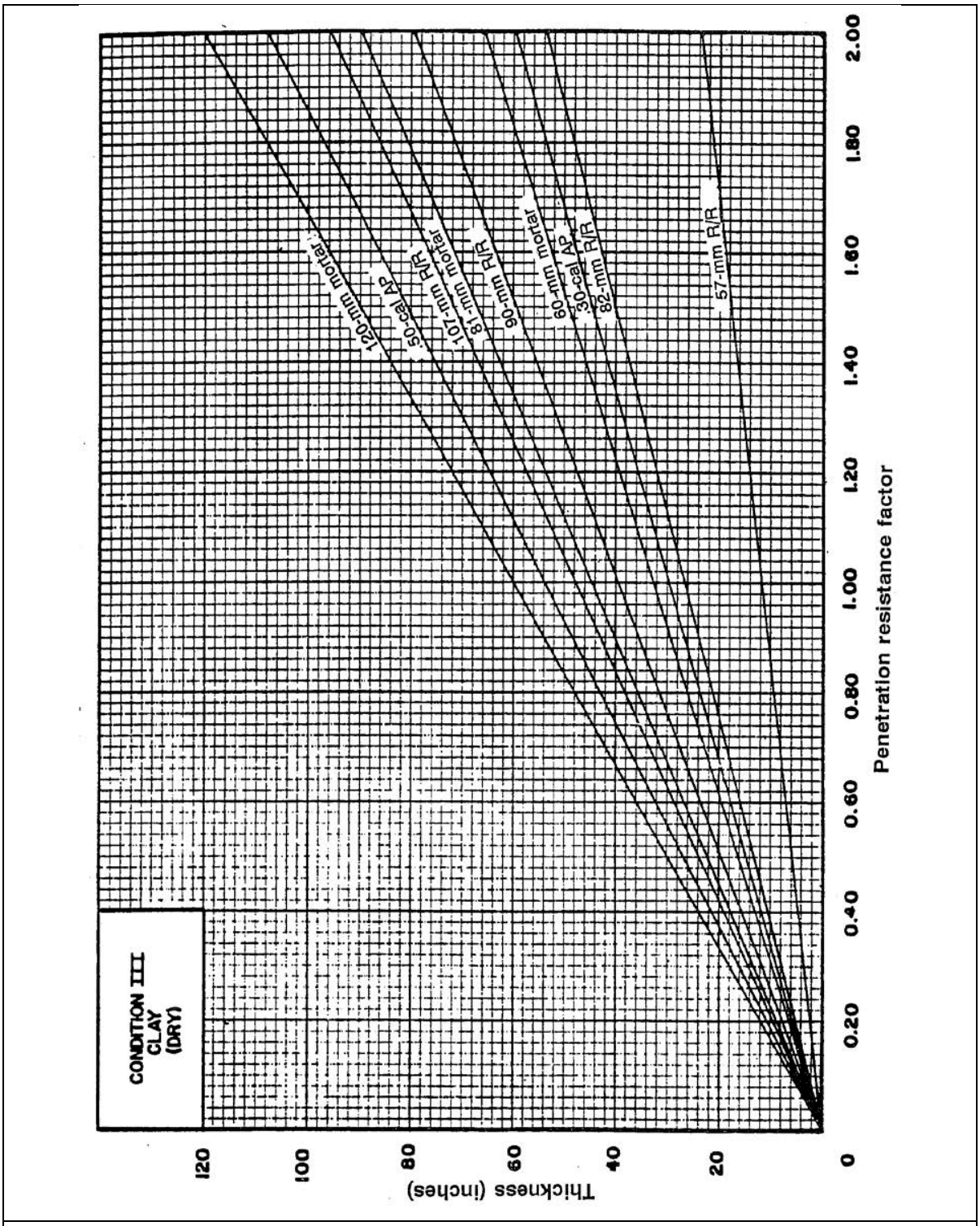
Figure K-26. Ballistic graphs for Condition III for dry sand



