AC 150/5320-6A
Reprinted 9/15/7
Incorporates changes
1 Through 3

AIRPORT PAVING

May 9, 1967

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

AC NO: Reprinted 9/15/71
Incorporated Changes 1, 2 & 3
AC 150/5320-6A
DATE: May 9, 1967

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: AIRPORT PAVING

1. PURPOSE. This circular provides guidance to the public for the design and construction of pavements at civil airports.

2. CANCELLATION. Advisory Circular 150/5320-6, dated June 10, 1964, is cancelled.

3. REFERENCES.

a. Obtain copies of the following advisory circulars and additional copies of this circular from the Department of Transportation, Distribution Unit, TAD-484.3, Washington, D.C. 20590:

(1) AC 150/5325-2A, Airport Surface Areas Gradient Standards.

(2) AC 150/5325-5A, Aircraft Data.

(3) AC 150/5325-6, Effects of Jet Blast.

(4) AC 150/5330-2A, Runway/Taxiway Widths and Clearances for Airline Airports.

(5) AC 150/5335-1, Airport Taxiways.

(6) AC 150/5335-2, Airport Aprons.

(7) Aviation Demand and Airport Facility Requirement Forecasts for Large Air Transportation Hubs Through 1980, dated August 1967.

(8) Aviation Demand and Airport Facility Requirement Forecasts for Medium Air Transportation Hubs Through 1980, dated January 1969.

b. Copies of the following publications may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Send a check or money order in the amount listed for each document. No c.o.d. orders are accepted.

(1) AC 150/5370-1A, Standard Specifications for Construction of Airports, dated May 1968 - $3.50.

(2) AC 150/5320-5B, Airport Drainage, dated July 1970 - $1.00.

c. Copies of MIL-STD-621A, Subgrade, Subbase, and Test Methods for Pavement Base-Course Materials may be obtained from the Commanding Officer, Naval Supply Depot, 5901 Tabor Avenue, Philadelphia, Pennsylvania. 19120.

Chester G. Bowers, Director
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CHAPTER 1. AIRPORT PAVEMENTS - THEIR FUNCTIONS AND PURPOSES

1. GENERAL. Airport pavements are constructed to provide adequate support for the loads imposed by aircraft using the airport and to produce a firm, stable, smooth, all-year, all-weather surface, free from dust or other particles that may be blown or picked up by propeller wash or jet blast. In order to satisfactorily fulfill these requirements, the pavement must be of such quality and thickness that it will not fail under the load imposed. In addition, it must possess sufficient inherent stability to withstand, without damage, the abrasive action of traffic, adverse weather conditions, and other deteriorating influences. To produce such pavements requires a coordination of many factors of design, construction, and inspection to assure the best possible combination of available materials and a high standard of workmanship.

a. Types of Pavement. Pavements are divided into two general types:

(1) Flexible pavements are those consisting of a bituminous surface course, a base course of suitable granular material, and in most cases a granular subbase course.

(2) Rigid pavements are those pavements constructed of portland cement concrete and may or may not include a subbase course.

b. Flexible or rigid pavements, when properly designed and constructed, will provide a satisfactory airport pavement for any or all types of civil aircraft. However, a few areas where a specific type of pavement has proven beneficial are:

(1) The areas subjected to appreciable fuel spillage at the aircraft gate positions and the service or maintenance portions of the apron. Rigid pavements are recommended for these areas. This does not preclude the use of existing flexible pavements with a fuel resistant seal coat in these areas.

(2) The areas where jet erosion occurs adjacent to pavement. Many low cost stabilized surfaces may be used as erosion control measures. These areas include runway ends, blast pads, holding apron shoulders, and taxiway shoulders where turf cannot be established. This stabilization is further discussed in the Federal Aviation Administration publication, AC 150/5325-6, Effects of Jet Blast.

c. Pavement Courses.

(1) Surface courses include portland cement concrete, bituminous concrete, sand-bituminous mixtures, and bituminous surface treatments.

(2) Base courses consist of a variety of different materials which generally fall into two main classes, treated and untreated. The untreated bases consist of stone, slag, caliche, gravel, limerock, shell, sand-clay, coral, or any one of a variety of other approved materials. The treated bases normally consist of a crushed or uncrushed aggregate that has been mixed with cement or bitumen.

* (3) Subbase courses consist of a granular material, a stabilized granular material, or a stabilized soil. *

2. STANDARDS AND SPECIFICATIONS.

a. Dimensional standards applicable to the various airports are covered in the referenced advisory circulars. These standards establish recommendations for lengths, widths, grades, and slopes of the pavements on airports.

b. The FAA publication, Standard Specifications for Construction of Airports, includes descriptions of the various pavement components and specifies the requirements governing the control, handling, quality, gradation, and quantity of individual materials included in the pavement mixes. It also contains detailed information on excavation, embankment, construction, and subgrade preparation.

(1) These specifications are necessarily broad in scope because they are for use throughout the United States and its possessions. They may not be completely satisfactory to cover a particular situation or a condition peculiar to a certain locality without some modification. However, the types of paving covered by the specifications have been used successfully on airports for many years; and experience has shown that radical departures from the standards will accomplish no useful purpose.

(2) It is not the intent of these specifications to restrict the use of local materials which will serve as acceptable alternates, nor to preclude the adoption of local construction methods if they are predicated upon sound engineering and construction practices and experience has shown them to be
* satisfactory. Materials normally produced by local suppliers in accordance with State and local highway specifications may be satisfactory for use on smaller airports without modification. When gross aircraft weights exceed 12,500 pounds, the local material shall be carefully examined from the *

* standpoints of durability, toughness, and gradation. Blending or treatment will often improve the local materials. Many state highway materials specifications, used in major trunk route or interstate system construction, will provide adequate pavements for gross aircraft weights to 60,000 pounds. For pavements to receive substantial use by aircraft exceeding 60,000 pounds gross weight, our highest material standards shall be employed. *

3. SPECIAL CONSIDERATIONS.

a. In addition to the property of furnishing support for the aircraft loads which will be applied, the pavements of aircraft operating areas must be so designed and constructed in order to assure maximum safety and efficiency of operations which normally are to be expected. As previously mentioned, gradient and similar standards are specified in the referenced circulars. Particular care must be excercised to assure satisfactory transition of grades and slopes at pavement intersections and to provide fillets at such points which will permit maximum operational utilization of the facility.

b. The surface or wearing course shall be dense and well bonded to prevent displacement of surface aggregates. The wearing surface * texture shall provide a nonskid property. A trowel finish shall never be applied to portland cement concrete operational surfaces. A longitudinal burlap drag may be applied to apron and taxiway surfaces, but shall not be permitted on runway pavement unless immediate grooving is intended. In other cases, portland cement runways shall be finished by transverse brooming or belting and for air carrier or turbojet operations, limited to transverse brooming or "combing" with a stiff bristle broom or steel comb. Bituminous concrete runways may be given a satisfactory surface by utilizing high quality aggregate and by careful control of the minus 1/4-inch aggregate fractions. When hard, sharp, crushed aggregates are used with a gradation following FAA recommendations, a good texture should be achieved without sacrifice in stability or durability. *

c. Certain areas of the pavement will be subjected to repeated loadings occasioned by channelization or concentration of traffic. These areas (which include taxiways, aprons, run-up aprons, and runway ends) must be designed to withstand the stresses from such loadings.

4. STAGE CONSTRUCTION OF AIRPORT PAVEMENTS.

a. It may be desirable to construct the airport pavement by stages, that is, to build up the surface or improve the pavement profile, layer by layer, as the traffic using the facility increases in weight and numbers. In addition, such a method of construction can be utilized to advantage when construction funds are limited.

b. If stage construction is to be undertaken, the need for sound planning cannot be too highly stressed. The complete pavement should be designed prior to the start of any stage, and each stage undertaken must result in a usable surface. Such a procedure, in addition to providing interim surfaces to serve the immediate need, will assure that development accomplished in each stage
* will form an integral part of the ultimate pavement. While either flexible or rigid pavement may be planned for stage construction, the use of a flexible or "sandwich" overlay shall not be included in any planned stage. *

c. The division of work into stages can be arranged in any manner suitable to the financial or physical condition particular to the site in question as long as the above principles are applied.

CHAPTER 2. SOIL INVESTIGATIONS AND EVALUATION

5. GENERAL.

a. The importance of accurate identification and evaluation of the pavement foundation cannot be overemphasized. Although it is impossible to explore the entire field of soil mechanics in a publication such as this, the following text will highlight those aspects which are particularly important to the airport paving engineer.

b. Classification systems of soils and subgrades which are to be used in connection with design of airport pavements are set forth in this chapter. To avoid misunderstanding, certain terms employed are defined below.

(1) For engineering purposes, and particularly as it applies to airports, soil includes all natural deposits which, without requiring blasting under unfrozen conditions, can be moved with excavating equipment.

(2) Soil conditions include such items as the elevation of the water table, the presence of water bearing strata, and the field properties of the soil. Field properties of the soil include the soil's structure, identification, plasticity, moisture content, and density.

(3) The soil profile is the vertical arrangement of layers of soils, each of which possesses different physical properties from the adjacent layer.

(4) Subgrade soil is that soil which forms the foundation for the pavement. It is the soil directly beneath the pavement structure.

c. Soil conditions and the availability of suitable construction materials are the most important items affecting the cost of construction of the landing areas and the pavements. Grading costs are directly related to the difficulty with which excavation can be accomplished and compaction obtained.

d. It should be remembered that the subgrade soil carries the loads imposed by aircraft utilizing the facility. The pavement serves to distribute the imposed load to the subgrade over an area greater than that of the tire contact area. The greater the thickness of pavement, the greater is the area over which the load on the subgrade is distributed. It follows, therefore, that the more unstable the subgrade soil, the greater is the required area of load distribution and consequently the greater is the required thickness of pavement. The soils having the best engineering characteristics encountered in the grading and excavating operations should be worked into the upper layers of the subgrade.

* e. In addition to the relationship which soil conditions bear to grading and paving operations, they determine the necessity for underdrains and materially influence the amount of surface runoff. Thus, they have a consequent effect on the size and extent of other drainage structures and facilities. (See FAA publication, AC 150/5320-5A, Airport Drainage). *

6. SOIL INVESTIGATIONS.

a. To provide essential information on the various types of soils, investigations should be made to determine their distribution and physical properties. The information so obtained, when combined with data on site topography and area climatic records, provides basic planning material essential to the logical and effective development of the airport. An investigation of soil conditions at an airport site will include:

(1) A soil survey to determine the arrangement of different layers of the soil profile with relation to the proposed subgrade elevation.

(2) Sampling of the layers of soil.

(3) Testing of samples to determine the physical properties of the various soil materials with respect to stability and subgrade support.

(4) A survey to determine the availability of materials for use in construction of the subgrade and pavement.

b. With respect to sampling and surveying procedures and techniques, Method T 86 of the American Association of State Highway Officials (AASHO) is one of those most frequently used. This method is based entirely on the soil profile. In the field, the various layers that comprise the soil profile are identified by such characteristics as color, texture, structure, consistency, compactness, cementation, and to varying degrees, chemical composition.

(1) This method of soil identification parallels that used by the Department of Agriculture, which appears on their soils maps. The intelligent use of these maps can prove an invaluable aid in the study of soils at and in the vicinity of the airport. Although the pedological classification, determined from these maps, does not treat soil as engineering

* or construction material, data so obtained are extremely useful to the agronomist in connection with the development of turf areas on airports and to the engineer concerned with preliminary investigations of site selection, development costs, and alignment. *

(2) The practice of determining data on soils by use of aerial photographs is becoming more widespread. Relief and soil patterns may be determined from the photographs, and an experienced photo-interpreter can define differences in characteristics of soils. By employing this method of investigation, it is possible to expedite soil studies and reduce the amount of effort required to gather data.

7. SURVEYING AND SAMPLING.

a. The initial step in an investigation of soil conditions is a soil survey to determine the quantity and extent of the different types of soil, the arrangement of soil layers, and the presence of any subsurface water. Samples of soil are usually obtained by means of borings made with a soil auger or similar device. Inasmuch as each location presents its particular problems and variations, the spacing of borings cannot always be definitely specified by rule or preconceived plan. A suggested criterion for the location, depth, and number of borings is tabulated below.

AREA	SPACING	DEPTH
Runways and Taxiways	Along Centerline, 200 Feet on Centers	Cut Areas - 10' Below Finished Grade 1/Fill Areas - 10' Below Existing Ground Surface
Other Areas of Pavement	1 Boring per 10,000 Square Feet of Area	Cut Areas - 10' Below Finished Grade 1/Fill Areas - 10' Below Existing Ground Surface
Borrow Areas	Sufficient Tests to Clearly Define the Borrow Material	To Depth of Proposed Excavation of Borrow

* 1/ For deep fills, boring depths shall be used as necessary to determine the extent of consolidation and slippage, which the fill to be placed may cause. *

b. Obviously, the locations, depths, and number of borings must be such that all important soil variations can be determined and mapped. Whenever past experience at the location in question has indicated that settlement or stability in deep fill areas may be a problem, or if in the opinion of the engineer additional investigations are warranted, more and/or deeper borings may be required in order that the proper design, location, and construction procedures may be determined. Conversely, where uniform soil conditions are encountered, fewer borings may be acceptable.

c. The soil survey is not confined to soils encountered in grading or necessarily to the area within the boundaries of the airport site. Possible sources of locally available material that may be used in the paving operation should be investigated.

d. Samples representative of the different layers of the various soils encountered, and various construction materials discovered, should be obtained and tested in the laboratory to determine their physical and engineering properties. Because the results of a test can only be as good as the sampling, it is of utmost importance that each sample be representative of a particular type of soil material and not be a careless and indiscriminate mixture of several materials.

* e. Pits, open cuts, or both may be required for making in-place bearing tests, for the taking of undisturbed samples, for charting variable soil strata, etc. This type of supplemental soil investigation is recommended for all heavy load runway areas and for other problem soil areas as may be encountered. *

8. SOIL TESTS.

a. Physical Soil Properties. To determine the physical properties of a soil and to provide an estimate of its behavior under various conditions, it is necessary to conduct certain soil tests. In this regard, a number of field and laboratory tests have been developed and standardized. Details of methods of performing soil tests are completely covered in publications of the AASHO and
* ASTM and in Military Standards. *

b. Testing Requirements. Soil tests are usually identified by terms indicating the soil characteristics which the tests will reveal.
* Terms which identify the tests considered to be the minimum or basic requirement for airport pavement, with their AASHO designations and brief explanations, follow. *

(1) Dry Preparation of Disturbed Soil Samples for Test (AASHO T 87) or Wet Preparation of Disturbed Soil Samples for Test (AASHO T 146). The dry method (T 87) should be used only for clean, cohesionless granular materials. The wet method (T 146) should be used for all cohesive or borderline materials.

(2) Mechanical Analysis of Soils (AASHO T 88). The mechanical analysis of soils is a test for determining, quantitatively, the distribution of particle sizes in soils.

(3) Determining the Plastic Limit of Soils (AASHO T 90). The plastic limit is defined as the minimum moisture content at which the soil becomes plastic. At moisture contents above the plastic limit, there is a sharp drop in the stability of a soil.

(4) Determining the Liquid Limit of Soils (AASHO T 89). The liquid limit is the water content at which the soil passes from a plastic to a liquid state. The liquid state is defined as the condition in which the shear resistance of the soil is so slight that a small force will cause it to flow.

* (5) Calculating the Plasticity Index of Soils. The plasticity index is the numerical difference between the plastic limit and the liquid limit. It indicates the range in moisture content over which a soil remains in a plastic state prior to changing into a liquid.

(a) Maximum density is defined as the maximum dry weight, in pounds per cubic foot, obtained when a material is mixed with different percentages of water and compacted in a standard manner.

(b) Optimum moisture content is the percentage of water at which maximum density is obtained with a specified compactive effort. Compaction Control Tests are covered in Division VII, Tests, Item T-611 of AC 150/5370-1A, Standard Specifications for Construction of Airports.

(6) Determination of Maximum Density and Optimum Moisture. For purposes of compaction control during construction, it will be necessary to perform tests to determine the maximum density and optimum moisture content of the different types of soils. *

c. Supplemental Tests.

(1) In many cases special or unusual soil conditions exist or are anticipated, and supplemental soil tests will be required. These will vary in the areas of occurrence and in available treatment methods to such an extent that thorough discussion is beyond the scope of this circular. As examples, an expansive soil combined with high seasonal moisture change may require stabilization as noted in paragraph 12f or, alternately, compaction at higher moisture and lower density, with the choice influenced by area practice, surface type, and design loadings. Soils with low field densities and/or subject to consolidation may require densification to greater depths than the normal design requirement. Such problem soils must be recognized and corrective measures taken where required.

* (2) For many soils, it is essential that the in-place density and bearing strength be determined. Drive samples can be used if sufficient correlation with other test procedures has been established for a particular soil. In other cases, pits shall be carefully opened for the taking of undisturbed samples and penetration bearing tests. Density and moisture content should be carefully charted when heavy load pavements may require compaction at depth in accordance with Figure 8-1. This information permits establishment of a reasonable shrinkage factor, and aids both designer and contractor in estimating compaction requirements in cut areas.

(3) California Bearing Ratio (CBR) tests, laboratory and field, and plate bearing tests are included in this text as applicable to specific design and evaluation options. These are not intended to limit the supplemental testing which may be appropriate to a specific soil, such as tests for shrinkage and swell, consolidation under load, frost susceptability, etc. *

9. SOIL CLASSIFICATION.

a. While the results of individual tests indicate certain physical properties of the soil, the principal value is derived from the fact that through correlation of the data so obtained it is possible to prepare an engineering classification of soils related to their field behavior. Such a classification is presented in Table 1.

TABLE 1. CLASSIFICATION OF SOILS FOR AIRPORT PAVEMENT CONSTRUCTION

Soil group		Mechanical analysis				Liquid limit	Plasticity index
		Material retained on No. 10 sieve—percent [1]	Material finer than No. 10 sieve—percent				
			Coarse sand, passing No. 10; retained on No. 40	Fine sand, passing No. 40 retained on No. 200	Combined silt and clay; passing No. 200		
Granular	E-1	0-45	40+	60-	15-	25-	6-
	E-2	0-45	15+	85-	25-	25-	6-
	E-3	0-45	---------	---------	25-	25-	6-
	E-4	0-45	---------	---------	35-	35-	10-
Fine grained	E-5	0-55	---------	---------	45-	40-	15-
	E-6	0-55	---------	---------	45+	40-	10-
	E-7	0-55	---------	---------	45+	50-	10-30
	E-8	0-55	---------	---------	45+	60-	15-40
	E-9	0-55	---------	---------	45+	40+	30-
	E-10	0-55	---------	---------	45+	70-	20-50
	E-11	0-55	---------	---------	45+	80-	30+
	E-12	0-55	---------	---------	45+	80+	---------
	E-13	Muck and peat—field examination					

[1] If percentage of material retained on the No. 10 sieve exceeds that shown, the classification may be raised, provided such material is sound and fairly well graded.

b. The soil classification requires, basically, the performance of three tests - the mechanical analysis, determination of the liquid limit, and determination of the plastic limit. Tests for these properties have been utilized for many years as a means of evaluating soil for use in the construction of embankments and pavement subgrades. These tests identify a particular soil as having physical properties similar to those of a soil whose performance and behavior are known. Therefore, the test soil can be expected to possess the same characteristics and degree of stability under like conditions of moisture and climate.

c. As can be discerned from Table 1, the mechanical analyses provide the information to permit separation of the granular soils from the fine grained soils; whereas, the several groups are arranged in order of increasing values of liquid limit and plasticity index. The division between granular and fine grained soils is made upon the requirement that granular soils must have less than 35 percent of silt and clay combined. Determination of the sand, silt, and clay fractions is made on that portion of the sample passing the No. 10 sieve because this is considered to be the critical portion with respect to changes in moisture and other climatic influences. The classification of the soils with respect to different percentages of sand, silt, and clay is shown in Figure 1.

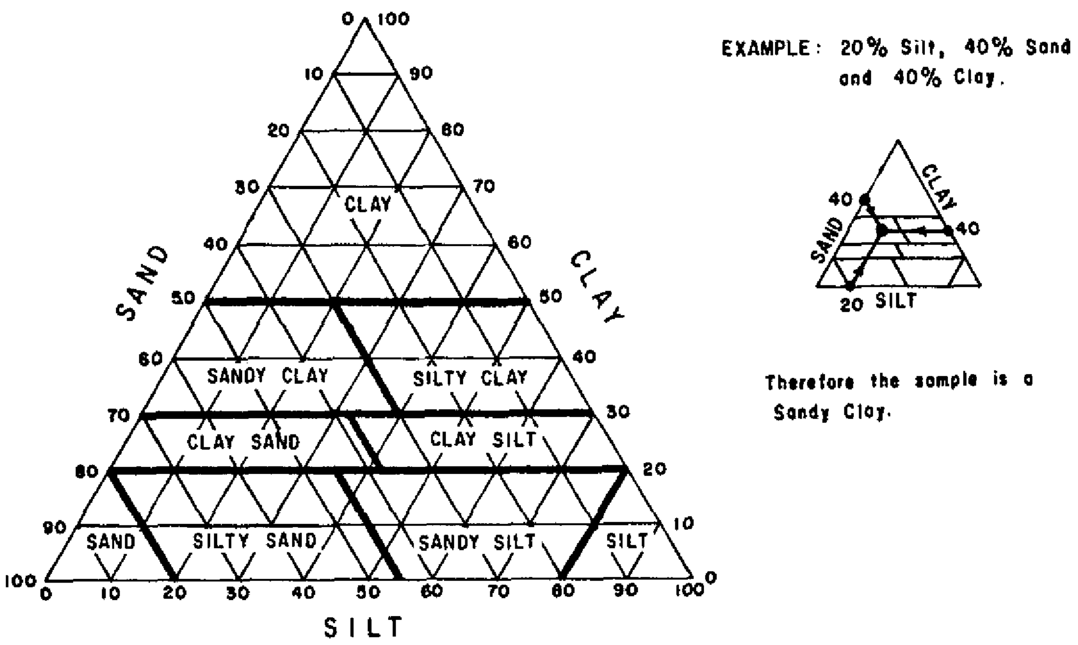


FIGURE 1. TEXTURAL CLASSIFICATION OF SOILS

(1) Group E-1 includes well-graded, coarse, granular soils that are stable even under poor drainage conditions and are not generally subject to detrimental frost heave. Soils of this group may conform to well-graded sands and gravels with little or no fines. If frost is a factor, the soil should be checked to determine the percentage of the material less than 0.02 mm in diameter (paragraph 12d).

(2) Group E-2 is similar to Group E-1 but has less coarse sand and may contain greater percentages of silt and clay. Soils of this group may become unstable when poorly drained as well as being subject to frost heave to a limited extent.

(3) Groups E-3 and E-4 include the fine, sandy soils of inferior grading. They may consist of fine cohesionless sand or sand-clay types with a fair-to-good quality of binder. They are less stable than Group E-2 soils under adverse conditions of drainage and frost action.

(4) Group E-5 comprises all poorly graded soils having more than 35 percent but less than 45 percent of silt and clay combined. This group also includes all soils with less than 45 percent of silt and clay but which have plasticity indices of 10 to 15. These soils are susceptible to frost action.

(5) Group E-6 consists of the silts and sandy silts having zero-to-low plasticity. These soils are friable and quite stable when dry or at low moisture contents. They lose stability and become very spongy when wet and for this reason are difficult to compact unless the moisture content is carefully controlled. Capillary rise in the soils of this group is very rapid; and they, more than soils of any other group, are subject to detrimental frost heave.

(6) Group E-7 includes the silty clay, sand clay, clayey sands, and clayey silts. They range from friable to hard consistency when dry and are plastic when wet. These soils are stiff and dense when compacted at the proper moisture content. Variations in moisture are apt to produce a detrimental volume change. Capillary forces acting in the soil are strong, but the rate of capillary rise is relatively slow and frost heave, while detrimental, is not as severe as in the E-6 soils.

(7) Group E-8 soils are similar to the E-7 soils but the higher liquid limits indicate a greater degree of compressibility, expansion, shrinkage, and lower stability under adverse moisture conditions.

(8) Group E-9 comprises the silts and clays containing micaceous and diatomaceous materials. They are highly elastic and very difficult to compact. They have low stability in both the wet and dry state and are subject to frost heave.

(9) Group E-10 includes the silty clay and clay soils that form hard clods when dry and are very plastic when wet. They are very compressible, possess the properties of expansion, shrinkage, and elasticity to a high degree and are subject to frost heave. Soils of this group are more difficult to compact than those of the E-7 or E-8 groups and require careful control of moisture to produce a dense, stable fill.

(10) Group E-11 soils are similar to those of the E-10 group but have higher liquid limits. This group includes all soils with liquid limits between 70 and 80 and plasticity indices over 30.

(11) Group E-12 comprises all soils having liquid limits over 80 regardless of their plasticity indices. They may be highly plastic clays that are extremely unstable in the presence of moisture, or they may be very elastic soils containing mica, diatoms, or organic matter in excessive amounts. Whatever the cause of their instability, they will require the maximum in corrective measures.

(12) Group E-13 encompasses organic swamp soils such as muck and peat which are recognized by examination in the field. In their natural state, they are characterized by very low stability, very low density, and very high moisture content.

10. SPECIAL CONDITIONS AFFECTING FINE GRAINED SOILS.

a. A soil may possibly contain certain constituents that will give test results which would place it, according to Table 1, in more than one group. This could happen with soils containing mica, diatoms, or a large proportion of colloidal material. Such overlapping can be avoided by the use of Figure 2 in conjunction with Table 1, with the exception of E-5 soils which should be classified strictly according to Table 1 and paragraph 9c(4).

b. Soils with plasticity indices higher than those corresponding to the maximum liquid limit of the particular group are not of common occurrence. When encountered, they are placed in the higher numbered group as shown in Figure 2. This is justified by the fact that, for equal liquid limits, the higher the plasticity index, the lower the plastic limit at which a slight increase in moisture causes the soil to rapidly lose stability.

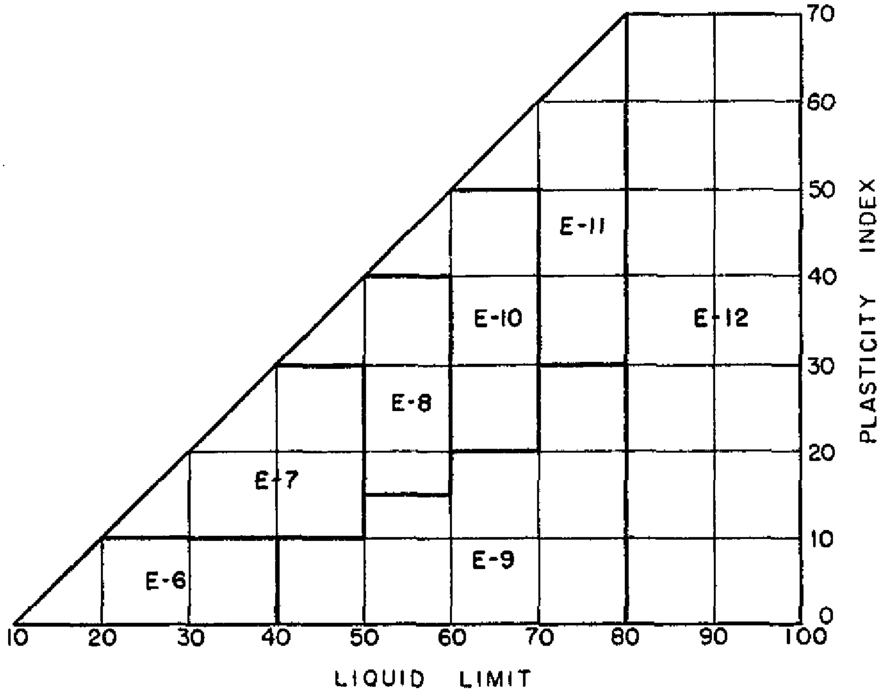


FIGURE 2. CLASSIFICATION CHART FOR FINE GRAINED SOILS

11. COARSE MATERIAL RETAINED ON NO. 10 SIEVE. Only that portion of the sample passing the No. 10 sieve is considered in the above-described classification. Obviously, the presence of material retained on the No. 10 sieve should serve to improve the overall stability of the soil. For this reason, upgrading the soil from 1 to 2 classes is permitted when the percentage of the total sample retained on the No. 10 sieve exceeds 45 percent for soils of the E-1 to E-4 groups and 55 percent for the others. This applies when the coarse fraction consists of reasonably sound material which is fairly well graded from the maximum size down to the No. 10 sieve size. Stones or rock fragments scattered through a soil should not be considered of sufficient benefit to warrant upgrading.

12. SUBGRADE CLASSIFICATION.

a. For each soil group there are corresponding subgrade classes. These classes are based on the performance of the particular soil as a subgrade for rigid or flexible pavements under different conditions of drainage and frost. The subgrade class is determined from the results of soil tests and the information obtained by means of the soil survey and a study of climatological and topographical data. The subgrade classes and their relationship to the soil groups are shown in Table 2. The prefixes "R" and "F" indicate subgrade classes for rigid and flexible pavements, respectively. These subgrade classes determine the total pavement thickness for a given aircraft load. The requirements are fully discussed under rigid and flexible pavement design in following parts of this text. Therefore, only a brief description of the classes will be presented here.

TABLE 2. AIRPORT PAVING SUBGRADE CLASSIFICATION

Soil Group	Subgrade Class		
	Good Drainage	Poor Drainage	
	No Frost or Frost	No Frost	Frost
E-1	Fa or Ra	Fa or Ra	F1 or Ra
E-2	Fa or Ra	F1 or Ra	F2 or Rb
E-3	F1 or Ra	F2 or Rb	F3 or Rb
E-4	F1 or Ra	F2 or Rb	F4 or Rb
E-5	----------	F3 or Rb	F5 or Rb
E-6	----------	F4 or Rc	F6 or Rc
E-7	----------	F5 or Rc	F7 or Rc
E-8	----------	F6 or Rc	F8 or Rd
E-9	----------	F7 or Rd	F9 or Rd
E-10	----------	F8 or Rd	F10 or Rd
E-11	----------	F9 or Re	F10 or Re
E-12	----------	F10 or Re	F10 or Re
E-13	Not suitable for subgrade		

b. Subgrades classed as Fa for flexible pavements and Ra for rigid pavements furnish adequate subgrade support without the addition of subbase material. The soil's value as a subgrade material decreases as the number increases.

c. Good and poor drainage in this classification refers to the subsurface soil drainage.

(1) Poor Drainage is defined for the purpose of this circular as soil that cannot be drained because of its composition or because of the conditions at the site. Soils primarily composed of silts and clays for all practical purposes are impervious and as long as a water source is available the soils' natural affinity for moisture will render these materials unstable. These fine grain soils cannot be drained and are classified as poor drainage as indicated in Table 2. A granular soil that would drain and remain stable except for conditions at the site such as high water table, flat terrain, or impervious strata, should also be designated as poor drainage. In some cases this condition may be corrected by the use of subdrains.

(2) Good Drainage is defined as a condition where the internal soil drainage characteristics are such that the material can and does remain well drained resulting in a stable subgrade material under all conditions.

d. There is a tendency to overlook the detrimental effects of frost in pavement design. The effects of frost are widely known; however, experience shows that all too often pavements are damaged or destroyed by frost that was not properly taken into account in the design. Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weights are frost susceptible for pavement design purposes. The subgrade soil should be classified either as "No Frost" or "Frost" depending on one of the two following conditions:

(1) No Frost should be used in the design when the average frost penetration anticipated is less than the thickness of the pavement section.

(2) Frost should be used when the anticipated average frost penetration exceeds the pavement sections. The design should consider including non-frost susceptible material below the required subbase to minimize or eliminate the detrimental frost effect on the subgrade. The extent of the subgrade protection needed depends on the soil and the surface and subsurface environment at the site.

e. Figure 3 shows the average annual frost penetration throughout the conterminous United States. It is included primarily as a guide. Actual depth of frost penetration should be determined for each particular site on the basis of reliable local information.

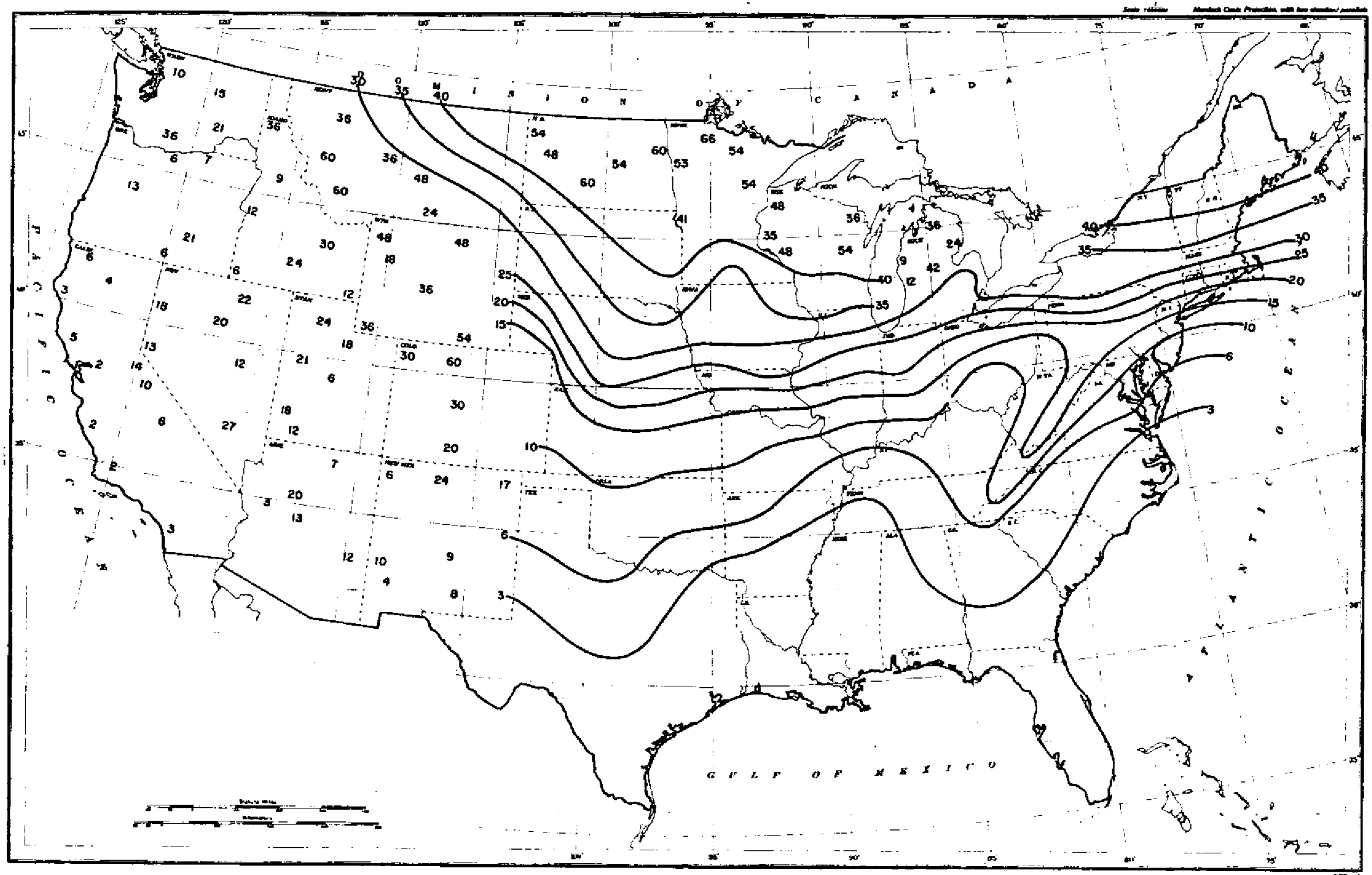


FIGURE 3. AVERAGE DEPTH OF ANNUAL FROST PENETRATION - IN INCHES

f. Subgrade treatment should be considered in the pavement design if one or more of the following conditions exists: poor drainage, adverse surface drainage, or frost. A stabilized or modified subgrade will to some degree make a hard-to-work soil more workable, provide a working platform for construction, act as a moisture barrier between untreated soil and the pavement section, and is frost resistant. The agent for the treatment will depend on the soil and site conditions. Lime is used for most clay, silt, and silt-clay soils, while portland cement and bituminous materials are readily adaptable to some soils.

* g. While the Atterburg limits and mechanical gradation are indicators of inherent soil stability, they are not infallible in this regard. Variations in grain shape, grittiness, etc., influence the stability and performance of a soil under load. The possibility of performance at variance with these tests can be greatly lessened by the use of CBR tests as a supplemental classification procedure. A CBR-F classification and adjustment procedure is shown in Chapter 6, Figure 20 and paragraph 35a. For design purposes, the CBR-F classification can be related to the rigid pavement subgrade classification by reference to Table 2. *

13. SOIL TESTS REQUIRED.

a. A summary of the preceding text discloses that the following tests are required in order to analyze correctly the conditions on the site and to prepare design plans and construction specifications.

(1) Mechanical analysis to show the percentage of coarse sand, fine sand, silt and clay, as well as the amount of material retained on the No. 10 sieve.

(2) Liquid and plastic limit tests.

(3) Maximum density and optimum moisture content determination.

* b. Additional tests, such as those for bearing, shrinkage, permeability, consolidation, in-place density and moisture content should be performed where applicable in order to properly evaluate the performance of a soil (see paragraph 8c). *

CHAPTER 3. PAVEMENT DESIGN

14. GENERAL. This chapter covers pavement design for major civil airports, i.e., airports serving aircraft with gross weights of 30,000 pounds or more. Chapter 5 is devoted to the construction of pavements serving the lighter aircraft with gross weights under 30,000 pounds.

a. Determination of pavement thickness requirements is not an exact science. Although a great deal of research work has been completed and more is underway, it has been impossible to arrive at a formula that would provide a direct mathematical solution of thickness requirements. For this reason the determination of pavement thickness must be based on a theoretical analysis of load distribution through pavements and soils, the analysis of experimental data, and a study of the performance of pavements under actual service conditions. Pavement thickness curves presented in this chapter have been developed from a correlation of the data obtained from these sources. Pavements constructed in accordance with these standards have generally proven satisfactory. Use of the curves is described in paragraphs 17 and 19.

b. Structural design of airport pavements consists of determining both the overall pavement thickness and the thicknesses of the component parts of the pavement. There are a number of factors which influence the thickness of pavement required to provide satisfactory service. These include the magnitude and character of the aircraft loads to be supported, the volume of traffic, the concentration of traffic in certain areas, and the quality of the subgrade soil as a pavement foundation.

(1) Aircraft Wheel Loadings. Practically all large civil aircraft are supported on a tricycle arrangement of landing wheels, consisting of a nose gear and two main undercarriage assemblies. The exact percentage of the gross weight on the main gear undercarriages depends upon the type of aircraft and whether the aircraft is loaded with a forward or aft center of gravity. Recent information on current aircraft indicates that from 88 to 98 percent of the aircraft weight may be distributed to the two main gear undercarriages. This publication considers that 5 percent of the gross weight of the aircraft is supported by the nose wheel and that the remaining 95 percent is distributed equally between the two main undercarriage assemblies. The design curves, based on gross aircraft weight, will cover the three types of main gear assemblies in current civil use (single, dual, and dual-tandem). As new civil aircraft are developed with other gear arrangements, new curves will be developed for them in the same manner as described in Appendix 1

(2) Traffic. It is general practice to design the pavement for "capacity operations" of the most critical aircraft that will normally operate from the airport. The curves presented in this publication are based on this condition.

* (3) Concentration of Traffic. Airport pavements may be divided into two or more categories by reason of the thicknesses required to satisfy operating conditions. The areas requiring the thickest pavement (critical areas) are the aprons, taxiways (except certain exit taxiways), and the ends of the runway. In the remaining area of the runway, the noncritical area, the less adverse loading conditions permit a reduction in the required pavement thickness. Such a reduction can result in a considerable saving in both construction effort and funds. Typical layouts and sections are shown in Figures 4 and 5.

(a) Figure 5 illustrates a keel section recommended for runways serving turbojet aircraft primarily. However, the details of Figures 4 and 5 are interchangeable to the extent that the Figure 4 or conventional section can be used for jet runways by substituting 0.9T for the entire noncritical runway area, and the keel section may be used for runways serving propeller driven aircraft primarily by substitution of 0.8T for the 0.9T runway area. The 0.9 factor, as opposed to 0.8, shall be used for the noncritical runway when 25 percent or more of the planned operations will be by turbojet aircraft which gross 90 percent or more of the design weight.

(b) Figure 5 shows a 75-foot keel dimension for the 0.9T noncritical area. Optional sections may include a 50-foot keel with transition to 0.7T over a 25-foot width, a 100-foot keel with transition through the outer 25-foot width only.

(c) The exit taxiway thicknesses shown in Figures 4 and 5 are for typical domestic operations by propeller and jet aircraft, respectively. Gross landing weight shall control the design thickness, per paragraph 14b(3), where these will vary from the standard by more than nominal thickness.

(d) There are certain areas of airport pavements which aircraft normally will not traverse. These areas include blast pads, taxiway and apron shoulders, and certain portions of the terminal apron adjacent to buildings. Normally, the only vehicles that traverse these areas are maintenance vehicles, fuel trucks, snowplows, and baggage carts. These areas shall be designed for their intended use. *

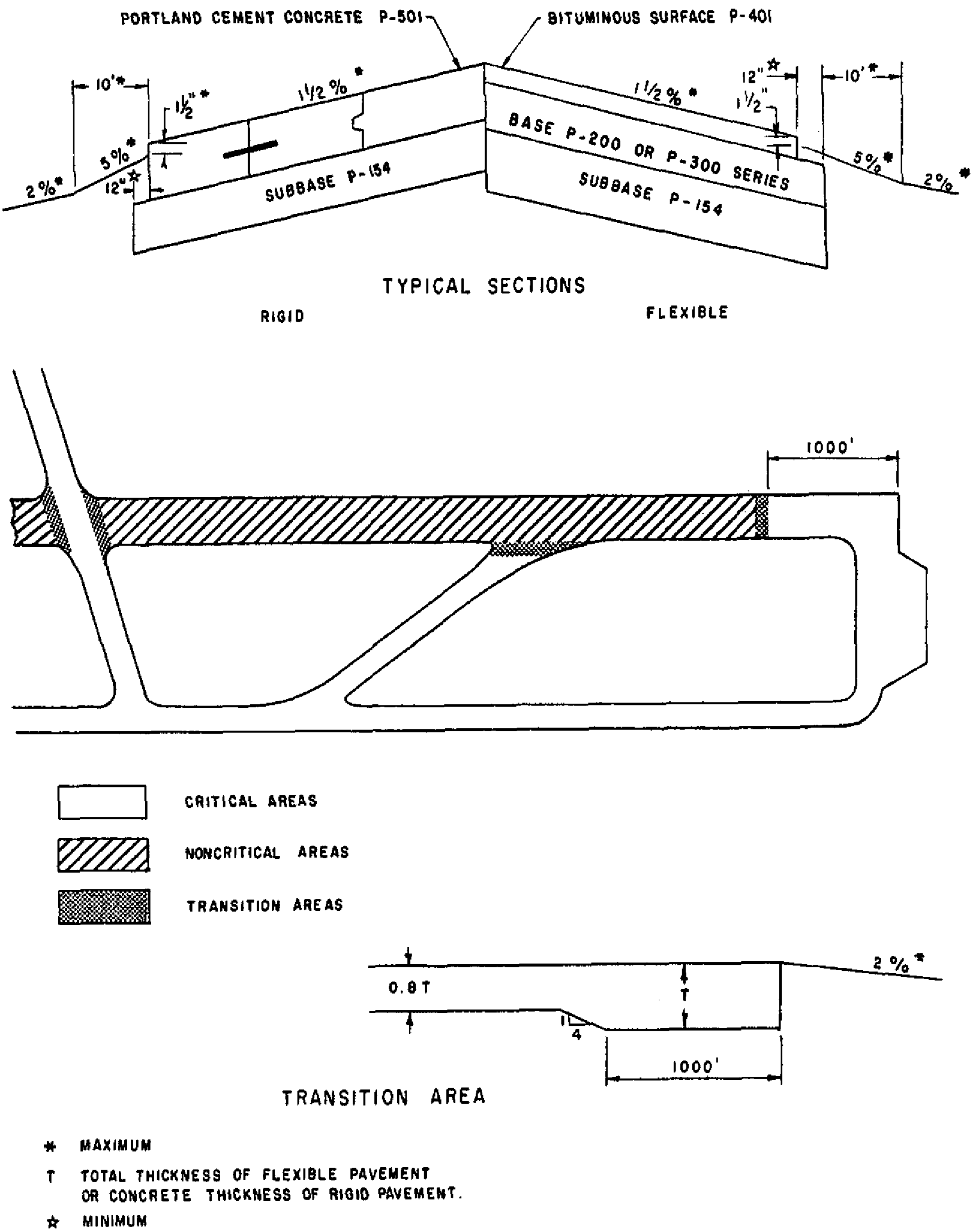
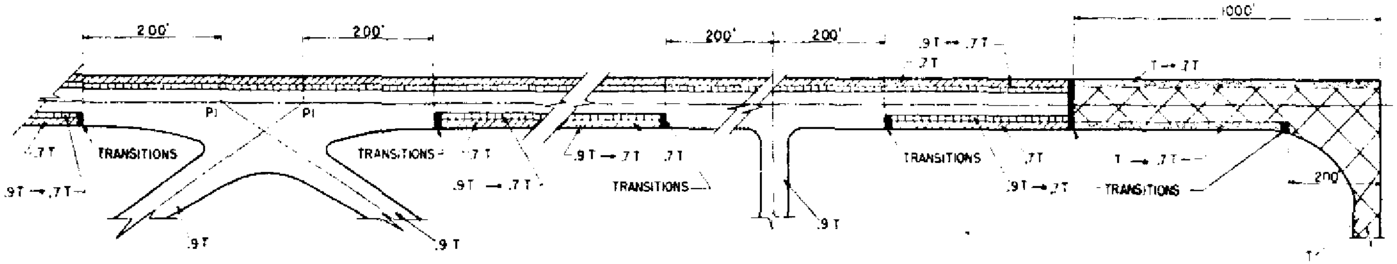
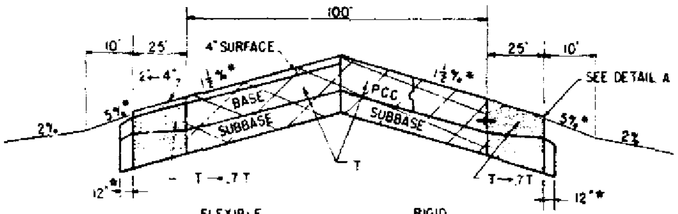


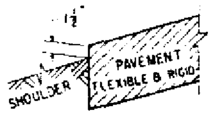
FIGURE 4. TYPICAL SECTIONS AND CRITICAL AREAS



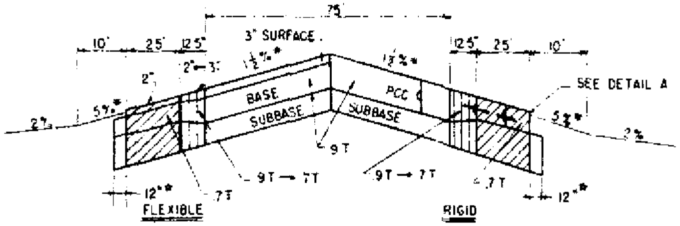
RUNWAY CRITICAL OR NONCRITICAL DESIGNATION
RECOMMENDED FOR JET RUNWAYS



CRITICAL
NO SCALE



TYPICAL PAVEMENT EDGE
DETAIL A



NONCRITICAL
NO SCALE

NOTES

1. T = Critical thickness
2. Thickness reductions are applicable to PCC for rigid; to the base and subbase courses for the center 75' of flexible and only the base course for the remaining width.
3. Rigid - 6" minimum PCC.
4. Flexible - 6" minimum surface plus base course
5. If noncritical R/W or exit T/W pavement areas are used by aircraft taxiing for take-off use "T" in lieu of ".9T".
6. ✱ = Maximum
7. ✱ = Minimum

FIGURE 5. TYPICAL SECTIONS AND CRITICAL AREAS FOR JET AIRCRAFT

15. DESIGN REQUIREMENTS AS AFFECTED BY SOIL PROFILE.

a. In some cases the upper level of the subgrade may exist as a clearly defined thin layer of soil of a much better quality than the underlying soil. Obviously, to design on the basis of the thin upper layer only would be inadequate in many instances. However, it must be realized that the upper layout of superior quality soil, even though thin in section, will provide some benefits which can be
* utilized in the pavement design. The following paragraphs illustrate the means by which these benefits may be realized. It should be noted, however, that this procedure does not apply when the underlying soil is a swelling soil for which the compaction criteria of FAA Specification P-152 and Figure 8-1 are not achieved. For these soils, see paragraph 16d. *

b. As an illustration, assume the upper layer of soil is designated "A" and the underlying layer is designated "B." If the thickness of layer "A" is insufficient to reduce the stresses imposed on layer "B" to an acceptable level, then an increase in the thickness of subbase is necessary over that which would be required if the soil was composed entirely of layer "A" material. Conversely, the required subbase thickness would be less than the subbase thickness required to protect layer "B" because of some beneficial effect of layer "A."

c. Logically then, the thickness of subbase required to fulfill design requirements under conditions similar to those stated above lies somewhere between the thickness of subbases required for "A" and "B." A method which may be used to determine the subbase requirement on a thin layered subgrade is based on the relationship between the two subbase thicknesses. This relationship is expressed by the formula:

$$z = Y - \frac{t(y-x)}{x+y}$$ in which

z = required thickness of subbase
x = subbase thickness for layer "A" soil
y = subbase thickness for layer "B" soil
t = thickness of layer "A"

(1) It can be seen from the formula that "z" will be less than "x" if "t" is greater than "x" + "y." Therefore, if "t" is equal to or greater than the sum of "x" + "y," the subbase required for layer "A" should be used.

(2) For an example of the application of this formula, determine the subbase thickness required for a taxiway to accommodate a 120,000-pound dual gear aircraft where the subgrade consists of an 8-inch layer of E-3 soil overlaying an E-7 soil. Drainage conditions are poor and no frost problem exists.

Soil Layer	Soil Group	Subgrade Class	Subbase Thickness (Inches)
A	E-3	F2	3 inches
B	E-7	F5	11 inches

$$z = 11 - \frac{8(11-3)}{3+11} = 11 \quad - 5 = 6 \text{ inches}$$

(3) If "t" had been greater than 3+11 = 14 inches, the subbase requirements would have been that as required for layer "A", i.e., 3 inches. The same principle may be applied for both flexible and rigid pavements.

d. This illustrates the manner in which economic advantage may be gained by use of selective grading. If superior material is available on the site, it may be economical to remove inferior material, or a portion thereof, and replace it with the superior material thereby reducing the subbase thickness requirements.

16. FLEXIBLE PAVEMENTS. Flexible pavements consist of a bituminous wearing surface placed upon a base course and, when required by subgrade conditions, a subbase. Figures 4 and 5 show a typical cross-section of a flexible pavement.

a. The bituminous surface or wearing course must prevent the penetration of surface water to the base course; protect the base from raveling and disintegration caused by various abrasive effects of traffic; provide a smooth, well-bonded surface free from loose particles which might endanger aircraft or persons; resist the shearing stresses occasioned by aircraft loads; and furnish a texture of nonskid qualities, yet not cause undue wear on tires.

(1) To successfully fulfill these requirements, the surface must be composed of mixtures of aggregates and bituminous binders which will produce a uniform surface of suitable texture possessing maximum stability and durability. Since control of the mixture is of paramount importance, these requirements can best be achieved by use of a central mixing plant where proper control can be most readily obtained. A dense-graded, bituminous concrete such as Item P-401 produced in a central mixing plant will most satisfactorily meet all the above requirements.

(2) Wherever a flexible pavement is to be subjected to concentrated fuel spillage or other solvents, as at aircraft loading positions and maintenance areas, protection should be provided by use of a solvent resistant seal coat such as Item P-625. A seal coat may be desirable in other operational areas for protection of the pavement structure. Seals on newly paved runway surfaces, when used, should be limited to the chip variety in order to achieve the needed visibility and skid-resistant properties.

b. The base course is the principal structural component of the flexible pavement. It has the major function of distributing the imposed wheel load pressures to the pavement foundation, the subgrade. The base course must be of such quality and thickness to prevent failure in the subgrade, withstand the stresses produced in the base itself, resist vertical pressures tending to produce consolidation and resulting in distortion of the surface course, and resist volume changes caused by fluctuations in its moisture content.

* (1) These qualities of the base course depend upon composition, physical properties and compaction, and individual materials which make up the mixture. Many materials and combinations thereof have proved satisfactory as base courses. They are composed of select, hard and durable aggregates blended with binders or fillers of approved types so as to produce a uniform mixture which will meet specifications as to gradation and soil constants and to permit compaction into a dense, well-bonded mass. *

(2) Specifications covering the quality of components, gradation, manipulation, control, and preparation of various types of base courses for use on airports for design loads above 30,000 pounds gross aircraft weight are as follows:

(a) Item P-201 - Bituminous Base Course

(b) Item P-209 - Crushed Aggregate Base Course

(c) Item P-210 - Caliche Base Course

(d) Item P-211 - Lime Rock Base Course

(e) Item P-212 - Shell Base Course

(f) Item P-214 - Penetration Macadam Base Course

* (g) Item P-215 - Cold Laid Bituminous Base Course *

(h) Item P-304 - Cement Treated Base Course

* (3) Experience has shown that when high quality aggregates are used, asphalt and portland cement treatments produce bases that are more effective than untreated bases. In recognition of the superior effectiveness of such bases, one inch of treated base material is considered to be equivalent to 1.5 inches of untreated base material and may be substituted in the pavement construction on this basis. These reductions are applicable only when high quality base courses, specifically Item P-201, "Bituminous Base Course," and Item P-304, "Cement Treated Base Course," are used. However, the minimum permissible thickness of bituminous base course is 4 inches and the minimum permissible thickness of cement treated base course is 6 inches, in either critical or noncritical areas. *

c. A subbase is included as an integral part of the flexible pavement structure in all pavements except those on subgrades classified as Fa. The function of the subbase is similar to that of the base course. However, since it is protected by the base and surface courses, the material requirements are not as strict as for the base course.

(1) Specification Item P-154, "Subbase Course," covers the quality gradation, control, and preparation of the standard subbase course.

(2) Certain materials that are permitted only for base courses for pavements serving aircraft with gross weights of less than 30,000 pounds may be used as subbase courses for the larger aircraft. They are:

* (a) Item P-206 - Dry-Bound Macadam Base Course or Water-Bound Macadam Base Course

(b) Item P-208 - Aggregate Base Course

(c) Item P-213 - Sand-Clay Base Course

(d) Item P-216 - Mixed In-Place Base Course

(e) Item P-301 - Soil Cement Base Course *

* (3) When the material Items P-201 and P-304 are used as base courses, they may be used as subbase also on the basis that one-inch of P-201 or P-304 is equivalent to 1-1/2 inches of the approved subbase materials.

d. The subgrade soils are subjected to the same stresses, though to a lesser degree, as the surface, base, and subbase courses. These imposed stresses decrease with depth and are most critical at the top of the subgrade, unless unusual conditions prevail, such as a layered subgrade (see paragraph 15) or water content and/or density vary sharply with depth. These conditions should be checked during the soils investigation. The ability of a particular soil to resist shear and deformation is dependent on the soil density and moisture content.

(1) Specification Item P-152, Excavation and Embankment, covers the construction and density control of subgrade soils. Figure 8-1 shows depths below the subgrade surface to which compaction controls apply.

(2) Noncohesive soils, for the purpose of determining compaction density and depth, are those for which no plastic index is discernible in the Atterburg tests, or for which the moisture-density curve is either reversed or a straight line.

(3) For most soils, moisture-density curves show the water content at which the desired density can be most easily achieved. These soils when so compacted will provide a satisfactory level of in-place stability and will have voids and voids filled percentages that limit the detrimental effects of added available water. Some soils, when compacted to the optimum modified AASHO densities, due to chemical attraction or a low voids filled to voids ratio, will attract available water and swell. The swelling is accompanied by extreme loss in bearing value. Soils of this type shall be stabilized or modified where possible to the extent required to preclude the swelling. Where this is impractical, compaction with additional water to lower densities will minimize swelling, but will reduce bearing values. When this procedure is followed, the pavement section shall be increased by the increment shown in Figure 8-1 as the difference between the FAA Specification T-611 density required and achieved. The additional material may consist of a suitable nonswelling borrow or added subbase, compacted to the required Figure 8-1 densities. Exceptions may be considered as follows: *

* (a) For flexible pavement design based on CBR tests performed in the manner prescribed in MIL-STD-621A and converted to FAA subgrade class per Figure 20, no thickness adjustment is required. A transition or working platform to permit the required subbase compaction to 100 percent density may be specified, not to exceed 6 inches in thickness for each 5 percent density difference in excess of 5 percent.

(b) For rigid pavement design (using plate bearing tests in the manner prescribed in MIL-STD-621A and in paragraph 19b) no thickness adjustment is required. A working platform may be specified as in (a) above.

(c) For application of CBR to rigid pavement design, see paragraphs 12g and 35a.

(d) For heavy load pavements and for extensive areas, methods (a) and (b) above are the recommended design procedures.

(4) When P-201 and P-304 are used for subbase over swelling soils, they may be used for added subbase as required in (3) above on the same basis; i.e., one inch of P-201 or P-304 for each 1-1/2 inches of added subbase required. Other stabilized materials may be used for added subbase on a one-for-one basis.

(5) Example. For an apron extension to accommodate a 340,000-pound dual-tandem geared aircraft, a soils investigation has shown the subgrade will be F1 and noncohesive. In-place densities of the B horizon soils have been determined at even foot increments below the ground surface. Design calculations indicate that the top of subgrade in this area will be approximately 10 inches below the existing grade. Depths and densities may be tabulated as follows:

Depth Below Existing Ground	Depth Below Finished Subgrade	In-Place Density
1'	2"	70 %
2'	14"	84 %
3'	26"	86 %
4'	38"	90 %
5'	50"	93 %

In Figure 8-1, project a line downward from 340,000 pounds on the dual tandem scale; and from the point of intersection with the line representing each density requirement project a line to the noncohesive compacted subgrade depth scale. *

* Reference to the tabulation shows that for this example, in-place density is satisfactory at a depth of 38 inches, being 90 percent and within the required 90 percent zone. It will be necessary to compact an additional 2 inches at 90 percent, 15 inches at 95 percent, and the top 21 inches of subgrade at 100 percent density. With modern compaction equipment, these densities can usually be achieved from the surface in a noncohesive soil. *

17. DESIGNING THE FLEXIBLE PAVEMENT. Due to the variation in stress distribution of single, dual, and dual-tandem gear aircraft as discussed in Appendix 1, separate flexible pavement design curves for each of these gear arrangements have been prepared as shown in Figures 6, 7, and 8, respectively.

a. Figure 4. Figures 6, 7, and 8 are used to obtain the total critical pavement thickness, "T," and surface course requirements. To obtain the noncritical pavement thickness, the critical pavement base and subbase courses are reduced by a factor of .8T. The noncritical surface course requirements are noted in Figures 6, 7, and 8. For fractions of an inch of .5 or more, use the next higher whole number; and for less than .5, use the next lower number.

b. Figure 5. Figures 7 and 8 are used to obtain the total critical pavement and surface course thickness for the area designated as
* "T" in Figure 5. The .9T factor for the noncritical pavement applies to the base and subbase courses. The surface course is noted in Figures 7 and 8. For the variable section of the critical, transition section, and thinned edge of the noncritical section, the reduction applies only to the base course. The .7T thickness for subbase shall be the minimum permitted, and the subbase thickness shall be increased and/or varied to provide positive surface drainage from the entire subgrade surface. Use the same procedure outlined in paragraph 17a for rounding off fractions to whole numbers. For optional use of Figures 4 and 5 and for optional keel widths, see paragraph 14.3(b). *

c. Example. As an example of the use of these design curves and Figure 5, assume that a jet aircraft on dual gear has a gross weight of 140,000 pounds, and the soil classification is E-7 with
* poor drainage and 42 inches of frost penetration. From Table 2, the subgrade classification would be F5 or F7, depending on whether or not frost will penetrate the subgrade. In this case, the classification will be F7. *

(1) Enter Figure 7 on the left at 140,000 pounds gross weight and proceed horizontally to the intersection with subgrade classification F7 and then proceed vertically downward to the total pavement thickness scale. In this case, the 140,000-pound dual aircraft for an F7 requires 32 inches of pavement thickness.