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

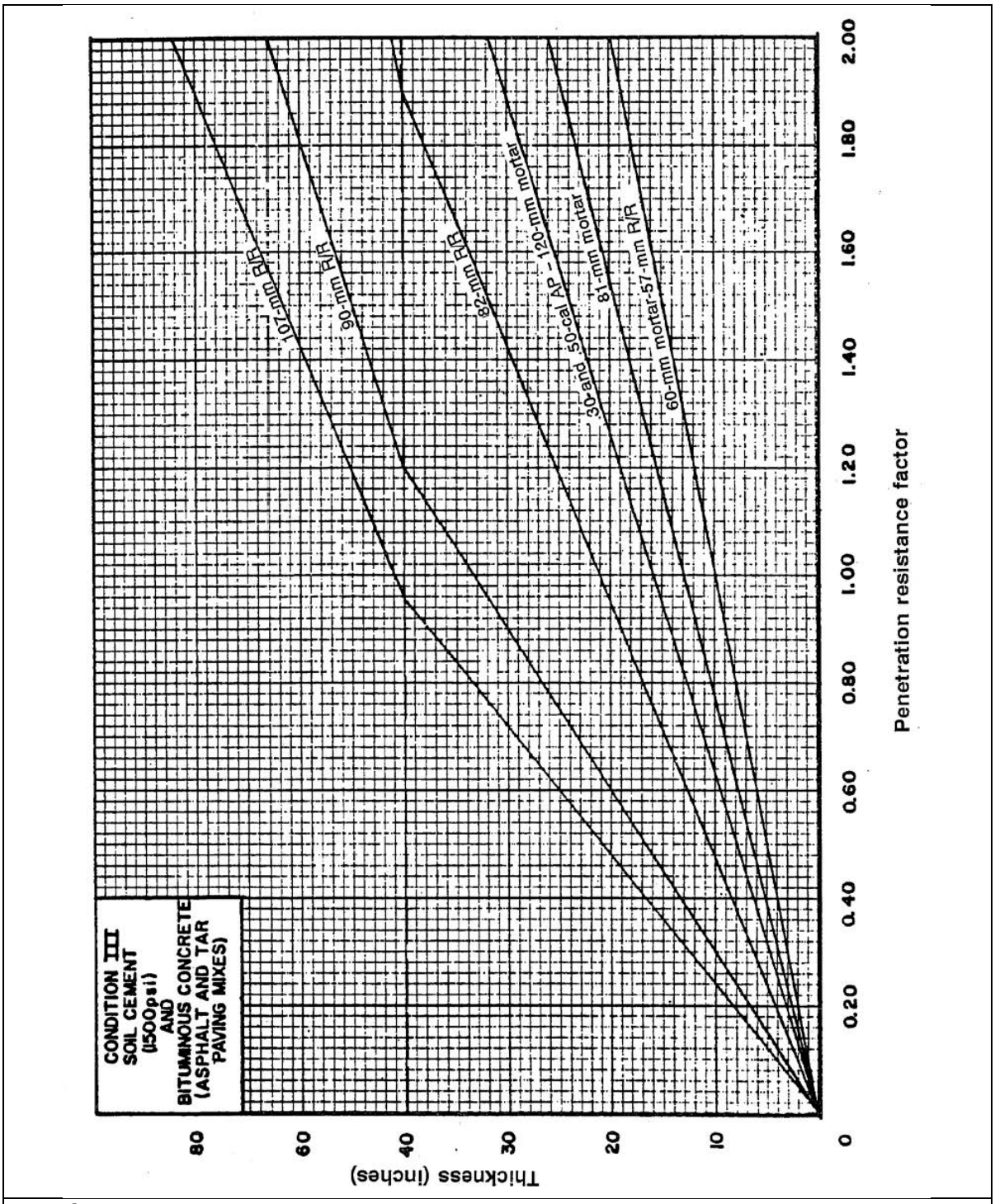
Figure K-27. Ballistic graphs for Condition III for wet clay