(2) Go back to the intersection of the 140,000-pound gross weight line and the F7 subgrade classification line, proceed to the * right, parallel with dashed lines, to the intersection of the required base thickness line and read 10 inches for the critical area. A 4-inch surface is required by this chart. The balance of the total thickness requirement is subbase, in this case 18 inches. *

(3) The total pavement thickness for noncritical is obtained by taking .9 of the critical pavement base and subbase courses plus the required surface course thickness. The thinned edge portion of the critical and noncritical pavement .7T factor applies only to the base course as the subbase must be increased to provide transverse subgrade drainage. The transition section and surface course requirements are noted in Figure 5.

(4) The final requirements of the dual gear aircraft are:

	"T" CRITICAL AREAS	.9T NONCRITICAL AREAS	.7T EDGE AREAS
Surface	4"	3"	2"
Base	10"	9"	7"
* Subbase	18"	16"	19" 2/
Frost Protection 1/	4"	8"	8"
TOTAL	36"	36"	36"

1/ Full depth frost protection shall be provided for the primary runway(s) at large hub airports. For other paved areas, protection shall be provided for depths between 65 percent and 90 percent of the total frost penetration. The degree of protection provided shall be determined considering the frost susceptibility of the underlying material, depth to water, the extent to which variable soils will contribute to differential heaving, and local experience with the construction materials being used.

2/ See discussion, paragraphs 17b and 19c. *

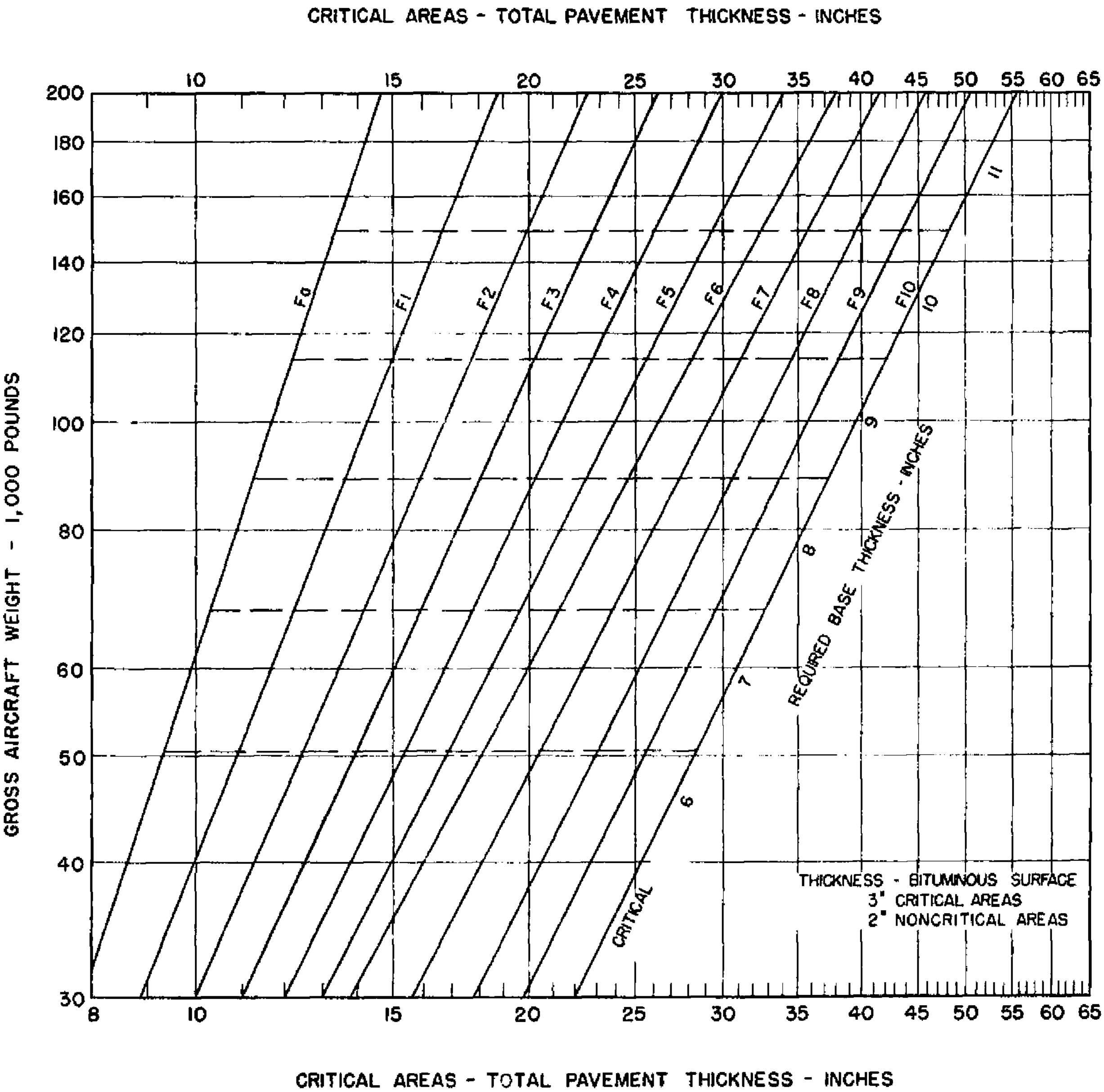


FIGURE 6. DESIGN CURVES - FLEXIBLE PAVEMENT - SINGLE GEAR

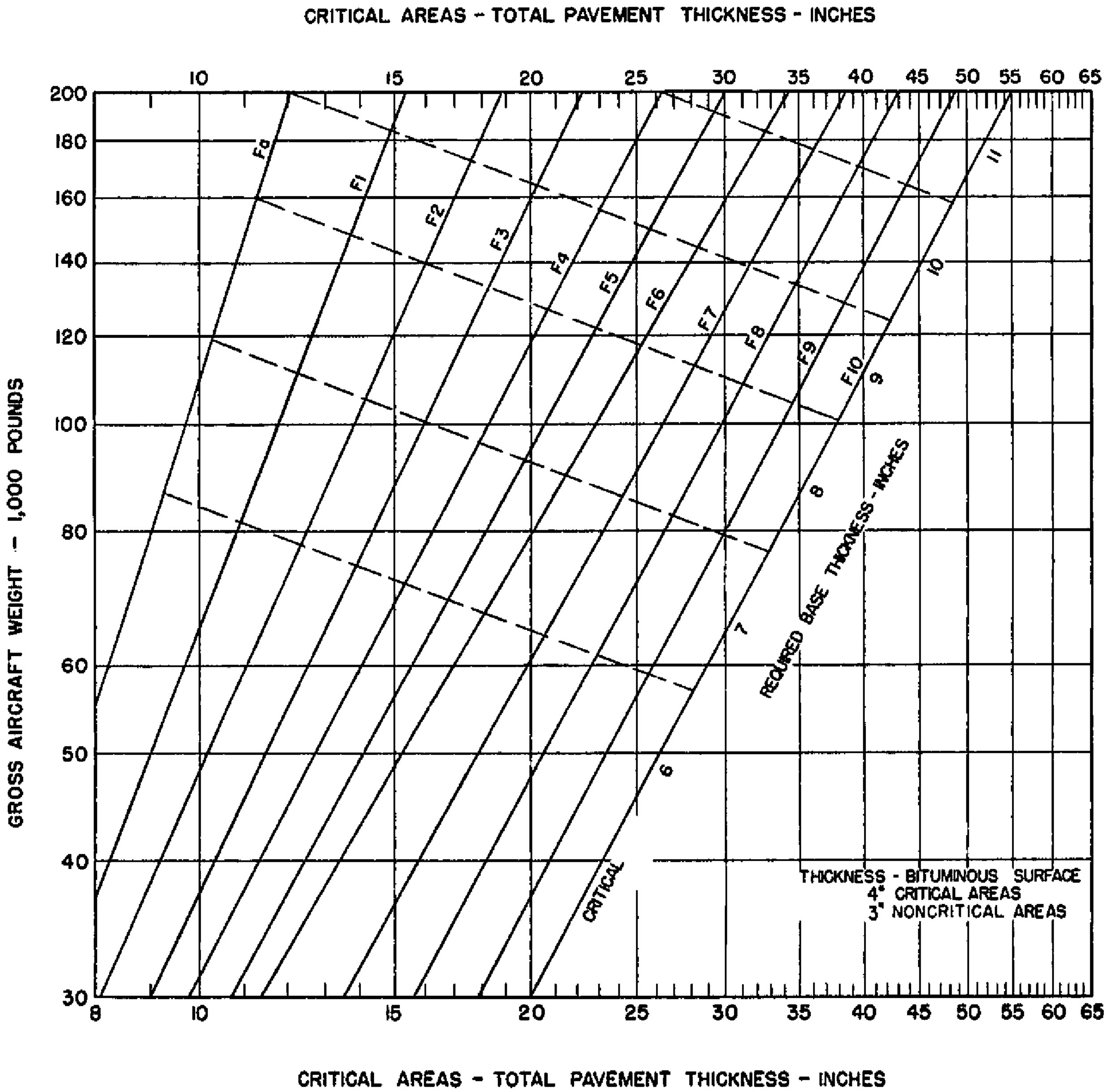


FIGURE 7. DESIGN CURVES - FLEXIBLE PAVEMENT - DUAL GEAR

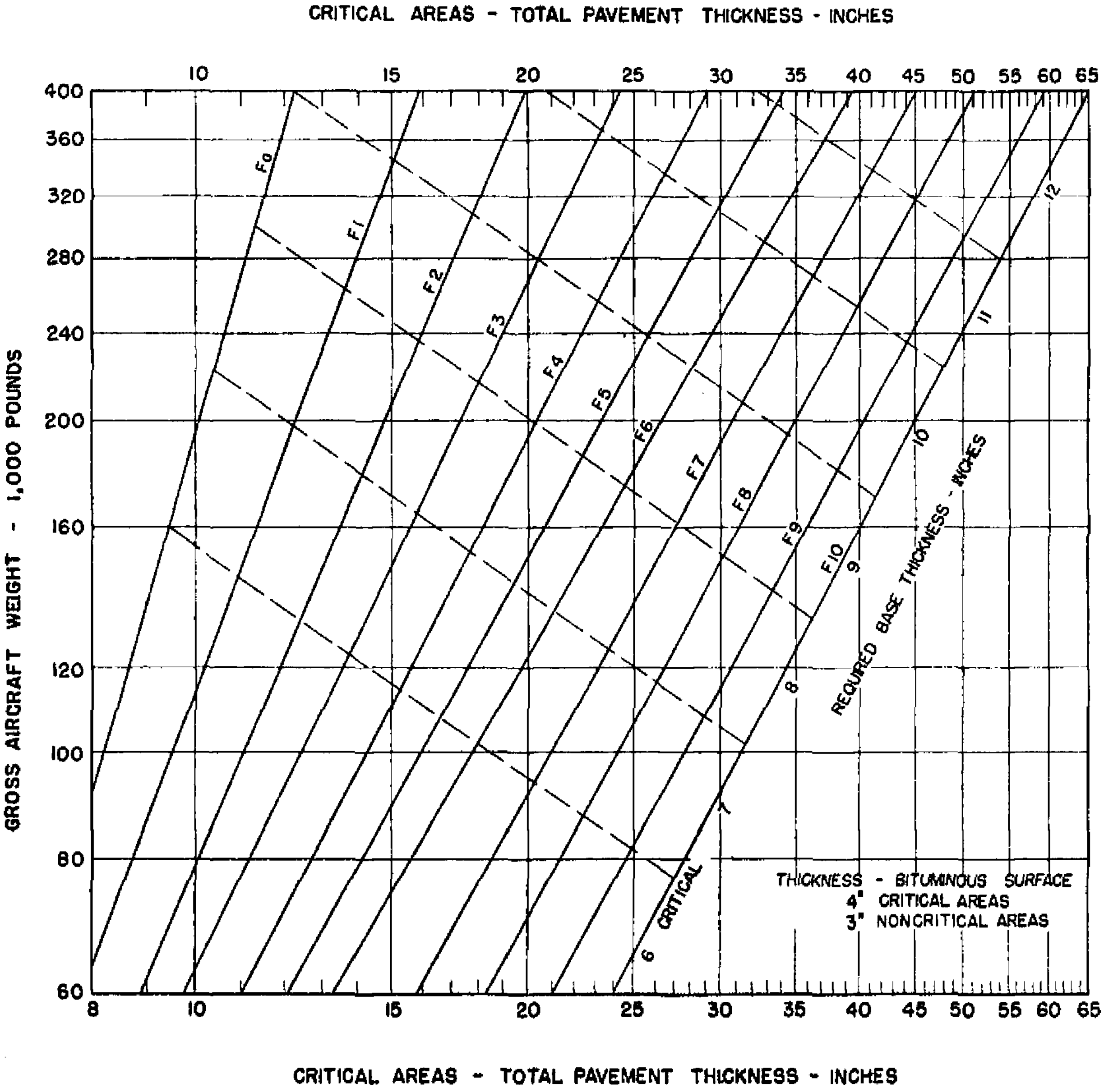
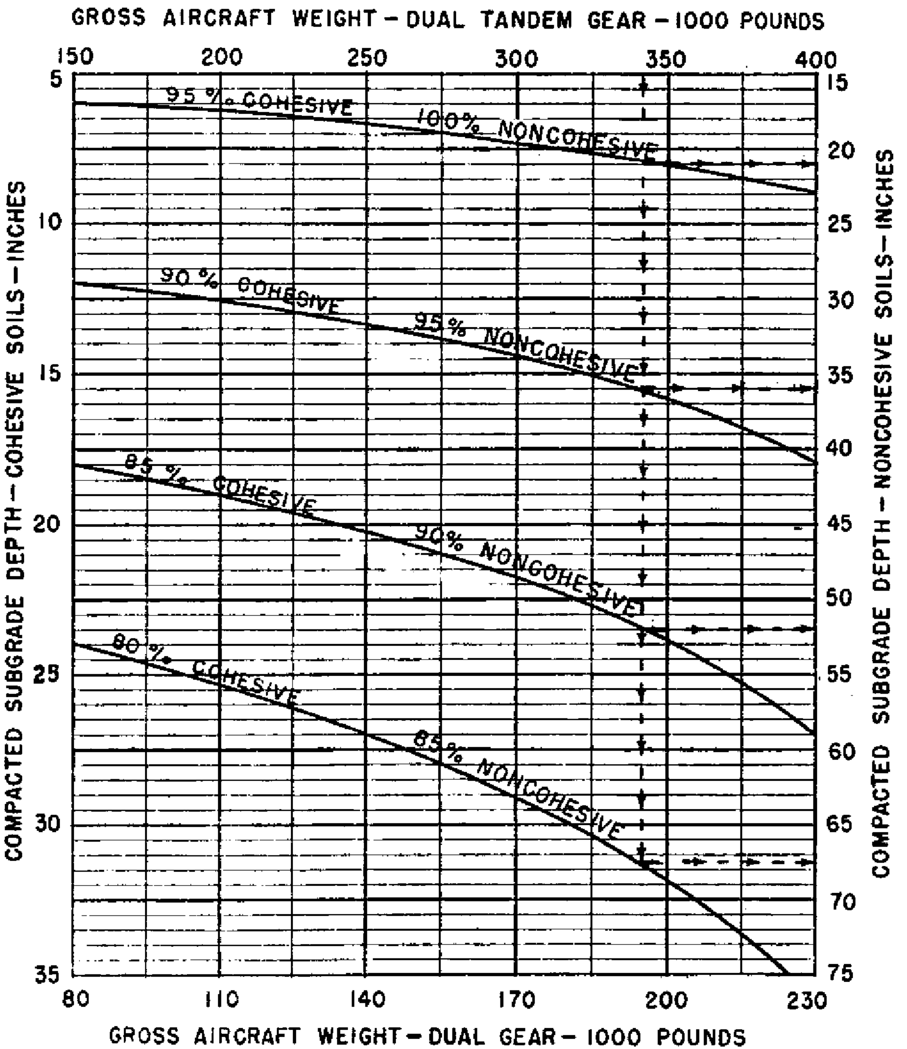


FIGURE 8. DESIGN CURVES - FLEXIBLE PAVEMENT - DUAL-TANDEM GEAR



NOTES:

1. Curved lines denote depths below the finished subgrade above which densities must equal or exceed the indicated percentage of the maximum density at optimum moisture as determined by the FAA compaction control T-611.

2. For embankment areas the charted criteria shall be met except that the minimum density of soils placed in fill shall be 90% for cohesive and 95% for noncohesive, and for the top nine inches in fill shall be not less than 95% for cohesive and 100% for noncohesive, of the T-611 density.

3. The subgrade in cut areas shall have natural densities equal to or greater than the densities shown or shall (a) be compacted from the surface to achieve the required densities, (b) shall be removed and replaced in which case the minimum densities for fills apply, or (c) when economics and grades permit, be covered with sufficient select or subbase material so that the uncompacted subgrade is at a depth where the in-place densities are satisfactory.

4. Where a noncohesive soil of F class 3 or 4 may exist, the difference in subbase thickness required in excess of that required for an F_2 soil may be deducted from the required subgrade compaction depths.

5. For swelling soils, reduced densities may be used in accordance with paragraph 16d. When reduced densities are employed, Figures 21, 22, and 23 shall be used for rigid pavement design.

FIGURE 8-1. SUBGRADE COMPACTION REQUIREMENTS FOR HEAVY AIRCRAFT

(5) In the preceding example, the design is for a jet aircraft using the criteria shown in Figure 5. If the design had been for a conventional aircraft, the pavement should conform to the criteria outlined in Figure 4. The .8T factor used to obtain the noncritical thickness applies to both the base and the subbase. The pavement sections as obtained from Figures 6, 7, and 8, and reduction required in Figures 4 and 5 provide only minimum thickness and do not provide for frost protection of the subgrade as previously discussed in Chapter 2, paragraph 12d(2).

d. Considerations for Thin Subbases. Where a pavement is to be constructed on an excellent subgrade, the subbase thickness requirement may be less than 3 inches. Where a subbase is less than 3 inches thick, it is recommended that additional base course be substituted for the thin subbase in the proportion of 1 inch of base course for each 1-1/2 inches of subbase. The final decision usually depends on the thickness of the subbase course and economic consideration as they are affected by construction problems, materials, and frost penetration.

* e. Design Based on CBR. When considered to be advantageous, California Bearing Ratio tests of the subgrade soils, made in accordance with the procedures discussed in paragraph 35a, may be used in the design of flexible pavements. The application of CBR test results to the F classification in Table 2 shall be the same as is spelled out for the evaluation procedure. *

18. RIGID PAVEMENTS. Rigid pavements for airports are composed of portland cement concrete placed upon a granular or treated subbase course that rests upon a compacted subgrade. An exception is made if the subgrade falls in the Ra classification, in this case no subbase is required.

a. The quality of the concrete, the mixes, the control tests, methods of construction and handling, and quality of workmanship are covered in detail in Item P-501, "Portland Cement Concrete Pavement."

b. The materials suitable for subbase courses under rigid pavements are covered in Item P-154, "Subbase Course," and Item P-301, "Soil Cement Base Course." Some of the benefits derived from the subbase course are:

(1) Increases the support and provides a more uniform bearing of the portland cement concrete pavement.

(2) Eliminates pumping action.

(3) Minimizes effects of volume changes in subgrade soils.

(4) Prevents detrimental effects of frost action.

*19. DESIGNING THE RIGID PAVEMENT. Two methods for determining rigid pavement thickness requirements are available. Separate design curves for each of the gear configurations (single, dual, dual-tandem) are prepared as shown in Figure 9 and discussed in Appendix 1. These are based on conservative assumptions and are recommended for limited areas of work. When economics or unusual soil conditions warrant the testing and investigation necessary to more closely determine the design requirements, rigid pavement thickness may be determined from Figures 21, 22, and 23 in Chapter 6.

a. Rigid Pavement for Critical Areas - Figure 9. Rigid pavement thickness for critical areas is read from the top group of design curves given in Figure 9. The thickness of the concrete pavement is figured independently of the subgrade classification. After determining the required thickness of the concrete pavement and knowing the subgrade classification, the bottom group of design curves is used to determine the subbase thickness. When the figure shows concrete thickness in fractional inches, the design thickness should be increased to the next full inch from fractions of an inch of .3 or more and reduced to the lower full inch from fractions of less than .3 inch. Pavement thickness thus increased by .5 inch or more may be compensated for by a reduction of 1 inch in subbase thickness.

b. Rigid Pavement for Critical Areas - Figures 21, 22, and 23. In addition to the soils survey, analysis, and classification discussed in Chapter 2, rigid pavement design by application of Figures 21, 22, and 23 requires additional testing and design procedures as explained below.

(1) Determination of the Modulus of Soil Reaction (k value) should be measured at the top of subbase (or Ra subgrade) and determined by construction to required densities of a limited test section. The section should consist of the design subgrade and subbase material and utilization of plate bearing test procedures specified in Military Standard MIL-STD-621A, Subgrade, Subbase, and Test Method for Pavement Base-Course Materials.

(2) Determination of the design flexural strength should be reduced by a safety factor of 1.75 to compute working stress for critical area pavement. The stress scale in Figures 21, 22, and 23 is the working stress.

(3) Flexural stress and k values may be investigated through a range of pavement and subbase thicknesses to arrive at the most economical section without regard to subgrade class. A minimum 4-inch subbase shall be used, however, for any subgrade classified as poor drainage. *

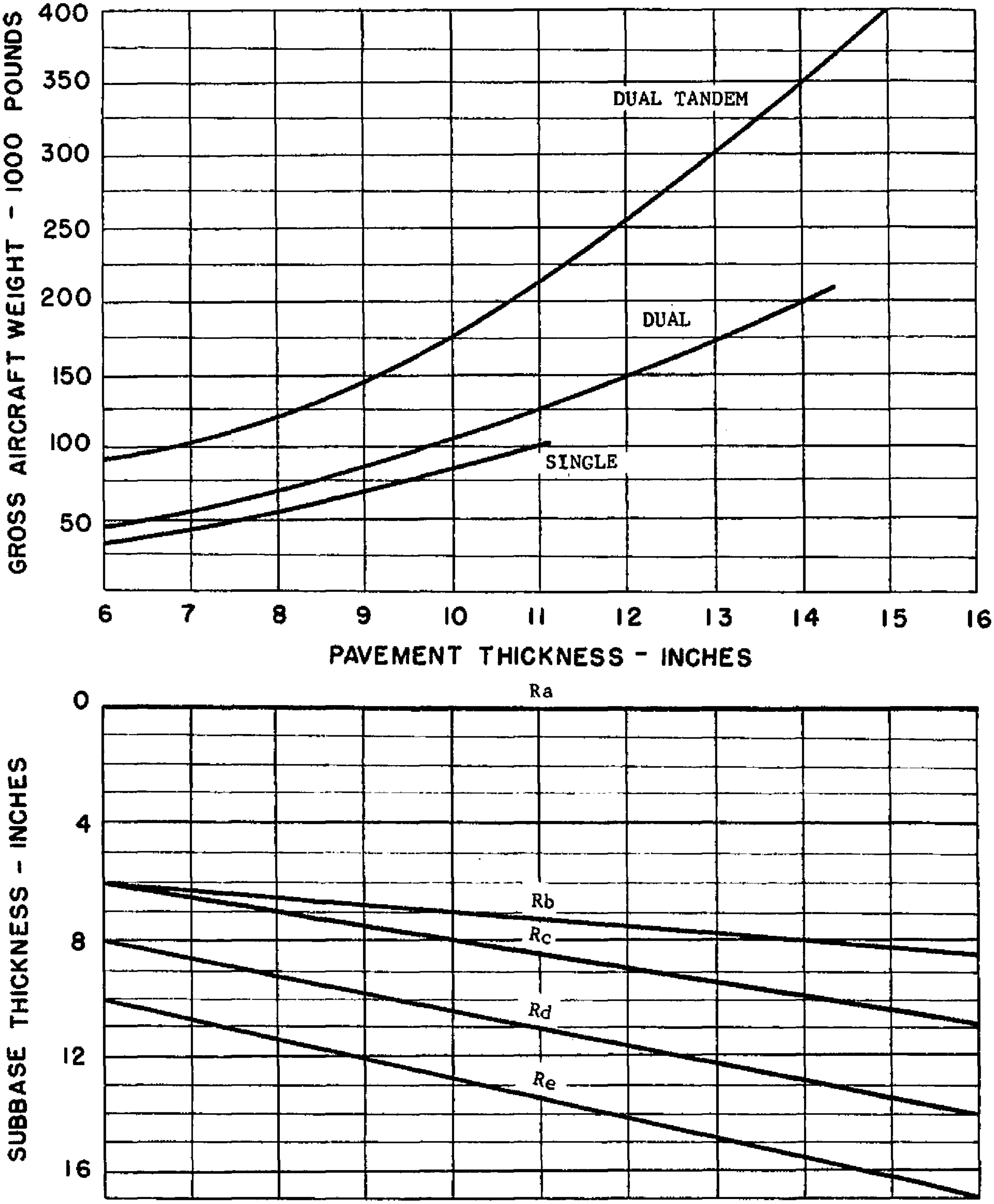


FIGURE 9. DESIGN CURVES - RIGID PAVEMENT - CRITICAL AREA

(4) It is recommended, and particularly for frost areas, that the PCC be designed for at least 700 p.s.i. flexural strength at 90 days. Where laboratory procedures are used to provide mix design and cement factor, beams shall be cast in accordance with ASTM C 192 and tested in accordance with ASTM C 78.

c. Rigid Pavement for Noncritical Areas. Noncritical area pavement is constructed to thicknesses of 0.9, 0.8, or 0.7 of the critical pavement thickness "T" depending on traffic type and relative location. See Figures 4 and 5. For the 0.9T and 0.8T factors, subbase thickness is not reduced. For the 0.7T factor, subbase is increased as required to provide the same total pavement thickness as for the adjacent pavement and subbase combination. Exceptions to the subbase requirement may be made in arid regions (see paragraph 20b) but no reduction in subbase thickness shall be provided which would preclude positive drainage of the subgrade surface.

d. Example Using Figure 9. Assume the design critical aircraft is propeller driven on dual gear, gross weight 160,000 pounds, with E-7 soil and no frost. From Table 2 the subgrade class is Rc.

(1) From Figure 9, the required thickness of concrete pavement for the 160,000-pound dual aircraft is 12.5 inches. This figure is obtained by proceeding horizontally from the 160,000-pound gross weight scale to the intersection with the dual curve then proceeding vertically downward to the pavement thickness scale.

(2) The subbase thickness is determined by proceeding vertically downward from 12.5 inches to the intersection with the Rc subbase curve and then proceeding horizontally to the left to the subbase thickness scale. The required thickness of the subbase (approximately 9 inches in this case) is obtained.

(3) The required pavement thickness for noncritical areas is obtained by taking 80 percent of the required critical area pavement thickness.

(4) Fractional thicknesses of portland cement concrete of .3 or more are rounded to the next higher full inch, and for the .5 inch increase in this example, a 1-inch reduction in subbase is appropriate. The design thickness becomes:

160,000 POUND DUAL

	Critical Area	Noncritical Area
Pavement	12.5" use 13"	12.5 x 0.8 = 10.0"
Subbase	9" - 1" = 8"	9"

* (5) In the above example, if the soil classification had been E-8 instead of E-7, the subgrade classification would have been Rd (see Table 2). The concrete thickness requirement would remain the same but the subbase thickness would have been 12 inches instead of 9 inches. Also note that the noncritical pavement thicknesses are computed from the charted thickness prior to rounding off.

e. Example Using Figure 22. For the same aircraft and soil as the previous example, assure additional design effort has been made and that a test section has shown k values of 170 on a 6-inch subbase and 210 on a 9-inch subbase. A subbase thicker than shown in Figure 9 would not normally be used. Concrete design strength of 700 p.s.i. at 90 days is selected.

(1) Enter Figure 22 at the 400 p.s.i. stress point of the left hand vertical scale and proceed across to the 210 k line. From this line (interpolated between 200 and 300 k) move vertically to the 160,000-pound load line. From this point proceed horizontally to the pavement thickness scale on the right. The required pavement thickness is 12.8 inches and 13 inches critical pavement will be used. The .8T factor applied to the noncritical area pavement results in a 10.2-inch section requirement rounded off to 10 inches.

(2) Similar analysis for the 170 k value results in a critical area pavement thickness of 13.1 inches (13 inches would be used) and 0.8 noncritical thickness of 10.5 inches rounded off to 11 inches.

(3) Additional design options remain which may be applied, such as:

(a) Working from the 13-inch slab thickness proceed horizontally to the load line and vertically to intersect the 400 p.s.i. stress line. These intersect at the 190 k reaction line. This would permit a reduction in subbase thickness of 1 inch, as a conservative application of assumed linear relationship between the subbase and k values investigated.

(b) Again working from the 13-inch slab thickness as above, intersect the 170 k line and read a working concrete stress of 408 p.s.i. This section and 6-inch subbase require a 715 p.s.i. flexural strength to satisfy the design requirement. *

(4) The four design options and thicknesses are charted below.

k	s	Critical Area Slab	Subbase	Noncritical (0.8) Area Slab	Subbase
210	700	12.8" use 13"	9"	10.2" use 10"	9"
190	700	13"	8"	10.4" use 11"	7"
170	700	13.1" use 13"	6"	10.5" use 11"	5"
170	715	13"	6"	10.4" use 11"	5"

Since any of these design approaches are considered satisfactory, the design decision should be made primarily on a cost comparison basis. Additional consideration based on cost would be needed for frost protection as discussed below, subgrade stabilization, etc.

20. SPECIAL DESIGN CONSIDERATIONS.

a. Increase in Subbase Thickness Due to Frost. There may be locations and conditions where the combined thickness of portland cement concrete and subbase course is not adequate to prevent frost heave which would result in pavement deterioration. Where such a condition exists, the thickness of the subbase course should be increased over that which results from the use of curves. The total thickness of pavement required in such a case should be determined from a study of conditions prevailing at the site. Portland cement concrete has considerable insulating value which has the effect of reducing the depth of penetration of frost. This beneficial insulating effect should be considered in all areas where frost might be encountered. For purposes of rigid pavement design, frost penetration may be reduced by an amount equal to one-half the thickness of concrete slab.

b. Decrease in Subbase Thickness. In arid regions, subbase course thickness may be reduced below that shown in Figure 9, but not less than 4 inches. Such reduction, however, must be predicated upon knowledge of the particular subgrade soil as a rigid pavement foundation.

21. JOINTS IN CONCRETE PAVEMENT. Variations in temperature and moisture content cause volume changes in concrete pavements. These volume changes produce compressive, tensile, and flexural stresses. In order to reduce the effects of these stresses and to minimize random cracking, it is necessary to divide the pavement into a series of slabs of predetermined dimensions by means of joints.

a. Joint Types. A joint can be placed in a specific category depending upon its principal function or its purpose in the pavement. The categories are expansion, contraction, and construction joints. No matter which type of joint is installed, it should be finished in a manner that permits the joint to be sealed. The types of joints are shown in Figures 10 and 11 and summarized in Table 3. These various joints are described as follows:

(1) Expansion Joints. The function of an expansion joint is to provide space for the expansion of the pavement, to isolate pavement intersections, and to isolate structures from the pavement. There are two types of expansion joints.

(a) Type A is used when load transfer between the slabs of the pavement is required. This joint contains a 3/4-inch nonextruding compressible material and is provided with dowel bars for load transfer.

(b) Type B is used when load transfer is not practicable; such as, where the pavement abuts a structure or where horizontal differences in movement of the pavements may occur. These joints are formed by increasing the thickness of the pavement along the edge of the slab. No dowels are provided.

(2) Construction Joints. Construction joints are those joints which occur as a result of the construction operations. Proper construction joints are shown as Types C, D, and E in Figures 10 and 11.

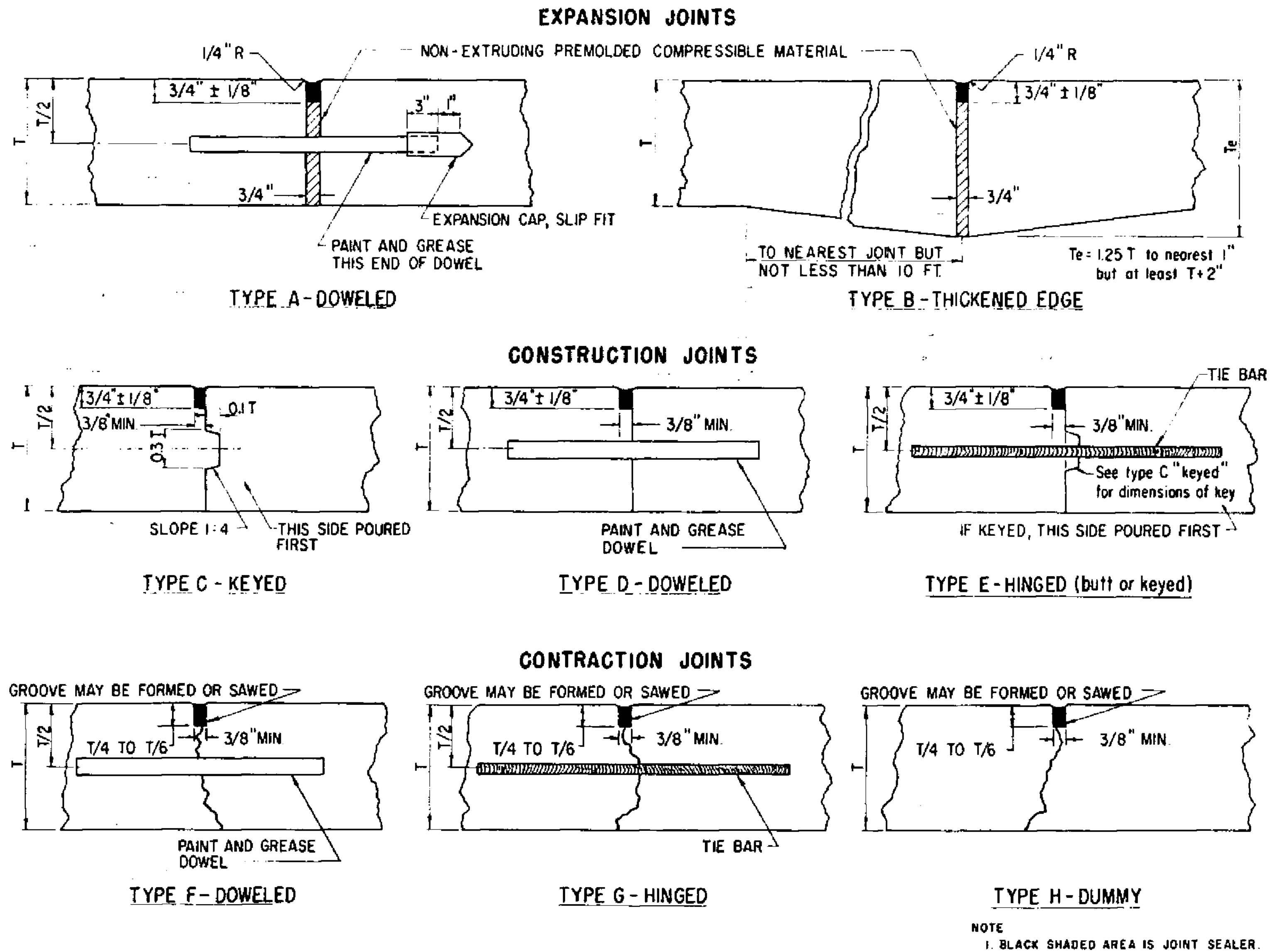
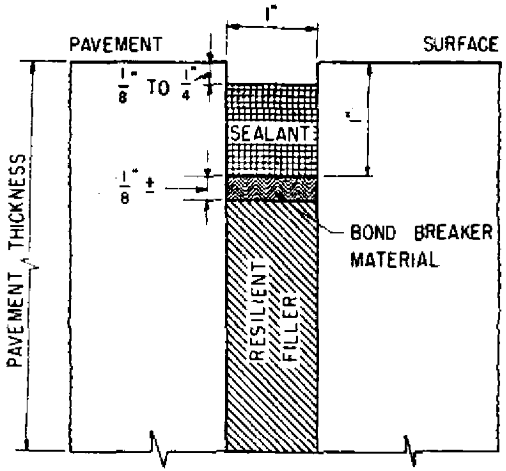
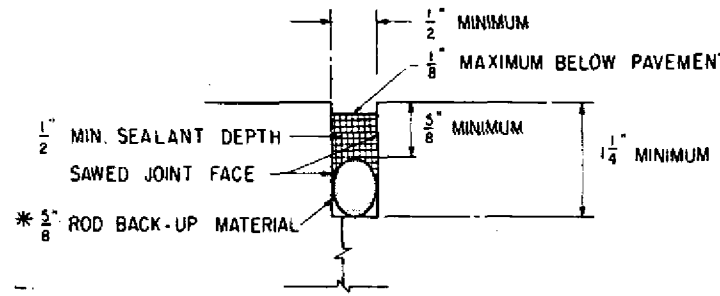


FIGURE 10. DETAILS OF JOINTS IN RIGID PAVEMENTS



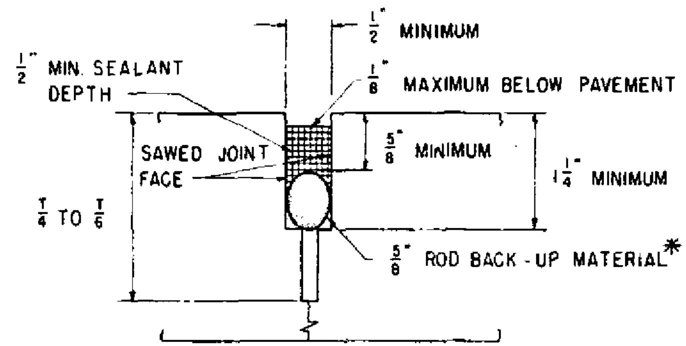
EXPANSION JOINTS TYPE A AND B



CONSTRUCTION JOINT TYPE C, D AND E

SYMBOLS

- SEALANT
- ROD BACK-UP MATERIAL *
- BOND BREAKER MATERIAL
- RESILIENT FILLER
- * CLOSED-CELL RESILIENT FOAM OR SPONGE RUBBER



CONTRACTION JOINT TYPE F, G AND H

FIGURE 11. DETAILS OF JOINTS IN RIGID PAVEMENT FOR USE WITH TYPE VI SEALING MATERIAL

TABLE 3. JOINT TYPES - DESCRIPTION AND USE

TYPE	DESCRIPTION	LONGITUDINAL	TRANSVERSE
A	Doweled expansion joint.		Use near intersections to isolate them.
B	Thickened edge expansion joint.	Use at intersections where dowels are not suitable and where pavements abut structures.	Provide thickened edge (or keyway) where pavement enlargement is likely.
C or D	Keyed or doweled construction joint.	Use for all construction joints except where Type E is used.	Use Type D where paving operations are delayed or stopped.
E	Hinged construction joint.	Use for all construction joints of the taxiways and for all other construction joints that are 25' or less from the pavement edge.	
F	Doweled contraction joint.		Use for all contraction joints in critical areas, for all reinforced pavement areas, and for the first two joints on each side of expansion joints.
G	Hinged contraction joint.	Use for all contraction joints of the taxiway and for all other contraction joints placed 25' or less from the pavement edge.	
H	Dummy contraction joint.	Use for all other contraction joints in pavement.	Use for all remaining contraction joints in nonreinforced pavements.

(3) Contraction Joints. The function of a contraction joint is to provide controlled cracking of the pavement when the pavement contracts due to shrinkage caused by curing, decrease in moisture content, or a temperature drop. The contraction joints are shown as Types F, G, and H in Figures 10 and 11.

b. Joint Spacing. Table 4 summarizes the recommended spacing of joints. As indicated, pavements 10 inches or less in thickness generally require closer spacing of joints.

TABLE 4. JOINT SPACING

Slab Thickness	PLAIN CONCRETE		REINFORCED CONCRETE	
Inches	Longitudinal	Transverse	Longitudinal	Transverse
10 or less	12.5' Max.	15' - 20'	12.5' Max.	45' - 75'
Over 10	25.0' Max.1/	20' - 25'	25.0' Max.1/	45' - 75'

1/ Where 25-foot paving lanes are used in construction of 75-foot taxiways, a Type G or H dummy joint shall be provided along the centerline.

c. Special Joint Consideration. When a runway or taxiway is likely to be extended at some future date, it is recommended that a thickened edge joint be provided at that end of the runway or taxiway. Likewise, if any pavement is to be widened in the future, a keyway or thickened edge should be provided at the appropriate edge.

d. Tie Bars. Tie bars are used across certain longitudinal contraction joints and keyed construction joints to permit hinge action while holding the slab faces in close contact. The tie bars themselves do not act as load transfer devices. By preventing excessive opening of the joint, load transference is provided by either the tongue and groove of the keyed joint or by aggregate interlock in the crack below the groove-type hinged joint. Where tie bars are required, they should consist of deformed bars of new-billet steel. The bars should be 5/8 of an inch in diameter and 30 inches long and spaced 30 inches on center.

e. Dowels. Dowels are used at joints to provide for transfer of part of the wheel load across the joints and to prevent relative displacement of adjacent slab ends. Dowels permit longitudinal movement of adjacent slabs.

(1) Where Used. Provision for load transfer by dowel installation is provided at all transverse expansion joints and all butt type construction joints. Dowels should also be installed across all transverse contraction joints in critical areas (aprons, taxiways, and runway ends) to provide an increased margin of safety with respect to load transfer in these areas.

(2) Size, Length, and Spacing. Dowels should be of such size that they will safely resist the shearing and bending stresses produced by loads on the pavement. They should be of such length and spacing that the bearing pressures they exert in the slab will not be excessive and thus cause failures. Table 5 indicates dowel dimensions and spacing for various pavement thicknesses.

TABLE 5. DIMENSIONS AND SPACING OF STEEL DOWELS

Thickness of Slab (inches)	DOWEL Diameter (inches)	Length (inches)	Spacing (inches)
6-7	3/4	18	12
* 8-14	1	18	12
12-16	1-1/4	20	12 *

f. Joint Sealers and Fillers. Sealers are used in all joints to prevent the entrance of water or foreign material. Premolded compressible fillers are used in expansion joints to permit expansion of the adjacent slabs. Joint sealer is applied above the filler in expansion joints to prevent the infiltration of water.

22. JOINT LAYOUT NEAR PAVEMENT INTERSECTIONS. It is a general engineering practice to isolate the intersection from the rest of the pavement areas by the use of expansion joints. This allows the pavement to move independently. The treatment of the joints near the intersection, however, is not so general. Varying experience precludes stating any but general comments pertaining to the joints in this area.

a. Since cracks tend to form in odd shaped slabs, it is important to eliminate these shapes when designing the rigid pavement. The use of off-sets will help eliminate some of these irregular shapes around fillets. Except in the near 90 degree intersections, it is difficult to design a rigid pavement without a few of these irregularly shaped slabs. Pie-shaped sections will cause the most trouble and therefore should not be allowed except in areas where there is little or no traffic. Generally, sections should be roughly square or rectangular in shape. Figure 12 shows one possible intersection layout that reduces troublesome sections to a minimum in nonreinforced pavement.

b. When the proper amount of steel reinforcement is used in a rigid pavement, the allowable transverse joint spacing may be increased up to a maximum of 75 feet. By using greater joint spacing, the number of odd shaped slabs is automatically reduced. Figure 13 shows one example of joint layout for reinforced pavement.

c. Both Figures 12 and 13 show typical joint arrangement for pavements more than 10 inches in thickness. For pavements 10 inches or less in thickness, intermediate longitudinal hinged or dummy contraction joints are required, as shown in Table 3.

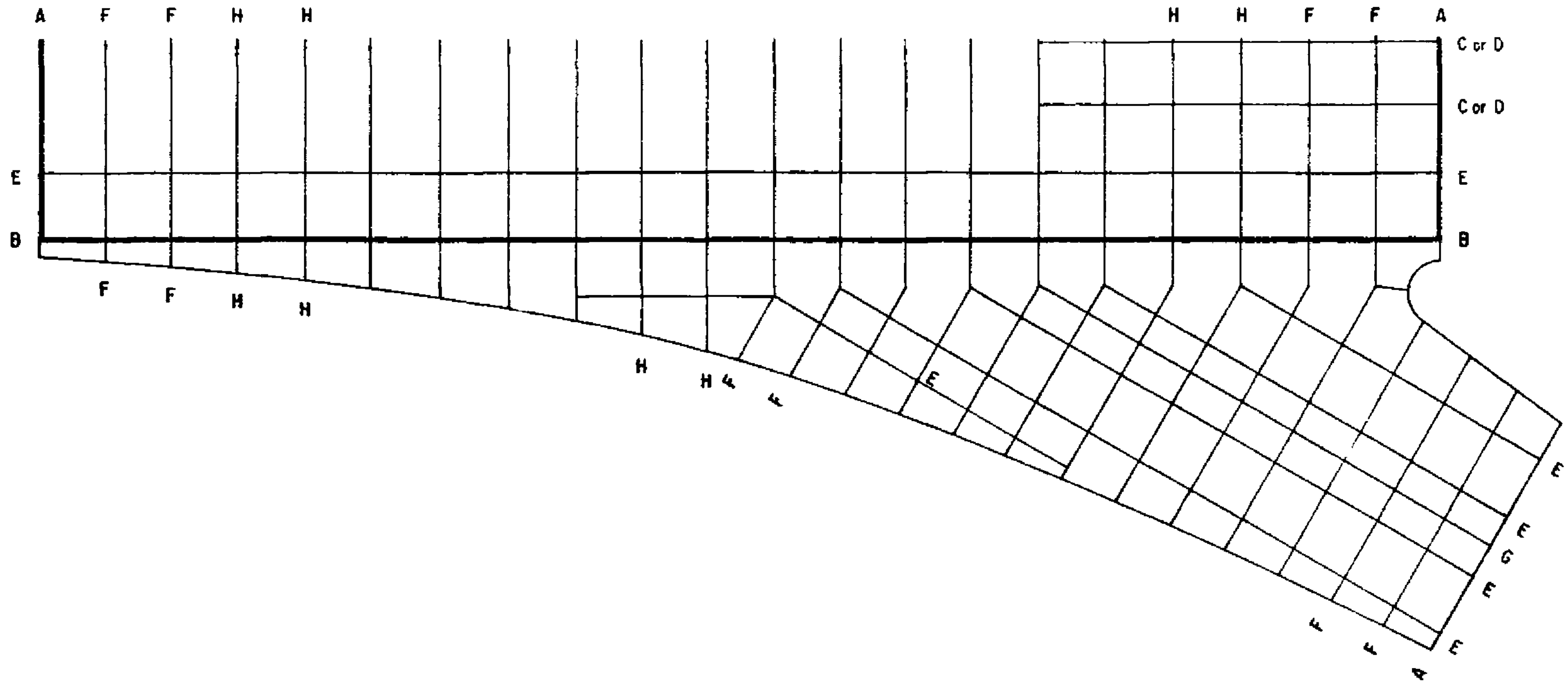


FIGURE 12. ARRANGEMENT OF JOINTS AT INTERSECTION OF RUNWAY AND TAXIWAY (NONREINFORCED)

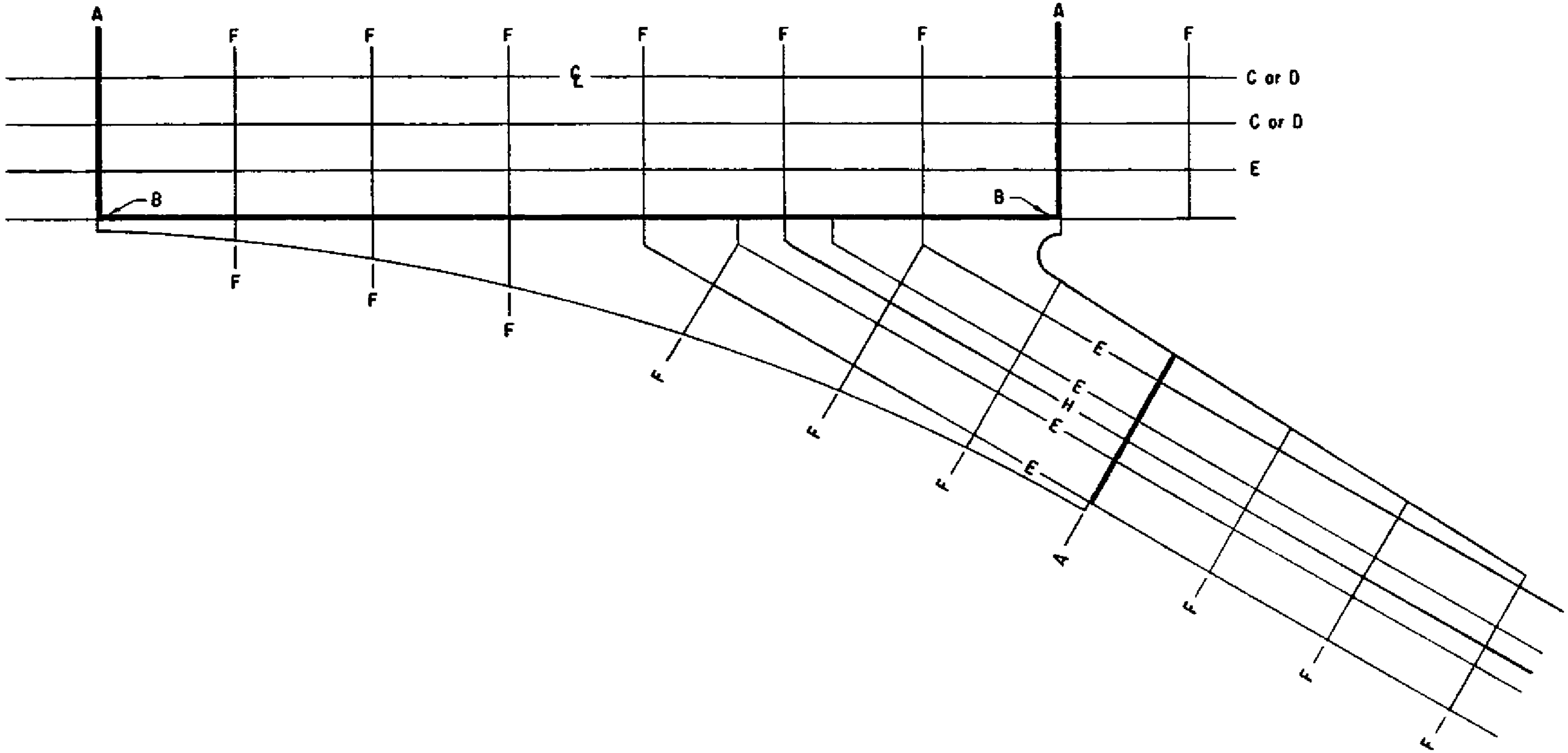


FIGURE 13. ARRANGEMENT OF JOINTS AT INTERSECTION OF RUNWAY AND TAXIWAY (REINFORCED)

23. REINFORCED CONCRETE. The main benefit of the steel reinforcing is that, although it does not prevent cracking, it keeps the cracks that form tightly closed so that the interlock of the irregular faces provide load transference. By holding the cracks tightly closed, the steel minimizes the infiltration of dirt, soil, and other materials. The thickness requirements for reinforced concrete pavements are the same as plain concrete and are determined from the curves in Figure 9.

a. Type and Spacing of Reinforcement. Reinforcement may be either welded wire fabric or bar mats installed with end and side laps to provide continuous reinforcement throughout the slab panel. Longitudinal members should be spaced not less than 3 inches nor more than 12 inches apart; transverse members should be spaced not less than 3 inches nor more than 18 inches apart.

b. Amount of Reinforcement. The required steel area is determined by the "subgrade drag" formula which is as follows:

$$A_s = \frac{FLw}{2f_s}$$

A_s = required area of steel per foot of width or length, square inches

F = coefficient of subgrade friction

L = length or width of slab, feet

w = weight of slab, pounds per square foot

f_s = allowable tensile stress in steel, psi

In this formula the slab weight is calculated on the basis of 12.5 pounds per square foot, per inch of thickness, and the allowable tensile stress will vary with the type and grade of steel. It is recommended that allowable tensile stress be taken as two-thirds of the yield strength of the steel. Based on current specifications the yield strengths and corresponding design stresses (f_s) are as follows:

Type & Grade of Steel	Yield Strength psi	f_s psi
Billet steel, intermediate grade	40,000	27,000
Rail steel or hard grade of billet steel	50,000	33,000
Rail steel, special grade	60,000	40,000
Billet steel, 60,000 psi minimum yield	60,000	40,000
Cold drawn wire	65,000	43,000

Force-displacement tests indicate that the coefficient of friction averaged over half the slab length or width may be expressed by

$$F = .585\sqrt{\frac{L}{T}}$$

Substituting for F in the subgrade drag formula

$$A_s = \frac{3.7L\sqrt{LT}}{f_s}$$

where T is the slab thickness in inches. To illustrate the use of this formula, assume that the slab dimensions have been established as 75 feet long, 25 feet wide, and 12 inches thick then for the longitudinal steel.

$$A_s = \frac{3.7(75)\sqrt{(75)(12)}}{43,000} = 0.194 \text{ sq. in.}$$

This is the required area of longitudinal steel per foot of width of the slab. The transverse steel area is computed in the same manner but L = 25 feet and A_s is equal to 0.037 square inches per foot of length of the slab.

c. Dimensions and Weights of Reinforcement. Dimensions and unit weights of standard deformed reinforcing bars are given in Table 6 and gauge numbers, diameters, areas, and weights of wires used in welded wire fabric are given in Table 7.

TABLE 6. DIMENSIONS AND UNIT WEIGHTS OF DEFORMED STEEL REINFORCING BARS

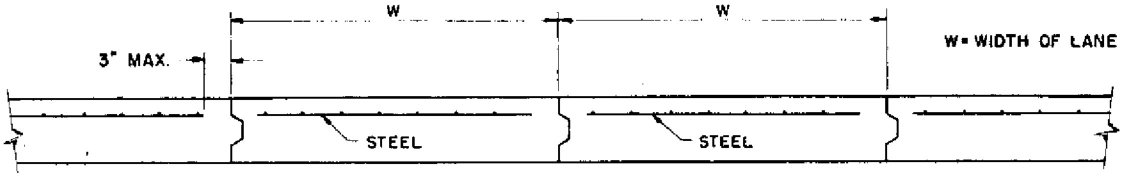
Bar Number	DIMENSIONS			Unit Weight, lb. per ft.
	Diameter, in.	Area, sq. in.	Perimeter, in.	
3	0.375	0.11	1.178	0.376
4	0.500	0.20	1.571	0.668
5	0.625	0.31	1.963	1.043
6	0.750	0.44	2.356	1.502
7	0.875	0.60	2.749	2.044
8	1.000	0.79	3.142	2.670
9	1.128	1.00	3.544	3.400
10	1.270	1.27	3.990	4.303
11	1.410	1.56	4.430	5.313

Steel Wire Gauge Numbers	Wire		Center to Center Spacing, in Inches									
	Diameter Inches	Area Square Inches	Weight Pounds per Foot	2	3	4	5	6	8	10	12	16
½"	.5000	.19635	.6668	1.178	.785	.589	.472	.393	.295	.236	.196	.147
0000000	.4900	.18857	.6404	1.131	.754	.566	.453	.377	.283	.226	.189	.141
000000	.4615	.16728	.5681	1.004	.669	.502	.401	.335	.251	.201	.167	.125
00000	.4305	.14556	.4943	.873	.582	.437	.349	.291	.218	.175	.146	.109
0000	.3938	.12180	.4136	.731	.487	.365	.292	.244	.183	.146	.122	.091
000	.3625	.10321	.3505	.619	.413	.310	.248	.206	.155	.124	.103	.077
00	.3310	.086049	.2922	.516	.344	.258	.207	.172	.129	.103	.086	.065
0	.3065	.073782	.2506	.443	.295	.221	.177	.148	.111	.089	.074	.055
1	.2830	.062902	.2136	.377	.252	.189	.151	.126	.094	.075	.063	.047
2	.2625	.054119	.1838	.325	.216	.162	.130	.108	.081	.065	.054	.041
¼"	.2500	.049087	.1667	.295	.196	.147	.118	.098	.074	.059	.049	.037
3	.2437	.046645	.1584	.280	.187	.140	.112	.093	.070	.056	.047	.035
4	.2253	.039867	.1354	.239	.159	.120	.096	.080	.060	.048	.040	.030
5	.2070	.033654	.1143	.202	.135	.101	.081	.067	.050	.040	.034	.025
6	.1920	.028953	.09832	.174	.116	.087	.069	.058	.043	.035	.029	.022
7	.1770	.024606	.08356	.148	.098	.074	.059	.049	.037	.030	.025	.018
8	.1620	.020612	.07000	.124	.082	.062	.049	.041	.031	.025	.021	.015
9	.1483	.017273	.05866	.104	.069	.052	.041	.035	.026	.021	.017	.013
10	.1350	.014314	.04861	.086	.057	.043	.034	.029	.021	.017	.014	.011
11	.1250	.011404	.03873	.068	.046	.034	.027	.023	.017	.014	.011	.009
12	.1055	.0087417	.02969	.052	.035	.026	.021	.017	.013	.010	.009	.007
13	.0915	.0065755	.02233	.039	.026	.020	.016	.013	.010	.008	.007	.005
14	.0800	.0050266	.01707	.030	.020	.015	.012	.010	.008	.006	.005	.004
15	.0720	.0040715	.01383	.024	.016	.012	.009	.008	.006	.005	.004	.003
16	.0625	.0030680	.01042	.018	.012	.009	.007	.006	.005	.004	.003	.002

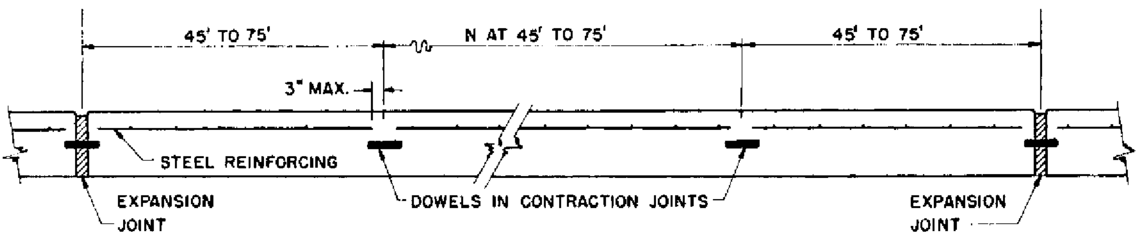
TABLE 7. SECTIONAL AREAS OF WELDED WIRE FABRIC
(Area in square inches per foot of width for various spacings of wire)

d. Minimum Size of Fabric. In connection with the use of welded wire fabric, it is recommended that the minimum size of longitudinal wire for slabs 10 inches or less in thickness should be No. 2 gauge, and for slabs over 10 inches thick it should not be smaller than No. 1 gauge. The minimum transverse wire should be no smaller than No. 4 gauge. In addition, should the calculated area of longitudinal steel be less than 0.1 percent of the cross-sectional area of the slab, the size and spacing of the steel members (bars or wire) should be determined on the premise that the minimum area should not be less than 0.1 percent. This percentage applies in the case of steel having a yield strength of 60,000 to 65,000 psi. If lower grades are used, the percentage should be revised proportionately upward. For the example cited above, Table 7 shows that No. 000 gauge wires, spaced 6 inches apart, furnish an area of 0.206 square inches which satisfies the requirement for longitudinal steel. Similarly, No. 4 gauge wires, on 12-inch centers, provide an area of 0.040 square inches which satisfies the requirement for transverse steel.

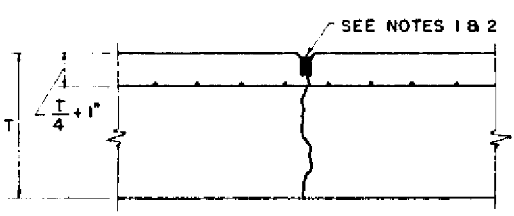
e. Contraction Joints in Reinforced Pavements. Contraction joints in reinforced pavements may be spaced up to 75 feet apart and all joints should be provided with load transfer dowels as shown in Figure 14. Also, this figure presents other reinforcement details such as clearance at joints and edges of pavement and depth below the surface.



TRANSVERSE CROSS-SECTION OF PAVING LANES



LONGITUDINAL CROSS-SECTION



LONGITUDINAL CONTRACTION JOINT
(SEE NOTE 3)

NOTES:

1. SEE FIGURES 10 & 11 FOR GROOVE DETAILS.
2. JOINT DETAILS ARE SIMILAR TO JOINT DETAILS FIGURES 10 & 11 EXCEPT FOR STEEL REINFORCING.
3. USE THIS JOINT WHEN THE SLAB THICKNESS IS 10 INCHES OR LESS AND PAVING LANE EXCEEDS $12\frac{1}{2}$ FEET. SEE TABLE 4.

FIGURE 14. DETAILS OF REINFORCED CONCRETE PAVEMENT

CHAPTER 4. AIRPORT PAVEMENT OVERLAYS

24. GENERAL.

a. A pavement that has been subjected to continual overloading may have been damaged to such an extent that it cannot be satisfactorily maintained. Similarly, a pavement in good condition may require strengthening to accommodate heavier aircraft than those for which the pavement was originally designed. Both situations may be remedied by the construction of overlays with either portland cement concrete, bituminous concrete, or a combination of bituminous concrete and flexible base course. Overlay types are defined as follows:

(1) Overlay refers to the pavement constructed on top of the existing pavement.

(2) Concrete overlay is an overlay consisting of portland cement concrete.

(3) Flexible overlay consists of a combination of high quality base course and a bituminous surface.

(4) Bituminous overlay consists entirely of bituminous concrete.

b. Typical overlay pavement cross sections are shown in Figure 15.

25. PRELIMINARY DESIGN DATA. Regardless of the type of overlay to be employed, several determinations should be made prior to the actual design. The following items will provide this essential information:

a. Determine the soil group and subgrade class of the soil underlying the existing pavement on the basis of soil tests, drainage, and climatic conditions.

b. Determine the actual thickness of each layer of existing pavement.

c. In accordance with the requirements for the particular type of overlay, as stipulated in the following text, determine the pavement thickness required for the loading and subgrade class under consideration, using the appropriate basic pavement design curves included in Chapter 3.

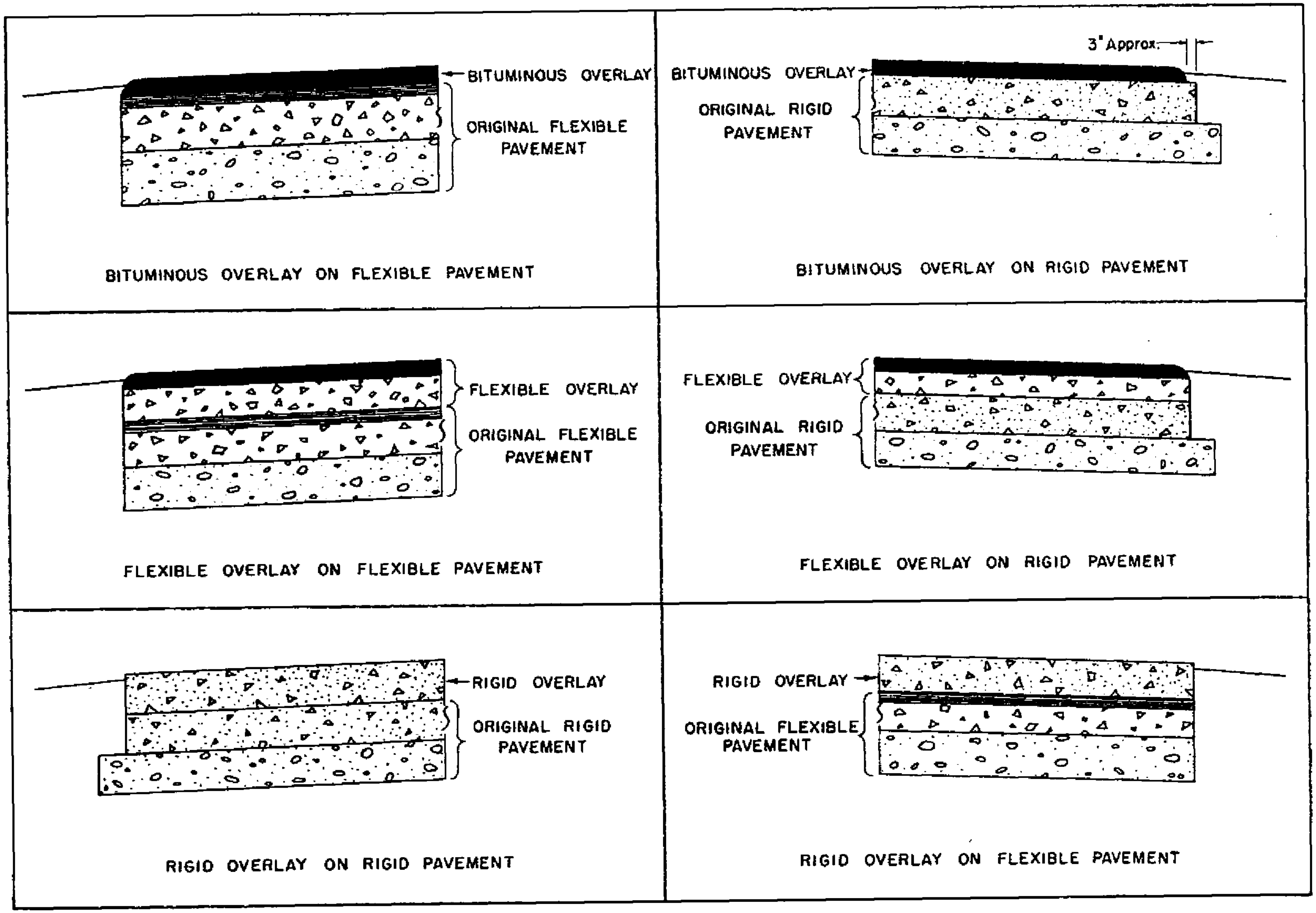


FIGURE 15. TYPICAL SECTIONS OF OVERLAY PAVEMENTS

26. DESIGN OF FLEXIBLE AND BITUMINOUS OVERLAYS.

a. General. Flexible or bituminous overlays can be applied to either flexible or rigid pavements. Design of the overlay is accomplished in a manner similar to the design of a new flexible pavement giving credit to the various layers of the existing pavement as pavement base courses. Certain criteria should be followed in the design of flexible or bituminous overlays, whether they are to be placed over existing rigid or flexible pavements, these are:

(1) Subbase courses should not be used in pavement overlays.

(2) Base courses should consist of materials discussed in paragraph 16b.

(3) Bituminous overlays for increasing strength should have a minimum thickness of 3 inches.

(4) All materials for base or surface courses should comply with AC 150/5370-1, Standard Specifications for Construction of Airports.

(5) Flexible overlays are susceptible to base course saturation which results in pavement failures due to the pore water pressure with rising temperature; thus, in most cases, a subdrainage system is required in order to maintain the moisture content at a tolerable level.

b. Flexible or Bituminous Overlays on Existing Flexible Pavements. Use the appropriate basic flexible pavement curves (Figure 6, 7, or 8) to determine the total thickness required for a flexible pavement for the desired load. The difference between the existing total pavement thickness and the required total pavement thickness represents the unadjusted thickness of the overlay.

(1) Adjustment to the overlay thickness is made on the basis of the character and condition of the existing surface and the type of overlay base as follows:

(a) An existing dense-graded plant-mix bituminous surface such as Item P-401, in sound condition, may be evaluated for base course purposes, on the basis that each inch of surface is equivalent to 1-1/2 inches of base course, provided a bituminous overlay is used.

(b) Under all other conditions, the existing surface course will be considered, inch for inch, as base course.

(c) If a bituminous base, such as Item P-201, is to be utilized, a thickness adjustment may be made on the basis of one inch of base being equivalent to 1-1/2 inches of nonbituminous base.

(2) With regard to flexible overlays, the thickness of the nonbituminous base should not be less than 4 inches unless the existing bituminous surface is broken to such an extent that it can be blended with the new base course material.

(3) To illustrate the procedure followed in designing flexible or bituminous overlays, assume an existing taxiway pavement, resting on an E-6 soil, consists of 2 inches of bituminous concrete surface course, 6 inches of crushed stone base, and 6 inches of subbase. Frost action is negligible and drainage is poor. The subgrade (under the stated condition) corresponds to class F4. It is desired to strengthen the pavement to accommodate a gross aircraft weight of 280,000 pounds on dual-tandem gear. The flexible pavement requirements (referring to Figure 8) for a taxiway under these conditions are:

Bituminous concrete surface	4"
Nonbituminous base	10"
Subbase	10"
Total pavement thickness	24"

Inasmuch as the existing pavement has a total thickness of 14 inches, it will be necessary to add an overlay approximately 10 inches thick to accommodate the load. Since the upper 4 inches of pavement consists of bituminous concrete, the required pavement may consist of any of the following sections depending on the existing pavement condition and type of overlay.

(a) Alternate 1 - The existing bituminous surface is broken due to overloading and a flexible overlay is to be employed. Under these conditions, the existing bituminous surface is considered as being equal, inch for inch, as base course and no thickness adjustment is warranted. The pavement will consist of:

New bituminous concrete surface	4"
New nonbituminous base	6"
Existing bituminous surface	2"
Existing nonbituminous base	6"
Existing subbase	6"
Total pavement thickness	24"

(b) Alternate 2 - On the existing pavement stipulated in Alternate 1, a bituminous overlay is to be constructed. In this case, the 10-inch design deficiency will be made of 4 inches of bituminous surface and the bituminous concrete equivalent to 6 inches of nonbituminous base. Applying allowable adjustment, 4 inches of bituminous base will suffice and the pavement should consist of:

New bituminous concrete surface	4"
New bituminous base	4"
Existing bituminous surface	2"
Existing nonbituminous base	6"
Existing subbase	6"
Total pavement thickness	22"

(c) Alternate 3 - The existing bituminous surface is in sound condition and a bituminous overlay is to be employed. The existing 2-inch bituminous surface is equivalent to 3 inches of base and the pavement will be made of the following:

New bituminous concrete surface	4"
New bituminous concrete base	3"
Existing bituminous surface	2"
Existing nonbituminous base	6"
Existing subbase	6"
Total pavement thickness	21"

c. Flexible or Bituminous Overlay on Existing Rigid Pavement. If an existing rigid pavement is to be strengthened with a bituminous or flexible overlay, the design procedure shown below should be followed.

(1) To establish the required thickness of a flexible or bituminous overlay, it is first necessary to determine from the basic rigid pavement design curves (Figure 9) the thickness of rigid pavement required to satisfy the design conditions. This thickness is then modified by a factor "F" which represents the subgrade and subbase conditions under the existing concrete. Table 8 shows values for the factor "F".

TABLE 8. FLEXIBLE AND BITUMINOUS OVERLAYS ON RIGID PAVEMENTS

Existing Subgrade Class	Value of F when subbase under existing pavement conforms to requirements for class of subgrade indicated below				
	Ra 1/	Rb	Rc	Rd	Re
Ra	0.80				
Rb	.90	0.80			
Rc	.94	.90	0.80		
Rd	.98	.94	.90	0.80	
Re	1.00	.98	.94	.90	0.80

1/ Figures in this column apply when no subbase has been provided.

Preliminary investigations will reveal the class of the subgrade upon which the existing pavement rests. This is the first or left column of Table 8. These investigations will also disclose whether the existing pavement includes a subbase and if so, its thickness. The appropriate value for "F" is found in the column which represents the subgrade class that would have to prevail for the existing thickness of subbase to be adequate for the design load. If no subbase exists, the factor will be selected from the column headed Ra.

(2) Having determined the value of "F", the overlay thickness can be computed from one of the following formulas:

(a) For flexible overlays:

$$t_f = 2.5\ (Fh - h_e) \text{ in which}$$

t_f = Required thickness of flexible overlay

F = Factor which varies with subgrade class

h = Required thickness of an equivalent single slab placed directly on the subgrade or subbase.

h_e = Thickness of existing slab

(b) For bituminous overlays: $t_b = \frac{t_f + 0.5t_s}{1.5}$ in which

t_b = Required thickness of bituminous overlay

t_f = Required thickness of flexible overlay

t_s = Required thickness of surface course

The following minimums apply to flexible and bituminous overlays on rigid pavements:

4 inches for nonbituminous base course

3 inches for a bituminous overlay

* 4 inches and 3 inches of bituminous surface over nonbituminous base course in critical and noncritical areas, respectively

Flexible overlay thickness should be rounded off to the nearest inch.

Bituminous overlay thickness should be rounded off to the nearest 1/2 inch.

(3) Example - An existing turbojet runway consists of 6 inches of concrete with no subbase provided. The subgrade soil is classified as E-5, frost action is negligible, and drainage is poor resulting in an Rb subgrade classification. It is necessary to strengthen the pavement to support a gross loading of 150,000 pounds on dual gear. Table 8 discloses that the factor "F" of 0.90 must be used in the overlay thickness formula. Other values in the formula are:

h_e = 6"

h = 12" for critical - from Figure 9

h = 10.8" for noncritical - 90% of critical thickness

Substituting in the formula for flexible overlays:

$t_f = 2.5 \left[(0.9 \times 12) - 6\right] =$ 12" for critical area

$t_f = 2.5 \left[(0.9 \times 10.8) - 6\right] =$ 9.3" for noncritical area (use 9")

The equivalent thicknesses of bituminous overlays are found as follows:

$t_b = \frac{12 + 2}{1.5} =$ 9.3" for critical (use 9.5")

$t_b = \frac{9.3 + 1.5}{2} =$ 7.2" for noncritical (use 7") *

(4) If adequate subbases have been provided under existing concrete pavements in accordance with the requirements in Table 8, the value of 0.80 for the factor "F" can be used in all cases. This condition would be equivalent to an Ra subgrade class. Since, in most cases, the subbase under the older pavements will not conform to these requirements, especially for the heavier loadings, the appropriate value of "F" must be obtained from Table 8. In further explanation of the use of Table 8 suppose that a design must be based on an Rd subgrade class. The desire is to determine the proper factor for the condition where no subbase has been provided, where the existing subbase conforms to the requirements for an Rb subgrade class, and where the existing subbase conforms to the requirements for an Rc subgrade class. The table shows that the factors will be 0.98, 0.94, and 0.90, respectively.

27. DESIGN OF CONCRETE OVERLAYS.

a. General. Concrete overlays can be constructed on existing rigid or flexible pavements. The minimum allowable thickness of a concrete overlay is 6 inches. Criteria for steel reinforcing, joint details and layout, size and spacing of dowels and tie bars, and other details of concrete overlays are similar to those applicable to conventional rigid pavement construction. These details are described in Chapter 3. Where a rigid pavement is to receive the overlay, some modification to these criteria may be necessary because of the design and joint arrangement of the existing pavement. The following points may be used as guides in connection with the design and layout of joints in concrete overlays.

(1) Joints need not be of the same type as in the old pavement.

(2) It is not necessary to provide an expansion joint for each expansion joint in the old pavement.

(3) Contraction joints may be placed directly over or within 1 foot of existing expansion, construction, or contraction joints. Should spacing result in slabs too long to control cracking, additional intermediate contraction joints may be necessary.

(4) If slabs longer than 20 feet are considered desirable, distributed reinforcement should be provided.

b. Concrete Overlay on Flexible Pavement. The design of concrete overlays on existing flexible pavements is taken from the curves in Figure 9. The existing flexible pavement is considered as subbase for the overlay slab. For a 150,000 pound aircraft on dual gear, the required pavement thickness is 11 inches. If frost is a problem in the area, the requirements of paragraph 20 should apply.

c. Concrete Overlay on Rigid Pavement. The design of concrete overlays on existing rigid pavements is also based on the curves in Figure 9. The rigid pavement design curves will disclose the thickness of concrete slab and subbase required to satisfy the design conditions for a pavement constructed directly on the existing subgrade. Since the concrete slab thickness, so determined, is predicated on the provision of a subbase varying in thickness with the subgrade class and aircraft loading, the thickness requirement for an equivalent single slab (h) must be adjusted for an existing subgrade class other than Ra. A satisfactory adjustment for the basic design curves can be made as follows:

(1) If less than 6 inches of subbase has been provided for a pavement supported by a subgrade other than Ra, add 1 inch of slab thickness to the required single slab thickness (h).

(2) No adjustment to the basic design curve thickness is required if the subgrade is classed as Ra or if a minimum of 6 inches of subbase has been provided on any other subgrade.

(3) Although these adjustments seem anomalous with the requirements of an original design based on Figure 9 with respect to subbase thickness, the condition of the existing pavement and the correction coefficient as discussed below should compensate for these differences.

(4) Based on the above and preliminary data obtained, the thickness of the concrete overlay slab to be applied to the existing rigid pavement is determined by the following formula:

$$h_c = \sqrt[1.4]{h^{1.4} - Ch_e^{1.4}}$$ in which

h_c = Required thickness of overlay slab

h = Required thickness of an equivalent single slab from Figure 9

h_e = Thickness of the existing slab

C = Coefficient

Values of the coefficient C are based on the condition of the existing pavement as determined from the pavement condition survey. Recommended values are:

C = 1.00 existing pavement in good condition.

C = 0.75 existing pavement with initial corner cracks due to loading but no progressive cracking.

C = 0.35 existing pavement badly cracked or crushed.

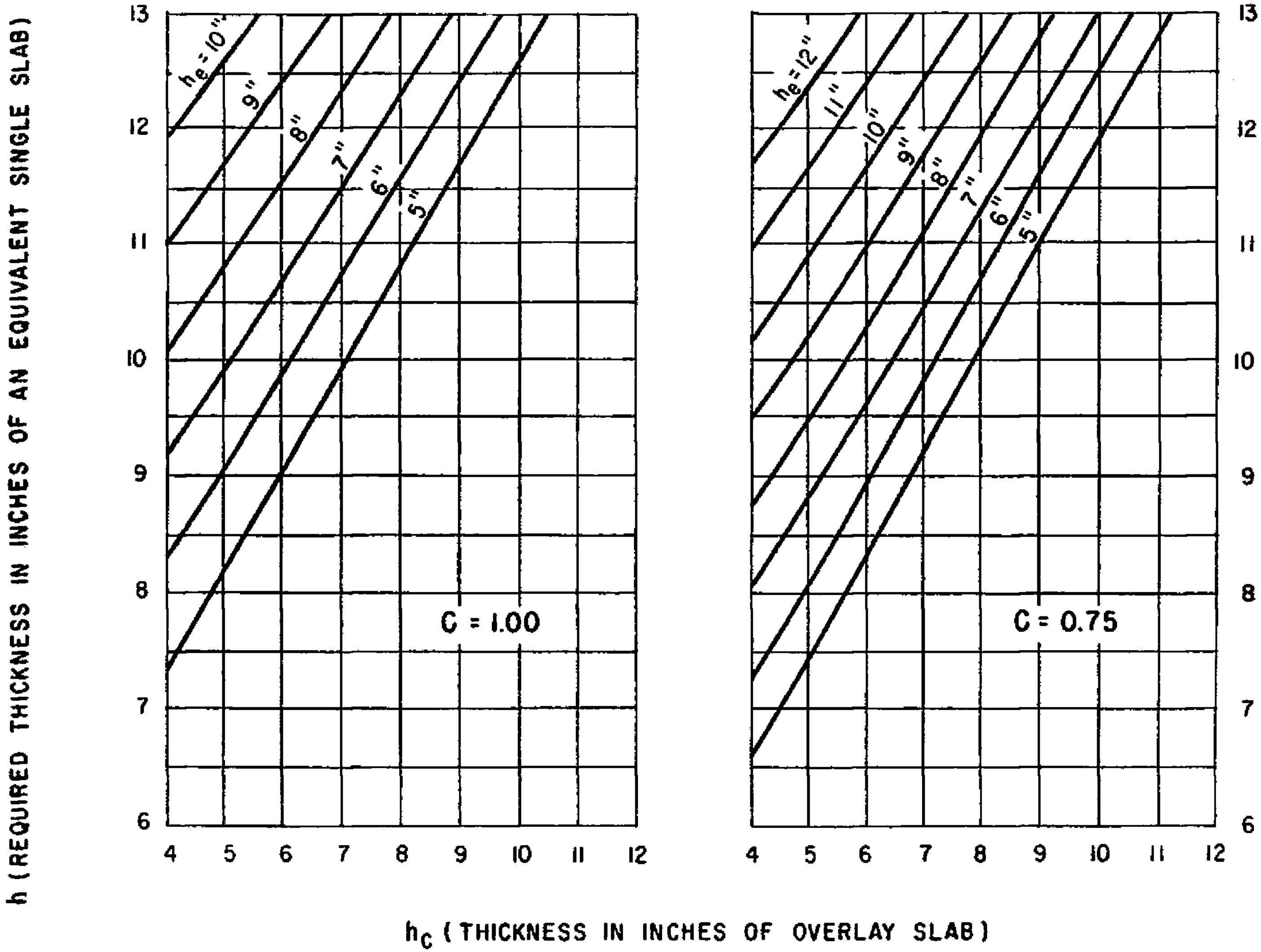
Conditions at a particular location may indicate the desirability of adopting intermediate values for C within the recommended range.

For convenience in determining the required thickness of concrete overlay slabs, the curves in Figure 16 have been prepared based on the above formula. Values may be interpolated on these curves.

(5) Under some circumstances, as discussed in paragraph 28b(3), it may be necessary to apply a leveling course of bituminous concrete to the surface prior to the application of the rigid overlay. If such is the case, an increase in the overlay thickness is warranted and the curves in Figure 17 may be employed to establish the thickness of the overlay slab. These curves are based on the formula:

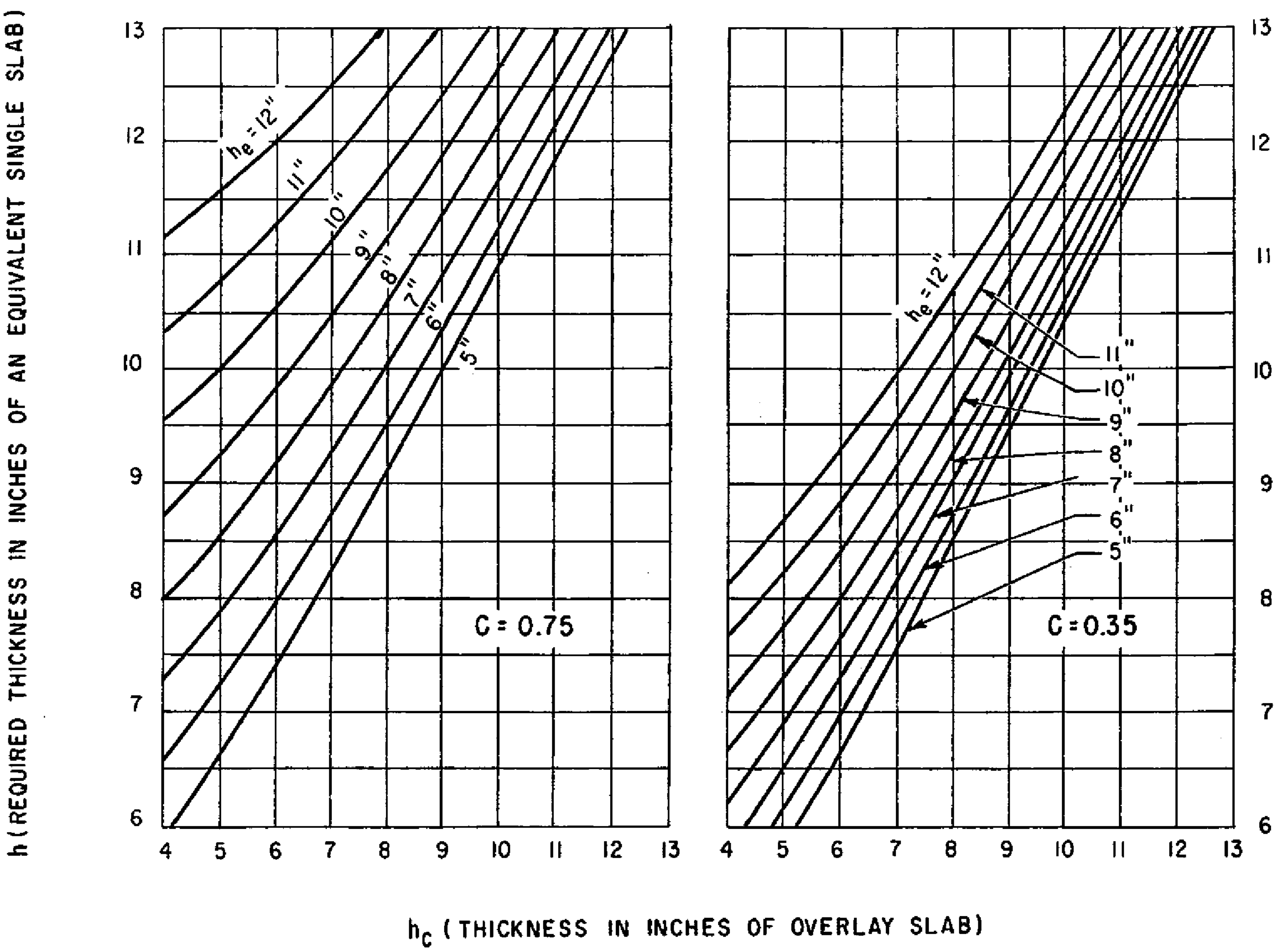
$$hc = \sqrt{h^2 - Ch_e^2} \quad \text{in which}$$

the variables have the same identity as in the previous formula.



$$h_c = \sqrt[1.4]{h^{1.4} - C\,h_e^{1.4}}$$

FIGURE 16. CONCRETE OVERLAY ON RIGID PAVEMENT



$$h_c = \sqrt{h^2 - C\, h_e^2}$$

FIGURE 17. CONCRETE OVERLAY ON RIGID PAVEMENT WITH LEVELING COURSE

28. PREPARATION OF THE EXISTING SURFACE FOR THE OVERLAY. Before proceeding with construction of the overlay, steps should be taken to correct all defective areas in the existing surface, base, subbase, and subgrade.

a. Failures in flexible pavements can take the form of pavement breakups, potholes and surface irregularities, and depressions.

(1) Localized areas of broken pavement will have to be removed and replaced with new pavement. This type of failure is usually encountered where the pavement is deficient in thickness, the subgrade consists of unstable material, or poor drainage has reduced the supporting power of the subgrade. To correct this condition, the subgrade material should be replaced with a select subgrade soil or by installation of proper drainage facilities; this is the first operation to be undertaken in repairing this type of failure. Following the correction of the subgrade condition, the subbase, base, and surface courses of the required thickness should be placed. Each layer comprising the total repair should be thoroughly compacted before the next layer is placed.

(2) Surface irregularities and depressions, such as shoving, rutting, scattered areas of settlement, and occasional "birdbaths" should be leveled by rolling, where practical, and/or by filling with suitable bituminous mixtures. If the "birdbaths" and settlements are found to exist over extensive areas, a bituminous leveling course may be required as part of the overlay. The leveling course should consist of a high quality bituminous concrete. Scattered areas requiring leveling or patching may be repaired with either hot or cold patch mixtures similar to those customarily used in the particular locality. In the case of a flexible overlay, the leveling may be accomplished with the aggregate used in the base course.

(3) A bleeding surface may detrimentally affect the stability of the overlay and for this reason any excess bituminous material accumulated on the surface should be bladed off if possible. In some instances, a light application of fine aggregate may blot up the excess material or a combination of the two processes may be necessary.

(4) Cracks, 1/2 inch or more in width, should be filled with a lean mixture of sand and bituminous material. This mixture should be well tamped in place and any excess removed level with the pavement surface.

(5) Potholes should be cleaned and filled with a suitable bituminous mixture, thoroughly tamped in place.

b. In rigid pavements, ordinary transverse, longitudinal and corner cracks will need no special attention unless there is an appreciable amount of displacement and faulting of the separate slabs. If the subgrade is stable and no pumping has occurred, the low areas can be taken care of as part of the overlay and no other corrective measures are needed. On the other hand, if pumping has occurred at the slab ends or the slabs are subject to rocking under the movement of aircraft, subgrade support should be improved by pumping cement grout under the pavement to fill the voids that have developed.

(1) If the pavement slabs are badly broken and subject to rocking because of uneven bearing on the subgrade, the rocking slabs can be broken into smaller slabs to obtain a more firm seating. Badly broken slabs that do not rock will not require repairs since the criteria make adjustments for such a condition in the pavement thickness when the overlay consists of portland cement concrete. In some cases, it may be desirable to replace certain badly broken slabs with new slabs before starting construction of the overlay. The decision in such cases will have to be made according to the merits of the individual project.

(2) When the existing rigid pavement is to be overlayed with a flexible pavement type, the badly broken slabs may be replaced with a bituminous concrete equal in thickness to the thickness of the old concrete slab. A subgrade soil under the slab which has become unstable due to accumulations of moisture should be removed to the required depth, as determined by a thorough investigation at the particular location, and replaced with a suitable well-compacted granular subbase or base course material.

(3) Where the existing pavement is rough due to slab distortion, faulting, or settlement, a provision should be made for a leveling course of bituminous concrete before the overlay is commenced.

(4) After all repairs have been completed and prior to the placing of the overlay, the surface should be swept clean of all dust, dirt, and foreign material that may tend to break the bond between the overlay and the existing pavement. Any extruding joint sealing material should be trimmed from rigid pavements.

29. MATERIALS AND METHODS. With regard to quality of materials and mixes, control tests, methods of construction, and quality of workmanship, the overlay pavement components are governed by the appropriate FAA standard specifications.

a. Where a flexible overlay is to be placed on either flexible or rigid pavement, the base course layer may be placed directly on the existing surface after necessary repairs have been made.

b. If a bituminous overlay is specified, the existing pavement should receive a light tack coat or fog coat immediately after cleaning. The overlay should not extend to the edges of the pavement but should be cut off approximately 3 inches from each edge.

c. After cleaning, existing concrete surfaces should be wetted prior to depositing the fresh concrete of a rigid overlay to insure as good a bond as possible.

d. Should the existing pavement require drilling to provide anchorage for the overlay pavement forms, the size and number of holes should be the minimum necessary to accomplish that purpose. Holes should not be located close to joints or cracks. Location of holes for form anchors should be such as to avoid causing additional cracking or spalling.

CHAPTER 5. PAVEMENTS FOR LIGHT AIRCRAFT

30. GENERAL.

a. Pavements for light aircraft may be defined as landing facilities intended to accommodate personal aircraft or other small aircraft engaged in nonscheduled activities as agricultural, industrial, executive, or instructional flying. These pavements will not be required to handle aircraft exceeding a gross weight of 30,000 pounds, and in many cases these aircraft will not exceed 12,500 pounds. The design for pavements which are to serve industrial or executive aircraft of 30,000 pounds gross weight or more should be based on the criteria contained in Chapter 3 of this publication.

b. Some airports may not require paved operational areas. Conditions at the site may be adaptable for the development of a turf surface adequate for limited operations of these light aircraft. It may be possible to construct an aggregate-turf surface by improving the stability of a soil with the addition of aggregate prior to development of the turf. Aggregate-turf construction is covered in some detail in the latter part of this chapter.

c. In most areas, however, it is not possible to provide and maintain a stable turf surface because of adverse weather conditions or high density of traffic. Under these conditions, construction of an all-weather pavement may be necessary.

d. Pavements for aircraft under 12,500 pounds gross weight will normally consist of locally available material with a bituminous surface course. Pavements to accommodate aircraft up to 30,000 pounds may consist of a similar type of flexible pavement or of rigid surfaces of minimum allowable thickness.

e. The design data in this chapter deal with flexible pavements only. No special design criteria are required for rigid pavements because the FAA standard 6-inch minimum thickness of concrete pavement will satisfactorily serve aircraft with gross weights up to 30,000 pounds.

31. FLEXIBLE PAVEMENT THICKNESS.

a. The curves in Figure 18 give the pavement thickness requirements for aircraft with gross weights up to 30,000 pounds. These curves, which are used in a similar manner to those for higher types of pavements, should be used for aircraft up to but not including 30,000 pounds gross weight. For aircraft of 30,000 pounds and above the curves in Chapter 3 should be used. The pavement thickness determined from the curves in Figure 18 should be used for all areas of the airport pavement. No reduction in thickness should be made for "noncritical" areas of runways for light aircraft.

b. As is the case of larger aircraft, a flexible pavement for light aircraft consists of a bituminous wearing surface placed on a nonrigid base and in some cases a nonrigid subbase. Figure 19 depicts a cross section of a typical flexible pavement for light aircraft.

c. Under certain conditions, it may be necessary to utilize a bituminous surface treatment on a prepared base course in lieu of a more durable surface. If such is the case, a pavement so constructed is a temporary one with no inherent strength other than that furnished by the underlying base and the application of a higher type surface course is recommended at the earliest possible date.

d. Since the base and subbase course materials discussed in Chapter 3 are more than adequate for light aircraft, full consideration should be given to the use of locally available, less expensive materials which are entirely satisfactory for these pavements. These materials may include locally available granular materials, soil aggregate mixtures, or soils stabilized with portland cement, bituminous materials, or lime. Soil stabilization is covered in greater detail on the following pages.

NOTE:

THE FO CURVE FIXES THE REQUIRED BASE PLUS SURFACE COURSE THICKNESS.

1" MINIMUM SURFACE THICKNESS ASSUMED FOR FO CURVE.

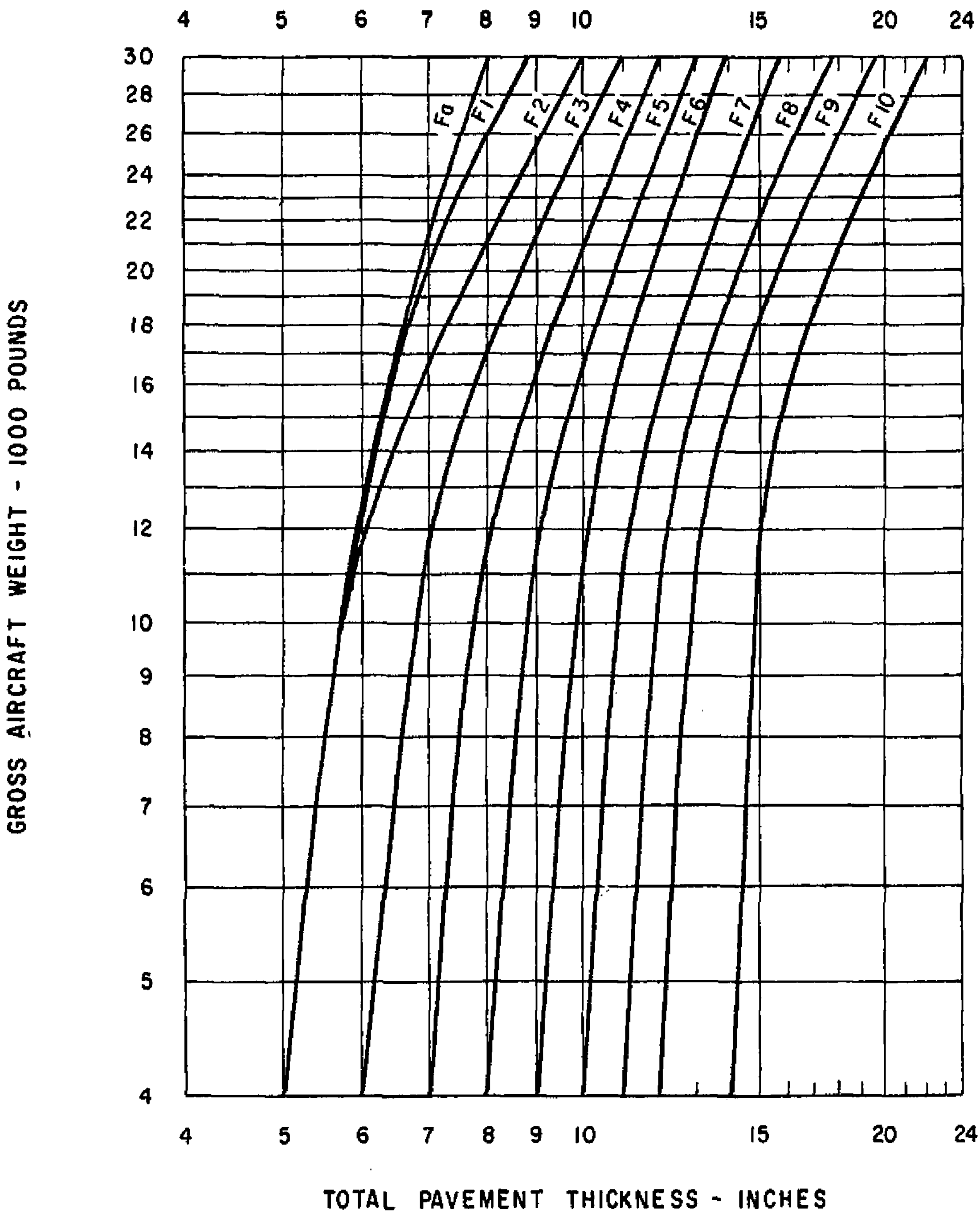


FIGURE 18. DESIGN CURVES FOR FLEXIBLE PAVEMENTS - LIGHT AIRCRAFT

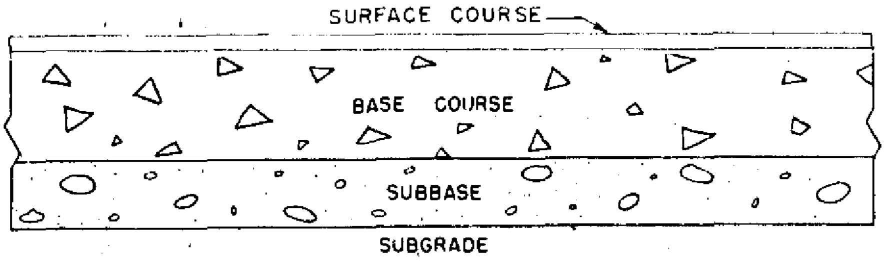


FIGURE 19. CROSS SECTION - TYPICAL FLEXIBLE PAVEMENT FOR LIGHT AIRCRAFT

e. The base course thicknesses in Figure 18 range from 4 inches to 7 inches, while the subbase thicknesses vary from 0 inch to 14 inches. The subgrade classes shown are obtained from the corresponding soil group, and frost and drainage conditions in Chapter 2, Table 2, of this circular.

f. Since the loads which these pavements must support are much less than those accommodated by pavements designed for heavier aircraft, certain reductions can be made in the compaction requirements for the base and subbase materials. Compaction control for these pavements is based on the standard AASHO Method T 99. This item is covered in Test T-611 of AC 150/5370-1, Standard Specifications for Construction of Airports.

32. SOIL STABILIZATION. Soil stabilization is the procedure whereby the properties of a soil are improved to the extent that it will meet the requirements for pavement bases or subbases. Stabilized soils are not intended to serve as a surface course but must be provided with a surface in order to resist the abrasive action of operating vehicles or aircraft. To be effective, stabilization should provide a foundation which will furnish adequate support for the loads transmitted through the paved surface, and will eliminate or reduce to an appreciable extent the detrimental effects of volume changes occurring in the soil due to climate influences or moisture variations. Mechanical and chemical stabilization are the two general types currently employed.

a. Mechanical stabilization on airports follows standard practices developed over the years, and requirements regarding materials as well as construction methods are quite definitely established. Performance studies have disclosed that the success of a granular stabilized base course depends on the gradation of the mixture and the physical properties of the material passing the No. 40 sieve.

(1) The gradation for gravel or stone is available in Item P-208, "Aggregate Base Course." Likewise, Item P-213, "Sand-Clay Base Course", gives gradations for the coarse and fine types. In addition to the gradation requirements, there are certain other requirements common to all granular type base courses. Among these are:

(a) The fraction passing the No. 200 sieve should not exceed one-half the fraction passing the No. 40 sieve.

(b) The liquid limit of the material passing the No. 40 sieve should not exceed 25 and the plasticity index should not exceed 6.

(c) For the fine aggregate type of sand-clay base, the plasticity index of the material passing the No. 40 sieve should not exceed 4.

(2) Granular type stabilized base courses meeting the requirements outlined above, when properly compacted, can give excellent service. It is emphasized, however, that the restriction placed upon the plasticity index must be rigidly adhered to if successful stabilization by these means is to be expected.

b. Bituminous stabilization is the combining of bituminous material with soil, soil-aggregate, or sand to produce the desired soil characteristics. Bituminous stabilizing agents include cutback asphalts, slow-curing asphalts or road oils, emulsified asphalts, and tars. Methods of construction vary with the type of equipment available but, regardless of the equipment, the different steps consist essentially of soil preparation by scarifying and pulverizing, thorough and uniform mixing of the bituminous material with the soil, curing of the mixture to get rid of excess moisture and volatile constituents, and compaction to a predetermined density.

(1) A successful job depends on the proper execution of each one of these steps. Test methods for determining the type and amount of bituminous material vary considerably in different areas. Manufacturers' recommendations also differ in this respect. Engineering services along these lines are available from the producers of the particular materials selected for use. In this connection, D-915, "Testing Soil-Bituminous Mixtures", has been adopted by the American Society for Testing and Materials.

(2) The type and grade of bituminous material to use depend on the characteristics of the soil, the climatic conditions, and the type of mixing equipment available. It is generally accepted that the best practice is to use the heaviest grade of bituminous material that can be readily mixed with the soil. Travel plants will permit the use of heavier grades of bitumens than will harrows and motor graders. The most commonly used grades of bituminous binders are:

(a) Rapid-Curing Cutback Asphalts. RC-1 to RC-4. (RC-70, RC-250, and RC-800)

(b) Medium-Curing Cutback Asphalts. MC-1 to MC-4. (MC-70, MC-250, and MC-800)

(c) Slow-Curing Oil. SC-1 to SC-4. (SC-70, SC-250, and SC-800)

(d) Tar. RT-3 to RT-7.

(e) Emulsified Asphalt. Slow setting.

(3) Bituminous stabilization on airports should be restricted to soils of a granular nature as opposed to plastic or cohesive soils. The following criteria are used to determine the suitability of a soil for bituminous stabilization:

(a) The silt and clay fractions combined should not exceed 45 percent.

(b) The liquid limit of the material passing the No. 40 sieve should not exceed 30 and the plasticity index should not be greater than 10.

(c) Soils containing appreciable amounts of mica are not suitable for bituminous stabilization.

(4) Bituminous stabilization will give satisfactory performance on airports when the mixtures are made with soils having the proper physical characteristics. On the other hand, serious failures can occur where the soils have high silt and clay contents, contain mica in appreciable amounts, mixtures are compacted before they have cured properly, or surfaces are placed on the stabilized base too soon, thus trapping the excess moisture and volatile materials.

(5) In general, Item P-216, "Mixed In-Place Base Course", covers the methods of construction for this form of stabilization. This item must be modified by deleting the sections referring to job mix formula, materials, and composition of mixture and substituting requirements applicable to the material to be stabilized. Changes in construction procedures may be desirable in certain localities.

c. By the addition of portland cement in the correct quantity, many types of soils and materials such as shale, gravel, sand, screenings, slag, and mine tailings can be stabilized. Construction of soil cement bases has been standardized to a large degree. Item P-301, "Soil Cement Base Course", covers the construction of soil cement base courses.

(1) Where soil cement is to be employed, the minimum thickness of such stabilization should be 6 inches. Stabilization of soils which are very plastic or which contain large percentages of clay presents a problem because of the difficulties encountered in processing the soils and the increased quantity of cement required to improve the soil. Although a definite improvement in stability is usually obtained with such soils, the increase is not sufficient to meet the requirements for base courses. Normally, only soils from E-1 to E-6 should be considered for soil cement base course construction.

(2) Portland cement can be used in the reconstruction of gravel base courses that have failed because of a high plasticity index of the soil binder. The reconstruction consists of scarifying and pulverizing the existing gravel base, adding and mixing the portland cement, and recompacting to a controlled density. The addition of the correct amount of cement can produce mixtures having plasticity indices well under the 6 percent maximum specification requirement.

(3) Inasmuch as soil cement base courses are constructed to a minimum thickness of 6 inches, the required thickness of subbase, as determined from Figure 18, can be reduced for gross weights less than 20,000 pounds. As an illustration, the figure indicates that for a gross weight of 12,000 pounds, a base course of 5 inches is required. The subbase requirements vary from approximately 1 inch for subgrade class F3 to 9 inches for F10 subgrade. The subbase thickness may be reduced by 1 inch so that the total thickness of soil cement base and subbase will be equal to the combined thickness of the base and subbase shown in Figure 18.

d. Lime, in small percentages, has been added to base course materials such as gravel, disintegrated granite, crusher run stone containing appreciable amounts of soil type overburden, and caliche in order to reduce the plasticity index to meet specification requirements. Performance records of highway pavements indicate this reduction in plasticity index accomplishes a marked improvement in the stability of the base course.

(1) The amount of lime required for stabilization should be determined by means of laboratory tests. Various percentages of lime should be mixed with the soil and the percentage which results in reducing the plasticity index to the desired amount may be selected. In general, 2 or 3 percent of hydrated lime will serve to reduce the plasticity index of pit-run gravel and similar base course materials to the extent that they meet specifications.

(2) Plastic soils should be treated with hydrated lime in amounts ranging from 3 to 10 percent. Investigations show that for each soil there is an optimum percentage of lime. An addition of lime in excess of this amount will not reduce the plasticity index to any significant degree. The lowest percentage above which improvement is negligible is the most satisfactory for the particular soil. At this stage of knowledge, plastic soils stabilized with lime should not be considered for base course purposes but they may be very effective as a subbase material.

(3) With respect to construction procedures, lime-soil combinations are processed in a manner similar to soil-cement combinations which are covered in Item P-301, "Soil Cement Base Course", except that the lime may be applied as a slurry or in the dry state.

e. Other chemical stabilizers such as resins, plastics, and metallic salts have been used as a means of improving the stability of soils. These methods are in various stages of development and more work is necessary to determine their effectiveness. None of these materials or processes have so far been developed to the stage where they can be utilized effectively in the construction of civil airports.

33. AGGREGATE TURF.

a. Aggregate-turf strips differ from the usual turf strip in that the stability of the soil has been increased by the addition of granular materials prior to establishment of the turf. The objective of this type of construction is to provide a landing area that will not soften appreciably during wet weather and yet will retain sufficient soil to promote the growing of turf. Such a strip is designed to serve aircraft having a gross weight not exceeding 12,500 pounds, although under certain conditions planes considerably in excess of this loading might be accommodated.

b. In general, the material used in the aggregate-turf combination consists of whatever suitable supply is locally available to permit construction work to be accomplished as economically as possible. The gradation requirements of the mixture and the stabilizer aggregate are presented in Item P-217, "Aggregate--Turf Pavement." The materials should be composed of natural or prepared mixtures of soil with gravel, stone, sand, or any other aggregate, and the aggregate retained on the No. 4 sieve should be reasonably sound and durable enough to resist weathering, abrasion, and crushing. Shales and similar materials that break up and weather rapidly should not be used.

c. Construction details and material requirements are covered in Item P-217, "Aggregate--Turf Pavement." The proportion of aggregate to soil and the degree of compaction that is permissible from the standpoint of stability should be weighed against the requirements for the establishment of turf. Local climatic conditions exert a great influence on these two factors. Compaction from 70 to 90 percent of maximum density, as determined in accordance with AASHO T 99, is considered satisfactory for stability and will not interfere with the growth of grass.

d. The desirable thickness to be stabilized with the granular materials varies with the type of soil and the drainage and climatic conditions. The subgrade classification should be determined from Chapter 2, Table 2 and the total stabilized thickness from Figure 18. That is, to handle aircraft weighing 9,000 pounds on a subgrade classification of F6, the thickness should be 10 inches.

CHAPTER 6. AIRPORT PAVEMENT EVALUATION

34. GENERAL.

a. This chapter covers evaluation of airport pavements and introduces relationships between the FAA classification procedures and other physical tests used for airport pavement design and evaluation, namely, plate bearing and California Bearing Ratio (CBR). These relationships will permit a more accurate evaluation of pavements constructed to FAA dimensional and materials standards as well as those at variance with them or for which record information is lacking.

b. Examination of the airport pavement design systems in common use in this country and abroad shows that each has accompanying evaluation systems based in part on the incorporation of physical test results into their design procedures. Also, while many have design steps in common, each has modifications and design parameters which make direct comparison impossible. Similarly, evaluation procedures are good only for the design system to which they are related. Thus, it should be noted that while plate bearing and CBR tests are admitted herein as evaluation and design tools, the test results obtained are admissible to the FAA design procedures only in the manner prescribed in this circular.

c. Proper airport pavement evaluation is important to intelligent long-range planning and in the scheduling of pavement maintenance procedures. It is required as a step in the design of an expanded or strengthened pavement area. As normally regarded, an adequate pavement evaluation consists of the following steps, each of which may be accomplished in varying degrees of thoroughness.

(1) Site Inspection. This may include, in addition to the immediate pavement area, examination of the existing drainage condition and drainage facilities of the site, area, outfall, etc.; evidence of frost effect, water table, and area development. The principles set forth in Chapter 2 of this circular and in AC 150/5320-5A, Airport Drainage, apply.

(2) Records Research and Evaluation. This step may, at least in part, precede step (1) above. This step is accomplished by thorough review of construction dates and history, design considerations, specifications, testing methods and results, and maintenance history. Weather records and the most complete traffic history available are also parts of a usable records file.

(3) Sampling and Testing. The need for and scope of physical tests and materials analysis will be based on the findings made from the site inspection and records research. These will consist primarily of the soil investigations discussed in paragraphs 6, 7, and 8 of this circular plus the materials, gradation, and density tests required for the various pavement components as set forth in the Standard Specifications for Construction of Airports. Where problem areas exist and where extensive and costly construction or reconstruction projects are anticipated, these may be supplemented by plate bearing or CBR test procedures.

(4) Evaluation Report. Analysis of steps (1), (2), and (3) should culminate in the assignment of load bearing values to the pavement sections under consideration. The analyses, findings, and test results should be incorporated in a permanent record for future reference. While these need not be in any particular form, it is recommended that a drawing identifying area limits of specific pavement sections be included.

d. In practice, the accuracy of evaluation results will vary depending on the purpose, time expended, physical tests accomplished, and the complexity of the site. Economics and the relative importance of the continued operation of the airport will normally determine the extent to which evaluation is carried. The methods adopted herein are intended to provide a maximum of flexibility in this regard.

e. The balance of this chapter covers evaluation methodology and computation procedures only. Factors are used to reflect condition of existing structural components. These should be used as provided. The results obtained should be further modified, however, by results of the inspection, research, and testing procedures discussed above. Sound engineering judgment is a necessary part of successful pavement evaluation. As in any endeavor, however, judgment is enhanced by extensive and accurate background information.

35. PROCEDURES. The basic evaluation procedure for airport pavement areas will be visual inspection and reference to the FAA design criteria, supplemented by the additional sampling, testing, and research which the evaluation purpose may warrant. For relatively new pavement constructed to FAA standards and without visible signs of wear or stress, strength may be based on inspection of the FAA Form 1773, the "as constructed" sections, and modification, if appropriate, for any materials variation or deficiencies of record. Where age or visible stress indicate the

original strength no longer exists, further modification should be applied on the basis of judgment or a combination of judgment and supplemental physical testing. For pavements not designed to FAA materials standards or which consist of sections not readily comparable to FAA design standards, evaluation should be based on FAA standards after materials comparison and equivalencies have been applied in the manner hereafter described.

a. <u>Sampling and Testing</u>. In addition to the materials' specifications contained in AC 150/5370-1A and the soil sampling, testing, and classification procedures covered in Chapter 2 of this circular, it may be desirable to perform additional tests which are especially suitable to evaluation needs. The curves and comparison charts included in this chapter are based, in addition to those tests and procedures noted above, on the following tests.

(1) <u>For Flexible Pavements</u>, California Bearing Ratio tests, laboratory and field, made in accordance with the procedures established in MIL-STD-621A, Method 101, may be used. The FAA design criteria can be compared to the CBR design system and, where some doubt exists of the validity of the "F" classification, CBR analysis is appropriate as one of the supplemental testing procedures discussed in paragraph 8 of Chapter 2. In order that CBR results may be incorporated into the FAA classification system, the comparison made by Figure 20 shall be applied. Application of CBR to FAA subgrade class shall be accomplished in the following manner:

(a) The CBR-F comparison is based on a "no frost" condition as shown in Table 2. Reference to good drainage or poor is not required as the CBR reflects soil drainage ability.

(b) For existing pavement less than 3 years old, soaked laboratory tests shall govern unless clear evidence exists that subgrade moisture content has stabilized at a lower value. Design properly based on good drainage should not be adversely affected by the soaked CBR.

(c) For pavement 3 years old or more, evaluation should be based on in-place CBR and moisture content determination primarily. Remolded lab CBR's may be utilized where the development of pore water pressure is suspected, adjustment is needed for low in-place densities, etc.

(d) CBR as determined in (b) or (c) may be used to revise "F" classes up or down, except that the maximum upward adjustment shall be one class.

(2) For Rigid Pavements, the flexural strength of concrete may be determined by the procedures specified in ASTM C 78. In addition, plate bearing tests may be made on the top of subbase or on top of subgrade where no subbase exists. These tests should be made in accordance with the procedures established in MIL-STD-621A, Method 104.

(a) Where a valid relationship between the flexure test and tensile splitting (ASTM - C 496) can be established, the less expensive method of determining strength may be utilized.

(b) An important part of the test procedure for determining the subgrade reaction modulus is the correction for soil saturation which is contained in the prescribed military standard. The normal application utilizes a correction factor determined by the consolidation testing of samples at in-site and saturated moisture content. For evaluation of older pavements, where evidence exists that the subgrade moisture has stabilized or varies through a limited range, the factor may be assumed as unity or established by consolidation of a less than saturated sample.

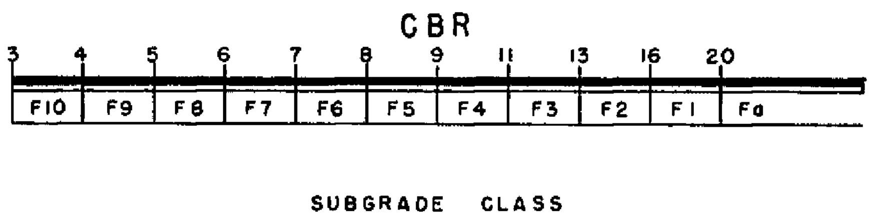


FIGURE 20 CBR-FAA SUBGRADE CLASS COMPARISONS

b. Materials Comparison and Equivalencies. When materials in a pavement structure to be evaluated are at variance with FAA standards, they shall be compared to them and classified as surface, base, subbase, etc., in accordance with paragraphs 1c, 16, and 18. After classification, the various pavement courses will be compared to the appropriate design requirement and, where necessary, non-standard sections shall be adjusted to conform to the highest strength standard section by application of the following equivalencies.

(1) Bituminous surface course (P-401 or equivalent) in sound condition shall be evaluated as stabilized base course at the rate of 1 inch of surface for 1 inch of stabilized base or as nonstabilized base course at the rate of 1½ inches of non-stabilized base for 1 inch of surface, to the extent required to achieve the combined surface and base requirement (per Figures 6, 7, or 18) for the lesser of the following:

(a) Design thickness required for the critical aircraft.

(b) Design thickness required for the total pavement section.

(2) Excess bituminous surface course or stabilized base course (P-401, P-201, P-304, or equivalent) in sound condition shall be evaluated as non-stabilized base at a rate of 1½ inches of nonstabilized base for 1 inch of surface or stabilized base.

(3) Broken bituminous surface course (shrinkage cracks due to age and weathering, without evidence of base failure) shall be evaluated inch for inch as nonstabilized base. A bituminous surface, with limited cracking and well maintained, may justify use of an equivalency between the limits noted. This may apply also to stabilized base, but in no event shall base course be assigned a higher equivalency or value than is assigned to a base or surface material which is above it in the pavement structure.

(4) Excess base course may be evaluated as subbase course at a rate of 1½ inches of subbase for 1 inch of base but not to exceed 3 inches of subbase for 2 inches of base. The minimum base course, existing or equivalent, shall be 5 inches in thickness or the pavement shall be evaluated using Figure 18.

(5) Conversion of material to a higher classification, such as subbase to base, will not be permitted, except that where excess stabilized base course (P-201 or P-304) exists immediately under a flexible surface which is deficient in thickness the stabilized material may be counted inch for inch as surface.

(6) For flexible pavements, strength will be based on the equivalent section that satisfies both of the following requirements of Figures 6, 7, and 8.

(a) Total section thickness.

(b) Combined surface and base thickness. For heavy pavements, when the entire surface (or stabilized base) has been converted to equivalent base course, fractional inches of base may be utilized in determining the total section thickness for evaluation. In this case the required base thicknesses in Figures 6, 7, and 8 will be regarded as the upper limit of the areas covered. Consider the F7 subgrade line in Figure 7, for instance, and providing sufficient subbase exists, a 5½-inch equivalent base may be evaluated as a 17-inch total section, a 6-inch equivalent base as a 21-inch total section, a 6½-inch equivalent base as a 23-inch total section, etc.

(7) For flexible pavements, the strengths given in Figures 6, 7, and 8 for the section evaluated will be reduced by 10 percent per inch of surface deficiency in excess of 1 inch of such deficiency. This shall apply whether the deficiency exists in the actual pavement or results from conversion to satisfy the evaluation requirement.

(8) For rigid pavement, the assumed "k" value for the top of subbase (or subgrade) shall be reduced from 300 by 10 pounds per cubic inch for each one inch of subbase deficiency as shown in Figure 9.

(9) For rigid pavement, the critical areas shall be evaluated utilizing working stress plus a safety factor of 1.75.

c. Other Values. The above equivalencies are essentially in keeping with the FAA design system. Any deviation is intentional and results in design procedures slightly more conservative than those used for evaluation. It should be noted that the equivalencies used are also considered to be conservative and, where area experience or physical test results show that other values are valid, they may be substituted for those used here.

d. Application. Equivalencies are assigned to specific pavement courses, and equivalencies less than 1 will not normally be assigned in the criteria previously discussed. Instead, where materials are clearly inferior they should be assigned a lower category, e.g., base to subbase. A judgment factor, on the other hand, may be assigned to an overall pavement section either upgrading or downgrading the facility. Extreme caution should be used in assigning a strength greater than the evaluation criteria would indicate and any such upgrading should not be considered in the design process when extension or strengthening are planned. Downgrading a pavement due to judgment factor should normally be limited to a reduction in strength of 25 percent. Any further deterioration would usually indicate actual or impending failure and the pavement should be so noted rather than a strength assignment being made. Exceptions may be made in cases where, for instance, an old runway has been limited to light aircraft operations by the airport management, etc.

(1) Recent changes in design criteria for turbojet runways call for stronger (from 0.8T to 0.9T) runway noncritical areas and lengthening the critical area from 500 feet to 1000 feet. The noncritical areas should be evaluated in accordance with the current criteria. Where older runways exist with the short critical area, however, the areas newly encompassed by the current standard should continue to be evaluated as noncritical unless visual inspection shows a necessity for downgrading.

(2) Where keel sections may exist, the thinner runway edges need not be evaluated as such but may be assigned the same strength as the keel. They will, of course, be subject to visual inspection.

6. FLEXIBLE PAVEMENT EVALUATION. Flexible pavements are defined in paragraph 16 and consist of bituminous wearing surface placed on a base and possibly a subbase. For evaluation purposes, they shall be considered as conventional or unconventional depending upon whether or not they are designed to FAA standards. In either case, the first steps are the verification of types and thicknesses of the flexible section, materials comparison, if required, and determination of the subgrade class. When the subgrade is classified in accordance with record information dated prior to 1967, it should be checked with Tables 1 and 2 of this circular.

a. Conventional Pavements. Comparison of standard FAA sections with the design charts, Figures 6, 7, 8, and 18, is straightforward and requires little comment. Where difficulty is encountered in evaluation of noncritical areas or by reason of a change in subgrade class, the procedures used in evaluating the unconventional pavements in the following discussion and examples may be used.

b. Unconventional Pavements. Most flexible pavements will fall in this category due to changes having occurred in the design standards, the application of rehabilitation or strengthening courses over the years, or having been constructed to other than FAA standards. As implied by the previous statement, the following method is also applicable to evaluation of flexible pavement with either flexible or bituminous overlays.