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

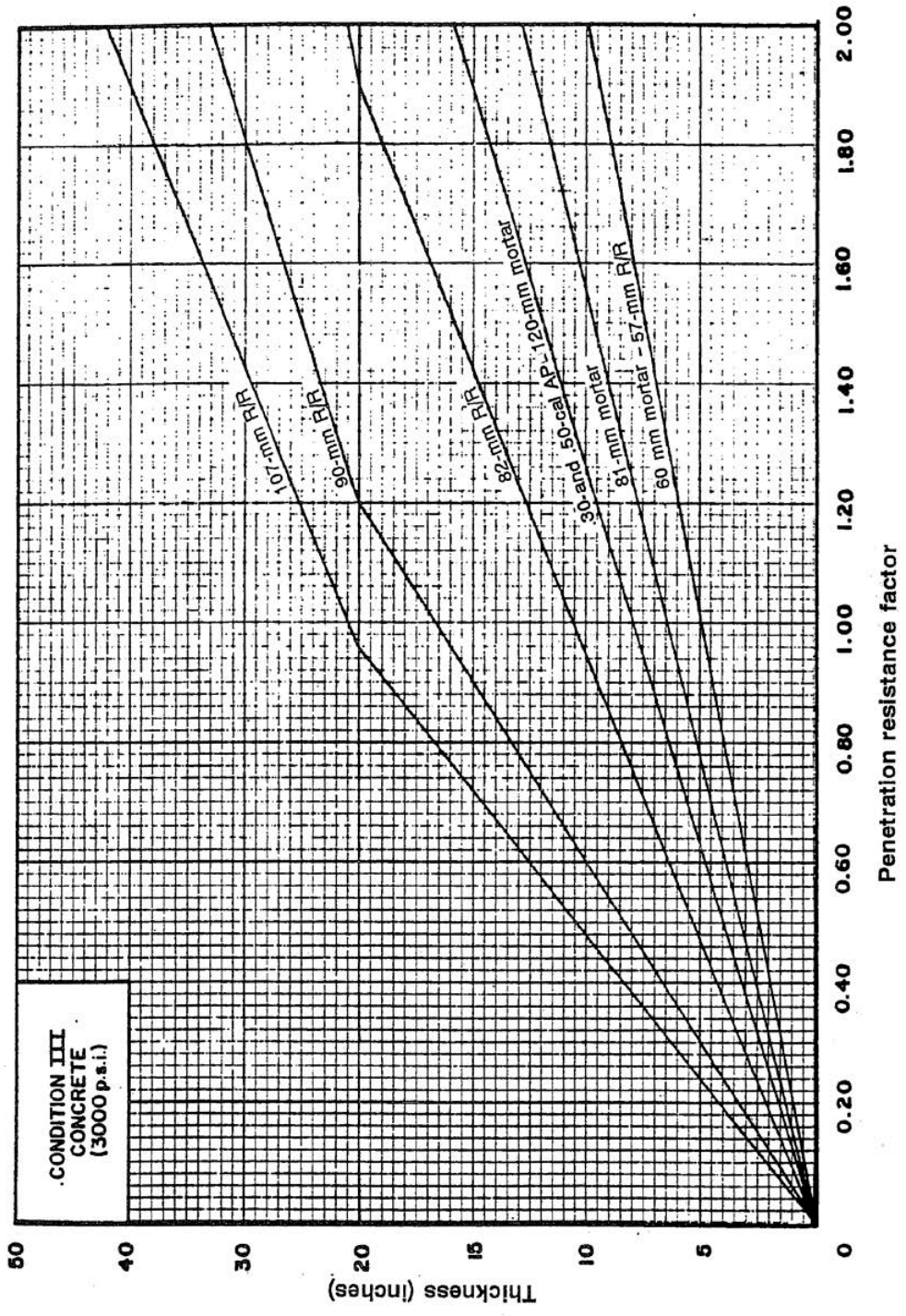
Figure K-28. Ballistic graphs for Condition III for dry clay