(1) In stage construction it is common practice to build a base and subbase to the design standard thickness and delay construction of a part of the surface. In these cases, evaluation in accordance with paragraphs 35b(1), (6), and (7) will result in sufficient reduction of capacity to alert the airport authority to the need of watchfulness and to encourage early completion of the full surface requirement.

(2) Example - Assume an air carrier airport, a design aircraft of 120,000 pounds on dual gear and that a pavement constructed in 1965 on an F2 subgrade had a critical section consisting of 8 inches base and 4 inches subbase as required by the then current standard, but a 1½ inch surface only has been provided to date. The 9½ inch total base and surface fails to meet today's minimum requirement. Close examination of the surface shows it to be sound, and in order to evaluate the section as an air carrier pavement, it will be necessary to apply equivalencies as follows: (Also note that use of equivalencies provides a bridge between the Figures 6, 7, and 8 and the light aircraft curves in Figure 18).

(a) 1½ inch surface = 0 inch surface + 2¼ inch base (reference paragraph 35b(1)).

(b) 2¼ inch base + 8 inch base existing = 10¼ inch surface + base.

(c) 10¼ inch surface + base + 4 inch subbase = 14¼ inch total section.

(d) 10¼ inch surface + base controls and limits the section to be evaluated to a total section of 13 inches (reference paragraph 35b(4), (6)). This gives a dual gear strength of 85,000 pounds per Figure 7.

(e) 85,000 pounds less 30 percent (10 percent/inch of surface deficiency greater than one) results in 60,000 pounds reported strength (reference paragraph 35b(7)).

(3) The extreme reduction in strength in this example is due to the marginal surface thickness for the aircraft concerned with a resulting short life expectancy. Consider the same example but with a 3-inch surface, and note that though surface and base thicknesses are in a usable range, strength may still be increased by application of equivalencies. This should be done to the extent possible but not to exceed the requirement for the critical aircraft using the facility or immediately planned.

(a) 3 inch surface + 8 inch base + 4 inch subbase = 15 inch total section = 120,000 pounds gross weight on dual gear.

(b) 120,000 pounds gross requires 12 inch surface + base. Conversion is required to meet the surface and base requirement.

(c) 3 inch surface = 1 inch surface + 3 inch base.

(d) 1 inch surface + 3 inch base + 8 inch base = 12 inch base + surface.

(e) 12 inch base + surface + 4 inch subbase = 16 inch total section equal to 140,000 pounds -20 percent = 112,000 pounds reported strength.

Had this section been 3 inch - 9 inch - 3 inch instead of 3 inch - 8 inch - 4 inch (combined surface and base satisfied), it could be reported as 120,000 pounds or design strength since there is no reduction in reported strength for the first inch of surface deficiency provided the surface plus base and the total section requirements are met. Fractional inches should be considered in pavement strength reduction. 2½ inch - 9½ inch - 3 inch in the above situation would require a reported strength reduction of 5 percent, or 114,000 pounds.

c. Noncritical Pavement Areas. The previous examples have been concerned with critical area strength only. Noncritical sections can be evaluated by multiplying the critical design section and the appropriate 0.7, 0.8, or 0.9 factor and adjusting surface thickness to achieve a noncritical design section for comparison. This method is awkward when any section adjustment is required, and the preferred method is to divide the existing noncritical pavement by the appropriate factor and then evaluate as critical thickness. This method will be illustrated in the following example evaluating a flexible pavement with flexible overlay.

(1) Example. Assume a pavement constructed in 1957 consisted of critical and noncritical sections as follows:

	Critical	Noncritical
P-401 Surface	2"	2"
P-209 Base	7½"	6½"
P-154 Subbase	5½"	4½"
Total Section	15 "	13 "

This design was based on an E-7 soil and a poor drainage - no frost condition. In 1964 a flexible overlay was constructed to accommodate the Douglas DC-8 at a gross weight of 300,000 pounds. Examination of the records show the following sections in place:

Materials	Critical	Noncritical
P-401 Surface	3"	2"
P-209 Base	11"	8"
P-401 Surface	2"	2"
P-209 Base	7½"	6½"
P-154 Subbase	5½"	4½"
	29"	23"

Examination of Tables 1 and 2 in the current paving circular and construction records indicate that the F5 subgrade class is still applicable. Figure 8 shows the total section still provides the 300,000 pound dual tandem critical strength. An inch surface deficiency exists for which no penalty is imposed. The flexible overlay with P-209 base precludes assigning an equivalency to the relatively new original surface, and it is counted inch for inch as base. The 20½ inch base thickness obviously provides a considerable amount of material available for conversion to subbase, and the allowable conversion of 2 inches base to 3 inches surface could be utilized with a 30-inch equivalent total thickness applicable for evaluation raising the dual tandem strength from 300,000 pounds to 320,000 pounds. Assuming the critical aircraft remains at 300,000 pounds, this would not be done. However, it will be seen to work to advantage below.

As a turbojet runway, the noncritical portion should be checked against the 0.9 requirement utilizing the conversion procedure. This can be accomplished by dividing the base and subbase courses by 0.9 and then evaluating as a critical section in the following manner:

Existing Noncritical			Critical
2" surface		=	2" surface
16½" base	÷ 0.9	=	18-1/3" base
4½" subbase	÷ 0.9	=	5" subbase

allowable base conversion provides
an equivalent section of = 2" surface
= 16-1/3" base
= 8" subbase
Total 26-1/3"

One inch of surface must be added to this section when reading bearing capacity from Figures 7 and 8 for the reasons that the one-inch surface deficiency is replaced by equal base thickness so no penalty is assessed, and the figures are based on 4-inch rather than 3-inch surfaces.

This section then evaluates as 27-1/3 inch. A further advantage of this method is that it is immediately apparent that this is the controlling section and will provide strength for 165,000 pounds dual, 270,000 pounds dual tandem, and 130,000 pounds single geared aircraft.

(2) Example. Assume the same pavement and situation as the above example, except that the overlay is a 5-inch bituminous overlay for both critical and noncritical sections. The pavement to be evaluated becomes:

Material	Critical	Noncritical
P-401	7"	7"
P-209	7½"	6½"
P-154	5½"	4½"
	20"	18"

and converts to: (reference 35b(1))

P-401	4"	3"
P-209	12"	12½"
P-154	5½"	4½"
	21½"	20"

Note from Figure 8 that these sections require 8 inches of base which in turn permits conversion of base to subbase as follows:

	Critical	Noncritical
P-401 surface	4"	3"
base	10"	10½"
subbase	8½"	7½"
	22½"	21"

The critical section evaluates at 90,000 pounds single, 120,000 pounds dual, and 190,000 pounds dual tandem.

Converting the noncritical sections to critical:

3" surface		= 3"
10½" base	÷ 0.9	= 11-2/3"
7½" subbase	÷ 0.9	= 8-1/3"
		23"

For runway strength reporting, the critical section would control. Note that the entire overlay in this example is treated as P-401. This may be done even though a portion may be P-201 since they are, in fact, interchangeable as stated in paragraphs 35b(1) and (5).

37. RIGID PAVEMENT EVALUATION. Rigid pavements are defined in paragraph 18 and consist of portland cement concrete placed on a prepared subgrade or subbase. They may be plain or reinforced. No credit will be given in reported pavement strength for reinforcing except that which may be provided by pavement conditions as noted in paragraph 35. As with the flexible evaluation, rigid pavements will be considered as conventional or unconventional depending upon whether or not they adhere to the FAA design standard. In either case, the first steps are the verification of types and thicknesses of the pavement section, materials strength and comparison, if required, and determination of subgrade class or reaction modulus. When the subgrade is classified in accordance with record information dated prior to 1967, it should be checked with Tables 1 and 2 of this circular.

a. Conventional Pavements. For the purpose of this discussion, these will be limited to pavements constructed in accordance with the FAA subgrade classification system, the assumptions detailed in Appendix 1 of this circular, and use of the Figure 9 design curves. These may now be found, due to changes in the Figure 9 curves, to have excess subbase thicknesses. No credit will be given for the additional thickness unless verified by plate bearing tests made in accordance with approved procedures.

b. Example. Assume a rigid pavement constructed in 1964 and similar to the design example in paragraph 19, for propeller driven, dual gear, 160,000 pounds gross weight, subgrade class Rc. The existing section is:

	Critical Area	Noncritical Area
Pavement	11"	9"
Subbase	9"	9"
Frost Protection	6"	9"

(1) Normal construction is indicated by the record information, and required strengths, gradations, and densities were obtained. Providing no unusual circumstances exist, evaluation may be made by reference to Figure 9 which shows the critical section to be capable of supporting 125,000 pounds gross weight.

(2) Evaluation of the noncritical areas is accomplished by dividing the pavement thickness by an appropriate factor as determined in paragraph 19. Since this is a nonjet runway, the noncritical pavement strength is equal to 9" ÷ 0.8 = 11-1/4" or 130,000 pounds. Subbase thickness is adequate and the reported pavement strength would be 125,000 pounds gross weight on dual gear.

c. Unconventional Pavements. These are pavements which vary from the Figure 9 and design assumptions as detailed in Appendix 1. The evaluator is provided a wide choice of tests and procedures which may be utilized. Any rigid pavement may be evaluated by the procedures below including those built to FAA standards.

(1) Separate evaluation charts for single, dual, and dual tandem gear configurations are contained in Figures 21, 22, and 23, respectively. From these the pavement strength can be determined for any known or assumed pavement thickness, concrete flexural strength, subgrade reaction modulus, or subgrade class. The charts are derived from the Westgaard liquid subgrade formula and the Pickett and Ray influence charts for center loading. While gear spacing and tire pressure are also variables in a complete pavement analysis, they are not treated as such here. Instead the curves are computed over a reasonable range of tire spacing and pressures, since these can and do vary among aircraft of the same class and weight. It should be noted in this regard that as total weight per gear increases, both gear spacing and tire pressure assert a lesser proportionate influence on maximum concrete stress. The following examples illustrate the use of these charts.

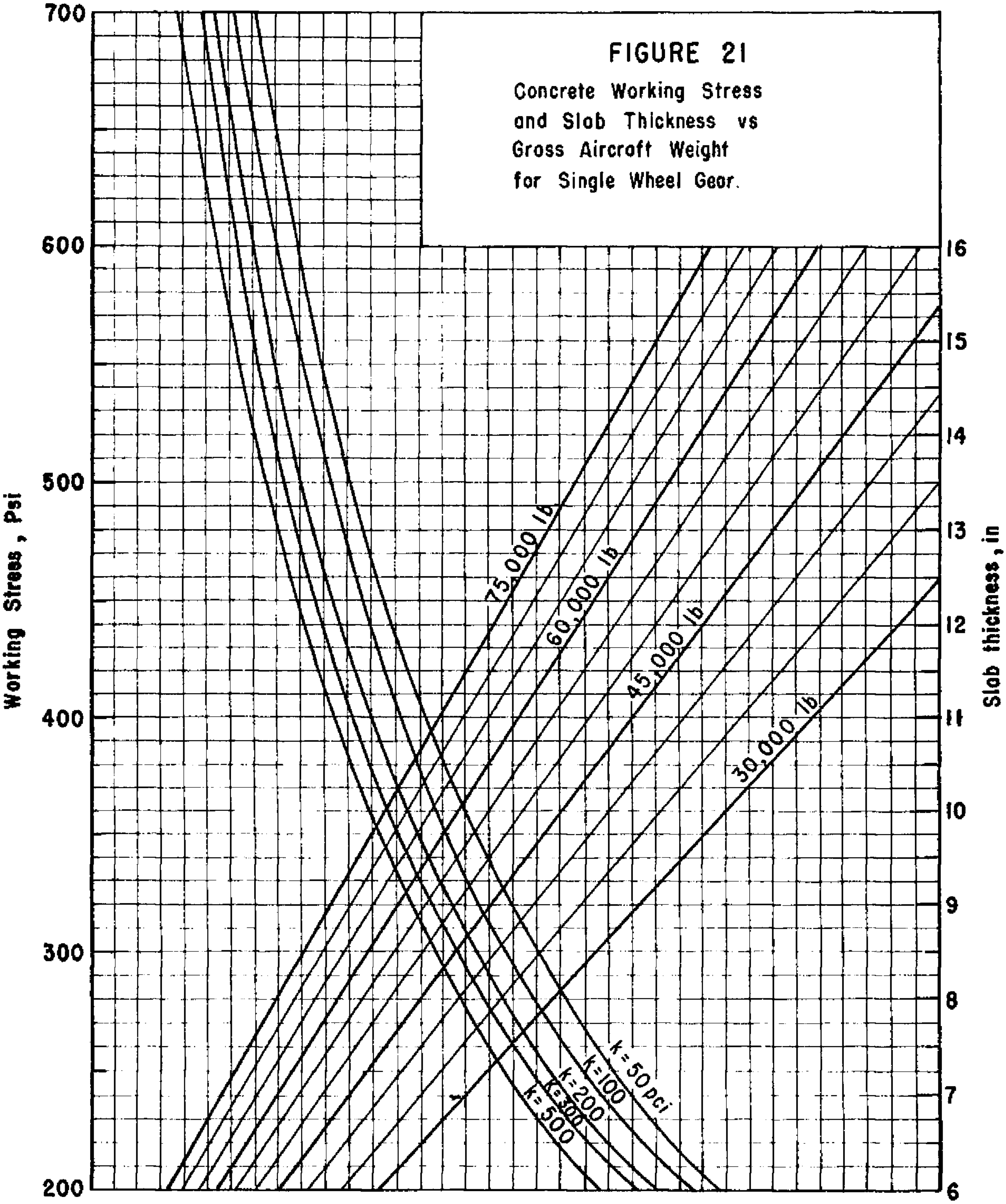


FIGURE 21
Concrete Working Stress and Slab Thickness vs Gross Aircraft Weight for Single Wheel Gear.
Working Stress, Psi
700
600
500
400
300
200
Slab thickness, in
16
15
14
13
12
11
10
9
8
7
6
75,000 lb
60,000 lb
45,000 lb
30,000 lb
k = 50 pci
k=100
k=200
k=300
k=500

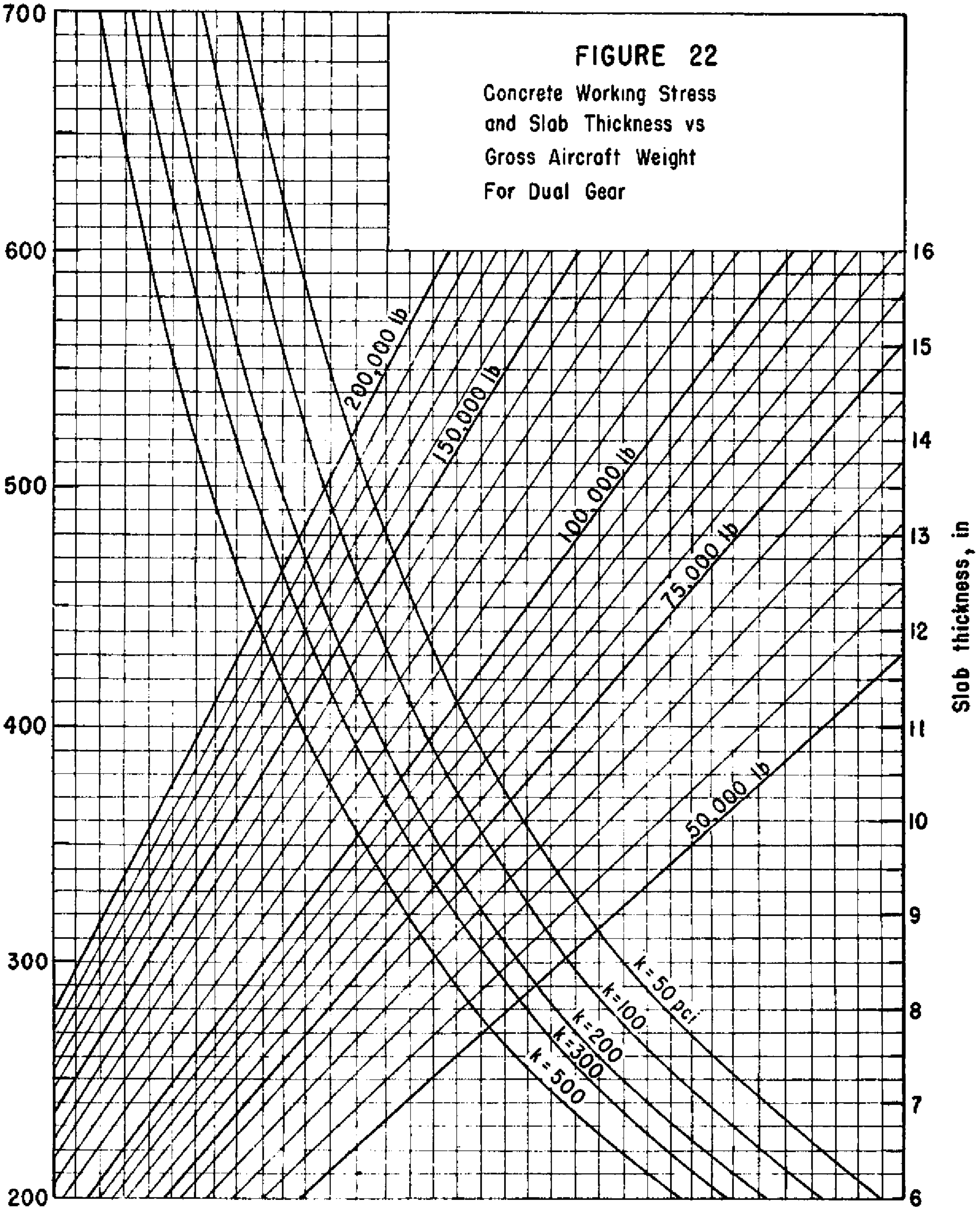


FIGURE 22
Concrete Working Stress
and Slab Thickness vs
Gross Aircraft Weight
For Dual Gear
700
600
500
400
300
200
16
15
14
13
12
11
10
9
8
7
6
Slab thickness, in
200,000 lb
150,000 lb
100,000 lb
75,000 lb
50,000 lb
k=50 pci
k=100
k=200
k=300
k=500

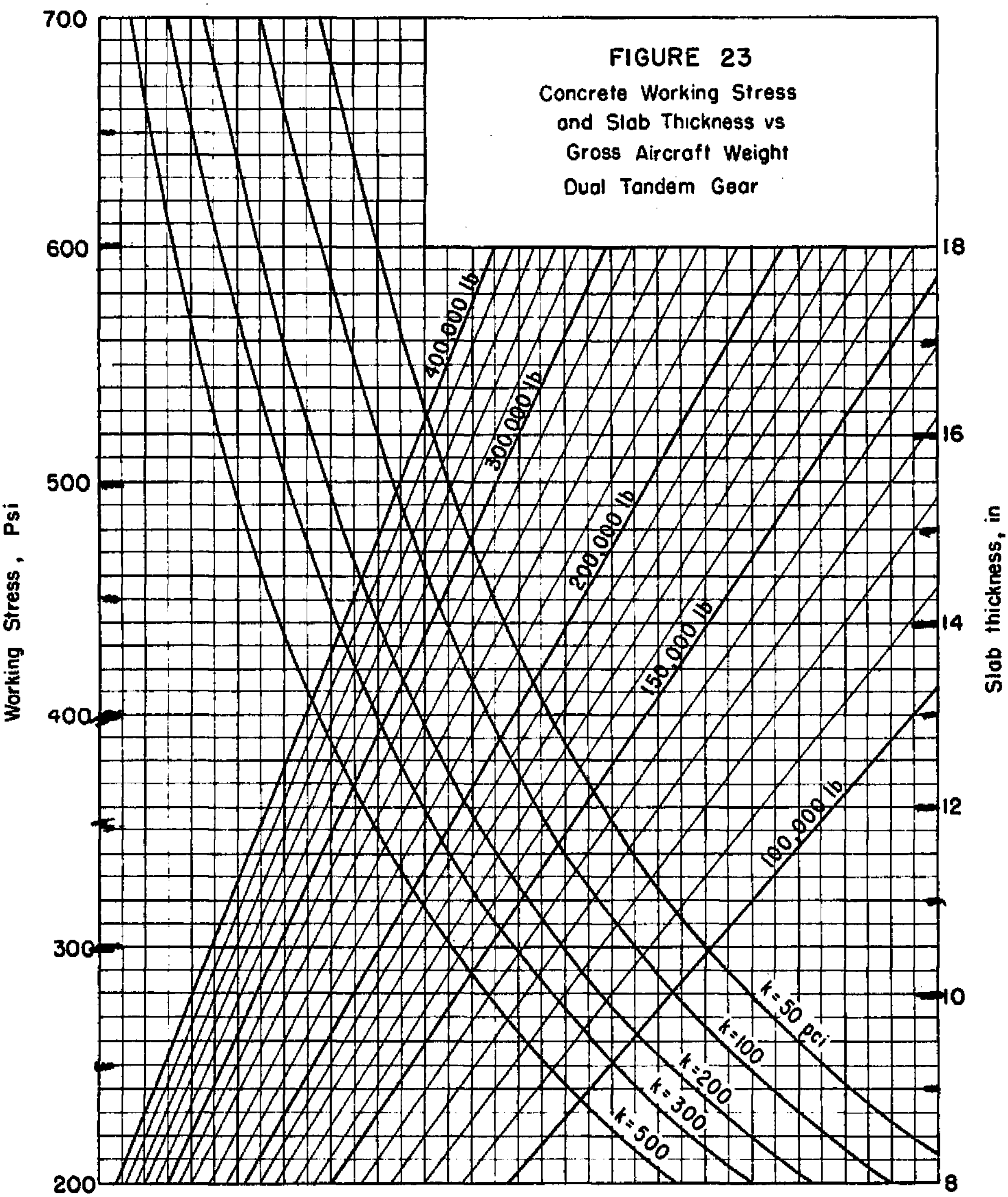


FIGURE 23
Concrete Working Stress
and Slab Thickness vs
Gross Aircraft Weight
Dual Tandem Gear
Working Stress, Psi
700
600
500
400
300
200
Slab thickness, in
18
16
14
12
10
8
400,000 lb
300,000 lb
200,000 lb
150,000 lb
100,000 lb
k=50 pci
k=100
k=200
k=300
k=500

(2) Consider the same pavement sections as in the previous example, except that frost is not a factor and no frost protection is provided. In this case also assume the pavement to be approximately 15 years old, and that record information is lacking. The critical aircraft to date has been the DC-6 and DC-9 averaging 10 operations per day. The balance of the traffic has consisted of a similar number of lighter twins averaging about 50,000 pounds gross, and a considerable amount of lighter general aviation traffic. Heavier traffic is anticipated, and the evaluation is undertaken to determine the strength of the existing pavement. Cores are taken to verify pavement and subbase thickness, and to check subbase and subgrade materials and densities. The cores are checked for compressive strength and are such that the concrete is considered as equal to the FAA 400 p.s.i. assumption. Densities are satisfactory, however, it is found that the subbase class is R_d, but no subbase has been provided. This precludes comparison with Figure 9, except to note that this slab thickness requires, for R_d subgrade, 12 inches of subbase.

(a) Enter Figure 22 at the 400 p.s.i. stress point and proceed horizontally to the 180 p.c.i. subgrade reaction (k) line, having deducted 10 p.c.i. for inch of subbase deficiency in accordance with paragraph 35b(8). From this point proceed vertically to intersect the slab thickness, located from the scale at the right side of the chart (coincident in this case). This intersection determines the load point. Interpolating between the 110,000 pound and 120,000 pound load lines, this point approximates 115,000 pounds.

(b) The noncritical sections are evaluated by the same procedure used in the previous example. Evaluation for turbojet use would be 9" + 0.9 = 10" and limit reported strength to 96,000 pounds.

(c) Measured flexural strength of concrete and/or k values can be used to obtain more accurate information with which to enter Figure 21, 22, or 23. In other respects the evaluation would be the same as in the above example.

d. Rigid Pavement with Flexible or Bituminous Overlay. The overlay formulas in paragraph 26 are irrational and cannot be used for evaluation purpose. Accordingly, Figure 24 has been incorporated herein and should be used to determine an equivalent concrete slab thickness, and some explanation of its derivation is in order.

(1) The reasons normally advanced for requiring a minimum overlay thickness is that in thinner sections, reflective cracking occurs and the pavement is dependent for continuity on the load transferability of the original thinner slab, usually deficient when considered against the thicker equivalent slab requirement. While this argument has strong backing, it is true that in at least some cases, thin overlays are performing satisfactorily, and in order that these may be given proper consideration in evaluation, Figure 24 was devised to provide a transition between the overlay formula at reasonable depths, and a thin overlay condition. The following assumptions were made:

(a) The first inch of overlay accomplishes a leveling function only and adds no strength to the basic pavement.

(b) Some safety factor is usually present in the existing load transfer function, whether by dowels, keyways, or aggregate interlock.

(c) Some aggregate interlock is realized in the bituminous overlay through cracked areas, just as with concrete, and the tightness and maintainability of the cracks increase with overlay thickness.

*

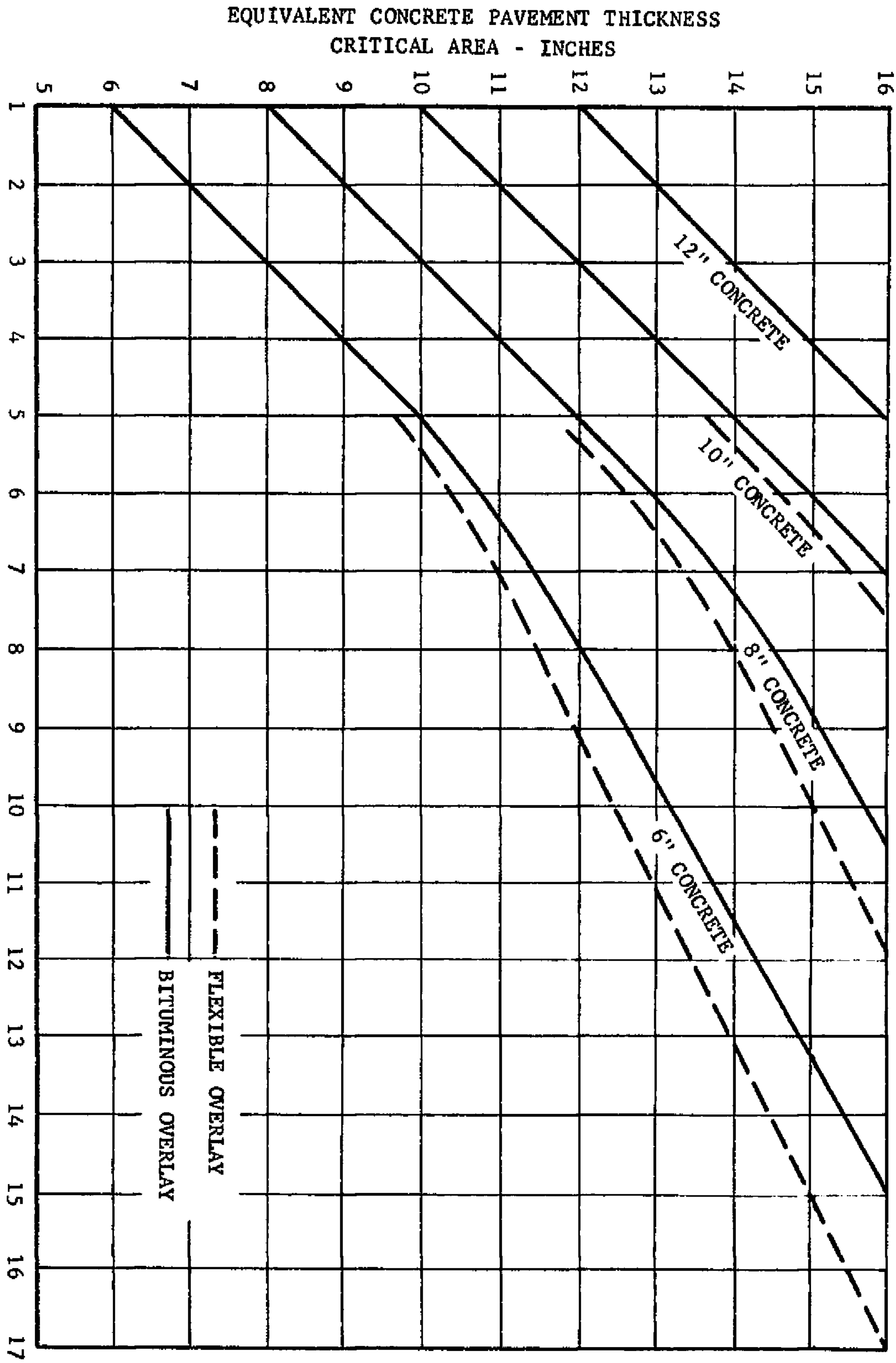


FIGURE 24. BITUMINOUS AND FLEXIBLE OVERLAY ON RIGID PAVEMENT *

(2) Evaluation of both flexible and bituminous overlays is the same insofar as procedures are concerned and should be accomplished in the following manner.

(a) First evaluate the concrete slab as described previously for rigid pavement. In the event the pavement is evaluated as nonstandard, it should be assigned a thickness from reference to Figure 9. A 12-inch pavement on a weak subgrade and no subbase might be evaluated as unconventional and capable of supporting 130,000 pounds on dual gear, using Figure 22. Reference to Figure 9 will show 11 inches conventional pavement with subbase required for this weight. Therefore, the original slab will be considered as 11 inches concrete for use in Figure 24.

(b) For a given overlay thickness, enter Figure 24 from the bottom scale and proceed vertically to the concrete slab thickness, interpolating where required. From the concrete thickness move horizontally to the left and read the equivalent concrete pavement thickness on the left hand scale. A three-inch bituminous overlay on the 11-inch pavement above would result in an equivalent 13-inch slab for evaluation purposes.

(c) The equivalent slab is again checked against Figure 9 to read the pavement strength. For the 13-inch slab above, the strength is 170,000 pounds on dual and 300,000 pounds on dual tandem gear.

(d) Noncritical pavement is evaluated in the same manner as in (a) and (b), with the equivalent slab being divided by the appropriate factor prior to re-entering Figure 9 as in (c) above.

(e) Reported strength of flexible overlays will be reduced by the 10 percent per inch of surface deficiency in excess of one inch, in the same manner as with flexible pavement evaluation, paragraph 35, except that bituminous surface will not be converted to equivalent base course. The required surface thickness for this purpose will be 4 inches in critical areas and 3 inches in noncritical areas (3 inches and 2 inches for single gear) as in Figures 6, 7, and 8.

(3) Example. A section to be evaluated has been tested, and the following determinations have been made:

Concrete Flexural Strength	725 p.s.i.
Subgrade Modulus k	150 p.c.i.

The critical aircraft is four-engine turbojet at 310,000 pounds. The following sections are in place:

	Critical	Noncritical
Bituminous Surface	3"	3"
Crushed Stone Base	7"	4"
PCC	8"	8"
Subbase	0"	0"

(a) Use Figure 23 to evaluate the 8-inch pavement. From the 415 p.s.i. working stress and 150 k intersection, drop a vertical to intersect the 8-inch slab thickness, and read approximately 115,000 pounds.

(b) From Figure 9, 115,000 pounds requires a 7¼-inch slab.

(c) From Figure 24, read equivalent slab thicknesses of 14 inches for the critical and 12½ inches for the noncritical sections.

(d) From Figure 9, read 350,000 pounds dual tandem and 200,000 pounds dual gear critical strength.

(e) Also from Figure 9, read 12½" ÷ 0.9 = 13.9" = 345,000 pounds dual tandem and 195,000 pounds dual gear noncritical strength.

e. Rigid Pavement with Rigid Overlay. Rigid overlays on rigid pavement are evaluated by application of Figures 16 and 17.

(1) The basic evaluation is a simple reversal of the design procedure. Enter the bottom of the appropriate chart at the overlay thickness and proceed vertically to the thickness of the underlying slab, and read the equivalent single slab thickness on the scale at left. This thickness is applied to Figure 9 to read single, dual, and dual tandem strengths.

(2) Evaluation of either pavement course can be accomplished by any of the means discussed in the paragraphs 37a and b above. When evaluating by other than standard Figure 9 assumptions, the following conditions apply.

(a) Use the same k value for each course.

(b) Use the flexural strength which applies to each course even though the two courses may vary.

(c) When the lower slab condition C factor must be assumed, use the lower values in Figures 16 and 17 for overlay without or with leveling course, respectively. For relatively new overlays, record or test information is of primary importance. For older overlays, condition of the overlay slab assumes greater importance. Although a C factor may be assumed based on condition of the overlay, it is still applied to the base pavement when using Figures 16 and 17.

(d) For noncritical areas, divide the equivalent single slab by the appropriate factor for turbojet or propeller aircraft use.

(3) Consider the original 8-inch concrete in the previous example, except that a concrete overlay has been provided. The overlay is 10 inches thick in the critical pavement areas and 8 inches thick in the noncritical. Record information shows the original pavement was considered as 8 inches and slabs were replaced or jacked as required to achieve a C factor of 0.75 and no leveling course was used. The overlay was designed to use 700 pounds concrete and very slightly greater strength was determined from beams cast during construction.

(a) The base pavement has been evaluated as 7¼ inches in the previous example.

(b) From Figure 24 determine the 10-inch and 8-inch pavements to be 150,000 pounds and 115,000 pounds for dual tandem, based on 400 p.s.i. working stress and subgrade modulus of 150 p.c.i.

(c) From Figure 9, the above strengths equate to 9-inch and 7-inch pavement, respectively.

(d) From Figure 16, the equivalent single slab thicknesses are read as 12¼" and 10½" critical and noncritical. 12¼" evaluates at 265,000 pounds on dual tandem gear, 160,000 pounds on dual gear; 10½" ÷ 0.9 = 11.7" and evaluates as 240,000 pounds on dual tandem and 140,000 pounds on dual gear, as shown in Figure 9.

f. Consideration for Layered Subgrade. In any of the previous examples it could be necessary, due to selective grading, use of a borrow material or soil modifier, to evaluate a subgrade which consists of a thin layer of superior material over a relatively poor one. Design requirements for such a situation are discussed in paragraph 15. The evaluation procedure is virtually the same as the design procedure with a change in meaning of the z term. In either case the analysis must be in relation to a critical aircraft. For convenience the formula is repeated here.

$$z = y - \frac{t\ (y-x)}{(x+y)} \quad \text{in which}$$

z = equivalent subbase thickness
x = subbase thickness for good soil
y = subbase thickness for poor soil
t = thickness of good soil layer

Evaluation will be illustrated in the following example.

g. Example. Assume a critical aircraft to be a 160,000-pound turbojet on dual gear. A 12-inch layer of borrow soil classified as F2 overlies a soil classified as F8. From Figure 7, the subbase required for the two soils would be 4 inches and 24 inches, respectively, in critical areas. Applying the formula -

$$z = 24 - \frac{12\ (24-4)}{(24+4)}$$

$$z = 24 - 8.6 = 15.4''$$

Returning to the 160,000-pound load line in Figure 7, the 15.4-inch subbase requirement best satisfied an F6 subgrade condition, and the pavement will be considered to be on an F6 subgrade.

APPENDIX 1. DEVELOPMENT OF PAVEMENT DESIGN CURVES BASED ON GROSS AIRCRAFT WEIGHT

1. BACKGROUND.

a. The previous method of airport pavement design used by the Federal Aviation Administration was related to the equivalent single wheel load (ESWL) concept. With this method, the loads transmitted by multiwheeled undercarriages were converted to a theoretical isolated single wheel load.

b. Past experience has indicated that the ESWL design method was misunderstood and misinterpreted by various segments of the aviation community. This was due to the fact that individuals unfamiliar with all aspects of airport pavement design had become interested in the subject and were attempting to use the criteria to design or evaluate pavements.

c. It, therefore, became apparent that a new method of presenting design curves was desirable. The method chosen was that of relating pavement thicknesses to subgrade classification and the total or gross weight of an aircraft. It also became apparent, after a check on the current civil aircraft, that the assumption that 10 percent of the gross weight of the aircraft is supported by the nose wheel was unconservative.

d. For the above reasons, it was decided to modify the design curves to reflect the change in the assumption from 10 percent to 5 percent supported on the nose wheel, and transform the weight scale from single wheel load to gross aircraft weight.

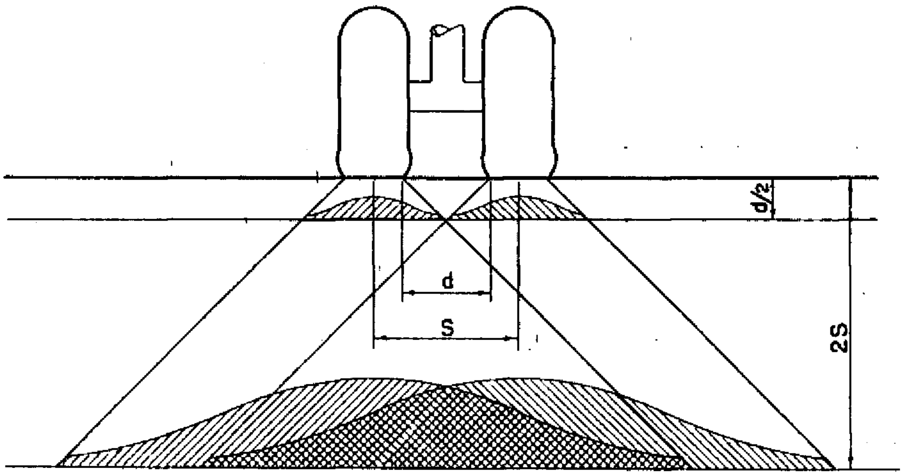
2. DEVELOPMENT OF NEW CURVES.

a. It would have been impractical to develop design curves for each different aircraft. However, since the thickness of both rigid and flexible pavement is dependent upon the gear dimensions and the type of gear, this would be necessary unless some valid assumptions could be made on these variables.

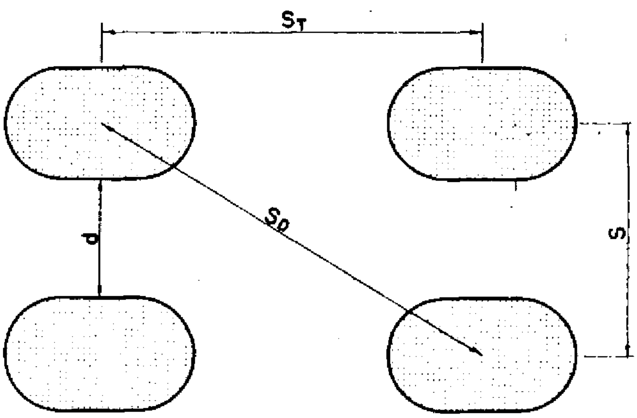
* b. In addition to gear type and dimension, other factors affecting pavement thickness design are the supporting value of the subgrade, the tire contact area and pressure, and the physical properties of the pavement structure. Examination of gear configuration and spacing, tire contact areas, and tire pressure in common use indicated that these follow a definite trend related to gross aircraft weight. Reasonable assumptions could therefore be made and design curves constructed from the assumed data.

*3. RIGID PAVEMENT CURVES.

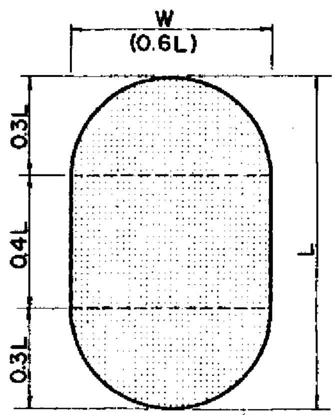
a. The rigid pavement design curves are based on the Westergaard equation for interior slab loading and the "Influence Charts for Concrete Pavement" developed by Pickett and Ray. Computer analyses of various aircraft gear configurations have established orientation versus stress relationships which show that maximum stress occurs, in other than single wheel gear, at some point removed from any tire print center. In the case of dual-tandem gear, rotation is also a critical factor. Stress increases of as much as 15 percent are found to exist when compared with the previous application of the influence charts with gear configurations centered and squared.



DISTRIBUTION OF WHEEL LOADS THROUGH FLEXIBLE PAVEMENTS



DUAL TANDEM GEAR TIRE IMPRINT



SINGLE TIRE IMPRINT

*

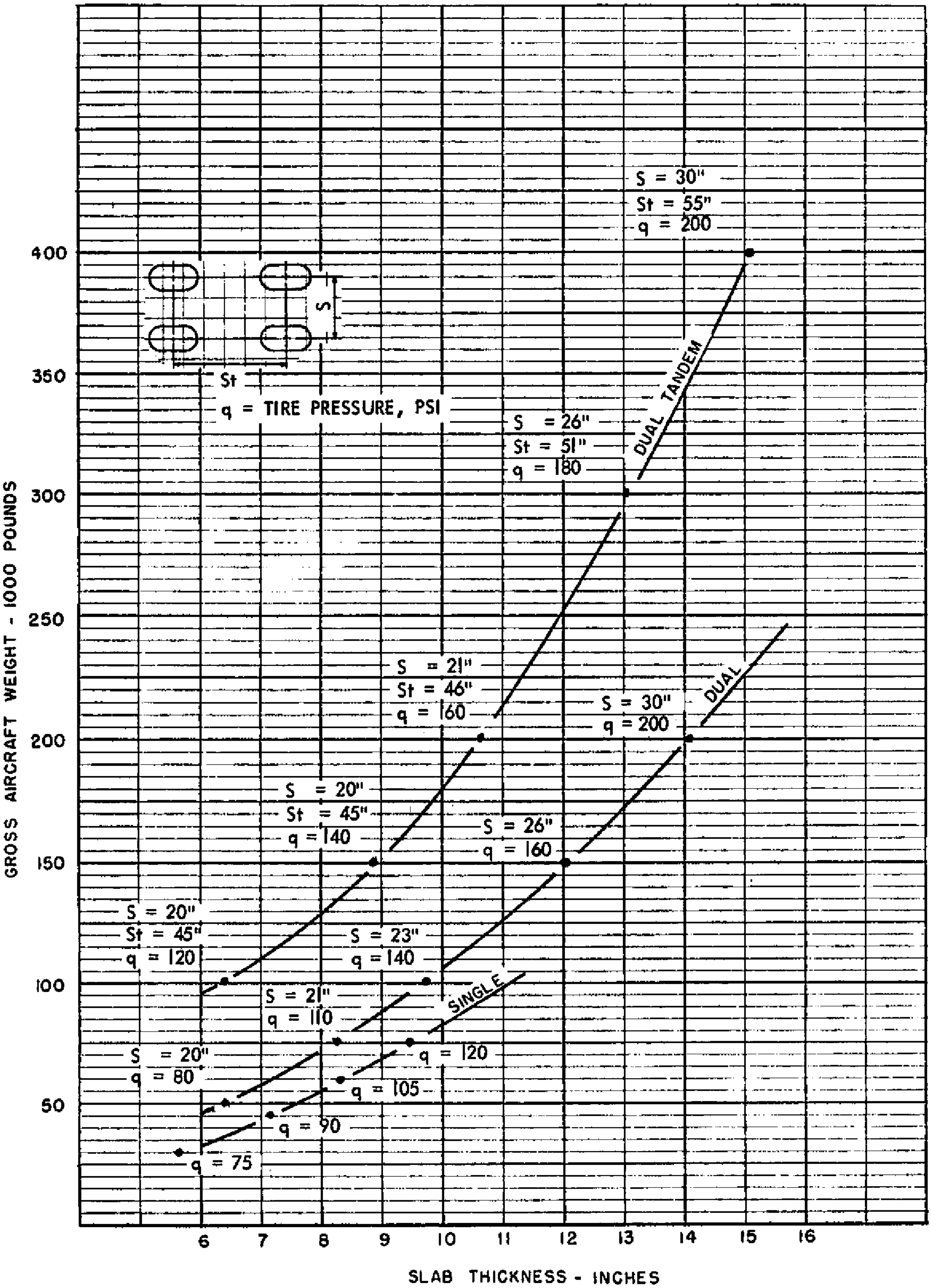


FIGURE 2. DEVELOPMENT OF RIGID PAVEMENT CURVES

* b. Curves have been developed from charts furnished by the Portland Cement Association, which reflect the increased stresses. These charts are shown in Figure 2. They are based also on assumed gear dimensions, tire pressures, and parameters explained in the following paragraphs. *

(1) Single Gear Aircraft - No special assumptions are needed.

(2) Dual Gear Aircraft - A study of the spacing between dual wheels for these aircraft indicated that a dimension of S=20 inches between centerline of tires agreed favorably for the lighter aircraft and a dimension of S=30 inches between centerline of tires agreed favorably for the heavier aircraft, see Figure 1.

(3) Dual-Tandem Gear Aircraft - The study indicated that dimensions of S=20 inches and ^{S}T=45 inches appeared reasonable for the lighter aircraft, and S=30 inches and ^{S}T=55 inches appeared reasonable for the heavier aircraft, see Figure 1.

* (4) Tire pressure (Q) varies between 75 p.s.i. and 200 p.s.i. depending on gear configuration and gross weight. It should be noted that tire pressure asserts less influence on stress as gross weights increase, and the 200 p.s.i. maximum pressure may be safely exceeded if other parameters are adhered to.

(5) Parameters - The following additional parameters were assumed in developing the rigid pavement thickness.

k = 300 pounds per cubic inch

s = 400 psi working stress

E = 4,000,000 psi

Poisson's Ratio = 0.15

(6) Safety Factor - The curves are based on a 700 psi flexural strength at 90 days (a safety factor of 1.75) and the requirements of critical area pavement.

c. The Figure 2 curves form the basis for the rigid pavement design curves in Figure 9 of Chapter 3, and the evaluation curves in Figures 21, 22, and 23 of Chapter 6. *

*
4. FLEXIBLE PAVEMENT CURVES.

a. As in the case of rigid pavements, it was necessary to make some reasonable compromise on gear dimensions in order to convert from equivalent single wheel loads to gross aircraft weight. Plots of the gear dimensions for civil aircraft indicated a trend of larger spacing for the larger aircraft.

(1) The design curves shown in Figures 3 and 4 were used to develop the present curves. After making the assumptions listed below, it was a simple matter to convert ESWL to gross weight.

(a) Single Gear Aircraft - No special assumptions were needed for the single gear aircraft because the ESWL is independent of depth. All that was necessary was to multiply the ESWL curves by 1/0.475 to convert directly to gross weight. A new gross weight grid was constructed for convenience and the new design curves are shown in Chapter 3, Figure 6.

(b) Dual Gear Aircraft - The plots of the gear dimensions versus ESWL for the dual gear aircraft indicated that a relationship between the d/2 distances and the ESWL's of the aircraft at this depth could be expressed by a straight line on the single wheel load versus pavement thickness curves (Figure 3). This line varied from a d/2 of 5 inches at an ESWL of 15,000 pounds to a d/2 of 10 inches at an ESWL of 50,000 pounds. This line is shown as line "a" in Figure 3. Similarly, these plots also indicated that a straight line could be assumed to express the relationship between the 2S distances and the ESWL's of the aircraft at that depth. This line varied from a 2S of 35 inches at an ESWL of 15,000 pounds to a 2S of 60 inches at an ESWL of 100,000 pounds. This line is shown as line "b" in Figure 3.

(c) Dual-Tandem Gear Aircraft - The plots of the gear dimensions versus ESWL for these aircraft indicated a relationship similar to those discovered for the dual gear aircraft. Plots of the lines expressing these relationships are shown in Figure 4 as lines "a" and "b".

*

* (2) Lines representing dual gear aircraft with gross weights of 50,000, 100,000, and 200,000 pounds are plotted in Figure 3. A new graph is plotted in Chapter 3, Figure 7, with gross aircraft weight on the vertical axis and the total pavement thickness on the horizontal axis. From Figure 3, total pavement thickness requirements for each gross aircraft weight are plotted for each subgrade classification. Connection of the three points for 50,000, 100,000, and 200,000 pounds gross weights for each subgrade classification by a straight line resulted in the reorientation of the subgrade curves. In Chapter 3, Figure 8 for dual-tandem gear aircraft was established by using Figure 4 in a like manner.

(3) The dashed lines in Figures 6, 7, and 8 of Chapter 3 represent the required nonbituminous base course thickness for critical pavement. The area between the two diagonally dashed lines represents the base course requirements for those gross aircraft weights. This base course thickness requirement is indicated along the right edge of the F10 subgrade classification line. *

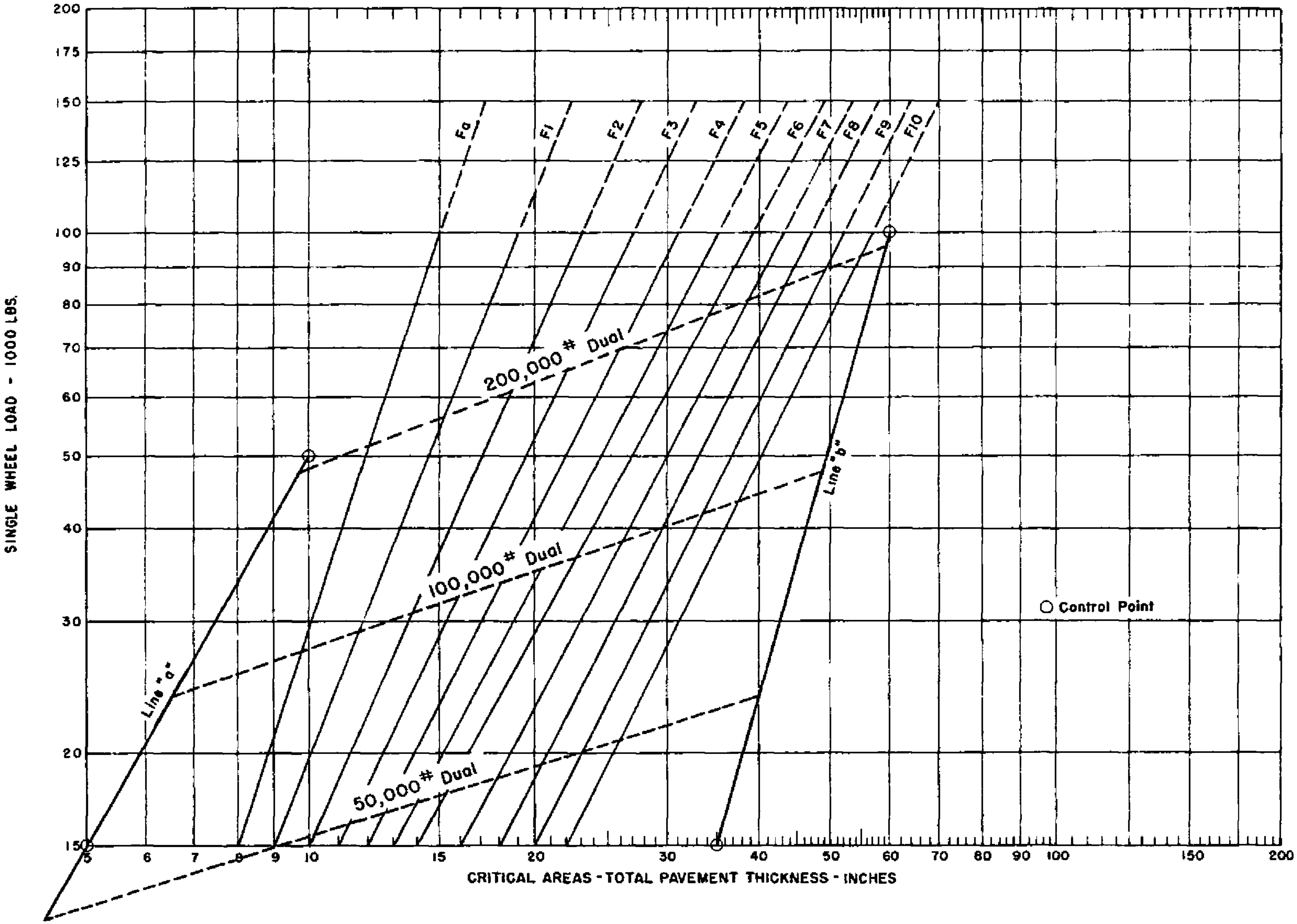


FIGURE 3. DEVELOPMENT OF FLEXIBLE PAVEMENT CURVES - DUAL GEAR

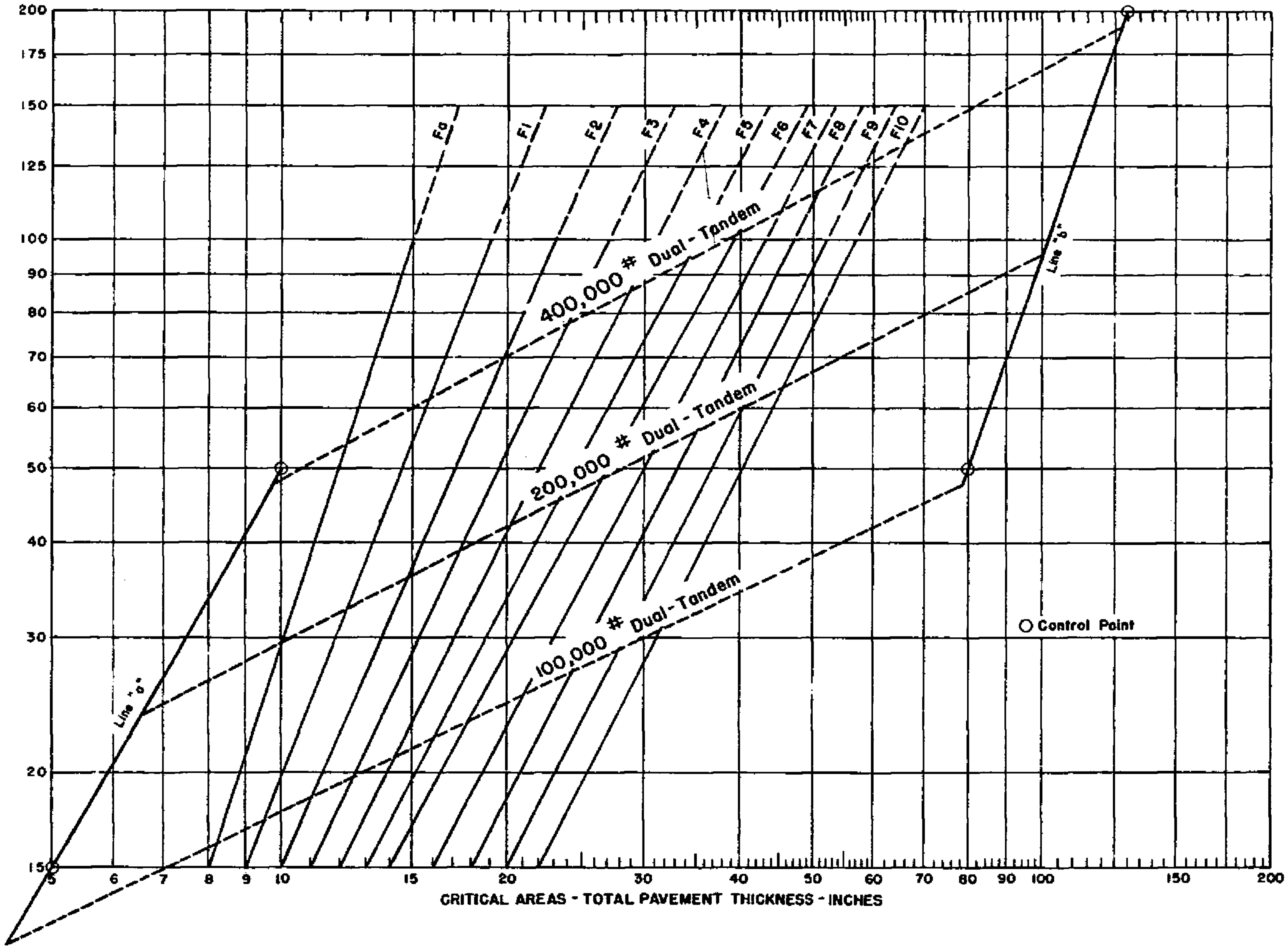


FIGURE 4. DEVELOPMENT OF FLEXIBLE PAVEMENT CURVES - DUAL-TANDEM GEAR

APPENDIX 2. DESIGN OF PAVEMENTS AND STRUCTURES FOR HEAVY AIRCRAFT

1. BACKGROUND.

a. Aircraft weighing more than 350,000 pounds will soon operate at a number of airports. These include the B-747, DC-10, L-1011, L-500, etc. Other aircraft of lesser weights, but with greater operating frequencies, will impose pavement stresses of large magnitude at these same airports. These include the B-707 (300 and 400 series), DC-8 (20 through 60 series), and B-727 (C, QC, 100C, 200).

b. Traffic forecasts and the predictions of industry associations and airline planners support the supposition that increasingly heavy subsonic aircraft will be developed and utilized within a 10- to 20-year period. A 1-1/2 million pound aircraft appears feasible and reasonably certain to materialize.

c. These data create concern regarding our design practices in the several areas of structures, coverages, heavy loads, stabilized components, and keel sections, as discussed below.

2. CULVERTS, BRIDGES, AND AIRPORT STRUCTURES SUPPORTING AIRCRAFT.

a. Little, if any, information is available concerning the flotation arrangement which the future heavy aircraft will employ; i.e., whether the primary weight distribution shall be longitudinal along the aircraft fuselage, lateral along the wings, or a combination of both.

b. It may be assumed that sufficient distribution of the imposed aircraft load will be accomplished to permit operation on present runway pavements or, conversely, that strengthening of pavements will not pose extreme problems. Point loading on some structures will be increased; while on overpasses, the entire aircraft weight may be imposed upon a deck span, pier, or footing. For these, strengthening is extremely difficult, costly, and time-consuming.

c. For structures with spans in excess of 10 feet, the slab or deck design, and to some degree, the design of piers and footings, become greatly dependent upon the aircraft gear configuration. Our assessment indicates that three basic configurations, shown in Figure 1, will, if all are considered in the design of the bridge components, provide sufficient support for any aircraft which may be forthcoming. These consist of two areas enclosing eight wheels each, or 16 wheels per aircraft comprising the main gear. Nose gears, as such, are not considered, except as they occur in the Type A bicycle configuration where they support roughly half of the static load. The "area" dimensions are six or eight feet by 20 feet, each supporting half of the aircraft gross weight or 750,000 pounds. Wheel prints are uniformly spaced within their respective areas.

d. Footing design will vary with depth and soil type. No departure from accepted methodology is anticipated; except that for shallow structures, such as inlets and culverts, the concentrated loads may require heavier and wider spread footings than those presently provided by the structures standards in current use.

e. It should be noted that all loads discussed herein are to be considered as live loads, and that braking loads as high as .7G (for no-slip brakes) must be anticipated on bridge decks and considered for other structures subject to direct wheel loads. Where clearances permit, the use of an earth cover over structures shall be used because of the earth's relative insensitivity to increased loadings and to minimize braking thrust and "bridge approach" settlement problems.

f. At airports where operations are occurring or anticipated by aircraft of the type mentioned in paragraph 1a, airport owners shall be encouraged to design decks and covers subject to direct aircraft loadings of this type, such as manhole covers, inlet grates, utility tunnel roofs, bridges, etc., to withstand the following loadings:

(1) For spans of two feet or less in the least direction, a uniform live load of 250 p.s.i.

(2) For spans between two feet and 10 feet in the least direction, a uniform live load varying between 250 p.s.i. and 50 p.s.i., in inverse proportion to the span length.

(3) For spans of 10 feet or greater in the least direction, the design shall be based on the most critical loading condition which may be applied by the gear configurations illustrated in Figure 2.

(4) Special consideration shall be given to structures that will be required to support both in-line and diagonal traffic lanes, such as diagonal taxiways or apron taxi routes. If structures require expansion joints, load transfer may not be possible.

3. PAVEMENT DESIGN AS AFFECTED BY COVERAGES.

a. Historically, the Federal Aviation Administration (FAA) pavement design has provided for "capacity" operations of the critical aircraft; and, based on the Corps of Engineers' criteria from which it was derived, "capacity" is considered as 5,000 coverages. While this is true for flexible pavement, the rigid pavement design changes, incorporated in Change 1 to the Airport Paving Circular, dated 11 June 1968, now provide for approximately 25,000 coverages.

b. The Corps of Engineers' formula for converting aircraft operations to coverages (a coverage occurs when each point of the pavement surface has been subjected to one maximum stress by the operating aircraft) is:

$$C = D \times \frac{0.75 \times N \times W}{T \times 12} \quad \text{where}$$

C = coverages

D = cycles of operations (one landing and one takeoff)

N = number of wheels on one main gear

W = width of tire contact area of one tire in inches

T = traffic width in feet (use 7.5)

c. Using a 13-inch tire width as typical and a 7.5-foot wide traffic lane, 5,000 and 25,000 coverages are achieved by about 12,000 and 60,000 "cycles of operations" by dual tandem gear aircraft. In FAA terminology, this would be expressed as 24,000 and 120,000 operations, respectively, or two D. Further, we consider jet aircraft departures only as being critical, since the maximum landing weight of today's jet is usually 3/4 of the maximum takeoff weight or less, and landings are not critical from a pavement stress standpoint. Accordingly, 24,000 and 120,000 departures are considered to be the design life of flexible and rigid pavements, respectively.

d. Pavement constructed with Federal-aid Airport Program (FAAP) funds should, with normal maintenance, have a life equal at least to the obligation term of the grant agreement or 20 years. Accordingly, pavement constructed to FAA standards now provides for 1,200 and 6,000 departures annually for flexible and rigid pavements, respectively. While this may appear to penalize flexible pavement from an eligibility standpoint, the provisions of this appendix will tend to cancel any discrepancy. We suggest that rather than attempt to provide the 25,000 coverages in original construction, the added thickness be reserved for stage completion at a time when the flexible surface will benefit from a new, dense cover.

e. References 7 and 8, as listed in the masthead page, forecast 1980 level of operations by aircraft such as those mentioned in the background statement. These figures are used as a convenient 20-year mean value.

f. There is a logarithmic relationship between cumulative pavement stress due to a given wheel load and repetitions thereof as compared to other wheel loads and repetitions. This relationship can be expressed as:

$$\log R_1 = \log R_2 \times \left(\frac{W_2}{W_1}\right)^{\frac{1}{2}} \quad \text{wherein}$$

R_2 and R_1 are the respective repetitions and W_2 and W_1 are the respective wheel loads. We can, thus, convert operations of an aircraft (or family) of known weight to an equivalent number of 350,000-pound gross weight operations (W_1 = 350,000 pounds) on dual tandem gear. Gross weight is used in this interpretation per the FAA design system.

g. From tabulated FY 1968 air carrier departures, we can tabulate equivalent departures and determine a factor for actual versus equivalent departures on a national basis, as shown below.

AIRCRAFT	MAX. GTW (W_2)	FY '68 DEPS. (R_2)	$\left(\frac{W_2}{W_1}\right)^{\frac{1}{2}}$	EQUIVALENT CRITICAL DEPS. (R_1)
707-300, 300B, 300C	312,000#	74,900	.944	39,950
DC-8 -20, 30, 40, 50	315,000	148,700	.949	81,110
DC-8 -61, 62, F	340,000	23,600	.985	20,290
1/ 727-100, QC, 100C, 200	170,000	900,900	.926	326,600
TOTALS		1,148,100		467,950

NOTE: Ratio of equivalent to actual departures = $\frac{467,950}{1,148,100} = .41$

1/ In order to avoid the cumbersome conversion of the dual gear 727 to coverages relative to dual tandem gear in the balance of the table, the 727 has been assigned a 300,000-pound dual tandem gross weight as determined by the equal pavement thickness requirement incorporated in the Airport Paving Circular, Figures 7, 8, and 9. It is assumed that this provides an equal stress magnitude per aircraft passage.

h. Figure 2 is a listing of locations where the forecast number of departures, after conversion to equivalent critical departures, exceeds 1,200 annually for 1980. For these and for any other location for which FAA planning procedures indicate more than 1,200 equivalent critical departures annually by the aircraft tabulated in paragraph 3g or equivalent, the minimum pavement design section for areas used by the heavy aircraft shall be the FAA 350,000-pound standard contained in Chapter 3. In addition, ground traffic and departure runway use shall be examined and the following design corrections applied to any runway, associated taxiway and terminal apron, when equivalent critical departures (planned by 1980) will exceed the following levels.

(1) For flexible pavements:

(a) For equivalent critical departures in excess of 1,200 annually, both critical and noncritical surface thicknesses shall be increased one inch. In addition, make one of the following adjustments.

(b) For departures between 1,200 and 3,000 annually, increase both base and subbase thicknesses by 10 percent.

(c) For departures between 3,000 and 6,000 annually, increase base and subbase thicknesses by 20 percent.

(d) For departures in excess of 6,000 annually, increase base and subbase thicknesses by 30 percent.

(2) For rigid pavements, when equivalent critical departures exceed 6,000 annually, concrete thickness shall be determined by Figure 23, Chapter 6, using a design safety factor of 2; i.e., for 700 p.s.i. concrete design flexural strength, use a working stress of 350 p.s.i.

4. AIRCRAFT EXCEEDING 350,000 POUNDS IN WEIGHT.

a. Several new aircraft which exceed the 350,000-pound loadings contemplated in FAA design criteria, and for which the flotation systems vary considerably from the assumptions and parameters noted in the Appendix 1 to this circular, are now in the advanced development or production stage. These include the B-747, DC-10, Lockheed L-1011, and L-500. For these, the manufacturers' published aircraft characteristics for airport planning typically include pavement design charts which are based on the PCA-Pickett & Ray-Interior loading design method for rigid pavement and a modified

CBR procedure for flexible pavement. These design methods have been satisfactory for aircraft which do not exceed 350,000 pounds in weight, as the aircraft to which they have been applied were in reasonable conformity to the experimental data from which the design criteria were derived.

b. In each of the large new aircraft, however, the experimental data have required extrapolation and/or additional factors have been introduced, such as the influence of remote wheels and the introduction of meaningful stresses into deeper subgrade strata. These combine to lessen somewhat the relative confidence which can be placed in the present design system as extended to the heavier aircraft. This problem is recognized in the industry, and considerable research is being undertaken to extend the design systems logically. Until such research produces useful criteria, we must make some conservative assumption in our design recommendations for these heavy aircraft.

c. The Figure 1 locations marked by a number sign (#) are considered likely to receive service by aircraft weighing in excess of 350,000 pounds. For these and for other locations designated by FAA planning procedures to receive service by aircraft weighing in excess of 350,000 pounds, the minimum pavement design section for any area on which the heavy aircraft will operate shall be the FAA 350,000-pound standard, regardless of the number of operations anticipated.

5. STABILIZED BASE AND SUBBASE COURSES.

a. A clear majority of pavement difficulties and failures which occurred under heavy aircraft loadings (except in those instances where extreme overloading of the pavement's design capability was at fault) have been attributed to excessive moisture in base and subbase courses. This is especially true for "sandwich" overlays where granular material is used between upper and lower impervious courses.

b. For new pavements to accommodate dual tandem gear aircraft weighing in excess of 200,000 pounds gross aircraft weight and sections of equal thickness for other gear types, it shall be the FAA policy to require that all base and subbase pavement courses be stabilized (P-201, P-304 or equivalent). These shall be substituted for granular base or subbase at the ratio of one inch of stabilized material for 1-1/2 inches of granular material. Exceptions should be based on proven performance of a granular material in a specific location, such as lime rock bases in the State of Florida.

c. Other exceptions may be made on the basis of superior materials being available, such as 100 percent crushed, hard, closely graded stone, or materials modified with cement, lime, or asphalt. These shall meet the present specification requirements, plus the following criteria. For nonfrost areas, base and subbase materials shall exhibit a remolded soaked CBR minimum of 100 and 35, respectively. In addition, where frost may penetrate the base or subbase, the materials must meet such tests as will be satisfactory to the respective regions that the materials used are impermeable or nonfrost susceptible. In no case, however, shall a nonstabilized material be used over a subgrade modified by lime, portland cement, or bituminous material.

d. The minimum combined bituminous surface and stabilized base thickness shall not be less than required by the Fa line in Chapter 3, Figures 7 and 8; nor shall P-201 and P-304 be less than 4" and 6" in thickness, respectively.

6. <u>KEEL SECTION DESIGN</u>.

The advent of heavier aircraft is accompanied by wider gear spacing; and pavement designers must consider the coverage limits in determining acceptable keel and transition section dimensions. Runway design based on the keel sections shown in Chapter 3, Figure 5, is to be encouraged. For runways to serve "X" and "L" category aircraft, as listed in references 7 and 8, the minimum keel width for both critical and noncritical runway areas shall be 100 feet.

(NOT TO SCALE)

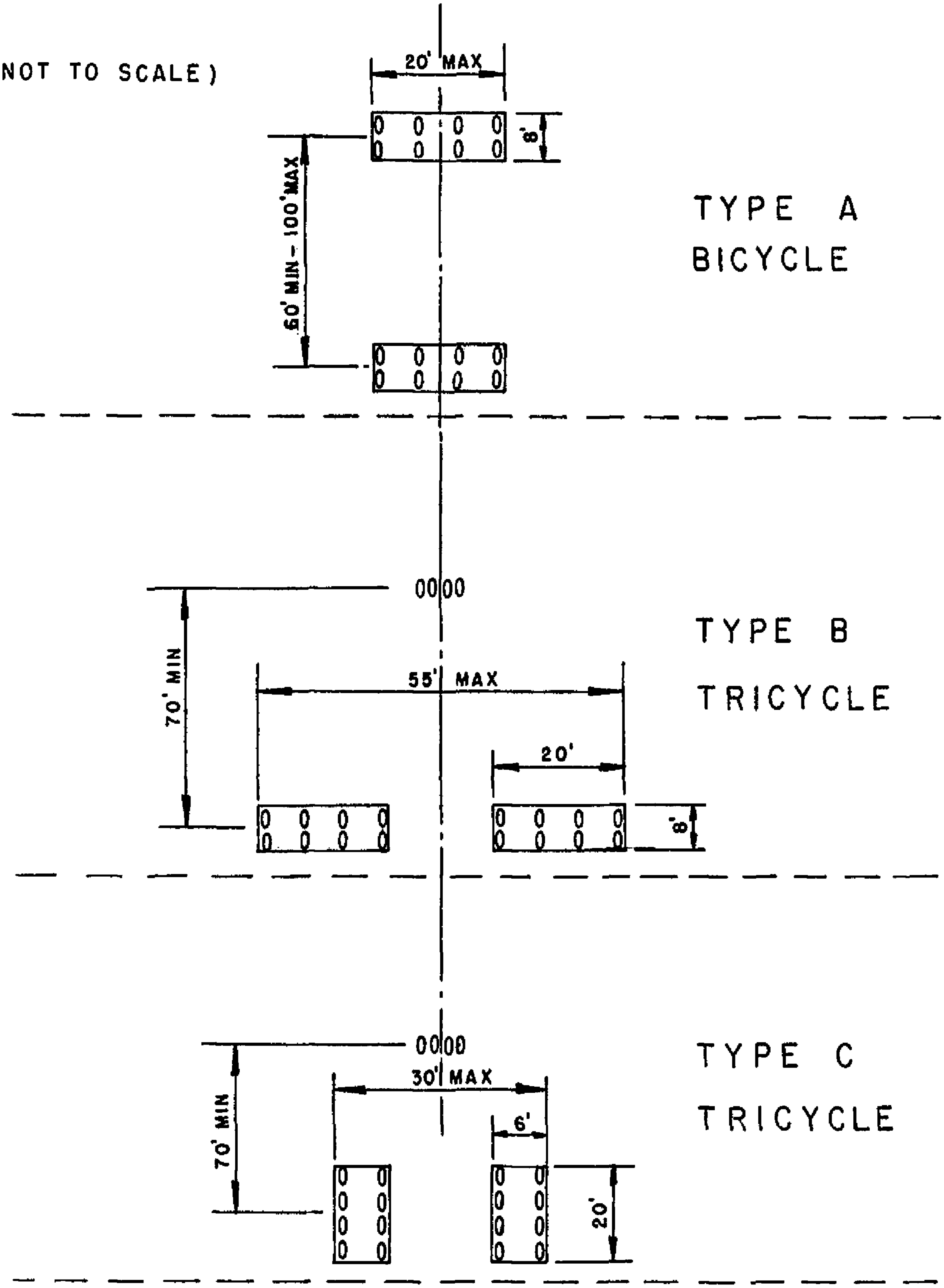


FIGURE 1. TYPICAL GEAR CONFIGURATIONS FOR DESIGN OF STRUCTURES

FIGURE 2. ESTIMATED 1980 EQUIVALENT CRITICAL DEPARTURES

The number sign (#) shows locations where service by aircraft exceeding 350,000 pounds is anticipated.

LOCATION	EQUIVALENT NO. OF DEPARTURES BY CRITICAL AIRCRAFT
Albany, N.Y.	3,050
#Albuquerque	5,300
#Anchorage, Alaska	1,636 (1)
#Atlanta	51,630
#Baltimore	26,400
Birmingham, Ala.	1,735
#Boston	43,775
#Buffalo	7,500
Charlotte, N.C.	1,200
#Chicago - O'Hare	108,200
Chicago - Midway	27,050
#Cincinnati	18,525
#Cleveland	29,650
#Columbus, Ohio	6,835
#Dallas	51,200
Dayton	2,250
#Denver	28,175
#Detroit	40,500
#El Paso	5,080
#Fort Lauderdale, Fla.	11,150
Hartford, Conn. (Bradley)	4,365
#Honolulu, Hawaii	12,978 (1)
#Houston	27,175
#Indianapolis	2,020
#Jacksonville, Fla.	7,710
#Kansas City	14,280
#Las Vegas	17,550
#Los Angeles	111,300
#Louisville	6,140
#Memphis	3,775
#Miami	60,425
#Milwaukee	7,240
#Minneapolis	21,215
Nashville	2,960
#New Orleans	26,600
#Newark	46,690
#New York (JFK)	83,905
#New York (La Guardia)	56,220
#Oakland	6,145

LOCATION	EQUIVALANT NO. OF DEPARTURES BY CRITICAL AIRCRAFT
#Oklahoma City	4,120
Omaha	1,940
Orlando	5,630
#Philadelphia	36,990
#Phoenix	13,830
#Pittsburg	26,600
#Portland, Oregon	17,015
#Rochester, N.Y.	4,900
Sacramento	2,850
#Salt Lake City	9,365
#San Antonio	8,445
#San Diego	15,690
#San Francisco	64,900
#San Juan, Puerto Rico	8,806 (1)
#Seattle-Tacoma	31,620
#St. Louis	25,680
Syracuse	3,040
#Tampa	26,480
#Tucson	3,980
#Tulsa	3,960
#Washington (Dulles)	13,730
Washington (National)	65,605
#West Palm Beach, Fla.	7,013 (1)

(1) Forecast data are not available for these locations in references 7 and 8, so individual calculations were made using hub growth factors.

☆U.S. GOVERNMENT PRINTING OFFICE: 1972 722-802/503 1-3

Repl. by -6B [redacted]

AIRPORT PAVING

May 9, 1967

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CHANGE

AC NO: 150/5320-6A CHG 3

DATE: 4/1/70

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: CHANGE 3 TO AC 150/5320-6A, AIRPORT PAVING

1. PURPOSE. This advisory circular change transmits several page changes and new subgrade compaction criteria.

2. EXPLANATION OF CHANGES. These changes add emphasis to proper soils investigation and materials selection, and are a part of the necessary upgrading of pavement standards required by increased traffic and heavier aircraft entering service. Particular attention is directed to the new paragraph 16d which defines noncohesive soil and provides a modified design procedure for use with swelling soil. This paragraph and the new Figure 8-1 also identify new requirements for subgrade compacted depths.

3. PAGE CONTROL CHART.

Remove Page	Dated	Insert Page	Dated
i and ii	6/11/68	i and ii	4/1/70
1 thru 3	5/9/67	1	5/9/67
		2 thru 4	4/1/70
5 thru 10	5/9/67	5	5/9/67
		6 thru 10-1 (and 10-2)	4/1/70
17 and 18	5/9/67	17	5/9/67
		18	4/1/70
19 and 20	5/9/67	19	5/9/67
		20	4/1/70
23 thru 28	5/9/67	23	4/1/70
		24	5/9/67
		25 (thru 28-2)	4/1/70
31 and 32	5/9/67	31 (and 32)	4/1/70

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Remove Page	Dated	Insert Page	Dated
35 thru 36-3	6/11/68	35	6/11/68
		36	4/1/70
		36-1 and 36-2	4/1/70
57 and 58	5/9/67	57	4/1/70
		58	5/9/67

4. HOW TO OBTAIN ADDITIONAL COPIES OF THIS PUBLICATION. Additional copies of this Change 3 to AC 150/5320-6A, Airport Paving, may be obtained from the Department of Transportation, Distribution Unit, TAD-484.3 Washington, D.C. 20590.

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CHANGE

AC NO: 150/5320-6A CHG 2

DATE: 2 February 1970

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

SUBJECT: AIRPORT PAVING

1. PURPOSE. This advisory circular change transmits new paragraphs 3, 4, and 5, on Masthead, and adds a new Appendix 2.

2. EXPLANATION OF CHANGES.

   a. Paragraph changes are made to include references erroneously omitted in previous change.

   b. Research is under way or is contemplated in the following areas of airport pavement design and strength requirements of airport structures:

      (1) Culverts, bridges, and airport structures supporting aircraft.

      (2) Pavement design as affected by coverages.

      (3) Stabilized pavement and subgrade components.

      (4) Aircraft exceeding 350,000 pounds in weight.

   As the criteria in Appendix 2 are refined as a result of research findings, they will be included in the basic text and deleted from the appendix. Meanwhile, Appendix 2 shall be used as the basis for design of airport pavement that serves aircraft weighing in excess of 110,000 pounds on dual gear, or 200,000 pounds on dual tandem gear. As such, it will supplement and supersede where applicable Chapters 1, 2, 3, 4, 6 and Appendix 1. It shall be effective for all allocations issued after the date of this change.

Initiated by: AS-580

3. CONTROL CHART.

Remove	Dated	Insert	Dated
Para 3 (Masthead)	5/9/67	Paras 3, 4, & 5 (below) on Masthead	2/5/70
iii	6/11/68	iii	2/5/70
		Appendix 2	2/5/70

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3. REFERENCES.

a. Obtain copies of the following advisory circulars and additional copies of this circular from the department of Transportation, Distribution Unit, TAD-484.3, Washington, D.C. 20590:

(1) AC 150/5325-2A, Airport Surface Areas Gradient Standards.

(2) AC 150/5325-5A, Aircraft Data.

(3) AC 150/5325-6, Effects of Jet Blast.

(4) AC 150/5330-2A, Runway/Taxiway Widths and Clearances for Airline Airports.

(5) AC 150/5335-1, Airport Taxiways.

(6) AC 150/5335-2, Airport Aprons.

(7) Aviation Demand and Airport Facility Requirement Forecasts for Large Air Transportation Hubs Through 1980, dated August 1967.

(8) Aviation Demand and Airport Facility Requirement Forecasts for Medium Air Transportation Hubs Through 1980, dated January 1969.

(9) Airport Activity Statistics of Certificated Route Air Carriers, for 12 Months Ended 30 June 1968.

(10) FAA Air Traffic Activity for Calendar Year 1968.

b. Copies of the following publications may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Send a check or money order in the amount listed for each document. No c.o.d. orders are accepted.

(1) AC 150/5370-1A, Standard Specifications for Construction of Airports, dated May 1968 - $3.50.

(2) AC 150/5320-5A, Airport Drainage, dated 28 January 1966 - $.45.

4. ADDITIONAL REFERENCE. In addition to the references listed on the masthead page of this circular in paragraph 3, MIL-STD-621A, Subgrade, Subbase, and Test Method for Pavement Base-Course Materials, pertains to this circular. This military standard may be obtained from the Commanding Officer, Naval Supply Depot, 5901 Tabor Avenue, Philadelphia, Pennsylvania 19120.

5. EXPLANATION OF REVISION.

a. This revision provides for lengthening the critical runway pavement and increasing the noncritical pavement strength.

b. Criteria are added to place emphasis on additional soil tests.

c. The list of referenced publications is updated.

HQ-630

CHANGE

AC NO: AC 150/5320-6A CHG 1

DATE: 6/11/68

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: AIRPORT PAVING

1. PURPOSE. This advisory circular change transmits page changes and an added new Chapter 6 to the subject advisory circular.

2. EXPLANATION OF CHANGES.

   a. Paragraph 17. A statement is added to permit a controlled correlation between CBR and F classification in flexible pavement design.

   b. Paragraph 19. This paragraph has been rewritten in its entirety to incorporate plate bearing and flexural strength of concrete as optional variables in rigid pavement design.

   c. Figure 9. The rigid pavement design curves have been revised to incorporate more realistic tire pressures and to reflect the stress findings resulting from sophisticated computer analyses of the Westergaard formula.

   d. Table 5. Slab thickness and dowel lengths are adjusted to reflect new design thicknesses.

   e. Chapter VI. A new chapter is added to provide guidance and methodology for airport pavement evaluation.

   f. Appendix 1. The section on development of rigid pavement curves has been revised to reflect the new design assumptions and computerized curves.

Initiated by: AS-580

3. ADDITIONAL REFERENCE. In addition to the references listed on the masthead page of this circular in paragraph 3, MIL-STD-621A, Subgrade, Subbase, and Test Method for Pavement Base-Course Materials, pertains to this circular. This military standard may be obtained from the Commanding Officer, Naval Supply Depot, 5901 Tabor Avenue, Philadelphia, Pennsylvania 19120.

4. PAGE CONTROL CHART.

Remove Pages	Dated	Insert Pages	Dated
i and ii	5/9/67	i, ii, and iii	6/11/68
33 - 38	5/9/67	33 - 38	6/11/68
41 - 42	5/9/67	41	5/9/67
		42	6/11/68
		Chapter 6	
		77 - 99	6/11/68
Appendix 1		Appendix 1	
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CHAPTER 1. AIRPORT PAVEMENTS - THEIR FUNCTIONS AND PURPOSES

1. GENERAL. Airport pavements are constructed to provide adequate support for the loads imposed by aircraft using the airport and to produce a firm, stable, smooth, all-year, all-weather surface, free from dust or other particles that may be blown or picked up by propeller wash or jet blast. In order to satisfactorily fulfill these requirements, the pavement must be of such quality and thickness that it will not fail under the load imposed. In addition, it must possess sufficient inherent stability to withstand, without damage, the abrasive action of traffic, adverse weather conditions, and other deteriorating influences. To produce such pavements requires a coordination of many factors of design, construction, and inspection to assure the best possible combination of available materials and a high standard of workmanship.

a. Types of Pavement. Pavements are divided into two general types:

(1) Flexible pavements are those consisting of a bituminous surface course, a base course of suitable granular material, and in most cases a granular subbase course.

(2) Rigid pavements are those pavements constructed of portland cement concrete and may or may not include a subbase course.

b. Flexible or rigid pavements, when properly designed and constructed, will provide a satisfactory airport pavement for any or all types of civil aircraft. However, a few areas where a specific type of pavement has proven beneficial are:

(1) The areas subjected to appreciable fuel spillage at the aircraft gate positions and the service or maintenance portions of the apron. Rigid pavements are recommended for these areas. This does not preclude the use of existing flexible pavements with a fuel resistant seal coat in these areas.

(2) The areas where jet erosion occurs adjacent to pavement. Many low cost stabilized surfaces may be used as erosion control measures. These areas include runway ends, blast pads, holding apron shoulders, and taxiway shoulders where turf cannot be established. This stabilization is further discussed in the Federal Aviation Administration publication, AC 150/5325-6, Effects of Jet Blast.

c. Pavement Courses.

(1) Surface courses include portland cement concrete, bituminous concrete, sand-bituminous mixtures, and bituminous surface treatments.

(2) Base courses consist of a variety of different materials which generally fall into two main classes, treated and untreated. The untreated bases consist of stone, slag, caliche, gravel, limerock, shell, sand-clay, coral, or any one of a variety of other approved materials. The treated bases normally consist of a crushed or uncrushed aggregate that has been mixed with cement or bitumen.

* (3) Subbase courses consist of a granular material, a stabilized granular material, or a stabilized soil. *

2. STANDARDS AND SPECIFICATIONS.

a. Dimensional standards applicable to the various airports are covered in the referenced advisory circulars. These standards establish recommendations for lengths, widths, grades, and slopes of the pavements on airports.

b. The FAA publication, Standard Specifications for Construction of Airports, includes descriptions of the various pavement components and specifies the requirements governing the control, handling, quality, gradation, and quantity of individual materials included in the pavement mixes. It also contains detailed information on excavation, embankment, construction, and subgrade preparation.

(1) These specifications are necessarily broad in scope because they are for use throughout the United States and its possessions. They may not be completely satisfactory to cover a particular situation or a condition peculiar to a certain locality without some modification. However, the types of paving covered by the specifications have been used successfully on airports for many years; and experience has shown that radical departures from the standards will accomplish no useful purpose.

(2) It is not the intent of these specifications to restrict the use of local materials which will serve as acceptable alternates, nor to preclude the adoption of local construction methods if they are predicated upon sound engineering and construction practices and experience has shown them to be
* satisfactory. Materials normally produced by local suppliers in accordance with State and local highway specifications may be satisfactory for use on smaller airports without modification. When gross aircraft weights exceed 12,500 pounds, the local material shall be carefully examined from the *

* standpoints of durability, toughness, and gradation. Blend or treatment will often improve the local materials. Many state highway materials specifications, used in major trunk route or interstate system construction, will provide adequ pavements for gross aircraft weights to 60,000 pounds. For pavements to receive substantial use by aircraft exceeding 60,000 pounds gross weight, our highest material standards shall be employed.

3. SPECIAL CONSIDERATIONS.

a. In addition to the property of furnishing support for the aircra loads which will be applied, the pavements of aircraft operating areas must be so designed and constructed in order to assure max safety and efficiency of operations which normally are to be expected. As previously mentioned, gradient and similar standar are specified in the referenced circulars. Particular care must excercised to assure satisfactory transition of grades and slope at pavement intersections and to provide fillets at such points which will permit maximum operational utilization of the facilit

b. The surface or wearing course shall be dense and well bonded to prevent displacement of surface aggregates. The wearing surface * texture shall provide a nonskid property. A trowel finish shall never be applied to portland cement concrete operational surface A longitudinal burlap drag may be applied to apron and taxiway surfaces, but shall not be permitted on runway pavement unless immediate grooving is intended. In other cases, portland cement runways shall be finished by transverse brooming or belting and for air carrier or turbojet operations, limited to transverse brooming or "combing" with a stiff bristle broom or steel comb. Bituminous concrete runways may be given a satisfactory surface utilizing high quality aggregate and by careful control of the minus 1/4-inch aggregate fractions. When hard, sharp, crushed aggregates are used with a gradation following FAA recommendatio a good texture should be achieved without sacrifice in stability or durability.

c. Certain areas of the pavement will be subjected to repeated load ings occasioned by channelization or concentration of traffic. These areas (which include taxiways, aprons, run-up aprons, and runway ends) must be designed to withstand the stresses from suc loadings.

4. <u>STAGE CONSTRUCTION OF AIRPORT PAVEMENTS</u>.

a. It may be desirable to construct the airport pavement by stages, that is, to build up the surface or improve the pavement profile, layer by layer, as the traffic using the facility increases in weight and numbers. In addition, such a method of construction can be utilized to advantage when construction funds are limited.

b. If stage construction is to be undertaken, the need for sound planning cannot be too highly stressed. The complete pavement should be designed prior to the start of any stage, and each stage undertaken must result in a usable surface. Such a procedure, in addition to providing interim surfaces to serve the immediate need, will assure that development accomplished in each stage
* will form an integral part of the ultimate pavement. While either flexible or rigid pavement may be planned for stage construction, the use of a flexible or "sandwich" overlay shall not be included in any planned stage. *

c. The division of work into stages can be arranged in any manner suitable to the financial or physical condition particular to the site in question as long as the above principles are applied.

CHAPTER 2. SOIL INVESTIGATIONS AND EVALUATION

5. GENERAL.

a. The importance of accurate identification and evaluation of the pavement foundation cannot be overemphasized. Although it is impossible to explore the entire field of soil mechanics in a publication such as this, the following text will highlight tho aspects which are particularly important to the airport paving engineer.

b. Classification systems of soils and subgrades which are to be u in connection with design of airport pavements are set forth in this chapter. To avoid misunderstanding, certain terms employe are defined below.

(1) For engineering purposes, and particularly as it applies t airports, soil includes all natural deposits which, withou requiring blasting under unfrozen conditions, can be moved with excavating equipment.

(2) Soil conditions include such items as the elevation of the water table, the presence of water bearing strata, and the field properties of the soil. Field properties of the soi include the soil's structure, identification, plasticity, moisture content, and density.

(3) The soil profile is the vertical arrangement of layers of soils, each of which possesses different physical properti from the adjacent layer.

(4) Subgrade soil is that soil which forms the foundation for the pavement. It is the soil directly beneath the pavemen structure.

c. Soil conditions and the availability of suitable construction materials are the most important items affecting the cost of construction of the landing areas and the pavements. Grading c are directly related to the difficulty with which excavation ca be accomplished and compaction obtained.

d. It should be remembered that the subgrade soil carries the load imposed by aircraft utilizing the facility. The pavement serve distribute the imposed load to the subgrade over an area greate than that of the tire contact area. The greater the thickness pavement, the greater is the area over which the load on the subgrade is distributed. It follows, therefore, that the more unstable the subgrade soil, the greater is the required area of load distribution and consequently the greater is the required thickness of pavement. The soils having the best engineering characteristics encountered in the grading and excavating operations should be worked into the upper layers of the subgrade.

* e. In addition to the relationship which soil conditions bear to grading and paving operations, they determine the necessity for underdrains and materially influence the amount of surface runoff. Thus, they have a consequent effect on the size and extent of other drainage structures and facilities. (See FAA publication, AC 150/5320-5A, Airport Drainage). *

6. <u>SOIL INVESTIGATIONS</u>.

a. To provide essential information on the various types of soils, investigations should be made to determine their distribution and physical properties. The information so obtained, when combined with data on site topography and area climatic records, provides basic planning material essential to the logical and effective development of the airport. An investigation of soil conditions at an airport site will include:

(1) A soil survey to determine the arrangement of different layers of the soil profile with relation to the proposed subgrade elevation.

(2) Sampling of the layers of soil.

(3) Testing of samples to determine the physical properties of the various soil materials with respect to stability and subgrade support.

(4) A survey to determine the availability of materials for use in construction of the subgrade and pavement.

b. With respect to sampling and surveying procedures and techniques, Method T 86 of the American Association of State Highway Officials (AASHO) is one of those most frequently used. This method is based entirely on the soil profile. In the field, the various layers that comprise the soil profile are identified by such characteristics as color, texture, structure, consistency, compactness, cementation, and to varying degrees, chemical composition.

(1) This method of soil identification parallels that used by the Department of Agriculture, which appears on their soils maps. The intelligent use of these maps can prove an invaluable aid in the study of soils at and in the vicinity of the airport. Although the pedological classification, determined from these maps, does not treat soil as engineering

or construction material, data so obtained are extremely us to the agronomist in connection with the development of tur areas on airports and to the engineer concerned with prelim investigations of site selection, development costs, and alignment.

*

(2) The practice of determining data on soils by use of aerial photographs is becoming more widespread. Relief and soil patterns may be determined from the photographs, and an experienced photo-interpreter can define differences in characteristics of soils. By employing this method of investigation, it is possible to expedite soil studies and reduce the amount of effort required to gather data.

7. SURVEYING AND SAMPLING.

a. The initial step in an investigation of soil conditions is a soil survey to determine the quantity and extent of the different types of soil, the arrangement of soil layers, and th presence of any subsurface water. Samples of soil are usually obtained by means of borings made with a soil auger or similar device. Inasmuch as each location presents its particular problems and variations, the spacing of borings cannot always be definitely specified by rule or preconceived plan. A suggested criterion for the location, depth, and number of borings is tabulated below.

AREA	SPACING	DEPTH
Runways and Taxiways	Along Centerline, 200 Feet on Centers	Cut Areas - 10' Below Finished Grade 1/Fill Areas - 10' Below Existing Ground Surface
Other Areas of Pavement	1 Boring per 10,000 Square Feet of Area	Cut Areas - 10' Below Finished Grade 1/Fill Areas - 10' Below Existing Ground Surface
Borrow Areas	Sufficient Tests to Clearly Define the Borrow Material	To Depth of Proposed Excavation of Borrow

* 1/ For deep fills, boring depths shall be used as necessary to determine the extent of consolidation and slippage, which the fill to be placed may cause.

b. Obviously, the locations, depths, and number of borings must be such that all important soil variations can be determined and mapped. Whenever past experience at the location in question has indicated that settlement or stability in deep fill areas may be a problem, or if in the opinion of the engineer additional investigations are warranted, more and/or deeper borings may be required in order that the proper design, location, and construction procedures may be determined. Conversely, where uniform soil conditions are encountered, fewer borings may be acceptable.

c. The soil survey is not confined to soils encountered in grading or necessarily to the area within the boundaries of the airport site. Possible sources of locally available material that may be used in the paving operation should be investigated.

d. Samples representative of the different layers of the various soils encountered, and various construction materials discovered, should be obtained and tested in the laboratory to determine their physical and engineering properties. Because the results of a test can only be as good as the sampling, it is of utmost importance that each sample be representative of a particular type of soil material and not be a careless and indiscriminate mixture of several materials.

* e. Pits, open cuts, or both may be required for making in-place bearing tests, for the taking of undisturbed samples, for charting variable soil strata, etc. This type of supplemental soil investigation is recommended for all heavy load runway areas and for other problem soil areas as may be encountered. *

8. SOIL TESTS.

a. Physical Soil Properties. To determine the physical properties of a soil and to provide an estimate of its behavior under various conditions, it is necessary to conduct certain soil tests. In this regard, a number of field and laboratory tests have been developed and standardized. Details of methods of performing soil tests are completely covered in publications of the AASHO and
* ASTM and in Military Standards. *

b. Testing Requirements. Soil tests are usually identified by terms indicating the soil characteristics which the tests will reveal.
* Terms which identify the tests considered to be the minimum or basic requirement for airport pavement, with their AASHO designations and brief explanations, follow. *

(1) Dry Preparation of Disturbed Soil Samples for Test (AASHO 87) or Wet Preparation of Disturbed Soil Samples for Test (AASHO T 146). The dry method (T 87) should be used only for clean, cohesionless granular materials. The wet meth (T 146) should be used for all cohesive or borderline materials.

(2) Mechanical Analysis of Soils (AASHO T 88). The mechanica analysis of soils is a test for determining, quantitative the distribution of particle sizes in soils.

(3) Determining the Plastic Limit of Soils (AASHO T 90). The plastic limit is defined as the minimum moisture content which the soil becomes plastic. At moisture contents abo the plastic limit, there is a sharp drop in the stability a soil.

(4) Determining the Liquid Limit of Soils (AASHO T 89). The liquid limit is the water content at which the soil passe from a plastic to a liquid state. The liquid state is de as the condition in which the shear resistance of the soil so slight that a small force will cause it to flow.

* (5) Calculating the Plasticity Index of Soils. The plasticit index is the numerical difference between the plastic lim and the liquid limit. It indicates the range in moisture content over which a soil remains in a plastic state prio to changing into a liquid.

(a) Maximum density is defined as the maximum dry weight pounds per cubic foot, obtained when a material is m with different percentages of water and compacted in standard manner.

(b) Optimum moisture content is the percentage of water which maximum density is obtained with a specified compactive effort. Compaction Control Tests are cov in Division VII, Tests, Item T-611 of AC 150/5370-1A Standard Specifications for Construction of Airports

(6) Determination of Maximum Density and Optimum Moisture. F purposes of compaction control during construction, it wil necessary to perform tests to determine the maximum densi and optimum moisture content of the different types of so

c. Supplemental Tests.

(1) In many cases special or unusual soil conditions exist or are anticipated, and supplemental soil tests will be required. These will vary in the areas of occurrence and in available treatment methods to such an extent that thorough discussion is beyond the scope of this circular. As examples, an expansive soil combined with high seasonal moisture change may require stabilization as noted in paragraph 12f or, alternately, compaction at higher moisture and lower density, with the choice influenced by area practice, surface type, and design loadings. Soils with low field densities and/or subject to consolidation may require densification to greater depths than the normal design requirement. Such problem soils must be recognized and corrective measures taken where required.

(2) For many soils, it is essential that the in-place density and bearing strength be determined. Drive samples can be used if sufficient correlation with other test procedures has been established for a particular soil. In other cases, pits shall be carefully opened for the taking of undisturbed samples and penetration bearing tests. Density and moisture content should be carefully charted when heavy load pavements may require compaction at depth in accordance with Figure 8-1. This information permits establishment of a reasonable shrinkage factor, and aids both designer and contractor in estimating compaction requirements in cut areas.

(3) California Bearing Ratio (CBR) tests, laboratory and field, and plate bearing tests are included in this text as applicable to specific design and evaluation options. These are not intended to limit the supplemental testing which may be appropriate to a specific soil, such as tests for shrinkage and swell, consolidation under load, frost susceptability, etc. *

9. SOIL CLASSIFICATION.

a. While the results of individual tests indicate certain physical properties of the soil, the principal value is derived from the fact that through correlation of the data so obtained it is possible to prepare an engineering classification of soils related to their field behavior. Such a classification is presented in Table 1.

TABLE 1. CLASSIFICATION OF SOILS FOR AIRPORT PAVEMENT CONSTRUCTION

	Soil group	Mechanical analysis				Liquid limit	Plasticity index
		Material retained on No. 10 sieve—percent[1]	Material finer than No. 10 sieve—percent				
			Coarse sand, passing No. 10; retained on No. 40	Fine sand, passing No. 40 retained on No. 200	Combined silt and clay; passing No. 200		
Granular	E-1	0-45	40+	60-	15-	25-	6-
	E-2	0-45	15+	85-	25-	25-	6-
	E-3	0-45	---------	---------	25-	25-	6-
	E-4	0-45	---------	---------	35-	35-	10-
Fine grained	E-5	0-55	---------	---------	45-	40-	15-
	E-6	0-55	---------	---------	45+	40-	10-
	E-7	0-55	---------	---------	45+	50-	10-30
	E-8	0-55	---------	---------	45+	60-	15-40
	E-9	0-55	---------	---------	45+	40+	30-
	E-10	0-55	---------	---------	45+	70-	20-50
	E-11	0-55	---------	---------	45+	80-	30+
	E-12	0-55	---------	---------	45+	80+	---------
	E-13	Muck and peat—field examination					

[1] If percentage of material retained on the No. 10 sieve exceeds that shown, the classification may be raised, provided such material is sound and fairly well graded.

b. The soil classification requires, basically, the performance of three tests - the mechanical analysis, determination of the liquid limit, and determination of the plastic limit. Tests for these properties have been utilized for many years as a means of evaluating soil for use in the construction of embankments and pavement subgrades. These tests identify a particular soil as having physical properties similar to those of a soil whose performance and behavior are known. Therefore, the test soil can be expected to possess the same characteristics and degree of stability under like conditions of moisture and climate.

c. As can be discerned from Table 1, the mechanical analyses provide the information to permit separation of the granular soils from the fine grained soils; whereas, the several groups are arranged in order of increasing values of liquid limit and plasticity index. The division between granular and fine grained soils is made upon the requirement that granular soils must have less than 35 percent of silt and clay combined. Determination of the sand, silt, and clay fractions is made on that portion of the sample passing the No. 10 sieve because this is considered to be the critical portion with respect to changes in moisture and other climatic influences. The classification of the soils with respect to different percentages of sand, silt, and clay is shown in Figure 1.

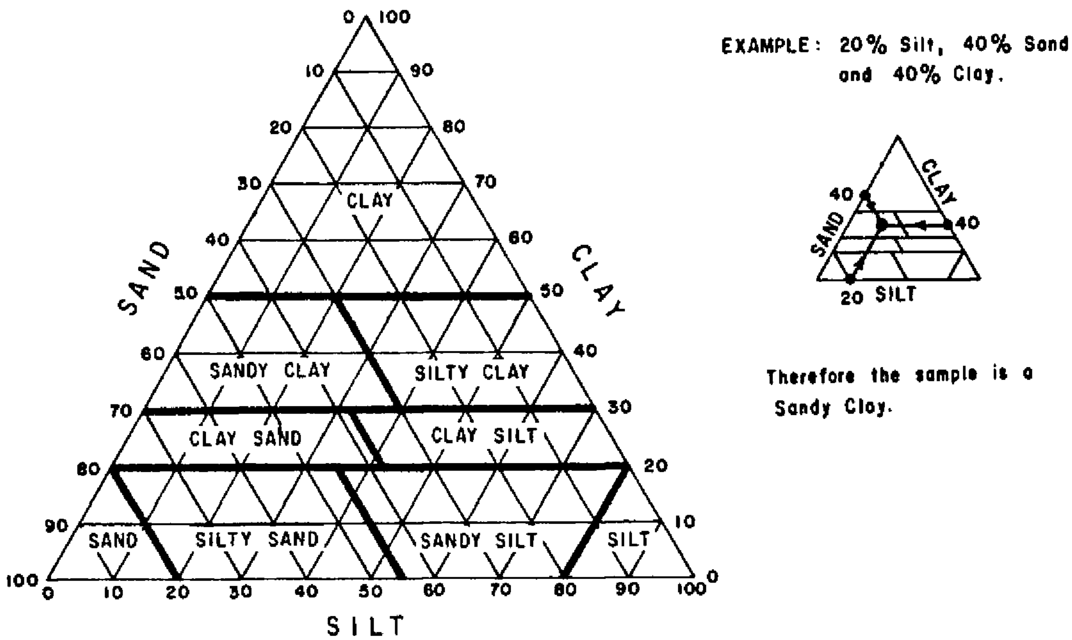

FIGURE 1. TEXTURAL CLASSIFICATION OF SOILS

(1) Group E-1 includes well-graded, coarse, granular soils that are stable even under poor drainage conditions and are not generally subject to detrimental frost heave. Soils of this group may conform to well-graded sands and gravels with little or no fines. If frost is a factor, the soil should be checked to determine the percentage of the material less than 0.02 mm in diameter (paragraph 12d).

(2) Group E-2 is similar to Group E-1 but has less coarse sand and may contain greater percentages of silt and clay. Soils of this group may become unstable when poorly drained as well as being subject to frost heave to a limited extent.

(3) Groups E-3 and E-4 include the fine, sandy soils of inferior grading. They may consist of fine cohesionless sand or sand-clay types with a fair-to-good quality of binder. They are less stable than Group E-2 soils under adverse conditions of drainage and frost action.

(4) Group E-5 comprises all poorly graded soils having more than 35 percent but less than 45 percent of silt and clay combined. This group also includes all soils with less than 45 percent of silt and clay but which have plasticity indices of 10 to 15. These soils are susceptible to frost action.

(5) Group E-6 consists of the silts and sandy silts having zero-to-low plasticity. These soils are friable and quite stable when dry or at low moisture contents. They lose stability and become very spongy when wet and for this reason are difficult to compact unless the moisture content is carefully controlled. Capillary rise in the soils of this group is very rapid; and they, more than soils of any other group, are subject to detrimental frost heave.

(6) Group E-7 includes the silty clay, sand clay, clayey sands, and clayey silts. They range from friable to hard consistency when dry and are plastic when wet. These soils are stiff and dense when compacted at the proper moisture content. Variations in moisture are apt to produce a detrimental volume change. Capillary forces acting in the soil are strong, but the rate of capillary rise is relatively slow and frost heave, while detrimental, is not as severe as in the E-6 soils.

(7) Group E-8 soils are similar to the E-7 soils but the higher liquid limits indicate a greater degree of compressibility, expansion, shrinkage, and lower stability under adverse moisture conditions.

(8) Group E-9 comprises the silts and clays containing micaceous and diatomaceous materials. They are highly elastic and very difficult to compact. They have low stability in both the wet and dry state and are subject to frost heave.

(9) Group E-10 includes the silty clay and clay soils that form hard clods when dry and are very plastic when wet. They are very compressible, possess the properties of expansion, shrinkage, and elasticity to a high degree and are subject to frost heave. Soils of this group are more difficult to compact than those of the E-7 or E-8 groups and require careful control of moisture to produce a dense, stable fill.

(10) Group E-11 soils are similar to those of the E-10 group but have higher liquid limits. This group includes all soils with liquid limits between 70 and 80 and plasticity indices over 30.

(11) Group E-12 comprises all soils having liquid limits over 80 regardless of their plasticity indices. They may be highly plastic clays that are extremely unstable in the presence of moisture, or they may be very elastic soils containing mica, diatoms, or organic matter in excessive amounts. Whatever the cause of their instability, they will require the maximum in corrective measures.

(12) Group E-13 encompasses organic swamp soils such as muck and peat which are recognized by examination in the field. In their natural state, they are characterized by very low stability, very low density, and very high moisture content.

10. SPECIAL CONDITIONS AFFECTING FINE GRAINED SOILS.

a. A soil may possibly contain certain constituents that will give test results which would place it, according to Table 1, in more than one group. This could happen with soils containing mica, diatoms, or a large proportion of colloidal material. Such overlapping can be avoided by the use of Figure 2 in conjunction with Table 1, with the exception of E-5 soils which should be classified strictly according to Table 1 and paragraph 9c(4).

b. Soils with plasticity indices higher than those corresponding to the maximum liquid limit of the particular group are not of common occurrence. When encountered, they are placed in the higher numbered group as shown in Figure 2. This is justified by the fact that, for equal liquid limits, the higher the plasticity index, the lower the plastic limit at which a slight increase in moisture causes the soil to rapidly lose stability.

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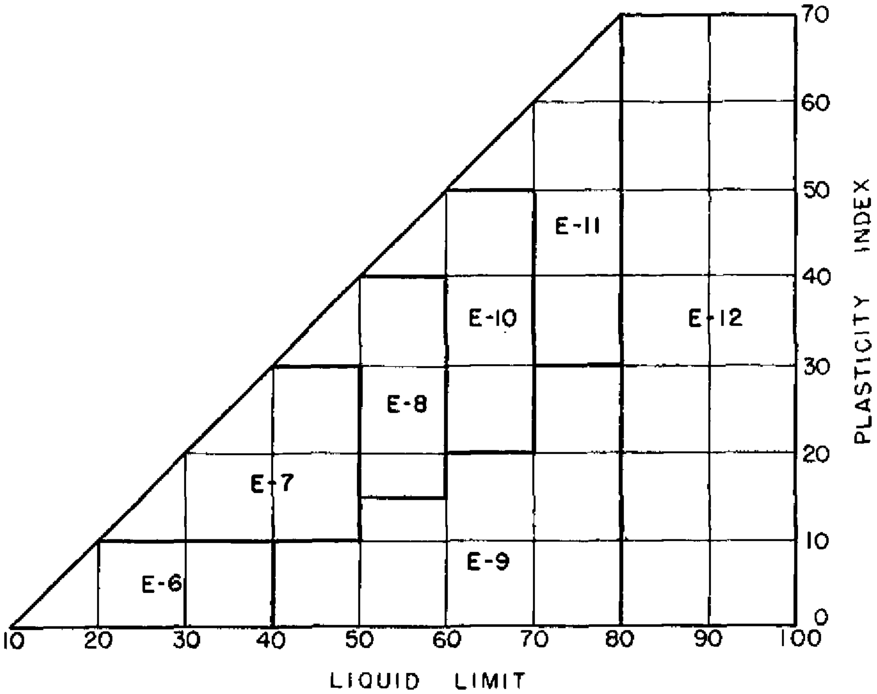


FIGURE 2. CLASSIFICATION CHART FOR FINE GRAINED SOILS

11. COARSE MATERIAL RETAINED ON NO. 10 SIEVE. Only that portion of the sample passing the No. 10 sieve is considered in the above-described classification. Obviously, the presence of material retained on the No. 10 sieve should serve to improve the overall stability of the soil. For this reason, upgrading the soil from 1 to 2 classes is permitted when the percentage of the total sample retained on the No. 10 sieve exceeds 45 percent for soils of the E-1 to E-4 groups and 55 percent for the others. This applies when the coarse fraction consists of reasonably sound material which is fairly well graded from the maximum size down to the No. 10 sieve size. Stones or rock fragments scattered through a soil should not be considered of sufficient benefit to warrant upgrading.

12. SUBGRADE CLASSIFICATION.

a. For each soil group there are corresponding subgrade classes. These classes are based on the performance of the particular soil as a subgrade for rigid or flexible pavements under different conditions of drainage and frost. The subgrade class is determined from the results of soil tests and the information obtained by means of the soil survey and a study of climatological and topographical data. The subgrade classes and their relationship to the soil groups are shown in Table 2. The prefixes "R" and "F" indicate subgrade classes for rigid and flexible pavements, respectively. These subgrade classes determine the total pavement thickness for a given aircraft load. The requirements are fully discussed under rigid and flexible pavement design in following parts of this text. Therefore, only a brief description of the classes will be presented here.

TABLE 2. AIRPORT PAVING SUBGRADE CLASSIFICATION

Soil Group	Subgrade Class		
	Good Drainage	Poor Drainage	
	No Frost or Frost	No Frost	Frost
E-1	Fa or Ra	Fa or Ra	F1 or Ra
E-2	Fa or Ra	F1 or Ra	F2 or Rb
E-3	F1 or Ra	F2 or Rb	F3 or Rb
E-4	F1 or Ra	F2 or Rb	F4 or Rb
E-5	----------	F3 or Rb	F5 or Rb
E-6	----------	F4 or Rc	F6 or Rc
E-7	----------	F5 or Rc	F7 or Rc
E-8	----------	F6 or Rc	F8 or Rd
E-9	----------	F7 or Rd	F9 or Rd
E-10	----------	F8 or Rd	F10 or Rd
E-11	----------	F9 or Re	F10 or Re
E-12	----------	F10 or Re	F10 or Re
E-13	Not suitable for subgrade		

b. Subgrades classed as Fa for flexible pavements and Ra for rigid pavements furnish adequate subgrade support without the addition of subbase material. The soil's value as a subgrade material decreases as the number increases.

c. Good and poor drainage in this classification refers to the subsurface soil drainage.

(1) Poor Drainage is defined for the purpose of this circular as soil that cannot be drained because of its composition or because of the conditions at the site. Soils primarily composed of silts and clays for all practical purposes are impervious and as long as a water source is available the soils' natural affinity for moisture will render these materials unstable. These fine grain soils cannot be drained and are classified as poor drainage as indicated in Table 2. A granular soil that would drain and remain stable except for conditions at the site such as high water table, flat terrain, or impervious strata, should also be designated as poor drainage. In some cases this condition may be corrected by the use of subdrains.

(2) Good Drainage is defined as a condition where the internal soil drainage characteristics are such that the material can and does remain well drained resulting in a stable subgrade material under all conditions.

d. There is a tendency to overlook the detrimental effects of frost in pavement design. The effects of frost are widely known; however, experience shows that all too often pavements are damaged or destroyed by frost that was not properly taken into account in the design. Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weights are frost susceptible for pavement design purposes. The subgrade soil should be classified either as "No Frost" or "Frost" depending on one of the two following conditions:

(1) No Frost should be used in the design when the average frost penetration anticipated is less than the thickness of the pavement section.

(2) Frost should be used when the anticipated average frost penetration exceeds the pavement sections. The design should consider including non-frost susceptible material below the required subbase to minimize or eliminate the detrimental frost effect on the subgrade. The extent of the subgrade protection needed depends on the soil and the surface and subsurface environment at the site.

e. Figure 3 shows the average annual frost penetration throughout the conterminous United States. It is included primarily as a guide. Actual depth of frost penetration should be determined for each particular site on the basis of reliable local information.

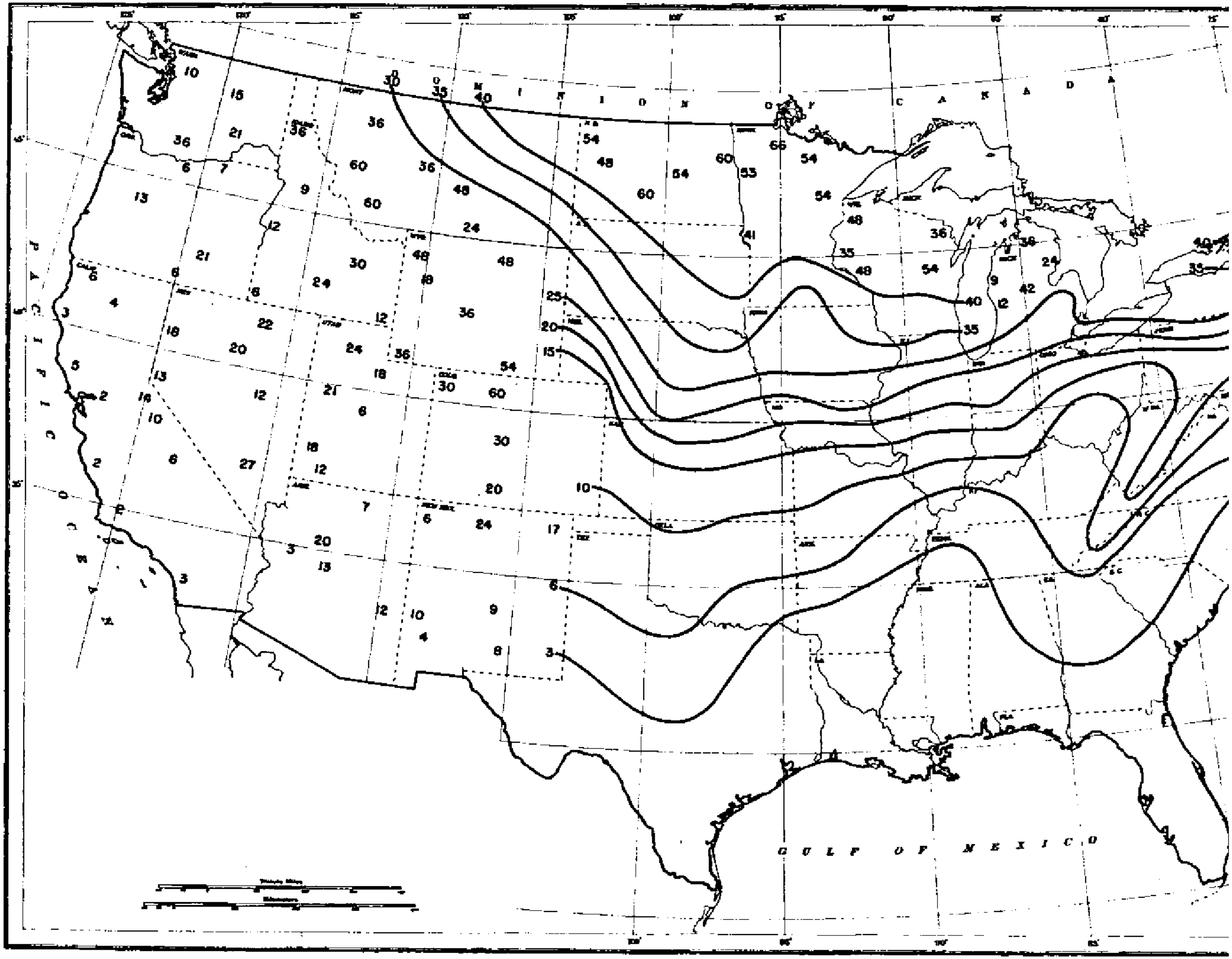


FIGURE 3. AVERAGE DEPTH OF ANNUAL FROST PENETRATION - IN INCHE

f. Subgrade treatment should be considered in the pavement design if one or more of the following conditions exists: poor drainage, adverse surface drainage, or frost. A stabilized or modified subgrade will to some degree make a hard-to-work soil more workable, provide a working platform for construction, act as a moisture barrier between untreated soil and the pavement section, and is frost resistant. The agent for the treatment will depend on the soil and site conditions. Lime is used for most clay, silt, and silt-clay soils, while portland cement and bituminous materials are readily adaptable to some soils.

* g. While the Atterburg limits and mechanical gradation are indicators of inherent soil stability, they are not infallible in this regard. Variations in grain shape, grittiness, etc., influence the stability and performance of a soil under load. The possibility of performance at variance with these tests can be greatly lessened by the use of CBR tests as a supplemental classification procedure. A CBR-F classification and adjustment procedure is shown in Chapter 6, Figure 20 and paragraph 35a. For design purposes, the CBR-F classification can be related to the rigid pavement subgrade classification by reference to Table 2. *

13. SOIL TESTS REQUIRED.

a. A summary of the preceding text discloses that the following tests are required in order to analyze correctly the conditions on the site and to prepare design plans and construction specifications.

(1) Mechanical analysis to show the percentage of coarse sand, fine sand, silt and clay, as well as the amount of material retained on the No. 10 sieve.

(2) Liquid and plastic limit tests.

(3) Maximum density and optimum moisture content determination.

* b. Additional tests, such as those for bearing, shrinkage, permeability, consolidation, in-place density and moisture content should be performed where applicable in order to properly evaluate the performance of a soil (see paragraph 8c). *

CHAPTER 3. PAVEMENT DESIGN

14. GENERAL. This chapter covers pavement design for major civil airports, i.e., airports serving aircraft with gross weights of 30,000 pounds or more. Chapter 5 is devoted to the construction of pavements serving the lighter aircraft with gross weights under 30,000 pounds.

a. Determination of pavement thickness requirements is not an exact science. Although a great deal of research work has been completed and more is underway, it has been impossible to arrive at a formula that would provide a direct mathematical solution of thickness requirements. For this reason the determination of pavement thickness must be based on a theoretical analysis of load distribution through pavements and soils, the analysis of experimental data, and a study of the performance of pavements under actual service conditions. Pavement thickness curves presented in this chapter have been developed from a correlation of the data obtained from these sources. Pavements constructed in accordance with these standards have generally proven satisfactory. Use of the curves is described in paragraphs 17 and 19.

b. Structural design of airport pavements consists of determining both the overall pavement thickness and the thicknesses of the component parts of the pavement. There are a number of factors which influence the thickness of pavement required to provide satisfactory service. These include the magnitude and character of the aircraft loads to be supported, the volume of traffic, the concentration of traffic in certain areas, and the quality of the subgrade soil as a pavement foundation.

(1) Aircraft Wheel Loadings. Practically all large civil aircraft are supported on a tricycle arrangement of landing wheels, consisting of a nose gear and two main undercarriage assemblies. The exact percentage of the gross weight on the main gear undercarriages depends upon the type of aircraft and whether the aircraft is loaded with a forward or aft center of gravity. Recent information on current aircraft indicates that from 88 to 98 percent of the aircraft weight may be distributed to the two main gear undercarriages. This publication considers that 5 percent of the gross weight of the aircraft is supported by the nose wheel and that the remaining 95 percent is distributed equally between the two main undercarriage assemblies. The design curves, based on gross aircraft weight, will cover the three types of main gear assemblies in current civil use (single, dual, and dual-tandem). As new civil aircraft are developed with other gear arrangements, new curves will be developed for them in the same manner as described in Appendix 1

(2) Traffic. It is general practice to design the pavement for "capacity operations" of the most critical aircraft that will normally operate from the airport. The curves presented in this publication are based on this condition.