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
psi	pounds per square inch
R/R	recoiless rifle

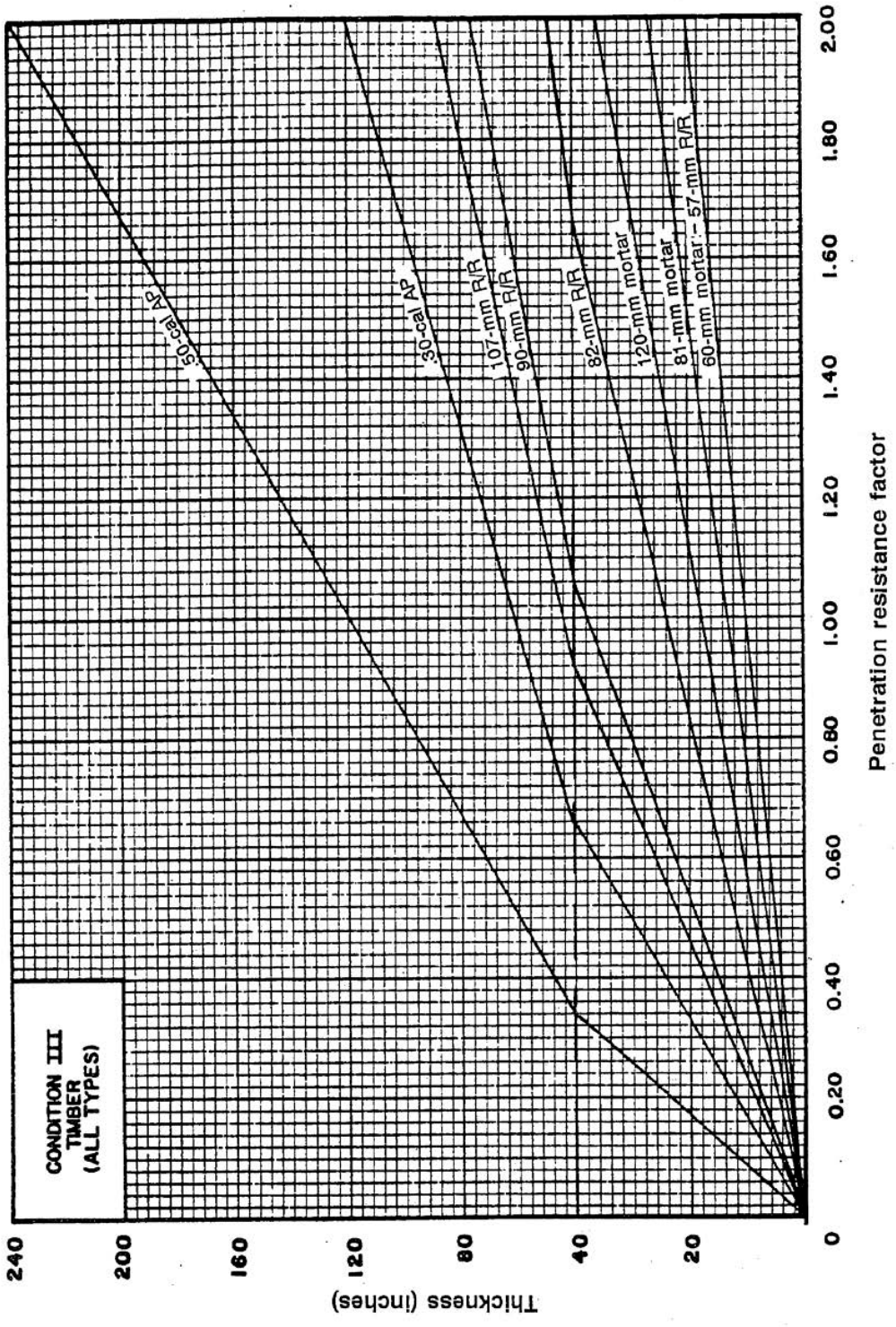
Figure K-29. Ballistic graphs for Condition III for soil cement and bituminous concrete