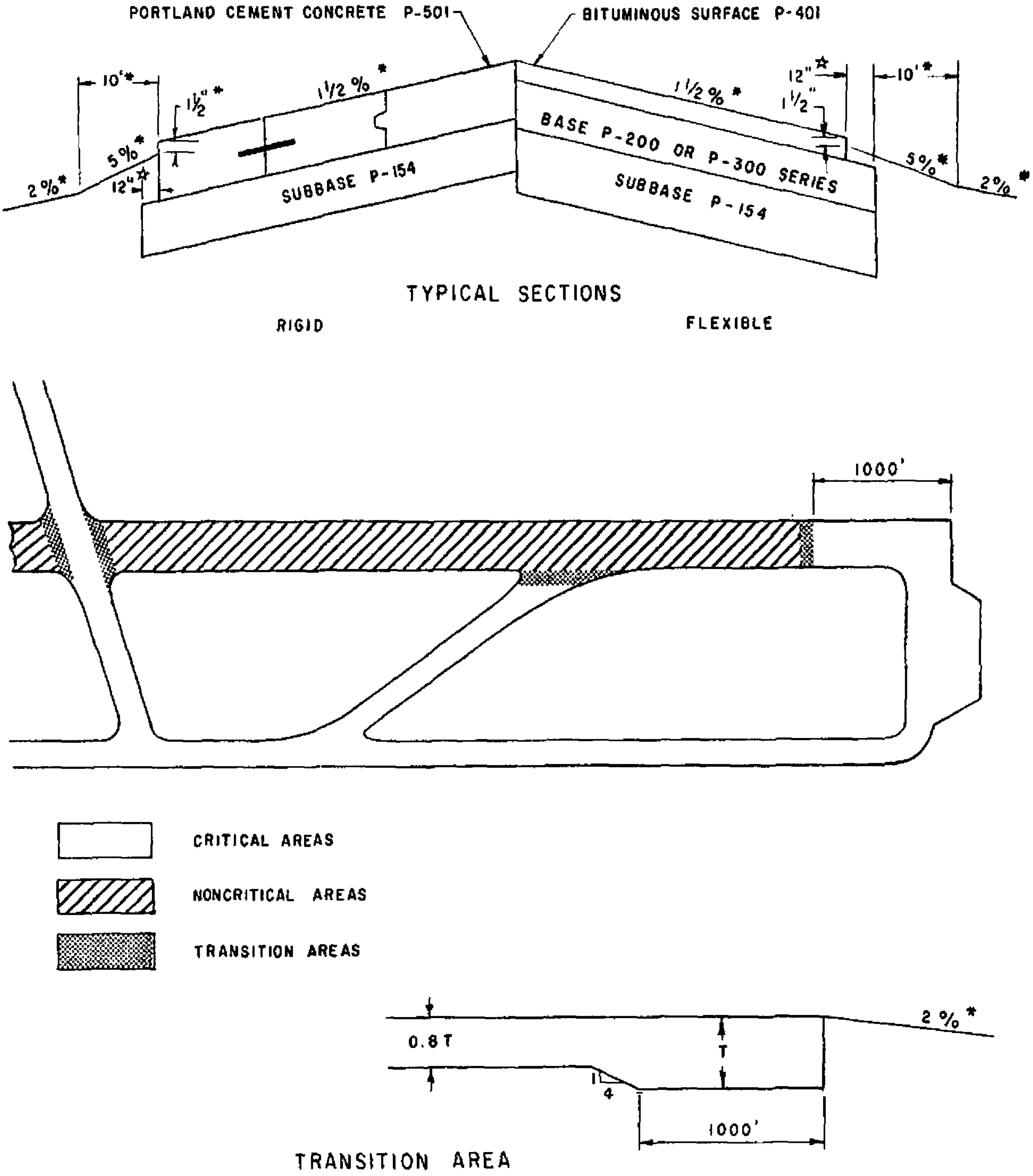
(3) Concentration of Traffic. Airport pavements may be divided * into two or more categories by reason of the thicknesses required to satisfy operating conditions. The areas requiring the thickest pavement (critical areas) are the aprons, taxiways (except certain exit taxiways), and the ends of the runway. In the remaining area of the runway, the noncritical area, the less adverse loading conditions permit a reduction in the required pavement thickness. Such a reduction can result in a considerable saving in both construction effort and funds. Typical layouts and sections are shown in Figures 4 and 5.

(a) Figure 5 illustrates a keel section recommended for runways serving turbojet aircraft primarily. However, the details of Figures 4 and 5 are interchangeable to the extent that the Figure 4 or conventional section can be used for jet runways by substituting 0.9T for the entire noncritical runway area, and the keel section may be used for runways serving propeller driven aircraft primarily by substitution of 0.8T for the 0.9T runway area. The 0.9 factor, as opposed to 0.8, shall be used for the noncritical runway when 25 percent or more of the planned operations will be by turbojet aircraft which gross 90 percent or more of the design weight.

(b) Figure 5 shows a 75-foot keel dimension for the 0.9T noncritical area. Optional sections may include a 50-foot keel with transition to 0.7T over a 25-foot width, a 100-foot keel with transition through the outer 25-foot width only.

(c) The exit taxiway thicknesses shown in Figures 4 and 5 are for typical domestic operations by propeller and jet aircraft, respectively. Gross landing weight shall control the design thickness, per paragraph 14b(3), where these will vary from the standard by more than nominal thickness.

(d) There are certain areas of airport pavements which aircraft normally will not traverse. These areas include blast pads, taxiway and apron shoulders, and certain portions of the terminal apron adjacent to buildings. Normally, the only vehicles that traverse these areas are maintenance vehicles, fuel trucks, snowplows, and baggage carts. These areas shall be designed for their intended use. *

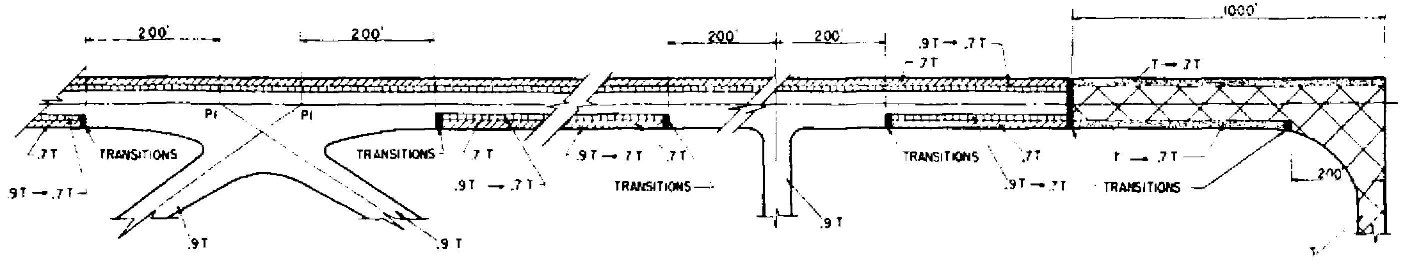


* MAXIMUM

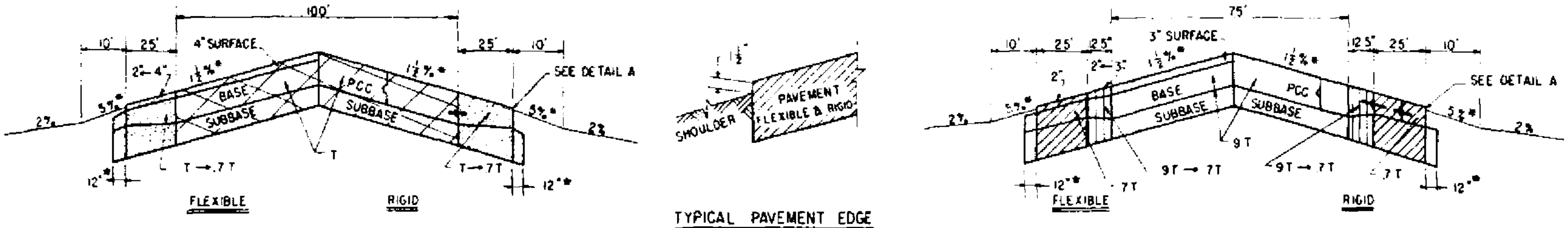
T TOTAL THICKNESS OF FLEXIBLE PAVEMENT OR CONCRETE THICKNESS OF RIGID PAVEMENT.

☆ MINIMUM

FIGURE 4. TYPICAL SECTIONS AND CRITICAL AREAS



RUNWAY CRITICAL OR NONCRITICAL DESIGNATION
RECOMMENDED FOR JET RUNWAYS



CRITICAL
NO SCALE

TYPICAL PAVEMENT EDGE
DETAIL A

NONCRITICAL
NO SCALE

NOTES

1. T = Critical thickness
2. Thickness reductions are applicable to PCC for rigid; to the base and subase courses for the center 75' of flexible and only the base course for the remaining width.
3. Rigid - 6" minimum PCC
4. Flexible - 6" minimum surface plus base course
5. If noncritical R/W or exit T/W pavement areas are used by aircraft taxiing for take-off use "T" in lieu of ".9T"
6. * = Maximum
7. * = Minimum

FIGURE 5. TYPICAL SECTIONS AND CRITICAL AREAS FOR JET AIRCRAFT

5. DESIGN REQUIREMENTS AS AFFECTED BY SOIL PROFILE.

a. In some cases the upper level of the subgrade may exist as a clearly defined thin layer of soil of a much better quality than the underlying soil. Obviously, to design on the basis of the thin upper layer only would be inadequate in many instances. However, it must be realized that the upper layout of superior quality soil, even though thin in section, will provide some benefits which can be utilized in the pavement design. The following paragraphs illustrate the means by which these benefits may be realized. It should be noted, however, that this procedure does not apply when the underlying soil is a swelling soil for which the compaction criteria of FAA Specification P-152 and Figure 8-1 are not achieved. For these soils, see paragraph 16d. *

b. As an illustration, assume the upper layer of soil is designated "A" and the underlying layer is designated "B." If the thickness of layer "A" is insufficient to reduce the stresses imposed on layer "B" to an acceptable level, then an increase in the thickness of subbase is necessary over that which would be required if the soil was composed entirely of layer "A" material. Conversely, the required subbase thickness would be less than the subbase thickness required to protect layer "B" because of some beneficial effect of layer "A."

c. Logically then, the thickness of subbase required to fulfill design requirements under conditions similar to those stated above lies somewhere between the thickness of subbases required for "A" and "B." A method which may be used to determine the subbase requirement on a thin layered subgrade is based on the relationship between the two subbase thicknesses. This relationship is expressed by the formula:

$$z = Y - \frac{t(y-x)}{x+y} \quad \text{in which}$$

z = required thickness of subbase
x = subbase thickness for layer "A" soil
y = subbase thickness for layer "B" soil
t = thickness of layer "A"

(1) It can be seen from the formula that "z" will be less than "x" if "t" is greater than "x" + "y." Therefore, if "t" is equal to or greater than the sum of "x" + "y," the subbase required for layer "A" should be used.

(2) For an example of the application of this formula, determine the subbase thickness required for a taxiway to accommodate a 120,000-pound dual gear aircraft where the subgrade consists of an 8-inch layer of E-3 soil overlaying an E-7 soil. Drainage conditions are poor and no frost problem exists.

Soil Layer	Soil Group	Subgrade Class	Subbase Thickness (Inches)
A	E-3	F2	3 inches
B	E-7	F5	11 inches

$$z = 11 - \frac{8(11-3)}{3+11} = 11 - 5 = 6 \text{ inches}$$

(3) If "t" had been greater than 3+11 = 14 inches, the subbase requirements would have been that as required for layer "A", i.e., 3 inches. The same principle may be applied for both flexible and rigid pavements.

d. This illustrates the manner in which economic advantage may be gained by use of selective grading. If superior material is available on the site, it may be economical to remove inferior material, or a portion thereof, and replace it with the superior material thereby reducing the subbase thickness requirements.

16. FLEXIBLE PAVEMENTS. Flexible pavements consist of a bituminous wearing surface placed upon a base course and, when required by subgrade conditions, a subbase. Figures 4 and 5 show a typical cross-section of a flexible pavement.

a. The bituminous surface or wearing course must prevent the penetration of surface water to the base course; protect the base from raveling and disintegration caused by various abrasive effects of traffic; provide a smooth, well-bonded surface free from loose particles which might endanger aircraft or persons; resist the shearing stresses occasioned by aircraft loads; and furnish a texture of nonskid qualities, yet not cause undue wear on tires.

(1) To successfully fulfill these requirements, the surface must be composed of mixtures of aggregates and bituminous binders which will produce a uniform surface of suitable texture possessing maximum stability and durability. Since control of the mixture is of paramount importance, these requirements can best be achieved by use of a central mixing plant where proper control can be most readily obtained. A dense-graded, bituminous concrete such as Item P-401 produced in a central mixing plant will most satisfactorily meet all the above requirements.

(2) Wherever a flexible pavement is to be subjected to concentrated fuel spillage or other solvents, as at aircraft loading positions and maintenance areas, protection should be provided by use of a solvent resistant seal coat such as Item P-625. A seal coat may be desirable in other operational areas for protection of the pavement structure. Seals on newly paved runway surfaces, when used, should be limited to the chip variety in order to achieve the needed visibility and skid-resistant properties.

b. The base course is the principal structural component of the flexible pavement. It has the major function of distributing the imposed wheel load pressures to the pavement foundation, the subgrade. The base course must be of such quality and thickness to prevent failure in the subgrade, withstand the stresses produced in the base itself, resist vertical pressures tending to produce consolidation and resulting in distortion of the surface course, and resist volume changes caused by fluctuations in its moisture content.

* (1) These qualities of the base course depend upon composition, physical properties and compaction, and individual materials which make up the mixture. Many materials and combinations thereof have proved satisfactory as base courses. They are composed of select, hard and durable aggregates blended with binders or fillers of approved types so as to produce a uniform mixture which will meet specifications as to gradation and soil constants and to permit compaction into a dense, well-bonded mass. *

(2) Specifications covering the quality of components, gradation, manipulation, control, and preparation of various types of base courses for use on airports for design loads above 30,000 pounds gross aircraft weight are as follows:

(a) Item P-201 - Bituminous Base Course

(b) Item P-209 - Crushed Aggregate Base Course

(c) Item P-210 - Caliche Base Course

(d) Item P-211 - Lime Rock Base Course

(e) Item P-212 - Shell Base Course

(f) Item P-214 - Penetration Macadam Base Course

* (g) Item P-215 - Cold Laid Bituminous Base Course *

(h) Item P-304 - Cement Treated Base Course

* (3) Experience has shown that when high quality aggregates are used, asphalt and portland cement treatments produce bases that are more effective than untreated bases. In recognition of the superior effectiveness of such bases, one inch of treated base material is considered to be equivalent to 1.5 inches of untreated base material and may be substituted in the pavement construction on this basis. These reductions are applicable only when high quality base courses, specifically Item P-201, "Bituminous Base Course," and Item P-304, "Cement Treated Base Course," are used. However, the minimum permissible thickness of bituminous base course is 4 inches and the minimum permissible thickness of cement treated base course is 6 inches, in either critical or noncritical areas. *

c. A subbase is included as an integral part of the flexible pavement structure in all pavements except those on subgrades classified as Fa. The function of the subbase is similar to that of the base course. However, since it is protected by the base and surface courses, the material requirements are not as strict as for the base course.

(1) Specification Item P-154, "Subbase Course," covers the quality gradation, control, and preparation of the standard subbase course.

(2) Certain materials that are permitted only for base courses for pavements serving aircraft with gross weights of less than 30,000 pounds may be used as subbase courses for the larger aircraft. They are:

* (a) Item P-206 - Dry-Bound Macadam Base Course or Water-Bound Macadam Base Course

(b) Item P-208 - Aggregate Base Course

(c) Item P-213 - Sand-Clay Base Course

(d) Item P-216 - Mixed In-Place Base Course

(e) Item P-301 - Soil Cement Base Course *

* (3) When the material Items P-201 and P-304 are used as base courses, they may be used as subbase also on the basis that one-inch of P-201 or P-304 is equivalent to 1-1/2 inches of the approved subbase materials.

d. <u>The subgrade soils</u> are subjected to the same stresses, though to a lesser degree, as the surface, base, and subbase courses. These imposed stresses decrease with depth and are most critical at the top of the subgrade, unless unusual conditions prevail, such as a layered subgrade (see paragraph 15) or water content and/or density vary sharply with depth. These conditions should be checked during the soils investigation. The ability of a particular soil to resist shear and deformation is dependent on the soil density and moisture content.

(1) Specification Item P-152, Excavation and Embankment, covers the construction and density control of subgrade soils. Figure 8-1 shows depths below the subgrade surface to which compaction controls apply.

(2) Noncohesive soils, for the purpose of determining compaction density and depth, are those for which no plastic index is discernible in the Atterburg tests, or for which the moisture-density curve is either reversed or a straight line.

(3) For most soils, moisture-density curves show the water content at which the desired density can be most easily achieved. These soils when so compacted will provide a satisfactory level of in-place stability and will have voids and voids filled percentages that limit the detrimental effects of added available water. Some soils, when compacted to the optimum modified AASHO densities, due to chemical attraction or a low voids filled to voids ratio, will attract available water and swell. The swelling is accompanied by extreme loss in bearing value. Soils of this type shall be stabilized or modified where possible to the extent required to preclude the swelling. Where this is impractical, compaction with additional water to lower densities will minimize swelling, but will reduce bearing values. When this procedure is followed, the pavement section shall be increased by the increment shown in Figure 8-1 as the difference between the FAA Specification T-611 density required and achieved. The additional material may consist of a suitable nonswelling borrow or added subbase, compacted to the required Figure 8-1 densities. Exceptions may be considered as follows: *

* (a) For flexible pavement design based on CBR tests performed in the manner prescribed in MIL-STD-621A and converted to FAA subgrade class per Figure 20, no thickness adjustment is required. A transition or working platform to permit the required subbase compaction to 100 percent density may be specified, not to exceed 6 inches in thickness for each 5 percent density difference in excess of 5 percent.

(b) For rigid pavement design (using plate bearing tests in the manner prescribed in MIL-STD-621A and in paragraph 19b) no thickness adjustment is required. A working platform may be specified as in (a) above.

(c) For application of CBR to rigid pavement design, see paragraphs 12g and 35a.

(d) For heavy load pavements and for extensive areas, methods (a) and (b) above are the recommended design procedures.

(4) When P-201 and P-304 are used for subbase over swelling soils, they may be used for added subbase as required in (3) above on the same basis; i.e., one inch of P-201 or P-304 for each 1-1/2 inches of added subbase required. Other stabilized materials may be used for added subbase on a one-for-one basis.

(5) Example. For an apron extension to accommodate a 340,000-pound dual-tandem geared aircraft, a soils investigation has shown the subgrade will be F1 and noncohesive. In-place densities of the B horizon soils have been determined at even foot increments below the ground surface. Design calculations indicate that the top of subgrade in this area will be approximately 10 inches below the existing grade. Depths and densities may be tabulated as follows:

Depth Below Existing Ground	Depth Below Finished Subgrade	In-Place Density
1'	2"	70 %
2'	14"	84 %
3'	26"	86 %
4'	38"	90 %
5'	50"	93 %

In Figure 8-1, project a line downward from 340,000 pounds on the dual tandem scale; and from the point of intersection with the line representing each density requirement project a line to the noncohesive compacted subgrade depth scale. *

* Reference to the tabulation shows that for this example, in-place density is satisfactory at a depth of 38 inches, being 90 percent and within the required 90 percent zone. It will be necessary to compact an additional 2 inches at 90 percent, 15 inches at 95 percent, and the top 21 inches of subgrade at 100 percent density. With modern compaction equipment, these densities can usually be achieved from the surface in a noncohesive soil. *

17. DESIGNING THE FLEXIBLE PAVEMENT. Due to the variation in stress distribution of single, dual, and dual-tandem gear aircraft as discussed in Appendix 1, separate flexible pavement design curves for each of these gear arrangements have been prepared as shown in Figures 6, 7, and 8, respectively.

a. Figure 4. Figures 6, 7, and 8 are used to obtain the total critical pavement thickness, "T," and surface course requirements. To obtain the noncritical pavement thickness, the critical pavement base and subbase courses are reduced by a factor of .8T. The noncritical surface course requirements are noted in Figures 6, 7, and 8. For fractions of an inch of .5 or more, use the next higher whole number; and for less than .5, use the next lower number.

b. Figure 5. Figures 7 and 8 are used to obtain the total critical pavement and surface course thickness for the area designated as * "T" in Figure 5. The .9T factor for the noncritical pavement applies to the base and subbase courses. The surface course is noted in Figures 7 and 8. For the variable section of the critical, transition section, and thinned edge of the noncritical section, the reduction applies only to the base course. The .7T thickness for subbase shall be the minimum permitted, and the subbase thickness shall be increased and/or varied to provide positive surface drainage from the entire subgrade surface. Use the same procedure outlined in paragraph 17a for rounding off fractions to whole numbers. For optional use of Figures 4 and 5 and for optional keel widths, see paragraph 14.3(b). *

c. Example. As an example of the use of these design curves and Figure 5, assume that a jet aircraft on dual gear has a gross weight of 140,000 pounds, and the soil classification is E-7 with * poor drainage and 42 inches of frost penetration. From Table 2, the subgrade classification would be F5 or F7, depending on whether or not frost will penetrate the subgrade. In this case, the classification will be F7. *

(1) Enter Figure 7 on the left at 140,000 pounds gross weight and proceed horizontally to the intersection with subgrade classification F7 and then proceed vertically downward to the total pavement thickness scale. In this case, the 140,000-pound dual aircraft for an F7 requires 32 inches of pavement thickness.

(2) Go back to the intersection of the 140,000-pound gross weight line and the F7 subgrade classification line, proceed to the right, parallel with dashed lines, to the intersection of the required base thickness line and read 10 inches for the critical area. A 4-inch surface is required by this chart. The balance of the total thickness requirement is subbase, in this case 18 inches.

(3) The total pavement thickness for noncritical is obtained by taking .9 of the critical pavement base and subbase courses plus the required surface course thickness. The thinned edge portion of the critical and noncritical pavement .7T factor applies only to the base course as the subbase must be increased to provide transverse subgrade drainage. The transition section and surface course requirements are noted in Figure 5.

(4) The final requirements of the dual gear aircraft are:

	"T" CRITICAL AREAS	.9T NONCRITICAL AREAS	.7T EDGE AREAS
Surface	4"	3"	2"
Base	10"	9"	7"
Subbase	18"	16"	19" 2/
Frost Protection 1/	4"	8"	8"
TOTAL	36"	36"	36"

1/ Full depth frost protection shall be provided for the primary runway(s) at large hub airports. For other paved areas, protection shall be provided for depths between 65 percent and 90 percent of the total frost penetration. The degree of protection provided shall be determined considering the frost susceptibility of the underlying material, depth to water, the extent to which variable soils will contribute to differential heaving, and local experience with the construction materials being used.

2/ See discussion, paragraphs 17b and 19c.

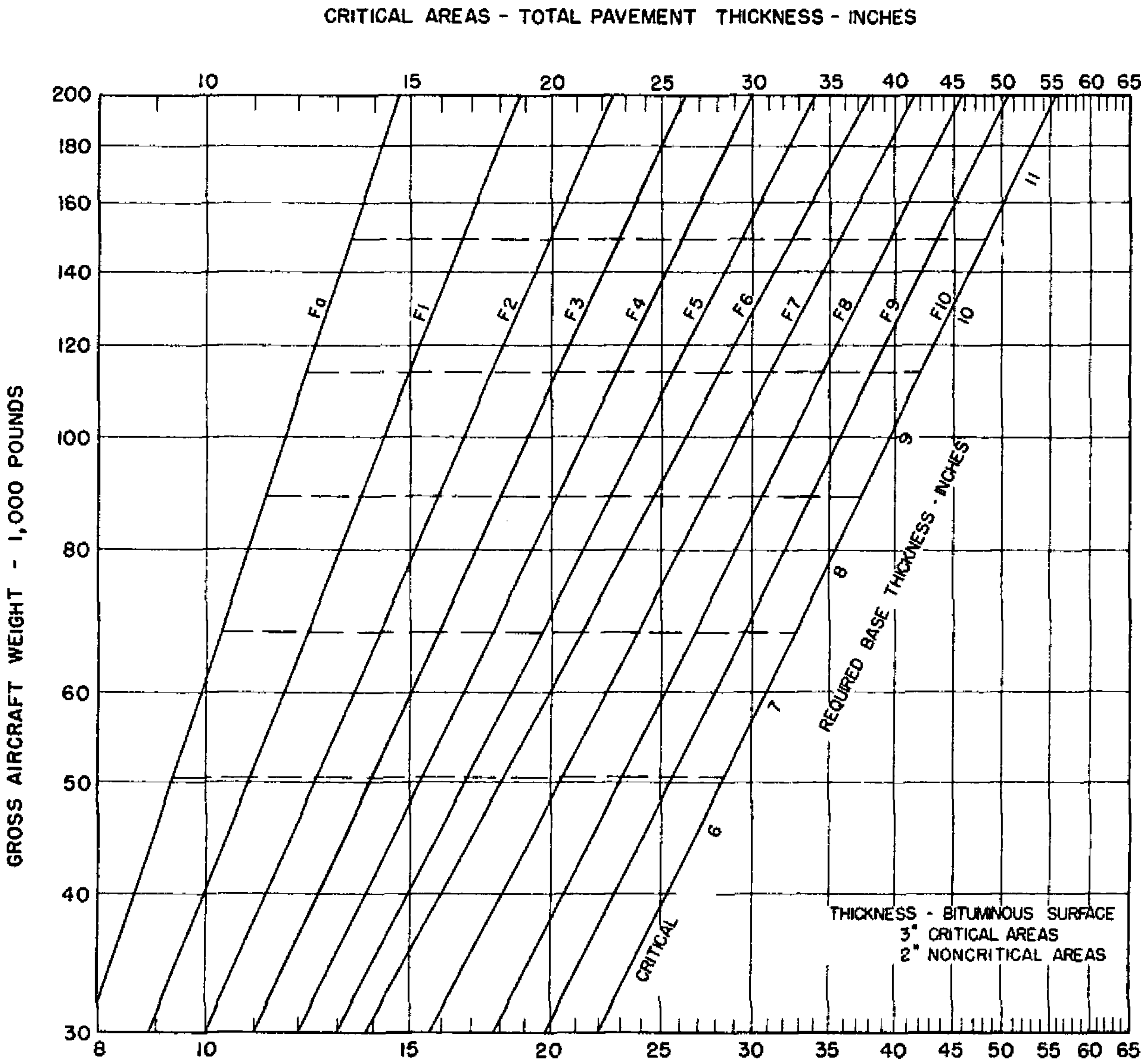


FIGURE 6. DESIGN CURVES - FLEXIBLE PAVEMENT - SINGLE GEAR

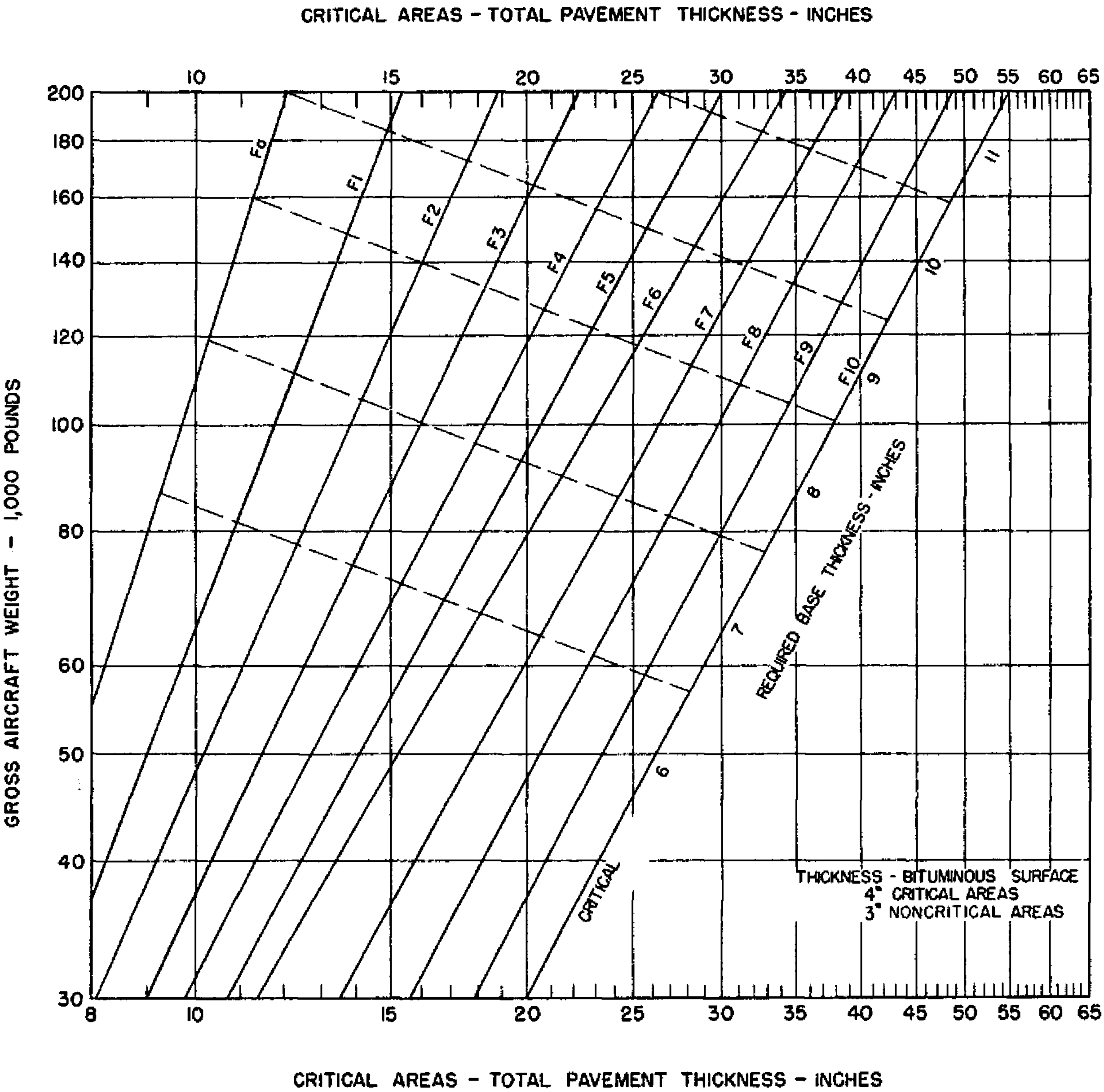


FIGURE 7. DESIGN CURVES - FLEXIBLE PAVEMENT - DUAL GEAR

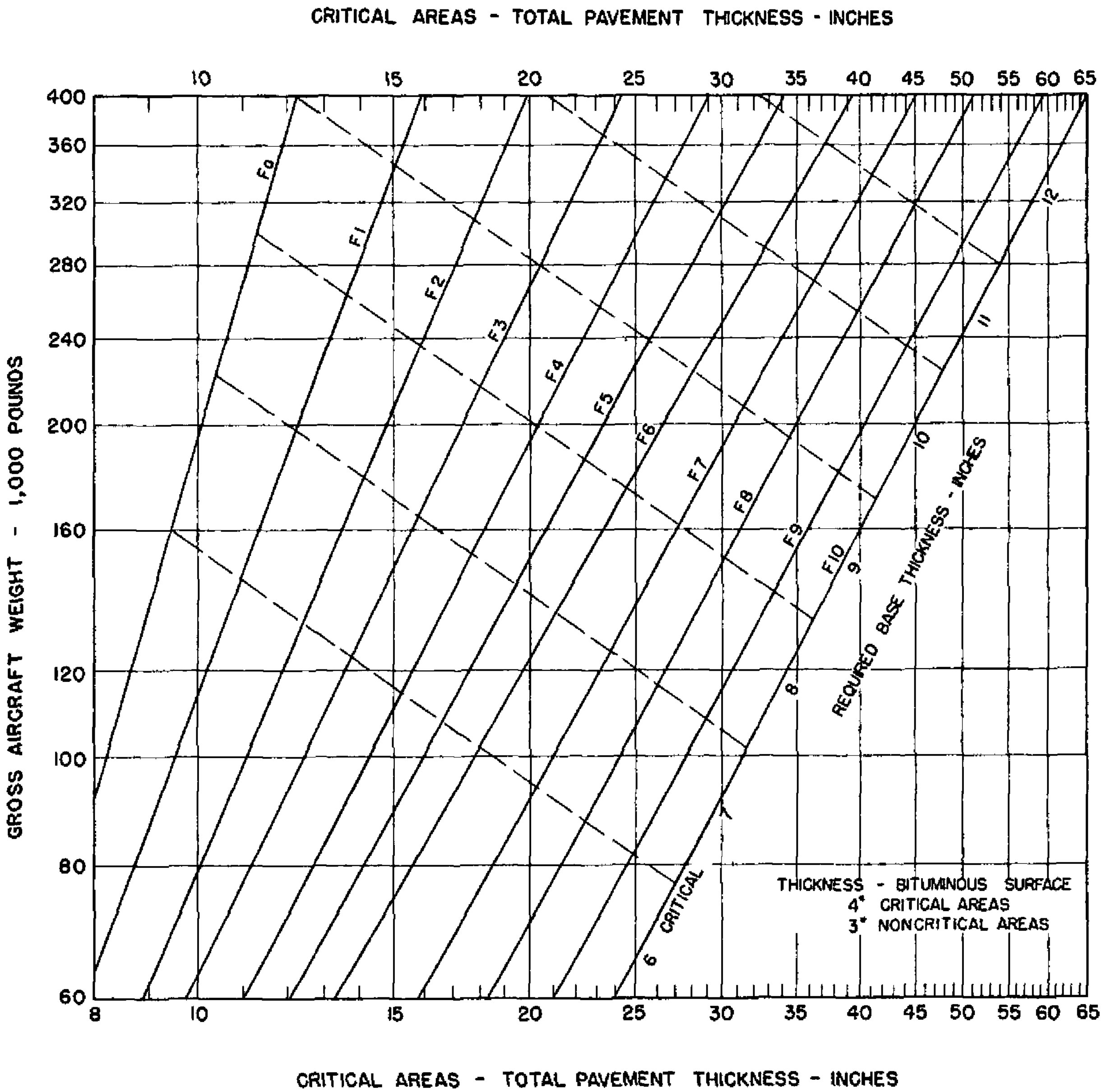
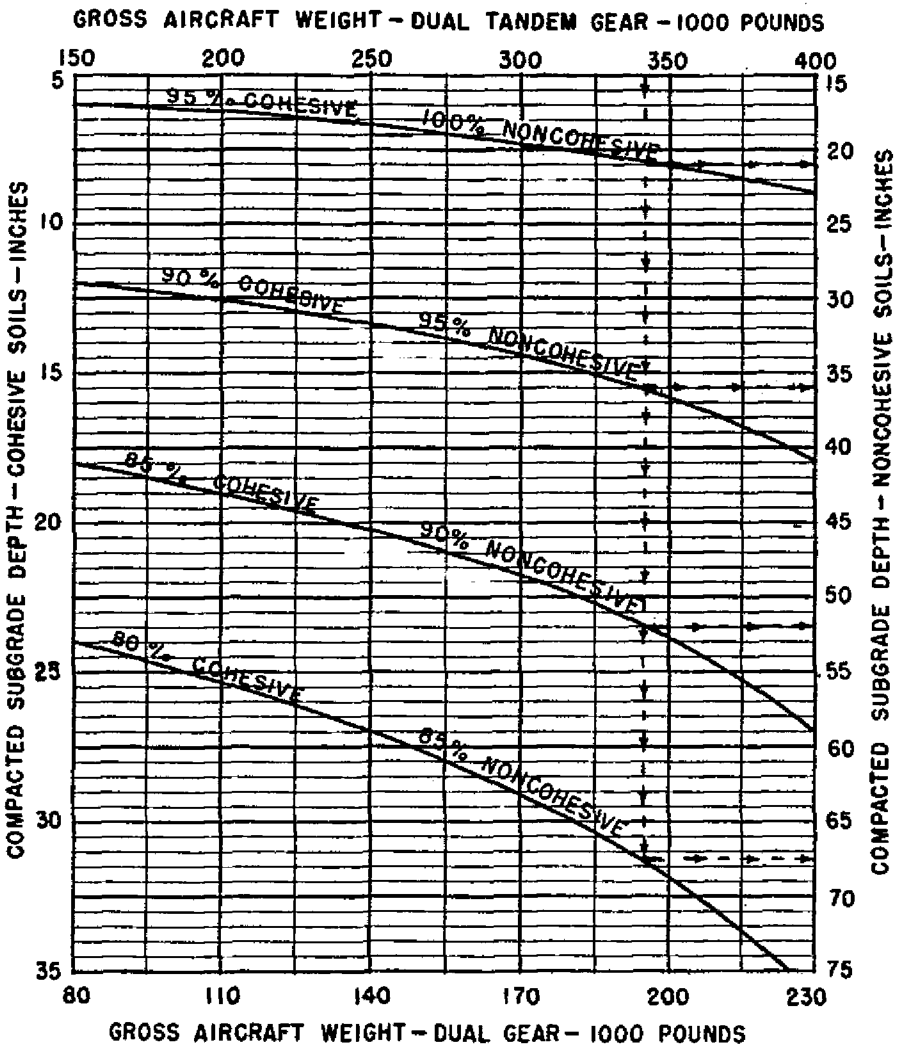


FIGURE 8. DESIGN CURVES - FLEXIBLE PAVEMENT - DUAL-TANDEM GEAR



NOTES:

1. Curved lines denote depths below the finished subgrade above which densities must equal or exceed the indicated percentage of the maximum density at optimum moisture as determined by the FAA compaction control T-611.

2. For embankment areas the charted criteria shall be met except that the minimum density of soils placed in fill shall be 90% for cohesive and 95% for noncohesive, and for the top nine inches in fill shall be not less than 95% for cohesive and 100% for noncohesive, of the T-611 density.

3. The subgrade in cut areas shall have natural densities equal to or greater than the densities shown or shall (a) be compacted from the surface to achieve the required densities, (b) shall be removed and replaced in which case the minimum densities for fills apply, or (c) when economics and grades permit, be covered with sufficient select or subbase material so that the uncompacted subgrade is at a depth where the in-place densities are satisfactory.

4. Where a noncohesive soil of F class 3 or 4 may exist, the difference in subbase thickness required in excess of that required for an F_2 soil may be deducted from the required subgrade compaction depths.

5. For swelling soils, reduced densities may be used in accordance with paragraph 16d. When reduced densities are employed, Figures 21, 22, and 23 shall be used for rigid pavement design.

FIGURE 8-1. SUBGRADE COMPACTION REQUIREMENTS FOR HEAVY AIRCRAFT

(5) In the preceding example, the design is for a jet aircraft using the criteria shown in Figure 5. If the design had been for a conventional aircraft, the pavement should conform to the criteria outlined in Figure 4. The .8T factor used to obtain the noncritical thickness applies to both the base and the subbase. The pavement sections as obtained from Figures 6, 7, and 8, and reduction required in Figures 4 and 5 provide only minimum thickness and do not provide for frost protection of the subgrade as previously discussed in Chapter 2, paragraph 12d(2).

d. <u>Considerations for Thin Subbases</u>. Where a pavement is to be constructed on an excellent subgrade, the subbase thickness requirement may be less than 3 inches. Where a subbase is less than 3 inches thick, it is recommended that additional base course be substituted for the thin subbase in the proportion of 1 inch of base course for each 1-1/2 inches of subbase. The final decision usually depends on the thickness of the subbase course and economic consideration as they are affected by construction problems, materials, and frost penetration.

* e. <u>Design Based on CBR</u>. When considered to be advantageous, California Bearing Ratio tests of the subgrade soils, made in accordance with the procedures discussed in paragraph 35a, may be used in the design of flexible pavements. The application of CBR test results to the F classification in Table 2 shall be the same as is spelled out for the evaluation procedure. *

18. <u>RIGID PAVEMENTS</u>. Rigid pavements for airports are composed of portland cement concrete placed upon a granular or treated subbase course that rests upon a compacted subgrade. An exception is made if the subgrade falls in the Ra classification, in this case no subbase is required.

a. The quality of the concrete, the mixes, the control tests, methods of construction and handling, and quality of workmanship are covered in detail in Item P-501, "Portland Cement Concrete Pavement."

b. The materials suitable for subbase courses under rigid pavements are covered in Item P-154, "Subbase Course," and Item P-301, "Soil Cement Base Course." Some of the benefits derived from the subbase course are:

(1) Increases the support and provides a more uniform bearing of the portland cement concrete pavement.

(2) Eliminates pumping action.

(3) Minimizes effects of volume changes in subgrade soils.

(4) Prevents detrimental effects of frost action.

*19. DESIGNING THE RIGID PAVEMENT. Two methods for determining rigid pavement thickness requirements are available. Separate design curves for each of the gear configurations (single, dual, dual-tandem) are prepared as shown in Figure 9 and discussed in Appendix 1. These are based on conservative assumptions and are recommended for limited areas of work. When economics or unusual soil conditions warrant the testing and investigation necessary to more closely determine the design requirements, rigid pavement thickness may be determined from Figures 21, 22, and 23 in Chapter 6.

a. Rigid Pavement for Critical Areas - Figure 9. Rigid pavement thickness for critical areas is read from the top group of design curves given in Figure 9. The thickness of the concrete pavement is figured independently of the subgrade classification. After determining the required thickness of the concrete pavement and knowing the subgrade classification, the bottom group of design curves is used to determine the subbase thickness. When the figure shows concrete thickness in fractional inches, the design thickness should be increased to the next full inch from fractions of an inch of .3 or more and reduced to the lower full inch from fractions of less than .3 inch. Pavement thickness thus increased by .5 inch or more may be compensated for by a reduction of 1 inch in subbase thickness.

b. Rigid Pavement for Critical Areas - Figures 21, 22, and 23. In addition to the soils survey, analysis, and classification discussed in Chapter 2, rigid pavement design by application of Figures 21, 22, and 23 requires additional testing and design procedures as explained below.

(1) Determination of the Modulus of Soil Reaction (k value) should be measured at the top of subbase (or Ra subgrade) and determined by construction to required densities of a limited test section. The section should consist of the design subgrade and subbase material and utilization of plate bearing test procedures specified in Military Standard MIL-STD-621A, Subgrade, Subbase, and Test Method for Pavement Base-Course Materials.

(2) Determination of the design flexural strength should be reduced by a safety factor of 1.75 to compute working stress for critical area pavement. The stress scale in Figures 21, 22, and 23 is the working stress.

(3) Flexural stress and k values may be investigated through a range of pavement and subbase thicknesses to arrive at the most economical section without regard to subgrade class. A minimum 4-inch subbase shall be used, however, for any subgrade classified as poor drainage. *

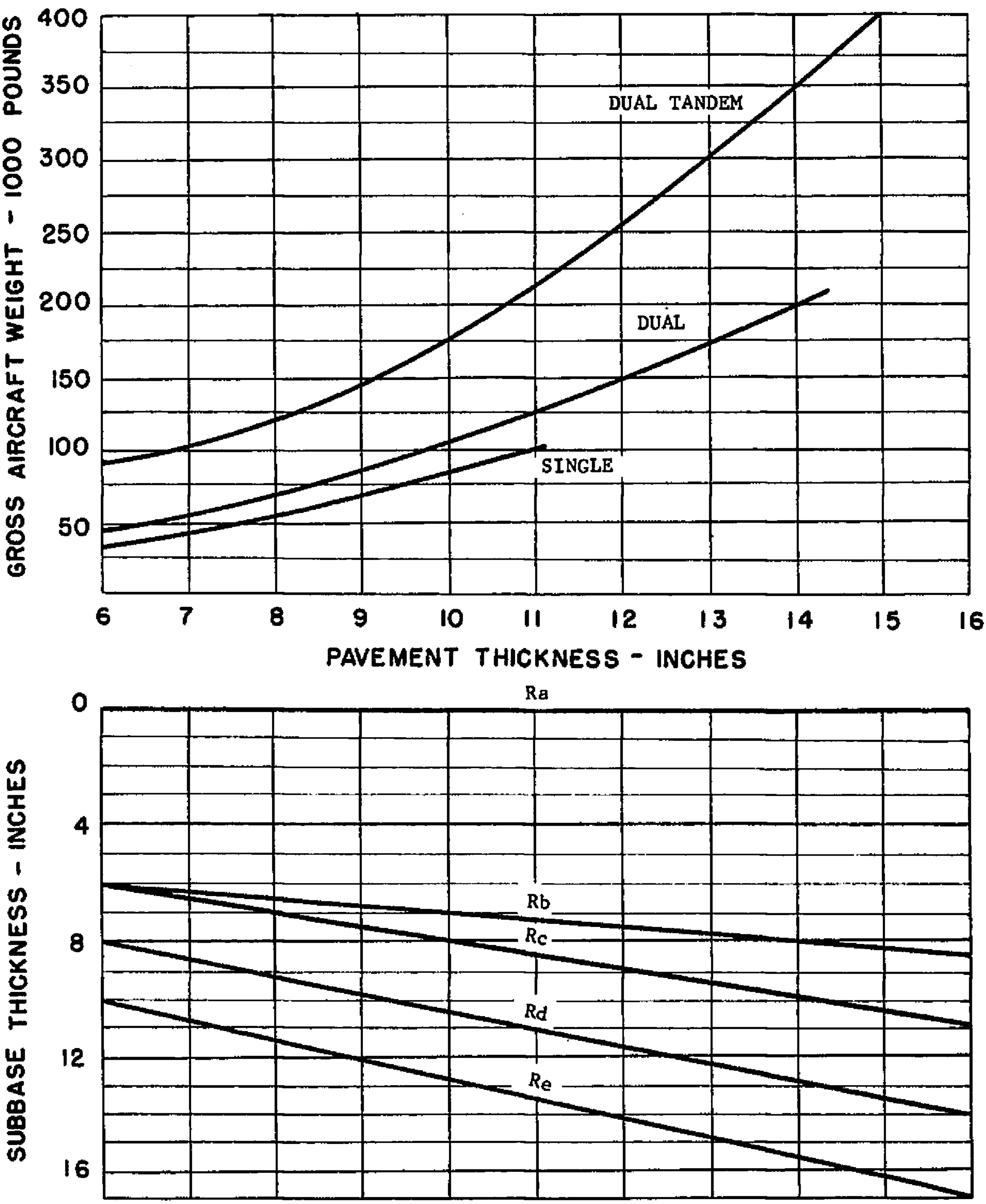


FIGURE 9. DESIGN CURVES - RIGID PAVEMENT - CRITICAL AREA

(4) It is recommended, and particularly for frost areas, that the PCC be designed for at least 700 p.s.i. flexural strength at 90 days. Where laboratory procedures are used to provide mix design and cement factor, beams shall be cast in accordance with ASTM C 192 and tested in accordance with ASTM C 78.

c. Rigid Pavement for Noncritical Areas. Noncritical area pavement is constructed to thicknesses of 0.9, 0.8, or 0.7 of the critical pavement thickness "T" depending on traffic type and relative location. See Figures 4 and 5. For the 0.9T and 0.8T factors, subbase thickness is not reduced. For the 0.7T factor, subbase is increased as required to provide the same total pavement thickness as for the adjacent pavement and subbase combination. Exceptions to the subbase requirement may be made in arid regions (see paragraph 20b) but no reduction in subbase thickness shall be provided which would preclude positive drainage of the subgrade surface.

d. Example Using Figure 9. Assume the design critical aircraft is propeller driven on dual gear, gross weight 160,000 pounds, with E-7 soil and no frost. From Table 2 the subgrade class is Rc.

(1) From Figure 9, the required thickness of concrete pavement for the 160,000-pound dual aircraft is 12.5 inches. This figure is obtained by proceeding horizontally from the 160,000-pound gross weight scale to the intersection with the dual curve then proceeding vertically downward to the pavement thickness scale.

(2) The subbase thickness is determined by proceeding vertically downward from 12.5 inches to the intersection with the Rc subbase curve and then proceeding horizontally to the left to the subbase thickness scale. The required thickness of the subbase (approximately 9 inches in this case) is obtained.

(3) The required pavement thickness for noncritical areas is obtained by taking 80 percent of the required critical area pavement thickness.

(4) Fractional thicknesses of portland cement concrete of .3 or more are rounded to the next higher full inch, and for the .5 inch increase in this example, a 1-inch reduction in subbase is appropriate. The design thickness becomes:

	160,000 POUND DUAL	
	Critical Area	Noncritical Area
Pavement	12.5" use 13"	12.5 x 0.8 = 10.0"
Subbase	9" - 1" = 8"	9"

* (5) In the above example, if the soil classification had been E-8 instead of E-7, the subgrade classification would have been Rd (see Table 2). The concrete thickness requirement would remain the same but the subbase thickness would have been 12 inches instead of 9 inches. Also note that the noncritical pavement thicknesses are computed from the charted thickness prior to rounding off.

e. Example Using Figure 22. For the same aircraft and soil as the previous example, assure additional design effort has been made and that a test section has shown k values of 170 on a 6-inch subbase and 210 on a 9-inch subbase. A subbase thicker than shown in Figure 9 would not normally be used. Concrete design strength of 700 p.s.i. at 90 days is selected.

(1) Enter Figure 22 at the 400 p.s.i. stress point of the left hand vertical scale and proceed across to the 210 k line. From this line (interpolated between 200 and 300 k) move vertically to the 160,000-pound load line. From this point proceed horizontally to the pavement thickness scale on the right. The required pavement thickness is 12.8 inches and 13 inches critical pavement will be used. The .8T factor applied to the noncritical area pavement results in a 10.2-inch section requirement rounded off to 10 inches.

(2) Similar analysis for the 170 k value results in a critical area pavement thickness of 13.1 inches (13 inches would be used) and 0.8 noncritical thickness of 10.5 inches rounded off to 11 inches.

(3) Additional design options remain which may be applied, such as:

(a) Working from the 13-inch slab thickness proceed horizontally to the load line and vertically to intersect the 400 p.s.i. stress line. These intersect at the 190 k reaction line. This would permit a reduction in subbase thickness of 1 inch, as a conservative application of assumed linear relationship between the subbase and k values investigated.

(b) Again working from the 13-inch slab thickness as above, intersect the 170 k line and read a working concrete stress of 408 p.s.i. This section and 6-inch subbase require a 715 p.s.i. flexural strength to satisfy the design requirement. *

(4) The four design options and thicknesses are charted below.

k	s	Critical Area Slab	Subbase	Noncritical (0.8) Area Slab	Subbase
210	700	12.8" use 13"	9"	10.2" use 10"	9"
190	700	13"	8"	10.4" use 11"	7"
170	700	13.1" use 13"	6"	10.5" use 11"	5"
170	715	13"	6"	10.4" use 11"	5"

Since any of these design approaches are considered satisfactory, the design decision should be made primarily on a cost comparison basis. Additional consideration based on cost would be needed for frost protection as discussed below, subgrade stabilization, etc.

20. SPECIAL DESIGN CONSIDERATIONS.

a. Increase in Subbase Thickness Due to Frost. There may be locations and conditions where the combined thickness of portland cement concrete and subbase course is not adequate to prevent frost heave which would result in pavement deterioration. Where such a condition exists, the thickness of the subbase course should be increased over that which results from the use of curves. The total thickness of pavement required in such a case should be determined from a study of conditions prevailing at the site. Portland cement concrete has considerable insulating value which has the effect of reducing the depth of penetration of frost. This beneficial insulating effect should be considered in all areas where frost might be encountered. For purposes of rigid pavement design, frost penetration may be reduced by an amount equal to one-half the thickness of concrete slab.

b. Decrease in Subbase Thickness. In arid regions, subbase course thickness may be reduced below that shown in Figure 9, but not less than 4 inches. Such reduction, however, must be predicated upon knowledge of the particular subgrade soil as a rigid pavement foundation.

21. JOINTS IN CONCRETE PAVEMENT. Variations in temperature and moisture content cause volume changes in concrete pavements. These volume changes produce compressive, tensile, and flexural stresses. In order to reduce the effects of these stresses and to minimize random cracking, it is necessary to divide the pavement into a series of slabs of predetermined dimensions by means of joints.

a. Joint Types. A joint can be placed in a specific category depending upon its principal function or its purpose in the pavement. The categories are expansion, contraction, and construction joints. No matter which type of joint is installed, it should be finished in a manner that permits the joint to be sealed. The types of joints are shown in Figures 10 and 11 and summarized in Table 3. These various joints are described as follows:

(1) Expansion Joints. The function of an expansion joint is to provide space for the expansion of the pavement, to isolate pavement intersections, and to isolate structures from the pavement. There are two types of expansion joints.

(a) Type A is used when load transfer between the slabs of the pavement is required. This joint contains a 3/4-inch nonextruding compressible material and is provided with dowel bars for load transfer.

(b) Type B is used when load transfer is not practicable; such as, where the pavement abuts a structure or where horizontal differences in movement of the pavements may occur. These joints are formed by increasing the thickness of the pavement along the edge of the slab. No dowels are provided.

(2) Construction Joints. Construction joints are those joints which occur as a result of the construction operations. Proper construction joints are shown as Types C, D, and E in Figures 10 and 11.

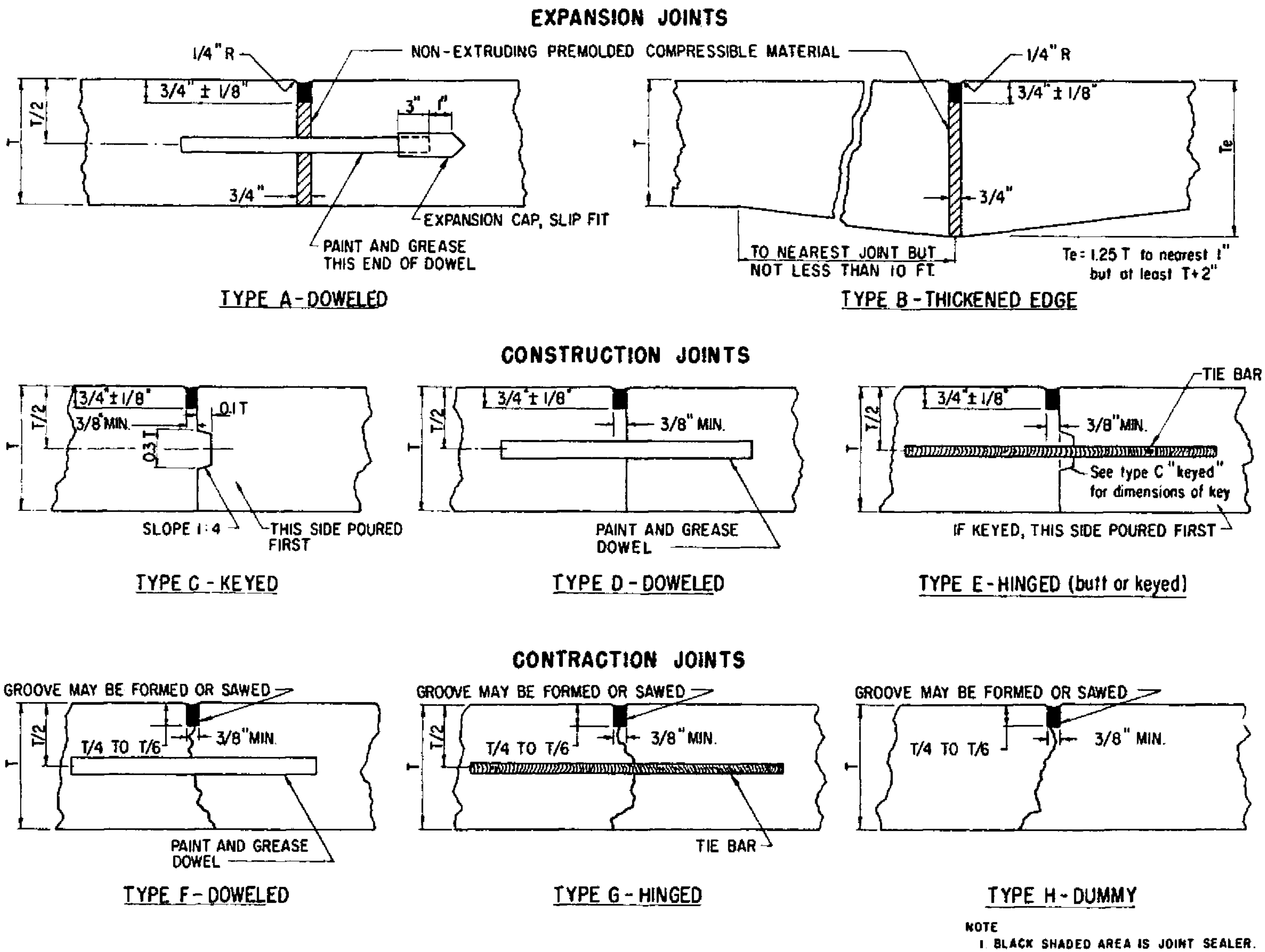
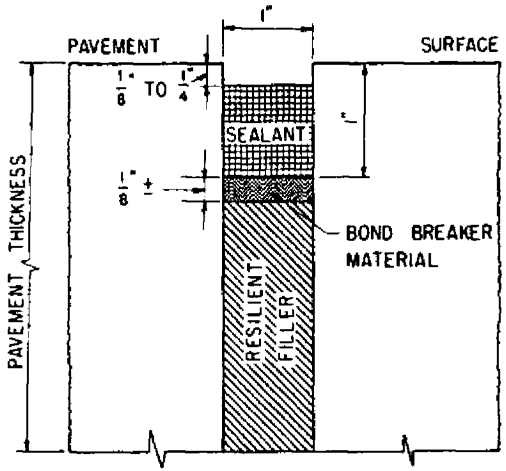
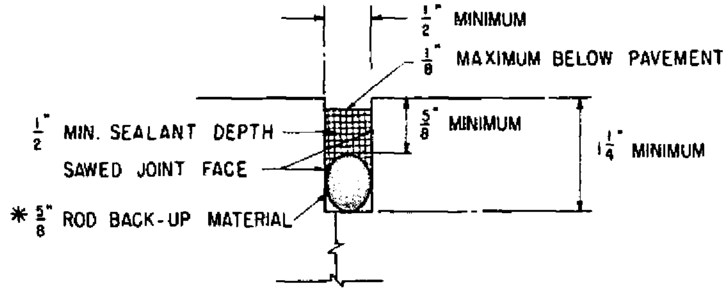


FIGURE 10. DETAILS OF JOINTS IN RIGID PAVEMENTS



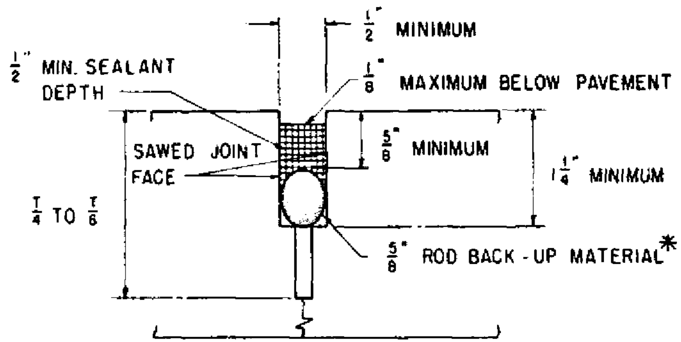
EXPANSION JOINTS TYPE A AND B



CONSTRUCTION JOINT TYPE C, D AND E

SYMBOLS

- SEALANT
- ROD BACK-UP MATERIAL *
- BOND BREAKER MATERIAL
- RESILIENT FILLER
- * CLOSED-CELL RESILIENT FOAM OR SPONGE RUBBER



CONTRACTION JOINT TYPE F, G AND H

FIGURE 11. DETAILS OF JOINTS IN RIGID PAVEMENT FOR USE WITH TYPE VI SEALING MATERIAL

TABLE 3. JOINT TYPES - DESCRIPTION AND USE

TYPE	DESCRIPTION	LONGITUDINAL	TRANSVERSE
A	Doweled expansion joint.		Use near intersections to isolate them.
B	Thickened edge expansion joint.	Use at intersections where dowels are not suitable and where pavements abut structures.	Provide thickened edge (or keyway) where pavement enlargement is likely.
C or D	Keyed or doweled construction joint.	Use for all construction joints except where Type E is used.	Use Type D where paving operations are delayed or stopped.
E	Hinged construction joint.	Use for all construction joints of the taxiways and for all other construction joints that are 25' or less from the pavement edge.	
F	Doweled contraction joint.		Use for all contraction joints in critical areas, for all reinforced pavement areas, and for the first two joints on each side of expansion joints.
G	Hinged contraction joint.	Use for all contraction joints of the taxiway and for all other contraction joints placed 25' or less from the pavement edge.	
H	Dummy contraction joint.	Use for all other contraction joints in pavement.	Use for all remaining contraction joints in nonreinforced pavements.

(3) Contraction Joints. The function of a contraction joint is to provide controlled cracking of the pavement when the pavement contracts due to shrinkage caused by curing, decrease in moisture content, or a temperature drop. The contraction joints are shown as Types F, G, and H in Figures 10 and 11.

b. Joint Spacing. Table 4 summarizes the recommended spacing of joints. As indicated, pavements 10 inches or less in thickness generally require closer spacing of joints.