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
psi	pounds per square inch
R/R	recoiless rifle

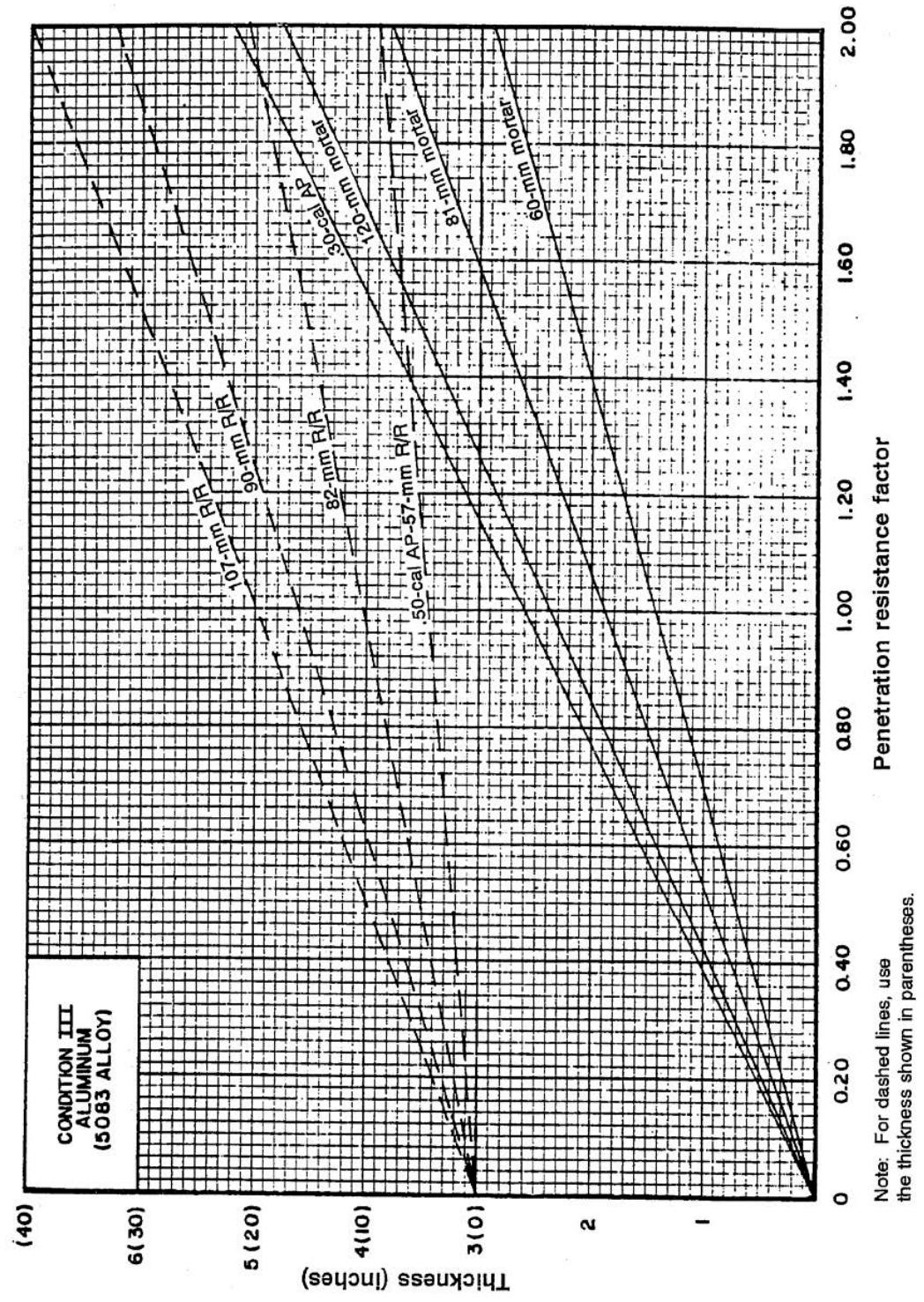
Figure K-30. Ballistic graphs for Condition III for concrete