TABLE 4. JOINT SPACING

Slab Thickness	PLAIN CONCRETE		REINFORCED CONCRETE	
Inches	Longitudinal	Transverse	Longitudinal	Transverse
10 or less	12.5' Max.	15' - 20'	12.5' Max.	45' - 75'
Over 10	25.0' Max.1/	20' - 25'	25.0' Max.1/	45' - 75'

1/ Where 25-foot paving lanes are used in construction of 75-foot taxiways, a Type G or H dummy joint shall be provided along the centerline.

c. Special Joint Consideration. When a runway or taxiway is likely to be extended at some future date, it is recommended that a thickened edge joint be provided at that end of the runway or taxiway. Likewise, if any pavement is to be widened in the future, a keyway or thickened edge should be provided at the appropriate edge.

d. Tie Bars. Tie bars are used across certain longitudinal contraction joints and keyed construction joints to permit hinge action while holding the slab faces in close contact. The tie bars themselves do not act as load transfer devices. By preventing excessive opening of the joint, load transference is provided by either the tongue and groove of the keyed joint or by aggregate interlock in the crack below the groove-type hinged joint. Where tie bars are required, they should consist of deformed bars of new-billet steel. The bars should be 5/8 of an inch in diameter and 30 inches long and spaced 30 inches on center.

e. Dowels. Dowels are used at joints to provide for transfer of part of the wheel load across the joints and to prevent relative displacement of adjacent slab ends. Dowels permit longitudinal movement of adjacent slabs.

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(1) Where Used. Provision for load transfer by dowel installation is provided at all transverse expansion joints and all butt type construction joints. Dowels should also be installed across all transverse contraction joints in critical areas (aprons, taxiways, and runway ends) to provide an increased margin of safety with respect to load transfer in these areas.

(2) Size, Length, and Spacing. Dowels should be of such size that they will safely resist the shearing and bending stresses produced by loads on the pavement. They should be of such length and spacing that the bearing pressures they exert in the slab will not be excessive and thus cause failures. Table 5 indicates dowel dimensions and spacing for various pavement thicknesses.

TABLE 5. DIMENSIONS AND SPACING OF STEEL DOWELS

		DOWEL		
	Thickness of Slab (inches)	Diameter (inches)	Length (inches)	Spacing (inches)
	6-7	3/4	18	12
*	8-14	1	18	12
	12-16	1-1/4	20	12 *

f. Joint Sealers and Fillers. Sealers are used in all joints to prevent the entrance of water or foreign material. Premolded compressible fillers are used in expansion joints to permit expansion of the adjacent slabs. Joint sealer is applied above the filler in expansion joints to prevent the infiltration of water.

22. JOINT LAYOUT NEAR PAVEMENT INTERSECTIONS. It is a general engineering practice to isolate the intersection from the rest of the pavement areas by the use of expansion joints. This allows the pavement to move independently. The treatment of the joints near the intersection, however, is not so general. Varying experience precludes stating any but general comments pertaining to the joints in this area.

a. Since cracks tend to form in odd shaped slabs, it is important to eliminate these shapes when designing the rigid pavement. The use of off-sets will help eliminate some of these irregular shapes around fillets. Except in the near 90 degree intersections, it is difficult to design a rigid pavement without a few of these irregularly shaped slabs. Pie-shaped sections will cause the most trouble and therefore should not be allowed except in areas where there is little or no traffic. Generally, sections should be roughly square or rectangular in shape. Figure 12 shows one possible intersection layout that reduces troublesome sections to a minimum in nonreinforced pavement.

b. When the proper amount of steel reinforcement is used in a rigid pavement, the allowable transverse joint spacing may be increased up to a maximum of 75 feet. By using greater joint spacing, the number of odd shaped slabs is automatically reduced. Figure 13 shows one example of joint layout for reinforced pavement.

c. Both Figures 12 and 13 show typical joint arrangement for pavements more than 10 inches in thickness. For pavements 10 inches or less in thickness, intermediate longitudinal hinged or dummy contraction joints are required, as shown in Table 3.

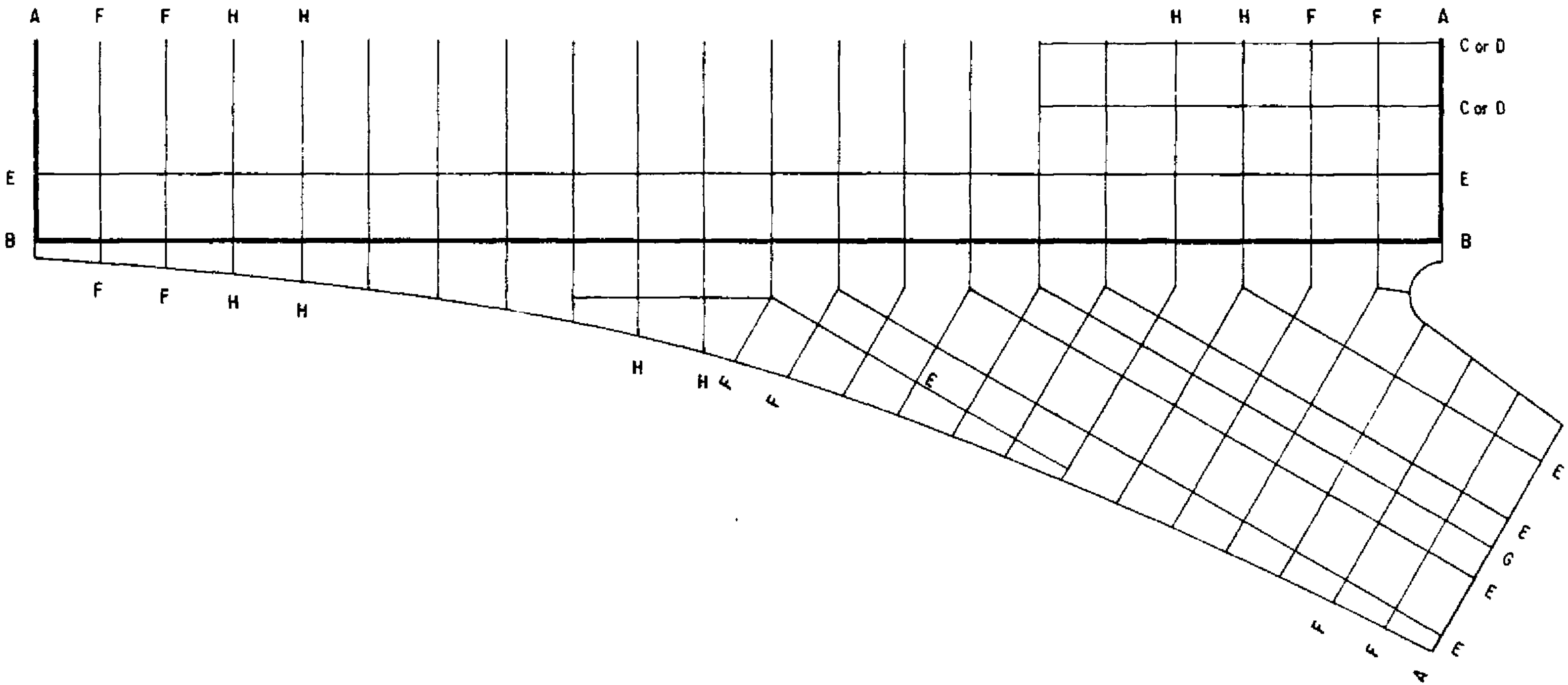

FIGURE 12. ARRANGEMENT OF JOINTS AT INTERSECTION OF RUNWAY AND TAXIWAY (NONREINFORCED)

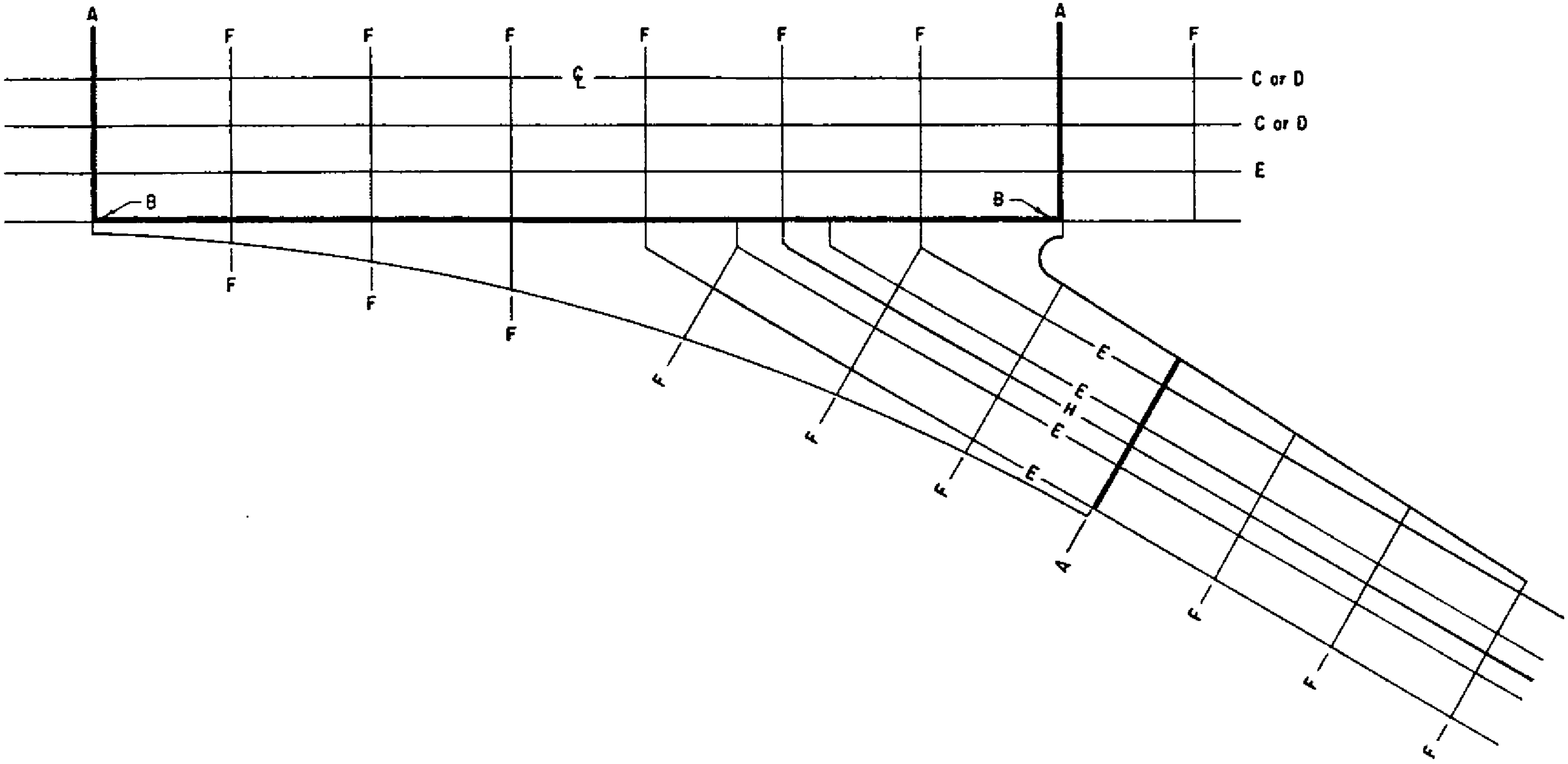

FIGURE 13. ARRANGEMENT OF JOINTS AT INTERSECTION OF RUNWAY AND TAXIWAY (REINFORCED)

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23. REINFORCED CONCRETE. The main benefit of the steel reinforcing is that, although it does not prevent cracking, it keeps the cracks that form tightly closed so that the interlock of the irregular faces provide load transference. By holding the cracks tightly closed, the steel minimizes the infiltration of dirt, soil, and other materials. The thickness requirements for reinforced concrete pavements are the same as plain concrete and are determined from the curves in Figure 9.

a. Type and Spacing of Reinforcement. Reinforcement may be either welded wire fabric or bar mats installed with end and side laps to provide continuous reinforcement throughout the slab panel. Longitudinal members should be spaced not less than 3 inches nor more than 12 inches apart; transverse members should be spaced not less than 3 inches nor more than 18 inches apart.

b. Amount of Reinforcement. The required steel area is determined by the "subgrade drag" formula which is as follows:

$$A_s = \frac{FLw}{2f_s}$$

A_s = required area of steel per foot of width or length, square inches

F = coefficient of subgrade friction

L = length or width of slab, feet

w = weight of slab, pounds per square foot

f_s = allowable tensile stress in steel, psi

In this formula the slab weight is calculated on the basis of 12.5 pounds per square foot, per inch of thickness, and the allowable tensile stress will vary with the type and grade of steel. It is recommended that allowable tensile stress be taken as two-thirds of the yield strength of the steel. Based on current specifications the yield strengths and corresponding design stresses (f_s) are as follows:

Type & Grade of Steel	Yield Strength psi	f_s psi
Billet steel, intermediate grade	40,000	27,000
Rail steel or hard grade of billet steel	50,000	33,000
Rail steel, special grade	60,000	40,000
Billet steel, 60,000 psi minimum yield	60,000	40,000
Cold drawn wire	65,000	43,000

Force-displacement tests indicate that the coefficient of friction averaged over half the slab length or width may be expressed by

$$F = .585\sqrt{\frac{L}{T}}$$

Substituting for F in the subgrade drag formula

$$A_s = \frac{3.7L\sqrt{LT}}{f_s}$$

where T is the slab thickness in inches. To illustrate the use of this formula, assume that the slab dimensions have been established as 75 feet long, 25 feet wide, and 12 inches thick then for the longitudinal steel.

$$A_s = \frac{3.7(75)\sqrt{(75)(12)}}{43{,}000} = 0.194 \text{ sq. in.}$$

This is the required area of longitudinal steel per foot of width of the slab. The transverse steel area is computed in the same manner but L = 25 feet and A_s is equal to 0.037 square inches per foot of length of the slab.

c. Dimensions and Weights of Reinforcement. Dimensions and unit weights of standard deformed reinforcing bars are given in Table 6 and gauge numbers, diameters, areas, and weights of wires used in welded wire fabric are given in Table 7.

TABLE 6. DIMENSIONS AND UNIT WEIGHTS OF DEFORMED STEEL REINFORCING BARS

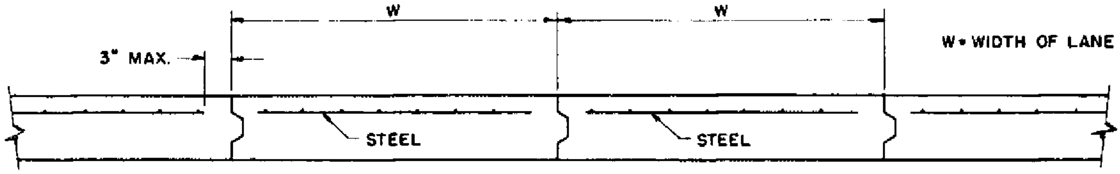
Bar Number	DIMENSIONS			Unit Weight, lb. per ft.
	Diameter, in.	Area, sq. in.	Perimeter, in.	
3	0.375	0.11	1.178	0.376
4	0.500	0.20	1.571	0.668
5	0.625	0.31	1.963	1.043
6	0.750	0.44	2.356	1.502
7	0.875	0.60	2.749	2.044
8	1.000	0.79	3.142	2.670
9	1.128	1.00	3.544	3.400
10	1.270	1.27	3.990	4.303
11	1.410	1.56	4.430	5.313

Steel Wire Gauge Numbers	Wire			Center to Center Spacing, in Inches								
	Diameter Inches	Area Square Inches	Weight Pounds per Foot	2	3	4	5	6	8	10	12	16
½"	.5000	.19635	.6668	1.178	.785	.589	.472	.393	.295	.236	.196	.147
0000000	.4900	.18857	.6404	1.131	.754	.566	.453	.377	.283	.226	.189	.141
000000	.4615	.16728	.5681	1.004	.669	.502	.401	.335	.251	.201	.167	.125
00000	.4305	.14556	.4943	.873	.582	.437	.349	.291	.218	.175	.146	.109
0000	.3938	.12180	.4136	.731	.487	.365	.292	.244	.183	.146	.122	.091
000	.3625	.10321	.3505	.619	.413	.310	.248	.206	.155	.124	.103	.077
00	.3310	.086049	.2922	.516	.344	.258	.207	.172	.129	.103	.086	.065
0	.3065	.073782	.2506	.443	.295	.221	.177	.148	.111	.089	.074	.055
1	.2830	.062902	.2136	.377	.252	.189	.151	.126	.094	.075	.063	.047
2	.2625	.054119	.1838	.325	.216	.162	.130	.108	.081	.065	.054	.041
¼"	.2500	.049087	.1667	.295	.196	.147	.118	.098	.074	.059	.049	.037
3	.2437	.046645	.1584	.280	.187	.140	.112	.093	.070	.056	.047	.035
4	.2253	.039867	.1354	.239	.159	.120	.096	.080	.060	.048	.040	.030
5	.2070	.033654	.1143	.202	.135	.101	.081	.067	.050	.040	.034	.025
6	.1920	.028953	.09832	.174	.116	.087	.069	.058	.043	.035	.029	.022
7	.1770	.024606	.08356	.148	.098	.074	.059	.049	.037	.030	.025	.018
8	.1620	.020612	.07000	.124	.082	.062	.049	.041	.031	.025	.021	.015
9	.1483	.017273	.05866	.104	.069	.052	.041	.035	.026	.021	.017	.013
10	.1350	.014314	.04861	.086	.057	.043	.034	.029	.021	.017	.014	.011
11	.1250	.011404	.03873	.068	.046	.034	.027	.023	.017	.014	.011	.009
12	.1055	.0087417	.02969	.052	.035	.026	.021	.017	.013	.010	.009	.007
13	.0915	.0065755	.02233	.039	.026	.020	.016	.013	.010	.008	.007	.005
14	.0800	.0050266	.01707	.030	.020	.015	.012	.010	.008	.006	.005	.004
15	.0720	.0040715	.01383	.024	.016	.012	.009	.008	.006	.005	.004	.003
16	.0625	.0030680	.01042	.018	.012	.009	.007	.006	.005	.004	.003	.002

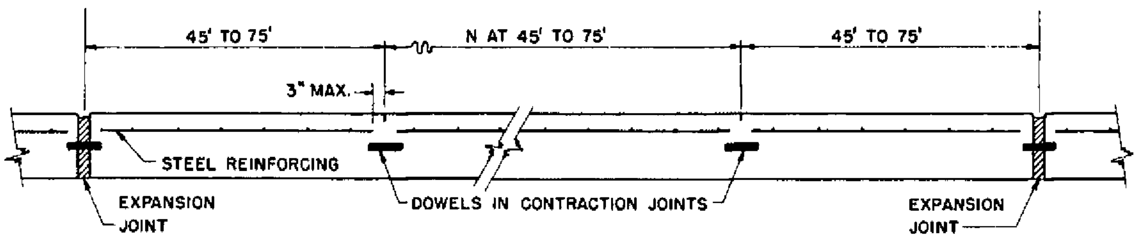
TABLE 7. SECTIONAL AREAS OF WELDED WIRE FABRIC
(Area in square inches per foot of width for various spacings of wire)

d. Minimum Size of Fabric. In connection with the use of welded wire fabric, it is recommended that the minimum size of longitudinal wire for slabs 10 inches or less in thickness should be No. 2 gauge, and for slabs over 10 inches thick it should not be smaller than No. 1 gauge. The minimum transverse wire should be no smaller than No. 4 gauge. In addition, should the calculated area of longitudinal steel be less than 0.1 percent of the cross-sectional area of the slab, the size and spacing of the steel members (bars or wire) should be determined on the premise that the minimum area should not be less than 0.1 percent. This percentage applies in the case of steel having a yield strength of 60,000 to 65,000 psi. If lower grades are used, the percentage should be revised proportionately upward. For the example cited above, Table 7 shows that No. 000 gauge wires, spaced 6 inches apart, furnish an area of 0.206 square inches which satisfies the requirement for longitudinal steel. Similarly, No. 4 gauge wires, on 12-inch centers, provide an area of 0.040 square inches which satisfies the requirement for transverse steel.

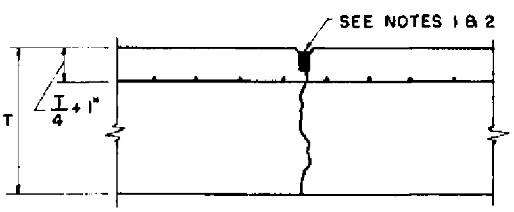
e. Contraction Joints in Reinforced Pavements. Contraction joints in reinforced pavements may be spaced up to 75 feet apart and all joints should be provided with load transfer dowels as shown in Figure 14. Also, this figure presents other reinforcement details such as clearance at joints and edges of pavement and depth below the surface.



TRANSVERSE CROSS-SECTION OF PAVING LANES



LONGITUDINAL CROSS-SECTION



LONGITUDINAL CONTRACTION JOINT
(SEE NOTE 3)

NOTES:

1. SEE FIGURES 10 & 11 FOR GROOVE DETAILS.
2. JOINT DETAILS ARE SIMILAR TO JOINT DETAILS FIGURES 10 & 11 EXCEPT FOR STEEL REINFORCING.
3. USE THIS JOINT WHEN THE SLAB THICKNESS IS 10 INCHES OR LESS AND PAVING LANE EXCEEDS 12½ FEET. SEE TABLE 4.

FIGURE 14. DETAILS OF REINFORCED CONCRETE PAVEMENT

CHAPTER 4. AIRPORT PAVEMENT OVERLAYS

24. GENERAL.

a. A pavement that has been subjected to continual overloading may have been damaged to such an extent that it cannot be satisfactorily maintained. Similarly, a pavement in good condition may require strengthening to accommodate heavier aircraft than those for which the pavement was originally designed. Both situations may be remedied by the construction of overlays with either portland cement concrete, bituminous concrete, or a combination of bituminous concrete and flexible base course. Overlay types are defined as follows:

(1) Overlay refers to the pavement constructed on top of the existing pavement.

(2) Concrete overlay is an overlay consisting of portland cement concrete.

(3) Flexible overlay consists of a combination of high quality base course and a bituminous surface.

(4) Bituminous overlay consists entirely of bituminous concrete.

b. Typical overlay pavement cross sections are shown in Figure 15.

25. PRELIMINARY DESIGN DATA. Regardless of the type of overlay to be employed, several determinations should be made prior to the actual design. The following items will provide this essential information:

a. Determine the soil group and subgrade class of the soil underlying the existing pavement on the basis of soil tests, drainage, and climatic conditions.

b. Determine the actual thickness of each layer of existing pavement.

c. In accordance with the requirements for the particular type of overlay, as stipulated in the following text, determine the pavement thickness required for the loading and subgrade class under consideration, using the appropriate basic pavement design curves included in Chapter 3.

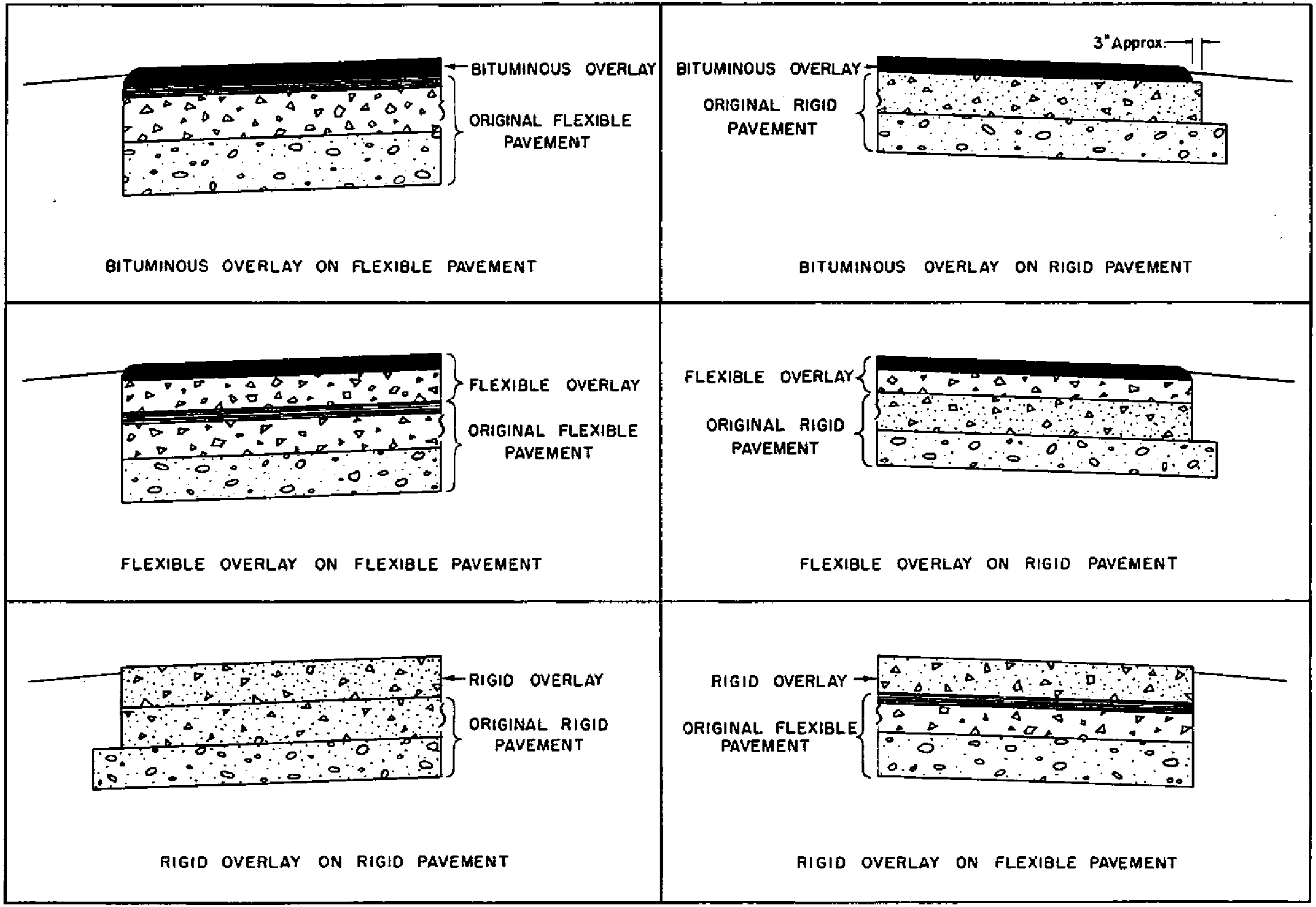


FIGURE 15. TYPICAL SECTIONS OF OVERLAY PAVEMENTS

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.XIBL .ND BITUMINOUS OVERLAYS.

ble or bituminous overlays can be applied to either
gid pavements. Design of the overlay is accomplished
milar to the design of a new flexible pavement giving
various layers of the existing pavement as pavement
Certain criteria should be followed in the design of
ituminous overlays, whether they are to be placed over
.d or flexible pavements, these are:

courses should not be used in pavement overlays.

ourses should consist of materials discussed in
aph 16b.

inous overlays for increasing strength should have a
mum thickness of 3 inches.

materials for base or surface courses should comply with
150/5370-1, Standard Specifications for Construction of
rports.

exible overlays are susceptible to base course saturation
ich results in pavement failures due to the pore water
ressure with rising temperature; thus, in most cases, a
ubdrainage system is required in order to maintain the
moisture content at a tolerable level.

.ble or Bituminous Overlays on Existing Flexible Pavements. Use appropriate basic flexible pavement curves (Figure 6, 7, or 8) etermine the total thickness required for a flexible pavement the desired load. The difference between the existing total ement thickness and the required total pavement thickness resents the unadjusted thickness of the overlay.

) Adjustment to the overlay thickness is made on the basis of the character and condition of the existing surface and the type of overlay base as follows:

(a) An existing dense-graded plant-mix bituminous surface such as Item P-401, in sound condition, may be evaluated for base course purposes, on the basis that each inch of surface is equivalent to 1-1/2 inches of base course, provided a bituminous overlay is used.

(b) Under all other conditions, the existing surface course will be considered, inch for inch, as base course.

(c) If a bituminous base, such as Item P-201, is to b utilized, a thickness adjustment may be made on th of one inch of base being equivalent to 1-1/2 inch nonbituminous base.

(2) With regard to flexible overlays, the thickness of the bituminous base should not be less than 4 inches unless existing bituminous surface is broken to such an extent it can be blended with the new base course material.

(3) To illustrate the procedure followed in designing flexib or bituminous overlays, assume an existing taxiway paveme resting on an E-6 soil, consists of 2 inches of bituminou concrete surface course, 6 inches of crushed stone base, 6 inches of subbase. Frost action is negligible and drai is poor. The subgrade (under the stated condition) corre to class F4. It is desired to strengthen the pavement to accommodate a gross aircraft weight of 280,000 pounds on d tandem gear. The flexible pavement requirements (referrin Figure 8) for a taxiway under these conditions are:

Bituminous concrete surface	4"
Nonbituminous base	10"
Subbase	10"
Total pavement thickness	24"

Inasmuch as the existing pavement has a total thickness of 14 inches, it will be necessary to add an overlay approximat 10 inches thick to accommodate the load. Since the upper 4 inches of pavement consists of bituminous concrete, the required pavement may consist of any of the following sectio depending on the existing pavement condition and type of overlay.

(a) Alternate 1 - The existing bituminous surface is broken due to overloading and a flexible overlay is to be employed. Under these conditions, the existing bituminous surface is considered as being equal, inch for inch, as base course and no thickness adjustment is warranted. The pavement will consist of:

New bituminous concrete surface	4"
New nonbituminous base	6"
Existing bituminous surface	2"
Existing nonbituminous base	6"
Existing subbase	6"
Total pavement thickness	24"

(b) Alternate 2 - On the existing pavement stipulated in Alternate 1, a bituminous overlay is to be constructed. In this case, the 10-inch design deficiency will be made of 4 inches of bituminous surface and the bituminous concrete equivalent to 6 inches of nonbituminous base. Applying allowable adjustment, 4 inches of bituminous base will suffice and the pavement should consist of:

New bituminous concrete surface	4"
New bituminous base	4"
Existing bituminous surface	2"
Existing nonbituminous base	6"
Existing subbase	6"
Total pavement thickness	22"

(c) Alternate 3 - The existing bituminous surface is in sound condition and a bituminous overlay is to be employed. The existing 2-inch bituminous surface is equivalent to 3 inches of base and the pavement will be made of the following:

New bituminous concrete surface	4"
New bituminous concrete base	3"
Existing bituminous surface	2"
Existing nonbituminous base	6"
Existing subbase	6"
Total pavement thickness	21"

c. <u>Flexible or Bituminous Overlay on Existing Rigid Pavement</u>. If an existing rigid pavement is to be strengthened with a bituminous or flexible overlay, the design procedure shown below should be followed.

(1) To establish the required thickness of a flexible or bituminous overlay, it is first necessary to determine from the basic rigid pavement design curves (Figure 9) the thickness of rigid pavement required to satisfy the design conditions. This thickness is then modified by a factor "F" which represents the subgrade and subbase conditions under the existing concrete. Table 8 shows values for the factor "F".

TABLE 8. FLEXIBLE AND BITUMINOUS OVERLAYS ON RIGID PAVEMENTS

Existing Subgrade Class	Value of F when subbase under existing pavement conforms to requirements for class of subgrade indicated below				
	Ra 1/	Rb	Rc	Rd	Re
Ra	0.80				
Rb	.90	0.80			
Rc	.94	.90	0.80		
Rd	.98	.94	.90	0.80	
Re	1.00	.98	.94	.90	0.80

1/ Figures in this column apply when no subbase has been provided.

Preliminary investigations will reveal the class of the subgrade upon which the existing pavement rests. This is the first or left column of Table 8. These investigations will also disclose whether the existing pavement includes a subbase and if so, its thickness. The appropriate value for "F" is found in the column which represents the subgrade class that would have to prevail for the existing thickness of subbase to be adequate for the design load. If no subbase exists, the factor will be selected from the column headed Ra.

(2) Having determined the value of "F", the overlay thickness can be computed from one of the following formulas:

(a) For flexible overlays:

$$t_f = 2.5\ (Fh - h_e) \text{ in which}$$

t_f = Required thickness of flexible overlay

F = Factor which varies with subgrade class

h = Required thickness of an equivalent single slab placed directly on the subgrade or subbase.

h_e = Thickness of existing slab

(b) For bituminous overlays: $t_b = \dfrac{t_f + 0.5t_s}{1.5}$ in which

t_b = Required thickness of bituminous overlay

t_f = Required thickness of flexible overlay

t_s = Required thickness of surface course

The following minimums apply to flexible and bituminous overlays on rigid pavements:

4 inches for nonbituminous base course

3 inches for a bituminous overlay

* 4 inches and 3 inches of bituminous surface over nonbituminous base course in critical and noncritical areas, respectively

Flexible overlay thickness should be rounded off to the nearest inch.

Bituminous overlay thickness should be rounded off to the nearest 1/2 inch.

(3) Example - An existing turbojet runway consists of 6 inches of concrete with no subbase provided. The subgrade soil is classified as E-5, frost action is negligible, and drainage is poor resulting in an Rb subgrade classification. It is necessary to strengthen the pavement to support a gross loading of 150,000 pounds on dual gear. Table 8 discloses that the factor "F" of 0.90 must be used in the overlay thickness formula. Other values in the formula are:

h_e = 6"

h = 12" for critical - from Figure 9

h = 10.8" for noncritical - 90% of critical thickness

Substituting in the formula for flexible overlays:

$t_f = 2.5\left[(0.9 \times 12) - 6\right] = 12$" for critical area

$t_f = 2.5\left[(0.9 \times 10.8) - 6\right] = 9.3$" for noncritical area (use 9")

The equivalent thicknesses of bituminous overlays are found as follows:

$t_b = \dfrac{12 + 2}{1.5} = 9.3$" for critical (use 9.5")

$t_b = \dfrac{9.3 + 1.5}{2} = 7.2$" for noncritical (use 7") *

(4) If adequate subbases have been provided under existing concrete pavements in accordance with the requirements in Table 8, the value of 0.80 for the factor "F" can be used in all cases. This condition would be equivalent to an Ra subgrade class. Since, in most cases, the subbase under the older pavements will not conform to these requirements, especially for the heavier loadings, the appropriate value of "F" must be obtained from Table 8. In further explanation of the use of Table 8 suppose that a design must be based on an Rd subgrade class. The desire is to determine the proper factor for the condition where no subbase has been provided, where the existing subbase conforms to the requirements for an Rb subgrade class, and where the existing subbase conforms to the requirements for an Rc subgrade class. The table shows that the factors will be 0.98, 0.94, and 0.90, respectively.

27. DESIGN OF CONCRETE OVERLAYS.

a. General. Concrete overlays can be constructed on existing rigid or flexible pavements. The minimum allowable thickness of a concrete overlay is 6 inches. Criteria for steel reinforcing, joint details and layout, size and spacing of dowels and tie bars, and other details of concrete overlays are similar to those applicable to conventional rigid pavement construction. These details are described in Chapter 3. Where a rigid pavement is to receive the overlay, some modification to these criteria may be necessary because of the design and joint arrangement of the existing pavement. The following points may be used as guides in connection with the design and layout of joints in concrete overlays.

(1) Joints need not be of the same type as in the old pavement.

(2) It is not necessary to provide an expansion joint for each expansion joint in the old pavement.

(3) Contraction joints may be placed directly over or within 1 foot of existing expansion, construction, or contraction joints. Should spacing result in slabs too long to control cracking, additional intermediate contraction joints may be necessary.

(4) If slabs longer than 20 feet are considered desirable, distributed reinforcement should be provided.

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b. Concrete Overlay on Flexible Pavement. The design of concrete overlays on existing flexible pavements is taken from the curves in Figure 9. The existing flexible pavement is considered as subbase for the overlay slab. For a 150,000 pound aircraft on dual gear, the required pavement thickness is 11 inches. If frost is a problem in the area, the requirements of paragraph 20 should apply.

c. Concrete Overlay on Rigid Pavement. The design of concrete overlays on existing rigid pavements is also based on the curves in Figure 9. The rigid pavement design curves will disclose the thickness of concrete slab and subbase required to satisfy the design conditions for a pavement constructed directly on the existing subgrade. Since the concrete slab thickness, so determined, is predicated on the provision of a subbase varying in thickness with the subgrade class and aircraft loading, the thickness requirement for an equivalent single slab (h) must be adjusted for an existing subgrade class other than Ra. A satisfactory adjustment for the basic design curves can be made as follows:

(1) If less than 6 inches of subbase has been provided for a pavement supported by a subgrade other than Ra, add 1 inch of slab thickness to the required single slab thickness (h).

(2) No adjustment to the basic design curve thickness is required if the subgrade is classed as Ra or if a minimum of 6 inches of subbase has been provided on any other subgrade.

(3) Although these adjustments seem anomalous with the requirements of an original design based on Figure 9 with respect to subbase thickness, the condition of the existing pavement and the correction coefficient as discussed below should compensate for these differences.

(4) Based on the above and preliminary data obtained, the thickness of the concrete overlay slab to be applied to the existing rigid pavement is determined by the following formula:

$$h_c = \sqrt[1.4]{h^{1.4} - Ch_e^{1.4}}$$ in which

h_c = Required thickness of overlay slab

h = Required thickness of an equivalent single slab from Figure 9

h_e = Thickness of the existing slab

C = Coefficient

Values of the coefficient C are based on the condition of the existing pavement as determined from the pavement condition survey. Recommended values are:

C = 1.00 existing pavement in good condition.

C = 0.75 existing pavement with initial corner cracks due to loading but no progressive cracking.

C = 0.35 existing pavement badly cracked or crushed.

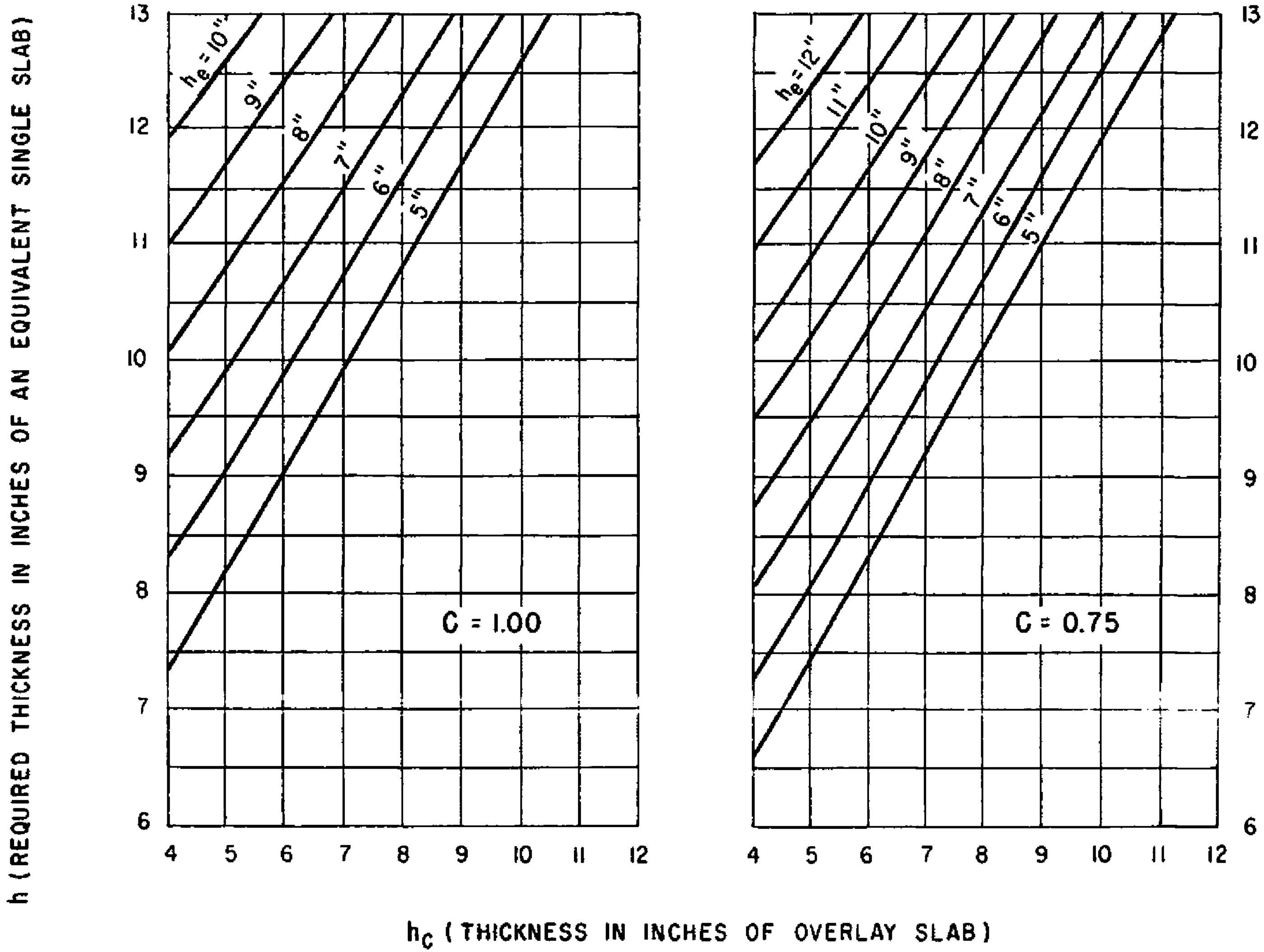
Conditions at a particular location may indicate the desirability of adopting intermediate values for C within the recommended range.

For convenience in determining the required thickness of concrete overlay slabs, the curves in Figure 16 have been prepared based on the above formula. Values may be interpolated on these curves.

(5) Under some circumstances, as discussed in paragraph 28b(3), it may be necessary to apply a leveling course of bituminous concrete to the surface prior to the application of the rigid overlay. If such is the case, an increase in the overlay thickness is warranted and the curves in Figure 17 may be employed to establish the thickness of the overlay slab. These curves are based on the formula:

$$hc = \sqrt{h^2 - Ch_e^2} \quad \text{in which}$$

the variables have the same identity as in the previous formula.



$$h_c = \sqrt[1.4]{h^{1.4} - C\,h_e^{1.4}}$$

FIGURE 16. CONCRETE OVERLAY ON RIGID PAVEMENT

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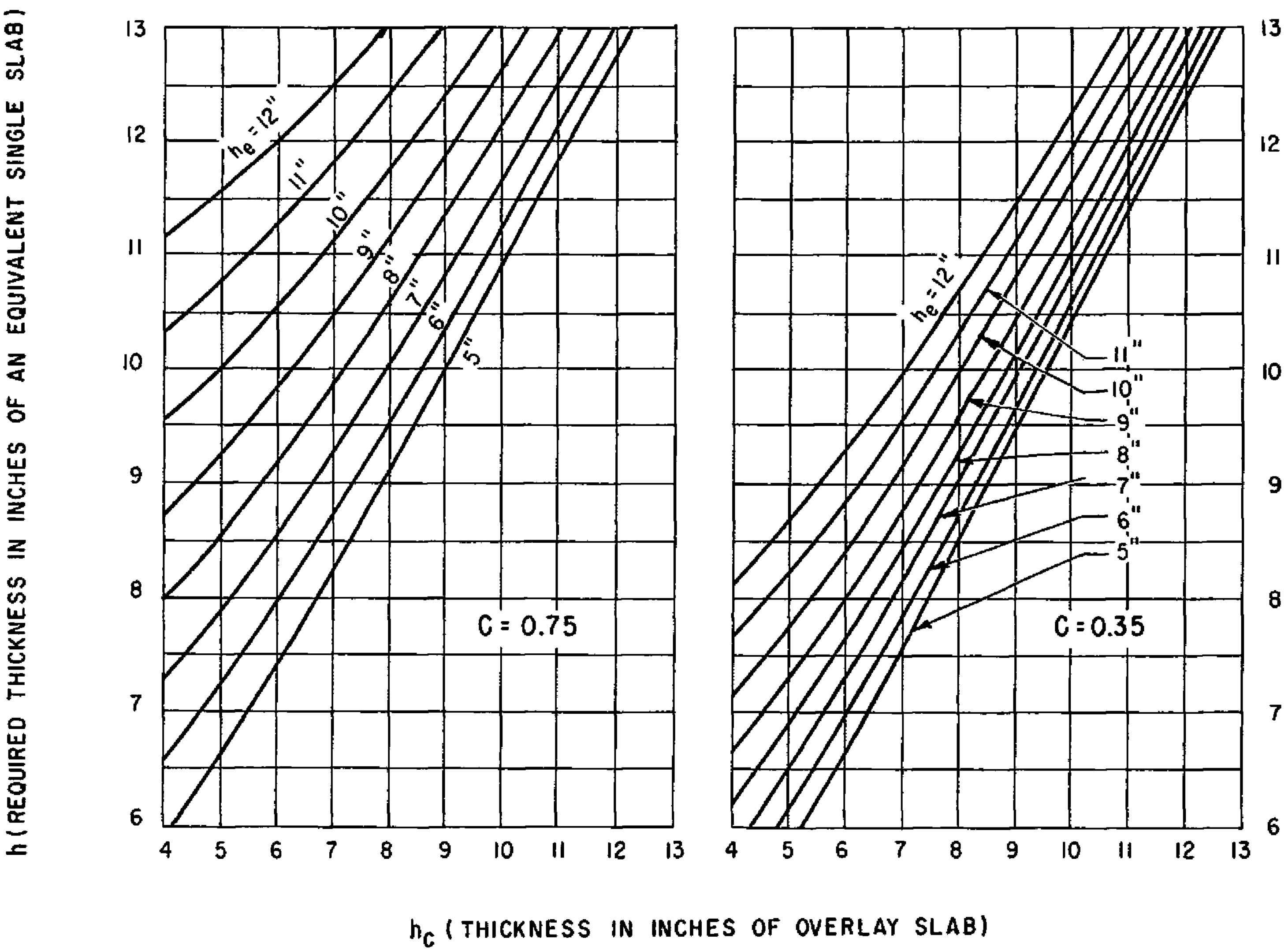


$$h_c = \sqrt{h^2 - C\,h_e^2}$$

FIGURE 17. CONCRETE OVERLAY ON RIGID PAVEMENT WITH LEVELING COURSE

28. PREPARATION OF THE EXISTING SURFACE FOR THE OVERLAY. Before proceeding with construction of the overlay, steps should be taken to correct all defective areas in the existing surface, base, subbase, and subgrade.

a. Failures in flexible pavements can take the form of pavement breakups, potholes and surface irregularities, and depressions.

(1) Localized areas of broken pavement will have to be removed and replaced with new pavement. This type of failure is usually encountered where the pavement is deficient in thickness, the subgrade consists of unstable material, or poor drainage has reduced the supporting power of the subgrade. To correct this condition, the subgrade material should be replaced with a select subgrade soil or by installation of proper drainage facilities; this is the first operation to be undertaken in repairing this type of failure. Following the correction of the subgrade condition, the subbase, base, and surface courses of the required thickness should be placed. Each layer comprising the total repair should be thoroughly compacted before the next layer is placed.

(2) Surface irregularities and depressions, such as shoving, rutting, scattered areas of settlement, and occasional "birdbaths" should be leveled by rolling, where practical, and/or by filling with suitable bituminous mixtures. If the "birdbaths" and settlements are found to exist over extensive areas, a bituminous leveling course may be required as part of the overlay. The leveling course should consist of a high quality bituminous concrete. Scattered areas requiring leveling or patching may be repaired with either hot or cold patch mixtures similar to those customarily used in the particular locality. In the case of a flexible overlay, the leveling may be accomplished with the aggregate used in the base course.

(3) A bleeding surface may detrimentally affect the stability of the overlay and for this reason any excess bituminous material accumulated on the surface should be bladed off if possible. In some instances, a light application of fine aggregate may blot up the excess material or a combination of the two processes may be necessary.

(4) Cracks, 1/2 inch or more in width, should be filled with a lean mixture of sand and bituminous material. This mixture should be well tamped in place and any excess removed level with the pavement surface.

(5) Potholes should be cleaned and filled with a suitable bituminous mixture, thoroughly tamped in place.

b. <u>In rigid pavements</u>, ordinary transverse, longitudinal and corner cracks will need no special attention unless there is an appreciable amount of displacement and faulting of the separate slabs. If the subgrade is stable and no pumping has occurred, the low areas can be taken care of as part of the overlay and no other corrective measures are needed. On the other hand, if pumping has occurred at the slab ends or the slabs are subject to rocking under the movement of aircraft, subgrade support should be improved by pumping cement grout under the pavement to fill the voids that have developed.

(1) If the pavement slabs are badly broken and subject to rocking because of uneven bearing on the subgrade, the rocking slabs can be broken into smaller slabs to obtain a more firm seating. Badly broken slabs that do not rock will not require repairs since the criteria make adjustments for such a condition in the pavement thickness when the overlay consists of portland cement concrete. In some cases, it may be desirable to replace certain badly broken slabs with new slabs before starting construction of the overlay. The decision in such cases will have to be made according to the merits of the individual project.

(2) When the existing rigid pavement is to be overlayed with a flexible pavement type, the badly broken slabs may be replaced with a bituminous concrete equal in thickness to the thickness of the old concrete slab. A subgrade soil under the slab which has become unstable due to accumulations of moisture should be removed to the required depth, as determined by a thorough investigation at the particular location, and replaced with a suitable well-compacted granular subbase or base course material.

(3) Where the existing pavement is rough due to slab distortion, faulting, or settlement, a provision should be made for a leveling course of bituminous concrete before the overlay is commenced.

(4) After all repairs have been completed and prior to the placing of the overlay, the surface should be swept clean of all dust, dirt, and foreign material that may tend to break the bond between the overlay and the existing pavement. Any extruding joint sealing material should be trimmed from rigid pavements.

29. MATERIALS AND METHODS. With regard to quality of materials and mixes, control tests, methods of construction, and quality of workmanship, the overlay pavement components are governed by the appropriate FAA standard specifications.

a. Where a flexible overlay is to be placed on either flexible or rigid pavement, the base course layer may be placed directly on the existing surface after necessary repairs have been made.

b. If a bituminous overlay is specified, the existing pavement should receive a light tack coat or fog coat immediately after cleaning. The overlay should not extend to the edges of the pavement but should be cut off approximately 3 inches from each edge.

c. After cleaning, existing concrete surfaces should be wetted prior to depositing the fresh concrete of a rigid overlay to insure as good a bond as possible.

d. Should the existing pavement require drilling to provide anchorage for the overlay pavement forms, the size and number of holes should be the minimum necessary to accomplish that purpose. Holes should not be located close to joints or cracks. Location of holes for form anchors should be such as to avoid causing additional cracking or spalling.

CHAPTER 5. PAVEMENTS FOR LIGHT AIRCRAFT

30. GENERAL.

a. Pavements for light aircraft may be defined as landing facilities intended to accommodate personal aircraft or other small aircraft engaged in nonscheduled activities as agricultural, industrial, executive, or instructional flying. These pavements will not be required to handle aircraft exceeding a gross weight of 30,000 pounds, and in many cases these aircraft will not exceed 12,500 pounds. The design for pavements which are to serve industrial or executive aircraft of 30,000 pounds gross weight or more should be based on the criteria contained in Chapter 3 of this publication.

b. Some airports may not require paved operational areas. Conditions at the site may be adaptable for the development of a turf surface adequate for limited operations of these light aircraft. It may be possible to construct an aggregate-turf surface by improving the stability of a soil with the addition of aggregate prior to development of the turf. Aggregate-turf construction is covered in some detail in the latter part of this chapter.

c. In most areas, however, it is not possible to provide and maintain a stable turf surface because of adverse weather conditions or high density of traffic. Under these conditions, construction of an all-weather pavement may be necessary.

d. Pavements for aircraft under 12,500 pounds gross weight will normally consist of locally available material with a bituminous surface course. Pavements to accommodate aircraft up to 30,000 pounds may consist of a similar type of flexible pavement or of rigid surfaces of minimum allowable thickness.

e. The design data in this chapter deal with flexible pavements only. No special design criteria are required for rigid pavements because the FAA standard 6-inch minimum thickness of concrete pavement will satisfactorily serve aircraft with gross weights up to 30,000 pounds.

31. FLEXIBLE PAVEMENT THICKNESS.

a. The curves in Figure 18 give the pavement thickness requirements for aircraft with gross weights up to 30,000 pounds. These curves, which are used in a similar manner to those for higher types of pavements, should be used for aircraft up to but not including 30,000 pounds gross weight. For aircraft of 30,000 pounds and above the curves in Chapter 3 should be used. The pavement thickness determined from the curves in Figure 18 should be used for all areas of the airport pavement. No reduction in thickness should be made for "noncritical" areas of runways for light aircraft.

b. As is the case of larger aircraft, a flexible pavement for light aircraft consists of a bituminous wearing surface placed on a nonrigid base and in some cases a nonrigid subbase. Figure 19 depicts a cross section of a typical flexible pavement for light aircraft.

c. Under certain conditions, it may be necessary to utilize a bituminous surface treatment on a prepared base course in lieu of a more durable surface. If such is the case, a pavement so constructed is a temporary one with no inherent strength other than that furnished by the underlying base and the application of a higher type surface course is recommended at the earliest possible date.

d. Since the base and subbase course materials discussed in Chapter 3 are more than adequate for light aircraft, full consideration should be given to the use of locally available, less expensive materials which are entirely satisfactory for these pavements. These materials may include locally available granular materials, soil aggregate mixtures, or soils stabilized with portland cement, bituminous materials, or lime. Soil stabilization is covered in greater detail on the following pages.

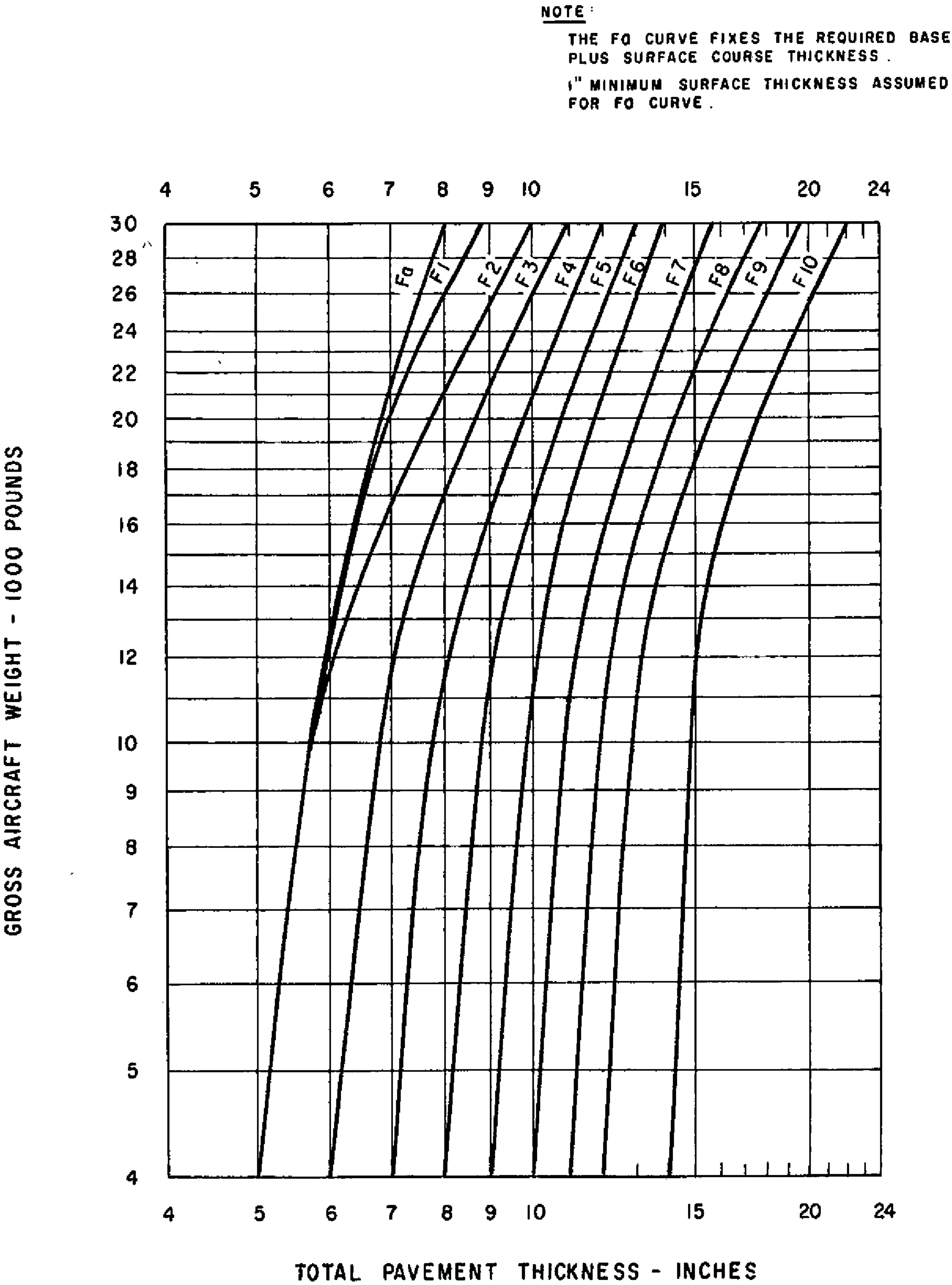


FIGURE 18. DESIGN CURVES FOR FLEXIBLE PAVEMENTS - LIGHT AIRCRAFT

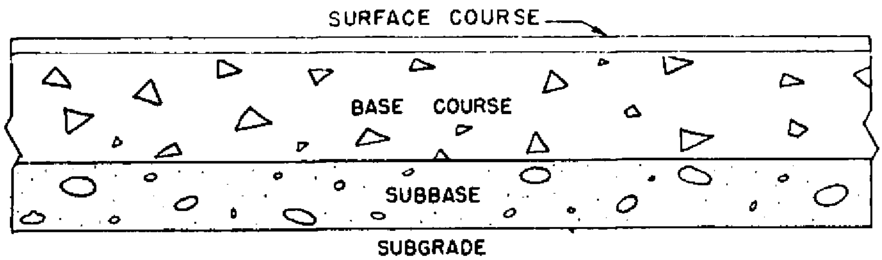


FIGURE 19. CROSS SECTION - TYPICAL FLEXIBLE PAVEMENT FOR LIGHT AIRCRAFT

e. The base course thicknesses in Figure 18 range from 4 inches to 7 inches, while the subbase thicknesses vary from 0 inch to 14 inches. The subgrade classes shown are obtained from the corresponding soil group, and frost and drainage conditions in Chapter 2, Table 2, of this circular.

f. Since the loads which these pavements must support are much less than those accommodated by pavements designed for heavier aircraft, certain reductions can be made in the compaction requirements for the base and subbase materials. Compaction control for these pavements is based on the standard AASHO Method T 99. This item is covered in Test T-611 of AC 150/5370-1, Standard Specifications for Construction of Airports.

32. SOIL STABILIZATION. Soil stabilization is the procedure whereby the properties of a soil are improved to the extent that it will meet the requirements for pavement bases or subbases. Stabilized soils are not intended to serve as a surface course but must be provided with a surface in order to resist the abrasive action of operating vehicles or aircraft. To be effective, stabilization should provide a foundation which will furnish adequate support for the loads transmitted through the paved surface, and will eliminate or reduce to an appreciable extent the detrimental effects of volume changes occurring in the soil due to climate influences or moisture variations. Mechanical and chemical stabilization are the two general types currently employed.

a. Mechanical stabilization on airports follows standard practices developed over the years, and requirements regarding materials as well as construction methods are quite definitely established. Performance studies have disclosed that the success of a granular stabilized base course depends on the gradation of the mixture and the physical properties of the material passing the No. 40 sieve.

(1) The gradation for gravel or stone is available in Item P-208, "Aggregate Base Course." Likewise, Item P-213, "Sand-Clay Base Course", gives gradations for the coarse and fine types. In addition to the gradation requirements, there are certain other requirements common to all granular type base courses. Among these are:

(a) The fraction passing the No. 200 sieve should not exceed one-half the fraction passing the No. 40 sieve.

(b) The liquid limit of the material passing the No. 40 sieve should not exceed 25 and the plasticity index should not exceed 6.

(c) For the fine aggregate type of sand-clay base, the plasticity index of the material passing the No. 40 sieve should not exceed 4.