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

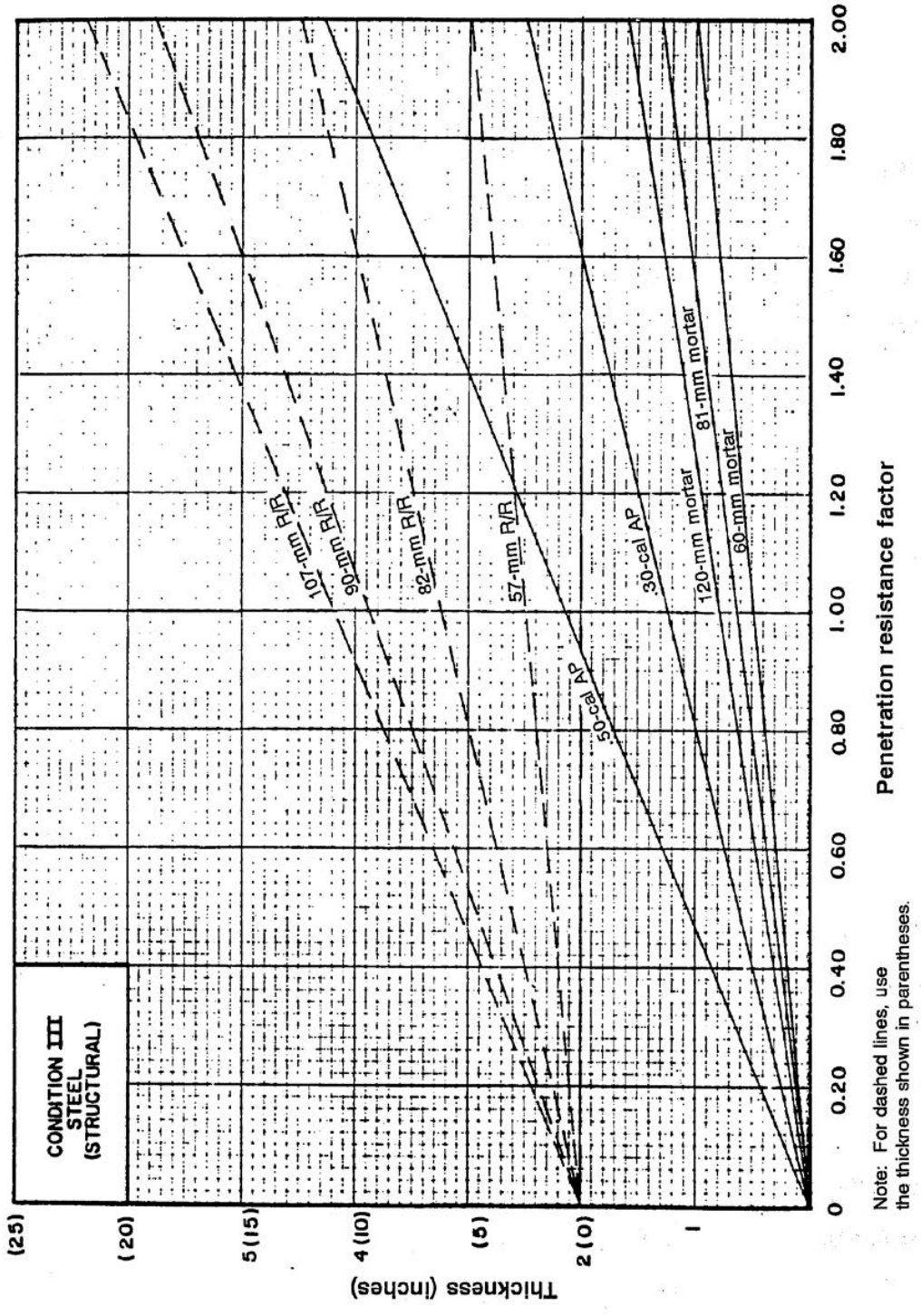
Figure K-31. Ballistic graphs for Condition III for timber



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

Figure K-32. Ballistic graphs for Condition III for aluminum



Legend:

AP	armor piercing
cal	caliber
mm	millimeter
R/R	recoiless rifle

Figure K-33. Ballistic graphs for Condition III for steel

Glossary

The glossary lists acronyms and terms with Army or joint definitions. Where Army and joint definitions differ, (Army) precedes the definition. Terms for which TM 3-34.48-2 is the proponent are marked with an asterisk (*). The proponent publication for other terms is listed in parentheses after the definition.

SECTION I – ACRONYMS AND ABBREVIATIONS

AC	asphalt concrete
ACN	aircraft classification number
ADRP	Army doctrine reference publication
AFCS	Army Facilities Components System
AFH	Air Force handbook
AFI	Air Force instruction
AFM	Air Force manual
AFMAN	Air Force manual
AFPAM	Air Force pamphlet
AFR	Air Force regulation
AH	attack helicopter
AI	airfield index
AL	Alabama
ALZ	assault landing zone
AMP	airfield marking patterns
AR	Army regulation
ASTM	American Society for Testing and Materials
attn	attention
AWG	American wire guage
CBR	California Bearing Ratio
CDID	Capabilities Development and Integration Directorate
CFR	Code of Federal Regulations
CH	cargo helicopter
CI	cone index
CL	clay low plasticity
CODDD	Concepts, Organizations, and Doctrine Development Division
DA	Department of the Army
DC	District of Columbia
DCP	dynamic cone penetrometer
DD	Department of Defense
dH	atmoshere pressure and altitude
DLA	Defense Logistics Agency
DOD	Department of Defense

DODD	Department of Defense Directive
DSN	defense switched network
DZ	drop zone
EM	engineer manual
ERDC	United States Army Engineer Research and Development Center
ETAC	Environmental Technical Applications Center
ETL	Engineering Technical Letter
EZ	extraction zone
FAA	Federal Aviation Administration
FASSI	frost area soil support index
FL	Florida
FM	field manual
FMTV	family of medium tactical vehicles
FOD	foreign object damage
HMMWV	high mobility multipurpose wheeled vechicle
http	hypertext transfer protocol
https	hypertext transfer protocol secure
IFR	instrument flight rules
IL	Illinois
IMC	instrument meteorological conditions
JP	joint publication
LAPES	Low-Altitude Parachute Extraction System
LZ	landing zone
MCRP	Marine Corps reference publication
METT-TC	mission, enemy, terrain and weather, troops and support available, time available, and civil considerations
MO	Missouri
MSCoE	Maneuver Support Center of Excellence
MTVR	medium tactical vehicle replacement
NAVAID	navigational aid
NAVAIR	Naval Air Systems Command
NAVFAC	Naval Facilities Engineering Command
NFS	nonfrost susceptible
NGA	National Geospatial Intelligence Agency
No.	number
NSN	national stock number
NTRP	Navy tactical reference publication
NVG	night vision goggles
OH	observation helicopter
PCASE	Pavement-Transportation Computer Assisted Structural Engineering
PCC	portland cement concrete
PCN	pavement classification number
PFS	partially frost-susceptible

PI	plasticity index
POI	point of impact
POL	petroleum, oils, and lubricants
RAM	rocket, artillery, mortar
RI	Rhode Islan
RPG	rocket-propelled grenade
SOF	special operations forces
STANAG	standardization agreement
STT	special tactics team
TC	training circular
TGR	takeoff ground run
TM	technical manual
TO	theater of operations
UFC	Unified Facilities Criteria
UH	utility helicopter
USACE	United States Army Corps of Engineers
USMC	United States Marine Corp
VA	Virginia
VCI	vehicle cone index
VFR	visual flight rules
VLZMP	visual landing zone marking panel
www	world wide web

SECTION II – TERMS

None

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