(2) Granular type stabilized base courses meeting the requirements outlined above, when properly compacted, can give excellent service. It is emphasized, however, that the restriction placed upon the plasticity index must be rigidly adhered to if successful stabilization by these means is to be expected.

b. Bituminous stabilization is the combining of bituminous material with soil, soil-aggregate, or sand to produce the desired soil characteristics. Bituminous stabilizing agents include cutback asphalts, slow-curing asphalts or road oils, emulsified asphalts, and tars. Methods of construction vary with the type of equipment available but, regardless of the equipment, the different steps consist essentially of soil preparation by scarifying and pulverizing, thorough and uniform mixing of the bituminous material with the soil, curing of the mixture to get rid of excess moisture and volatile constituents, and compaction to a predetermined density.

(1) A successful job depends on the proper execution of each one of these steps. Test methods for determining the type and amount of bituminous material vary considerably in different areas. Manufacturers' recommendations also differ in this respect. Engineering services along these lines are available from the producers of the particular materials selected for use. In this connection, D-915, "Testing Soil-Bituminous Mixtures", has been adopted by the American Society for Testing and Materials.

(2) The type and grade of bituminous material to use depend on the characteristics of the soil, the climatic conditions, and the type of mixing equipment available. It is generally accepted that the best practice is to use the heaviest grade of bituminous material that can be readily mixed with the soil. Travel plants will permit the use of heavier grades of bitumens than will harrows and motor graders. The most commonly used grades of bituminous binders are:

(a) Rapid-Curing Cutback Asphalts. RC-1 to RC-4. (RC-70, RC-250, and RC-800)

(b) Medium-Curing Cutback Asphalts. MC-1 to MC-4. (MC-70, MC-250, and MC-800)

(c) Slow-Curing Oil. SC-1 to SC-4. (SC-70, SC-250, and SC-800)

(d) Tar. RT-3 to RT-7.

(e) Emulsified Asphalt. Slow setting.

(3) Bituminous stabilization on airports should be restricted to soils of a granular nature as opposed to plastic or cohesive soils. The following criteria are used to determine the suitability of a soil for bituminous stabilization:

(a) The silt and clay fractions combined should not exceed 45 percent.

(b) The liquid limit of the material passing the No. 40 sieve should not exceed 30 and the plasticity index should not be greater than 10.

(c) Soils containing appreciable amounts of mica are not suitable for bituminous stabilization.

(4) Bituminous stabilization will give satisfactory performance on airports when the mixtures are made with soils having the proper physical characteristics. On the other hand, serious failures can occur where the soils have high silt and clay contents, contain mica in appreciable amounts, mixtures are compacted before they have cured properly, or surfaces are placed on the stabilized base too soon, thus trapping the excess moisture and volatile materials.

(5) In general, Item P-216, "Mixed In-Place Base Course", covers the methods of construction for this form of stabilization. This item must be modified by deleting the sections referring to job mix formula, materials, and composition of mixture and substituting requirements applicable to the material to be stabilized. Changes in construction procedures may be desirable in certain localities.

c. By the addition of portland cement in the correct quantity, many types of soils and materials such as shale, gravel, sand, screenings, slag, and mine tailings can be stabilized. Construction of soil cement bases has been standardized to a large degree. Item P-301, "Soil Cement Base Course", covers the construction of soil cement base courses.

(1) Where soil cement is to be employed, the minimum thickness of such stabilization should be 6 inches. Stabilization of soils which are very plastic or which contain large percentages of clay presents a problem because of the difficulties encountered in processing the soils and the increased quantity of cement required to improve the soil. Although a definite improvement in stability is usually obtained with such soils, the increase is not sufficient to meet the requirements for base courses. Normally, only soils from E-1 to E-6 should be considered for soil cement base course construction.

(2) Portland cement can be used in the reconstruction of gravel base courses that have failed because of a high plasticity index of the soil binder. The reconstruction consists of scarifying and pulverizing the existing gravel base, adding and mixing the portland cement, and recompacting to a controlled density. The addition of the correct amount of cement can produce mixtures having plasticity indices well under the 6 percent maximum specification requirement.

(3) Inasmuch as soil cement base courses are constructed to a minimum thickness of 6 inches, the required thickness of subbase, as determined from Figure 18, can be reduced for gross weights less than 20,000 pounds. As an illustration, the figure indicates that for a gross weight of 12,000 pounds, a base course of 5 inches is required. The subbase requirements vary from approximately 1 inch for subgrade class F3 to 9 inches for F10 subgrade. The subbase thickness may be reduced by 1 inch so that the total thickness of soil cement base and subbase will be equal to the combined thickness of the base and subbase shown in Figure 18.

d. Lime, in small percentages, has been added to base course materials such as gravel, disintegrated granite, crusher run stone containing appreciable amounts of soil type overburden, and caliche in order to reduce the plasticity index to meet specification requirements. Performance records of highway pavements indicate this reduction in plasticity index accomplishes a marked improvement in the stability of the base course.

(1) The amount of lime required for stabilization should be determined by means of laboratory tests. Various percentages of lime should be mixed with the soil and the percentage which results in reducing the plasticity index to the desired amount may be selected. In general, 2 or 3 percent of hydrated lime will serve to reduce the plasticity index of pit-run gravel and similar base course materials to the extent that they meet specifications.

(2) Plastic soils should be treated with hydrated lime in amounts ranging from 3 to 10 percent. Investigations show that for each soil there is an optimum percentage of lime. An addition of lime in excess of this amount will not reduce the plasticity index to any significant degree. The lowest percentage above which improvement is negligible is the most satisfactory for the particular soil. At this stage of knowledge, plastic soils stabilized with lime should not be considered for base course purposes but they may be very effective as a subbase material.

(3) With respect to construction procedures, lime-soil combinations are processed in a manner similar to soil-cement combinations which are covered in Item P-301, "Soil Cement Base Course", except that the lime may be applied as a slurry or in the dry state.

e. Other chemical stabilizers such as resins, plastics, and metallic salts have been used as a means of improving the stability of soils. These methods are in various stages of development and more work is necessary to determine their effectiveness. None of these materials or processes have so far been developed to the stage where they can be utilized effectively in the construction of civil airports.

33. AGGREGATE TURF.

a. Aggregate-turf strips differ from the usual turf strip in that the stability of the soil has been increased by the addition of granular materials prior to establishment of the turf. The objective of this type of construction is to provide a landing area that will not soften appreciably during wet weather and yet will retain sufficient soil to promote the growing of turf. Such a strip is designed to serve aircraft having a gross weight not exceeding 12,500 pounds, although under certain conditions planes considerably in excess of this loading might be accommodated.

b. In general, the material used in the aggregate-turf combination consists of whatever suitable supply is locally available to permit construction work to be accomplished as economically as possible. The gradation requirements of the mixture and the stabilizer aggregate are presented in Item P-217, "Aggregate--Turf Pavement." The materials should be composed of natural or prepared mixtures of soil with gravel, stone, sand, or any other aggregate, and the aggregate retained on the No. 4 sieve should be reasonably sound and durable enough to resist weathering, abrasion, and crushing. Shales and similar materials that break up and weather rapidly should not be used.

c. Construction details and material requirements are covered in Item P-217, "Aggregate--Turf Pavement." The proportion of aggregate to soil and the degree of compaction that is permissible from the standpoint of stability should be weighed against the requirements for the establishment of turf. Local climatic conditions exert a great influence on these two factors. Compaction from 70 to 90 percent of maximum density, as determined in accordance with AASHO T 99, is considered satisfactory for stability and will not interfere with the growth of grass.

d. The desirable thickness to be stabilized with the granular materials varies with the type of soil and the drainage and climatic conditions. The subgrade classification should be determined from Chapter 2, Table 2 and the total stabilized thickness from Figure 18. That is, to handle aircraft weighing 9,000 pounds on a subgrade classification of F6, the thickness should be 10 inches.

CHAPTER 6. AIRPORT PAVEMENT EVALUATION

34. GENERAL.

a. This chapter covers evaluation of airport pavements and introduces relationships between the FAA classification procedures and other physical tests used for airport pavement design and evaluation, namely, plate bearing and California Bearing Ratio (CBR). These relationships will permit a more accurate evaluation of pavements constructed to FAA dimensional and materials standards as well as those at variance with them or for which record information is lacking.

b. Examination of the airport pavement design systems in common use in this country and abroad shows that each has accompanying evaluation systems based in part on the incorporation of physical test results into their design procedures. Also, while many have design steps in common, each has modifications and design parameters which make direct comparison impossible. Similarly, evaluation procedures are good only for the design system to which they are related. Thus, it should be noted that while plate bearing and CBR tests are admitted herein as evaluation and design tools, the test results obtained are admissible to the FAA design procedures only in the manner prescribed in this circular.

c. Proper airport pavement evaluation is important to intelligent long-range planning and in the scheduling of pavement maintenance procedures. It is required as a step in the design of an expanded or strengthened pavement area. As normally regarded, an adequate pavement evaluation consists of the following steps, each of which may be accomplished in varying degrees of thoroughness.

(1) Site Inspection. This may include, in addition to the immediate pavement area, examination of the existing drainage condition and drainage facilities of the site, area, outfall, etc.; evidence of frost effect, water table, and area development. The principles set forth in Chapter 2 of this circular and in AC 150/5320-5A, Airport Drainage, apply.

(2) Records Research and Evaluation. This step may, at least in part, precede step (1) above. This step is accomplished by thorough review of construction dates and history, design considerations, specifications, testing methods and results, and maintenance history. Weather records and the most complete traffic history available are also parts of a usable records file.

(3) Sampling and Testing. The need for and scope of physical tests and materials analysis will be based on the findings made from the site inspection and records research. These will consist primarily of the soil investigations discussed in paragraphs 6, 7, and 8 of this circular plus the materials, gradation, and density tests required for the various pavement components as set forth in the Standard Specifications for Construction of Airports. Where problem areas exist and where extensive and costly construction or reconstruction projects are anticipated, these may be supplemented by plate bearing or CBR test procedures.

(4) Evaluation Report. Analysis of steps (1), (2), and (3) should culminate in the assignment of load bearing values to the pavement sections under consideration. The analyses, findings, and test results should be incorporated in a permanent record for future reference. While these need not be in any particular form, it is recommended that a drawing identifying area limits of specific pavement sections be included.

d. In practice, the accuracy of evaluation results will vary depending on the purpose, time expended, physical tests accomplished, and the complexity of the site. Economics and the relative importance of the continued operation of the airport will normally determine the extent to which evaluation is carried. The methods adopted herein are intended to provide a maximum of flexibility in this regard.

e. The balance of this chapter covers evaluation methodology and computation procedures only. Factors are used to reflect condition of existing structural components. These should be used as provided. The results obtained should be further modified, however, by results of the inspection, research, and testing procedures discussed above. Sound engineering judgment is a necessary part of successful pavement evaluation. As in any endeavor, however, judgment is enhanced by extensive and accurate background information.

35. PROCEDURES. The basic evaluation procedure for airport pavement areas will be visual inspection and reference to the FAA design criteria, supplemented by the additional sampling, testing, and research which the evaluation purpose may warrant. For relatively new pavement constructed to FAA standards and without visible signs of wear or stress, strength may be based on inspection of the FAA Form 1773, the "as constructed" sections, and modification, if appropriate, for any materials variation or deficiencies of record. Where age or visible stress indicate the

original strength no longer exists, further modification should be applied on the basis of judgment or a combination of judgment and supplemental physical testing. For pavements not designed to FAA materials standards or which consist of sections not readily comparable to FAA design standards, evaluation should be based on FAA standards after materials comparison and equivalencies have been applied in the manner hereafter described.

a. Sampling and Testing. In addition to the materials' specifications contained in AC 150/5370-1A and the soil sampling, testing, and classification procedures covered in Chapter 2 of this circular, it may be desirable to perform additional tests which are especially suitable to evaluation needs. The curves and comparison charts included in this chapter are based, in addition to those tests and procedures noted above, on the following tests.

(1) For Flexible Pavements, California Bearing Ratio tests, laboratory and field, made in accordance with the procedures established in MIL-STD-621A, Method 101, may be used. The FAA design criteria can be compared to the CBR design system and, where some doubt exists of the validity of the "F" classification, CBR analysis is appropriate as one of the supplemental testing procedures discussed in paragraph 8 of Chapter 2. In order that CBR results may be incorporated into the FAA classification system, the comparison made by Figure 20 shall be applied. Application of CBR to FAA subgrade class shall be accomplished in the following manner:

(a) The CBR-F comparison is based on a "no frost" condition as shown in Table 2. Reference to good drainage or poor is not required as the CBR reflects soil drainage ability.

(b) For existing pavement less than 3 years old, soaked laboratory tests shall govern unless clear evidence exists that subgrade moisture content has stabilized at a lower value. Design properly based on good drainage should not be adversely affected by the soaked CBR.

(c) For pavement 3 years old or more, evaluation should be based on in-place CBR and moisture content determination primarily. Remolded lab CBR's may be utilized where the development of pore water pressure is suspected, adjustment is needed for low in-place densities, etc.

(d) CBR as determined in (b) or (c) may be used to revise "F" classes up or down, except that the maximum upward adjustment shall be one class.

(2) For Rigid Pavements, the flexural strength of concrete may be determined by the procedures specified in ASTM C 78. In addition, plate bearing tests may be made on the top of subbase or on top of subgrade where no subbase exists. These tests should be made in accordance with the procedures established in MIL-STD-621A, Method 104.

(a) Where a valid relationship between the flexure test and tensile splitting (ASTM - C 496) can be established, the less expensive method of determining strength may be utilized.

(b) An important part of the test procedure for determining the subgrade reaction modulus is the correction for soil saturation which is contained in the prescribed military standard. The normal application utilizes a correction factor determined by the consolidation testing of samples at in-site and saturated moisture content. For evaluation of older pavements, where evidence exists that the subgrade moisture has stabilized or varies through a limited range, the factor may be assumed as unity or established by consolidation of a less than saturated sample.

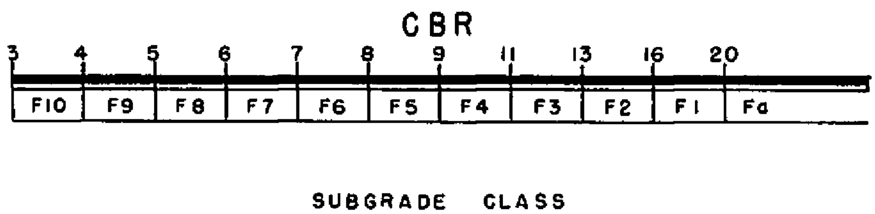


FIGURE 20 CBR-FAA SUBGRADE CLASS COMPARISONS

b. Materials Comparison and Equivalencies. When materials in a pavement structure to be evaluated are at variance with FAA standards, they shall be compared to them and classified as surface, base, subbase, etc., in accordance with paragraphs 1c, 16, and 18. After classification, the various pavement courses will be compared to the appropriate design requirement and, where necessary, non-standard sections shall be adjusted to conform to the highest strength standard section by application of the following equivalencies.

(1) Bituminous surface course (P-401 or equivalent) in sound condition shall be evaluated as stabilized base course at the rate of 1 inch of surface for 1 inch of stabilized base or as nonstabilized base course at the rate of 1½ inches of non-stabilized base for 1 inch of surface, to the extent required to achieve the combined surface and base requirement (per Figures 6, 7, or 18) for the lesser of the following:

(a) Design thickness required for the critical aircraft.

(b) Design thickness required for the total pavement section.

(2) Excess bituminous surface course or stabilized base course (P-401, P-201, P-304, or equivalent) in sound condition shall be evaluated as non-stabilized base at a rate of 1½ inches of nonstabilized base for 1 inch of surface or stabilized base.

(3) Broken bituminous surface course (shrinkage cracks due to age and weathering, without evidence of base failure) shall be evaluated inch for inch as nonstabilized base . A bituminous surface, with limited cracking and well maintained, may justify use of an equivalency between the limits noted. This may apply also to stabilized base, but in no event shall base course be assigned a higher equivalency or value than is assigned to a base or surface material which is above it in the pavement structure.

(4) Excess base course may be evaluated as subbase course at a rate of 1½ inches of subbase for 1 inch of base but not to exceed 3 inches of subbase for 2 inches of base. The minimum base course, existing or equivalent, shall be 5 inches in thickness or the pavement shall be evaluated using Figure 18.

(5) Conversion of material to a higher classification, such as subbase to base, will not be permitted, except that where excess stabilized base course (P-201 or P-304) exists immediately under a flexible surface which is deficient in thickness the stabilized material may be counted inch for inch as surface.

(6) For flexible pavements, strength will be based on the equivalent section that satisfies both of the following requirements of Figures 6, 7, and 8.

(a) Total section thickness.

(b) Combined surface and base thickness. For heavy pavements, when the entire surface (or stabilized base) has been converted to equivalent base course, fractional inches of base may be utilized in determining the total section thickness for evaluation. In this case the required base thicknesses in Figures 6, 7, and 8 will be regarded as the upper limit of the areas covered. Consider the F7 subgrade line in Figure 7, for instance, and providing sufficient subbase exists, a 5½-inch equivalent base may be evaluated as a 17-inch total section, a 6-inch equivalent base as a 21-inch total section, a 6½-inch equivalent base as a 23-inch total section, etc.

(7) For flexible pavements, the strengths given in Figures 6, 7, and 8 for the section evaluated will be reduced by 10 percent per inch of surface deficiency in excess of 1 inch of such deficiency. This shall apply whether the deficiency exists in the actual pavement or results from conversion to satisfy the evaluation requirement.

(8) For rigid pavement, the assumed "k" value for the top of subbase (or subgrade) shall be reduced from 300 by 10 pounds per cubic inch for each one inch of subbase deficiency as shown in Figure 9.

(9) For rigid pavement, the critical areas shall be evaluated utilizing working stress plus a safety factor of 1.75.

c. Other Values. The above equivalencies are essentially in keeping with the FAA design system. Any deviation is intentional and results in design procedures slightly more conservative than those used for evaluation. It should be noted that the equivalencies used are also considered to be conservative and, where area experience or physical test results show that other values are valid, they may be substituted for those used here.

d. Application. Equivalencies are assigned to specific pavement courses, and equivalencies less than 1 will not normally be assigned in the criteria previously discussed. Instead, where materials are clearly inferior they should be assigned a lower category, e.g., base to subbase. A judgment factor, on the other hand, may be assigned to an overall pavement section either upgrading or downgrading the facility. Extreme caution should be used in assigning a strength greater than the evaluation criteria would indicate and any such upgrading should not be considered in the design process when extension or strengthening are planned. Downgrading a pavement due to judgment factor should normally be limited to a reduction in strength of 25 percent. Any further deterioration would usually indicate actual or impending failure and the pavement should be so noted rather than a strength assignment being made. Exceptions may be made in cases where, for instance, an old runway has been limited to light aircraft operations by the airport management, etc.

(1) Recent changes in design criteria for turbojet runways call for stronger (from 0.8T to 0.9T) runway noncritical areas and lengthening the critical area from 500 feet to 1000 feet. The noncritical areas should be evaluated in accordance with the current criteria. Where older runways exist with the short critical area, however, the areas newly encompassed by the current standard should continue to be evaluated as noncritical unless visual inspection shows a necessity for downgrading.

(2) Where keel sections may exist, the thinner runway edges need not be evaluated as such but may be assigned the same strength as the keel. They will, of course, be subject to visual inspection.

36. <u>FLEXIBLE PAVEMENT EVALUATION</u>. Flexible pavements are defined in paragraph 16 and consist of bituminous wearing surface placed on a base and possibly a subbase. For evaluation purposes, they shall be considered as conventional or unconventional depending upon whether or not they are designed to FAA standards. In either case, the first steps are the verification of types and thicknesses of the flexible section, materials comparison, if required, and determination of the subgrade class. When the subgrade is classified in accordance with record information dated prior to 1967, it should be checked with Tables 1 and 2 of this circular.

a. <u>Conventional Pavements</u>. Comparison of standard FAA sections with the design charts, Figures 6, 7, 8, and 18, is straightforward and requires little comment. Where difficulty is encountered in evaluation of noncritical areas or by reason of a change in subgrade class, the procedures used in evaluating the unconventional pavements in the following discussion and examples may be used.

b. <u>Unconventional Pavements</u>. Most flexible pavements will fall in this category due to changes having occurred in the design standards, the application of rehabilitation or strengthening courses over the years, or having been constructed to other than FAA standards. As implied by the previous statement, the following method is also applicable to evaluation of flexible pavement with either flexible or bituminous overlays.

(1) In stage construction it is common practice to build a base and subbase to the design standard thickness and delay construction of a part of the surface. In these cases, evaluation in accordance with paragraphs 35b(1), (6), and (7) will result in sufficient reduction of capacity to alert the airport authority to the need of watchfulness and to encourage early completion of the full surface requirement.

(2) Example - Assume an air carrier airport, a design aircraft of 120,000 pounds on dual gear and that a pavement constructed in 1965 on an F2 subgrade had a critical section consisting of 8 inches base and 4 inches subbase as required by the then current standard, but a 1½ inch surface only has been provided to date. The 9½ inch total base and surface fails to meet today's minimum requirement. Close examination of the surface shows it to be sound, and in order to evaluate the section as an air carrier pavement, it will be necessary to apply equivalencies as follows: (Also note that use of equivalencies provides a bridge between the Figures 6, 7, and 8 and the light aircraft curves in Figure 18).

(a) 1½ inch surface = 0 inch surface + 2¼ inch base (reference paragraph 35b(1)).

(b) 2¼ inch base + 8 inch base existing = 10¼ inch surface + base.

(c) 10¼ inch surface + base + 4 inch subbase = 14¼ inch total section.

(d) 10¼ inch surface + base controls and limits the section to be evaluated to a total section of 13 inches (reference paragraph 35b(4), (6)). This gives a dual gear strength of 85,000 pounds per Figure 7.

(e) 85,000 pounds less 30 percent (10 percent/inch of surface deficiency greater than one) results in 60,000 pounds reported strength (reference paragraph 35b(7)).

(3) The extreme reduction in strength in this example is due to the marginal surface thickness for the aircraft concerned with a resulting short life expectancy. Consider the same example but with a 3-inch surface, and note that though surface and base thicknesses are in a usable range, strength may still be increased by application of equivalencies. This should be done to the extent possible but not to exceed the requirement for the critical aircraft using the facility or immediately planned.

(a) 3 inch surface + 8 inch base + 4 inch subbase = 15 inch total section = 120,000 pounds gross weight on dual gear.

(b) 120,000 pounds gross requires 12 inch surface + base. Conversion is required to meet the surface and base requirement.

(c) 3 inch surface = 1 inch surface + 3 inch base.

(d) 1 inch surface + 3 inch base + 8 inch base = 12 inch base + surface.

(e) 12 inch base + surface + 4 inch subbase = 16 inch total section equal to 140,000 pounds -20 percent = 112,000 pounds reported strength.

Had this section been 3 inch - 9 inch - 3 inch instead of 3 inch - 8 inch - 4 inch (combined surface and base satisfied), it could be reported as 120,000 pounds or design strength since there is no reduction in reported strength for the first inch of surface deficiency provided the surface plus base and the total section requirements are met. Fractional inches should be considered in pavement strength reduction. 2½ inch - 9½ inch - 3 inch in the above situation would require a reported strength reduction of 5 percent, or 114,000 pounds.

c. Noncritical Pavement Areas. The previous examples have been concerned with critical area strength only. Noncritical sections can be evaluated by multiplying the critical design section and the appropriate 0.7, 0.8, or 0.9 factor and adjusting surface thickness to achieve a noncritical design section for comparison. This method is awkward when any section adjustment is required, and the preferred method is to divide the existing noncritical pavement by the appropriate factor and then evaluate as critical thickness. This method will be illustrated in the following example evaluating a flexible pavement with flexible overlay.

(1) Example. Assume a pavement constructed in 1957 consisted of critical and noncritical sections as follows:

	Critical	Noncritical
P-401 Surface	2"	2"
P-209 Base	7½"	6½"
P-154 Subbase	5½"	4½"
Total Section	15 "	13 "

This design was based on an E-7 soil and a poor drainage - no frost condition. In 1964 a flexible overlay was constructed to accommodate the Douglas DC-8 at a gross weight of 300,000 pounds. Examination of the records show the following sections in place:

Materials	Critical	Noncritical
P-401 Surface	3"	2"
P-209 Base	11"	8"
P-401 Surface	2"	2"
P-209 Base	7½"	6½"
P-154 Subbase	5½"	4½"
	29"	23"

Examination of Tables 1 and 2 in the current paving circular and construction records indicate that the F5 subgrade class is still applicable. Figure 8 shows the total section still provides the 300,000 pound dual tandem critical strength. An inch surface deficiency exists for which no penalty is imposed. The flexible overlay with P-209 base precludes assigning an equivalency to the relatively new original surface, and it is counted inch for inch as base. The 20½ inch base thickness obviously provides a considerable amount of material available for conversion to subbase, and the allowable conversion of 2 inches base to 3 inches surface could be utilized with a 30-inch equivalent total thickness applicable for evaluation raising the dual tandem strength from 300,000 pounds to 320,000 pounds. Assuming the critical aircraft remains at 300,000 pounds, this would not be done. However, it will be seen to work to advantage below.

As a turbojet runway, the noncritical portion should be checked against the 0.9 requirement utilizing the conversion procedure. This can be accomplished by dividing the base and subbase courses by 0.9 and then evaluating as a critical section in the following manner:

Existing Noncritical			Critical
2" surface		=	2" surface
16½" base	÷ 0.9	=	18-1/3" base
4½" subbase	÷ 0.9	=	5" subbase
allowable base conversion provides an equivalent section of		=	2" surface
		=	16-1/3" base
		=	8" subbase
	Total		26-1/3"

One inch of surface must be added to this section when reading bearing capacity from Figures 7 and 8 for the reasons that the one-inch surface deficiency is replaced by equal base thickness so no penalty is assessed, and the figures are based on 4-inch rather than 3-inch surfaces.

This section then evaluates as 27-1/3 inch. A further advantage of this method is that it is immediately apparent that this is the controlling section and will provide strength for 165,000 pounds dual, 270,000 pounds dual tandem, and 130,000 pounds single geared aircraft.

(2) Example. Assume the same pavement and situation as the above example, except that the overlay is a 5-inch bituminous overlay for both critical and noncritical sections. The pavement to be evaluated becomes:

Material	Critical	Noncritical
P-401	7"	7"
P-209	7½"	6½"
P-154	5½"	4½"
	20"	18"

and converts to: (reference 35b(1))

P-401	4"	3"
P-209	12"	12½"
P-154	5½"	4½"
	21½"	20"

Note from Figure 8 that these sections require 8 inches of base which in turn permits conversion of base to subbase as follows:

	Critical	Noncritical
P-401 surface	4"	3"
base	10"	10½"
subbase	8½"	7½"
	22½"	21"

The critical section evaluates at 90,000 pounds single, 120,000 pounds dual, and 190,000 pounds dual tandem.

Converting the noncritical sections to critical:

3" surface			= 3"
10½" base	÷	0.9	= 11-2/3"
7½" subbase	÷	0.9	= 8-1/3"
			23"

For runway strength reporting, the critical section would control. Note that the entire overlay in this example is treated as P-401. This may be done even though a portion may be P-201 since they are, in fact, interchangeable as stated in paragraphs 35b(1) and (5).

37. RIGID PAVEMENT EVALUATION. Rigid pavements are defined in paragraph 18 and consist of portland cement concrete placed on a prepared subgrade or subbase. They may be plain or reinforced. No credit will be given in reported pavement strength for reinforcing except that which may be provided by pavement conditions as noted in paragraph 35. As with the flexible evaluation, rigid pavements will be considered as conventional or unconventional depending upon whether or not they adhere to the FAA design standard. In either case, the first steps are the verification of types and thicknesses of the pavement section, materials strength and comparison, if required, and determination of subgrade class or reaction modulus. When the subgrade is classified in accordance with record information dated prior to 1967, it should be checked with Tables 1 and 2 of this circular.

a. Conventional Pavements. For the purpose of this discussion, these will be limited to pavements constructed in accordance with the FAA subgrade classification system, the assumptions detailed in Appendix 1 of this circular, and use of the Figure 9 design curves. These may now be found, due to changes in the Figure 9 curves, to have excess subbase thicknesses. No credit will be given for the additional thickness unless verified by plate bearing tests made in accordance with approved procedures.

b. Example. Assume a rigid pavement constructed in 1964 and similar to the design example in paragraph 19, for propeller driven, dual gear, 160,000 pounds gross weight, subgrade class Rc. The existing section is:

	Critical Area	Noncritical Area
Pavement	11"	9"
Subbase	9"	9"
Frost Protection	6"	9"

(1) Normal construction is indicated by the record information, and required strengths, gradations, and densities were obtained. Providing no unusual circumstances exist, evaluation may be made by reference to Figure 9 which shows the critical section to be capable of supporting 125,000 pounds gross weight.

(2) Evaluation of the noncritical areas is accomplished by dividing the pavement thickness by an appropriate factor as determined in paragraph 19. Since this is a nonjet runway, the noncritical pavement strength is equal to 9" $\div$ 0.8 = 11-1/4" or 130,000 pounds. Subbase thickness is adequate and the reported pavement strength would be 125,000 pounds gross weight on dual gear.

c. Unconventional Pavements. These are pavements which vary from the Figure 9 and design assumptions as detailed in Appendix 1. The evaluator is provided a wide choice of tests and procedures which may be utilized. Any rigid pavement may be evaluated by the procedures below including those built to FAA standards.

(1) Separate evaluation charts for single, dual, and dual tandem gear configurations are contained in Figures 21, 22, and 23, respectively. From these the pavement strength can be determined for any known or assumed pavement thickness, concrete flexural strength, subgrade reaction modulus, or subgrade class. The charts are derived from the Westgaard liquid subgrade formula and the Pickett and Ray influence charts for center loading. While gear spacing and tire pressure are also variables in a complete pavement analysis, they are not treated as such here. Instead the curves are computed over a reasonable range of tire spacing and pressures, since these can and do vary among aircraft of the same class and weight. It should be noted in this regard that as total weight per gear increases, both gear spacing and tire pressure assert a lesser proportionate influence on maximum concrete stress. The following examples illustrate the use of these charts.

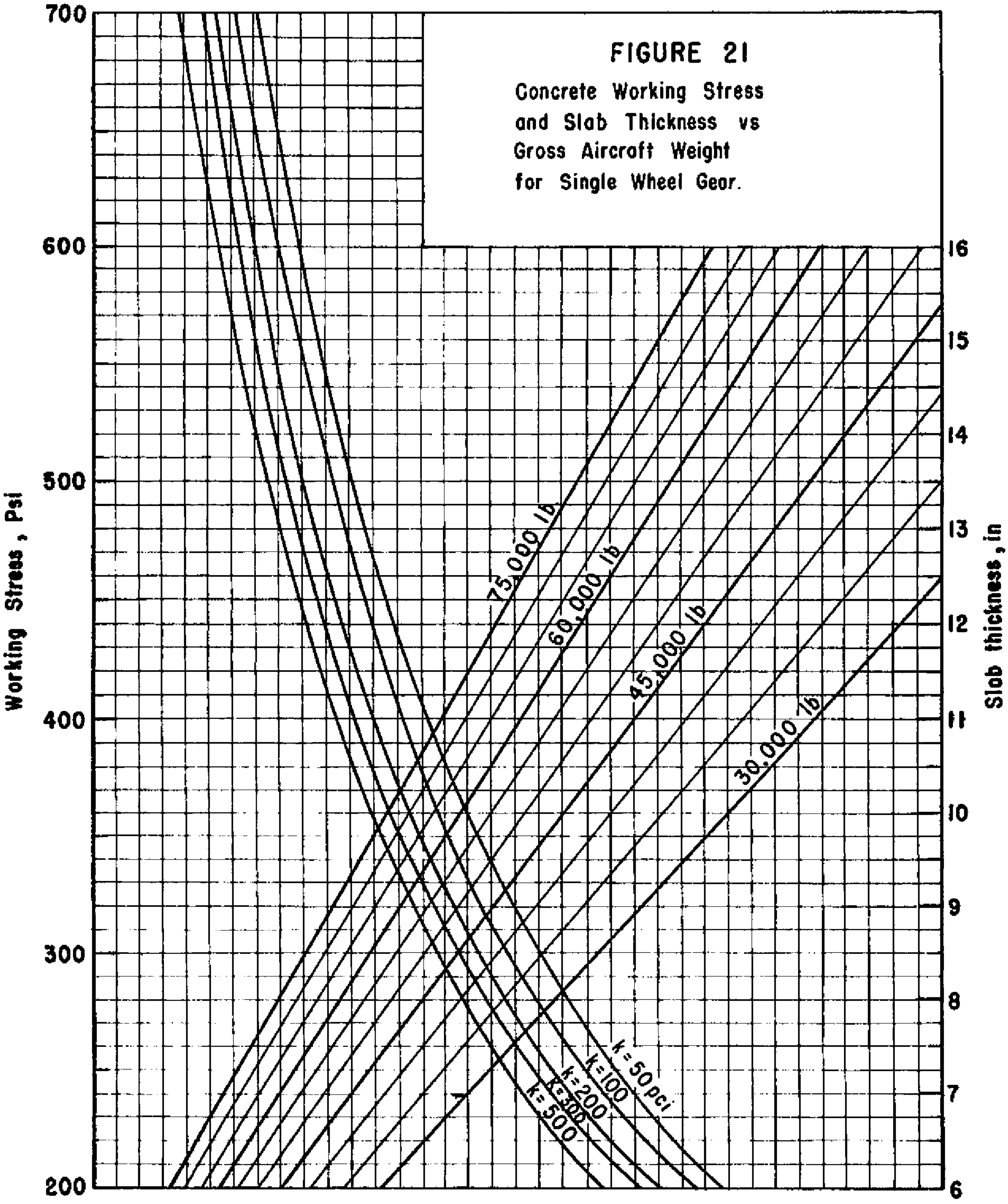
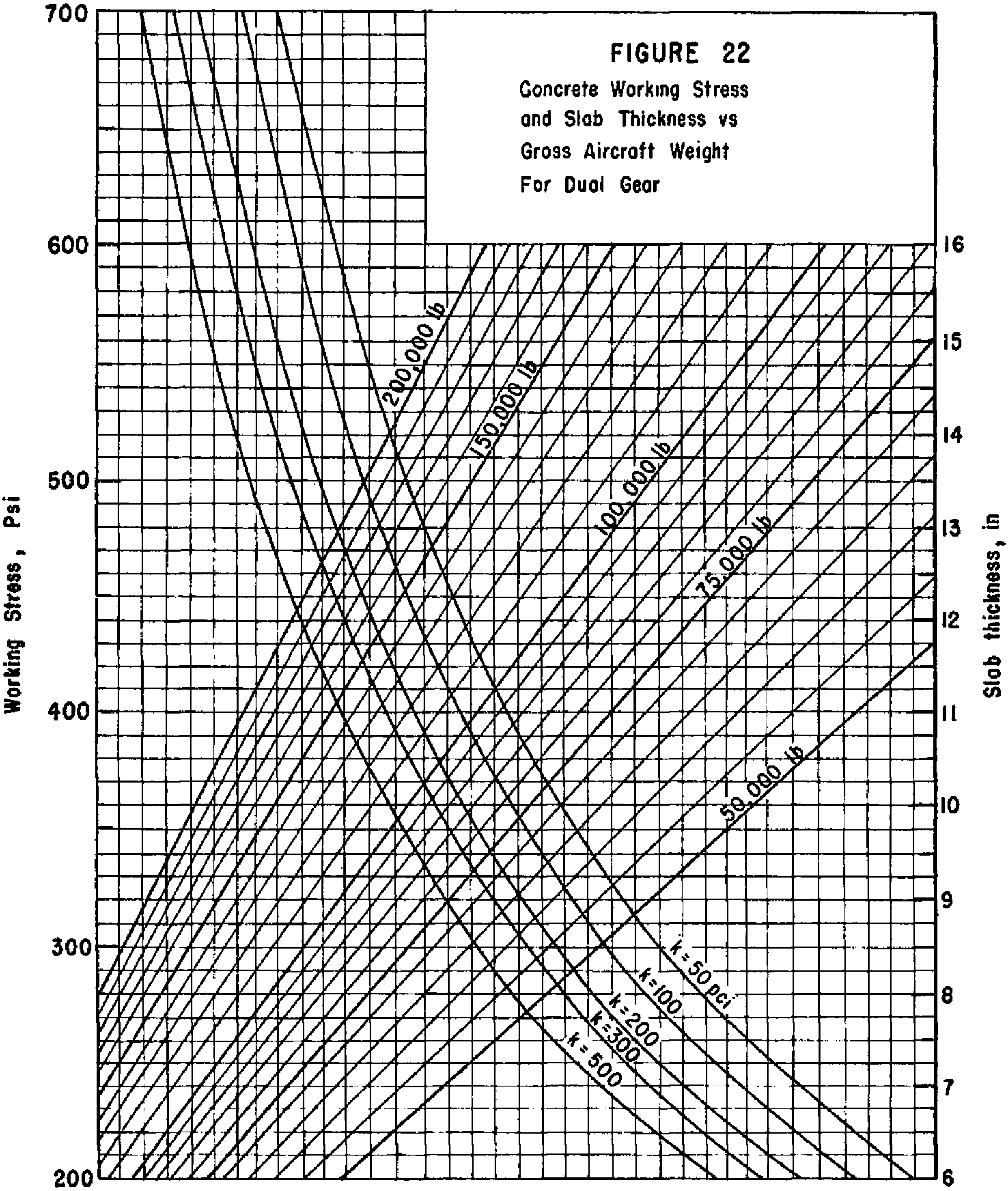


FIGURE 21
Concrete Working Stress and Slab Thickness vs Gross Aircraft Weight for Single Wheel Gear.
Working Stress , Psi
700
600
500
400
300
200
Slab thickness , in
16
15
14
13
12
11
10
9
8
7
6
75,000 lb
60,000 lb
45,000 lb
30,000 lb
k = 50 pci
k = 100
k = 200
k = 300
k = 500

FIGURE 22

Concrete Working Stress and Slab Thickness vs Gross Aircraft Weight For Dual Gear



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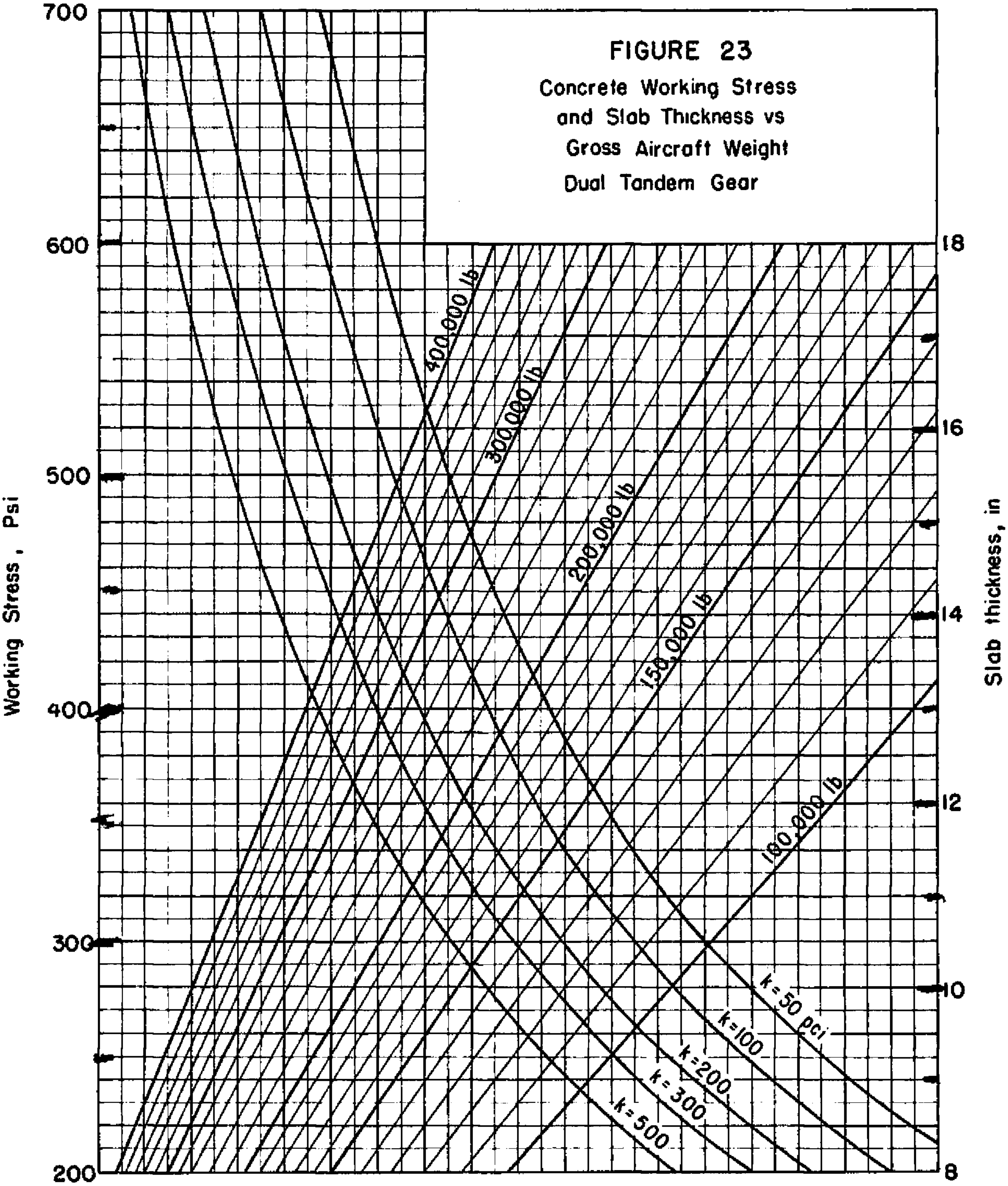


FIGURE 23
Concrete Working Stress
and Slab Thickness vs
Gross Aircraft Weight
Dual Tandem Gear
Working Stress, Psi
700
600
500
400
300
200
Slab thickness, in
18
16
14
12
10
8
400,000 lb
300,000 lb
200,000 lb
150,000 lb
100,000 lb
k=50 pci
k=100
k=200
k=300
k=500

(2) Consider the same pavement sections as in the previous example, except that frost is not a factor and no frost protection is provided. In this case also assume the pavement to be approximately 15 years old, and that record information is lacking. The critical aircraft to date has been the DC-6 and DC-9 averaging 10 operations per day. The balance of the traffic has consisted of a similar number of lighter twins averaging about 50,000 pounds gross, and a considerable amount of lighter general aviation traffic. Heavier traffic is anticipated, and the evaluation is undertaken to determine the strength of the existing pavement. Cores are taken to verify pavement and subbase thickness, and to check subbase and subgrade materials and densities. The cores are checked for compressive strength and are such that the concrete is considered as equal to the FAA 400 p.s.i. assumption. Densities are satisfactory, however, it is found that the subbase class is R_d, but no subbase has been provided. This precludes comparison with Figure 9, except to note that this slab thickness requires, for R_d subgrade, 12 inches of subbase.

(a) Enter Figure 22 at the 400 p.s.i. stress point and proceed horizontally to the 180 p.c.i. subgrade reaction (k) line, having deducted 10 p.c.i. for inch of subbase deficiency in accordance with paragraph 35b(8). From this point proceed vertically to intersect the slab thickness, located from the scale at the right side of the chart (coincident in this case). This intersection determines the load point. Interpolating between the 110,000 pound and 120,000 pound load lines, this point approximates 115,000 pounds.

(b) The noncritical sections are evaluated by the same procedure used in the previous example. Evaluation for turbojet use would be 9" ÷ 0.9 = 10" and limit reported strength to 96,000 pounds.

(c) Measured flexural strength of concrete and/or k values can be used to obtain more accurate information with which to enter Figure 21, 22, or 23. In other respects the evaluation would be the same as in the above example.

d. Rigid Pavement with Flexible or Bituminous Overlay. The overlay formulas in paragraph 26 are irrational and cannot be used for evaluation purpose. Accordingly, Figure 24 has been incorporated herein and should be used to determine an equivalent concrete slab thickness, and some explanation of its derivation is in order.

(1) The reasons normally advanced for requiring a minimum overlay thickness is that in thinner sections, reflective cracking occurs and the pavement is dependent for continuity on the load transferability of the original thinner slab, usually deficient when considered against the thicker equivalent slab requirement. While this argument has strong backing, it is true that in at least some cases, thin overlays are performing satisfactorily, and in order that these may be given proper consideration in evaluation, Figure 24 was devised to provide a transition between the overlay formula at reasonable depths, and a thin overlay condition. The following assumptions were made:

(a) The first inch of overlay accomplishes a leveling function only and adds no strength to the basic pavement.

(b) Some safety factor is usually present in the existing load transfer function, whether by dowels, keyways, or aggregate interlock.

(c) Some aggregate interlock is realized in the bituminous overlay through cracked areas, just as with concrete, and the tightness and maintainability of the cracks increase with overlay thickness.

*

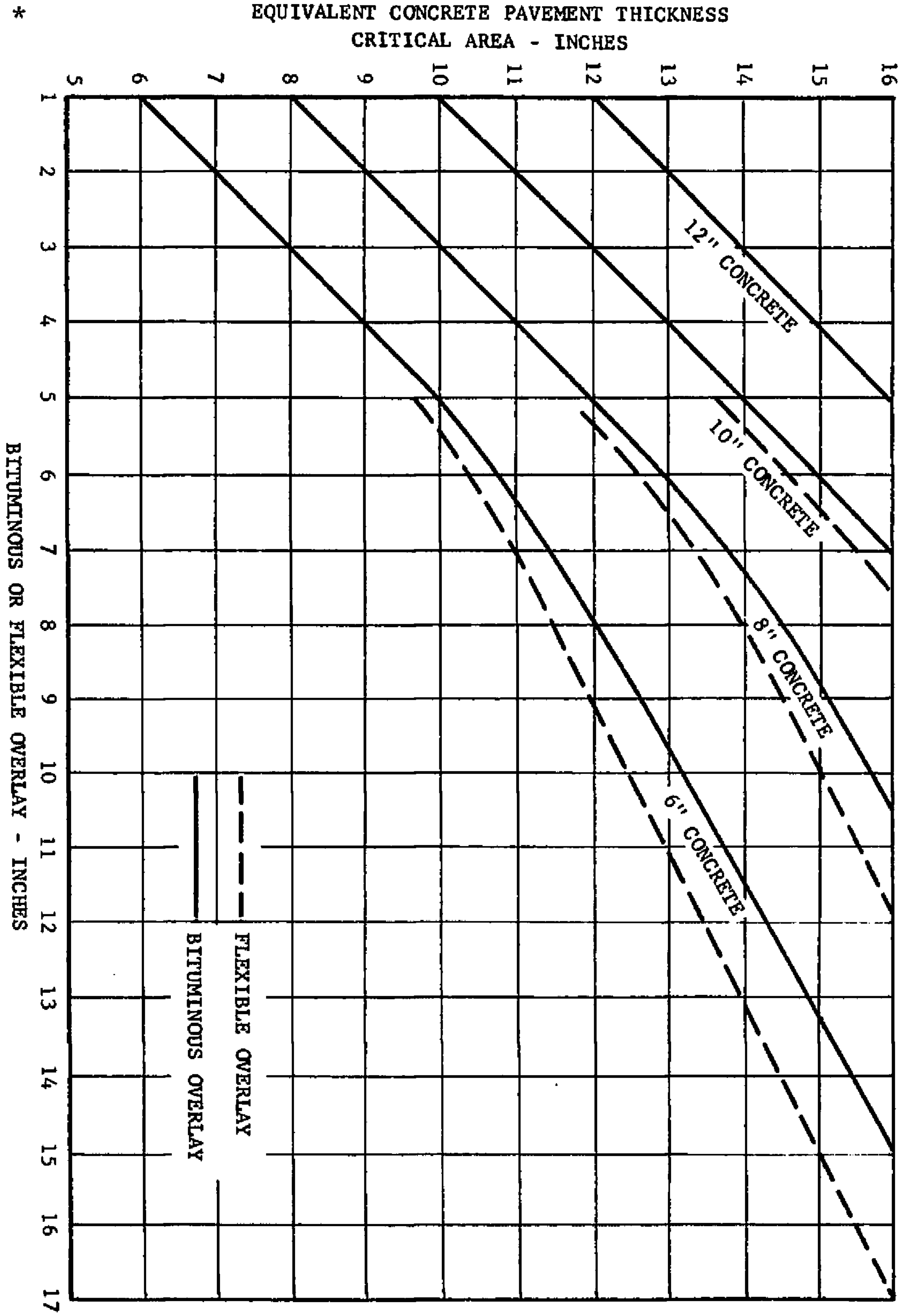


FIGURE 24. BITUMINOUS AND FLEXIBLE OVERLAY ON RIGID PAVEMENT

*

(2) Evaluation of both flexible and bituminous overlays is the same insofar as procedures are concerned and should be accomplished in the following manner.

(a) First evaluate the concrete slab as described previously for rigid pavement. In the event the pavement is evaluated as nonstandard, it should be assigned a thickness from reference to Figure 9. A 12-inch pavement on a weak subgrade and no subbase might be evaluated as unconventional and capable of supporting 130,000 pounds on dual gear, using Figure 22. Reference to Figure 9 will show 11 inches conventional pavement with subbase required for this weight. Therefore, the original slab will be considered as 11 inches concrete for use in Figure 24.

(b) For a given overlay thickness, enter Figure 24 from the bottom scale and proceed vertically to the concrete slab thickness, interpolating where required. From the concrete thickness move horizontally to the left and read the equivalent concrete pavement thickness on the left hand scale. A three-inch bituminous overlay on the 11-inch pavement above would result in an equivalent 13-inch slab for evaluation purposes.

(c) The equivalent slab is again checked against Figure 9 to read the pavement strength. For the 13-inch slab above, the strength is 170,000 pounds on dual and 300,000 pounds on dual tandem gear.

(d) Noncritical pavement is evaluated in the same manner as in (a) and (b), with the equivalent slab being divided by the appropriate factor prior to re-entering Figure 9 as in (c) above.

(e) Reported strength of flexible overlays will be reduced by the 10 percent per inch of surface deficiency in excess of one inch, in the same manner as with flexible pavement evaluation, paragraph 35, except that bituminous surface will not be converted to equivalent base course. The required surface thickness for this purpose will be 4 inches in critical areas and 3 inches in noncritical areas (3 inches and 2 inches for single gear) as in Figures 6, 7, and 8.

(3) Example. A section to be evaluated has been tested, and the following determinations have been made:

Concrete Flexural Strength	725 p.s.i.
Subgrade Modulus k	150 p.c.i.

The critical aircraft is four-engine turbojet at 310,000 pounds. The following sections are in place:

	Critical	Noncritical
Bituminous Surface	3"	3"
Crushed Stone Base	7"	4"
PCC	8"	8"
Subbase	0"	0"

(a) Use Figure 23 to evaluate the 8-inch pavement. From the 415 p.s.i. working stress and 150 k intersection, drop a vertical to intersect the 8-inch slab thickness, and read approximately 115,000 pounds.

(b) From Figure 9, 115,000 pounds requires a 7¾-inch slab.

(c) From Figure 24, read equivalent slab thicknesses of 14 inches for the critical and 12½ inches for the noncritical sections.

(d) From Figure 9, read 350,000 pounds dual tandem and 200,000 pounds dual gear critical strength.

(e) Also from Figure 9, read 12½" ÷ 0.9 = 13.9" = 345,000 pounds dual tandem and 195,000 pounds dual gear noncritical strength.

e. Rigid Pavement with Rigid Overlay. Rigid overlays on rigid pavement are evaluated by application of Figures 16 and 17.

(1) The basic evaluation is a simple reversal of the design procedure. Enter the bottom of the appropriate chart at the overlay thickness and proceed vertically to the thickness of the underlying slab, and read the equivalent single slab thickness on the scale at left. This thickness is applied to Figure 9 to read single, dual, and dual tandem strengths.

(2) Evaluation of either pavement course can be accomplished by any of the means discussed in the paragraphs 37a and b above. When evaluating by other than standard Figure 9 assumptions, the following conditions apply.

(a) Use the same k value for each course.

(b) Use the flexural strength which applies to each course even though the two courses may vary.

(c) When the lower slab condition C factor must be assumed, use the lower values in Figures 16 and 17 for overlay without or with leveling course, respectively. For relatively new overlays, record or test information is of primary importance. For older overlays, condition of the overlay slab assumes greater importance. Although a C factor may be assumed based on condition of the overlay, it is still applied to the base pavement when using Figures 16 and 17.

(d) For noncritical areas, divide the equivalent single slab by the appropriate factor for turbojet or propeller aircraft use.

(3) Consider the original 8-inch concrete in the previous example, except that a concrete overlay has been provided. The overlay is 10 inches thick in the critical pavement areas and 8 inches thick in the noncritical. Record information shows the original pavement was considered as 8 inches and slabs were replaced or jacked as required to achieve a C factor of 0.75 and no leveling course was used. The overlay was designed to use 700 pounds concrete and very slightly greater strength was determined from beams cast during construction.

(a) The base pavement has been evaluated as 7¼ inches in the previous example.

(b) From Figure 24 determine the 10-inch and 8-inch pavements to be 150,000 pounds and 115,000 pounds for dual tandem, based on 400 p.s.i. working stress and subgrade modulus of 150 p.c.i.

(c) From Figure 9, the above strengths equate to 9-inch and 7-inch pavement, respectively.

(d) From Figure 16, the equivalent single slab thicknesses are read as 12¼" and 10½" critical and noncritical. 12¼" evaluates at 265,000 pounds on dual tandem gear, 160,000 pounds on dual gear; 10½" ÷ 0.9 = 11.7" and evaluates as 240,000 pounds on dual tandem and 140,000 pounds on dual gear, as shown in Figure 9.

f. Consideration for Layered Subgrade. In any of the previous examples it could be necessary, due to selective grading, use of a borrow material or soil modifier, to evaluate a subgrade which consists of a thin layer of superior material over a relatively poor one. Design requirements for such a situation are discussed in paragraph 15. The evaluation procedure is virtually the same as the design procedure with a change in meaning of the z term. In either case the analysis must be in relation to a critical aircraft. For convenience the formula is repeated here.

$$z = y - \frac{t\ (y-x)}{(x+y)} \quad \text{in which}$$

z = equivalent subbase thickness
x = subbase thickness for good soil
y = subbase thickness for poor soil
t = thickness of good soil layer

Evaluation will be illustrated in the following example.

g. Example. Assume a critical aircraft to be a 160,000-pound turbojet on dual gear. A 12-inch layer of borrow soil classified as F2 overlies a soil classified as F8. From Figure 7, the subbase required for the two soils would be 4 inches and 24 inches, respectively, in critical areas. Applying the formula -

$$z = 24 - \frac{12\ (24-4)}{(24+4)}$$

$$z = 24 - 8.6 = 15.4''$$

Returning to the 160,000-pound load line in Figure 7, the 15.4-inch subbase requirement best satisfied an F6 subgrade condition, and the pavement will be considered to be on an F6 subgrade.

APPENDIX 1. DEVELOPMENT OF PAVEMENT DESIGN CURVES BASED ON GROSS AIRCRAFT WEIGHT

1. BACKGROUND.

a. The previous method of airport pavement design used by the Federal Aviation Administration was related to the equivalent single wheel load (ESWL) concept. With this method, the loads transmitted by multiwheeled undercarriages were converted to a theoretical isolated single wheel load.

b. Past experience has indicated that the ESWL design method was misunderstood and misinterpreted by various segments of the aviation community. This was due to the fact that individuals unfamiliar with all aspects of airport pavement design had become interested in the subject and were attempting to use the criteria to design or evaluate pavements.

c. It, therefore, became apparent that a new method of presenting design curves was desirable. The method chosen was that of relating pavement thicknesses to subgrade classification and the total or gross weight of an aircraft. It also became apparent, after a check on the current civil aircraft, that the assumption that 10 percent of the gross weight of the aircraft is supported by the nose wheel was unconservative.

d. For the above reasons, it was decided to modify the design curves to reflect the change in the assumption from 10 percent to 5 percent supported on the nose wheel, and transform the weight scale from single wheel load to gross aircraft weight.

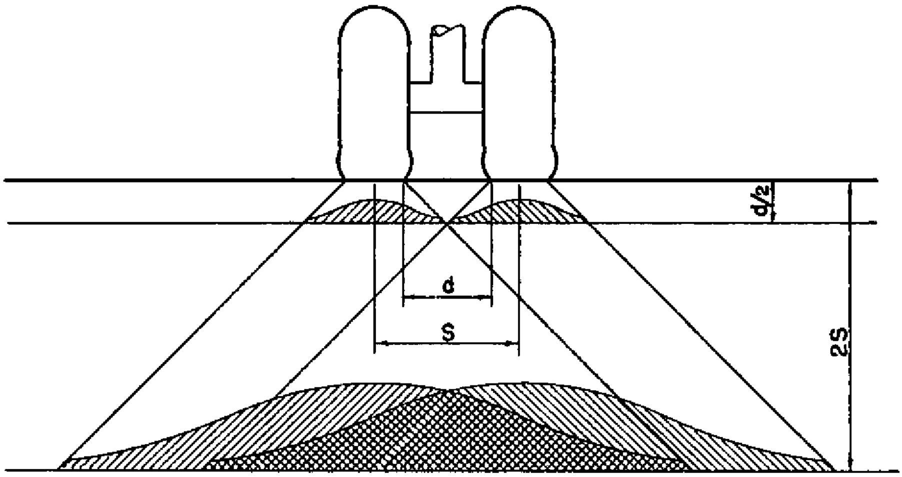
2. DEVELOPMENT OF NEW CURVES.

a. It would have been impractical to develop design curves for each different aircraft. However, since the thickness of both rigid and flexible pavement is dependent upon the gear dimensions and the type of gear, this would be necessary unless some valid assumptions could be made on these variables.

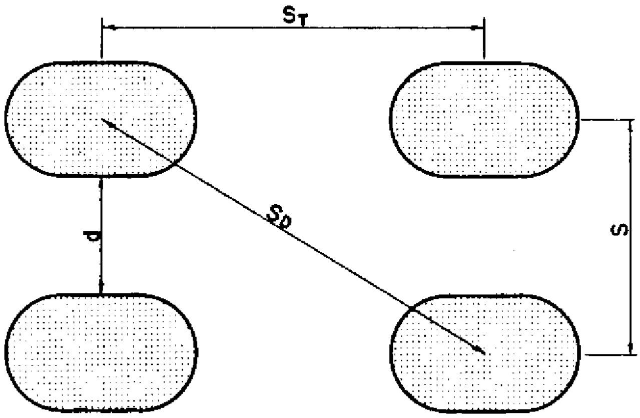
* b. In addition to gear type and dimension, other factors affecting pavement thickness design are the supporting value of the subgrade, the tire contact area and pressure, and the physical properties of the pavement structure. Examination of gear configuration and spacing, tire contact areas, and tire pressure in common use indicated that these follow a definite trend related to gross aircraft weight. Reasonable assumptions could therefore be made and design curves constructed from the assumed data.

*3. RIGID PAVEMENT CURVES.

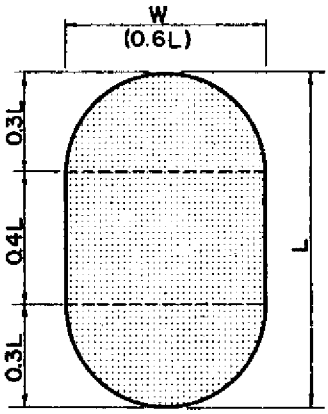
a. The rigid pavement design curves are based on the Westergaard equation for interior slab loading and the "Influence Charts for Concrete Pavement" developed by Pickett and Ray. Computer analyses of various aircraft gear configurations have established orientation versus stress relationships which show that maximum stress occurs, in other than single wheel gear, at some point removed from any tire print center. In the case of dual-tandem gear, rotation is also a critical factor. Stress increases of as much as 15 percent are found to exist when compared with the previous application of the influence charts with gear configurations centered and squared.



DISTRIBUTION OF WHEEL LOADS THROUGH FLEXIBLE PAVEMENTS



DUAL TANDEM GEAR TIRE IMPRINT



SINGLE TIRE IMPRINT

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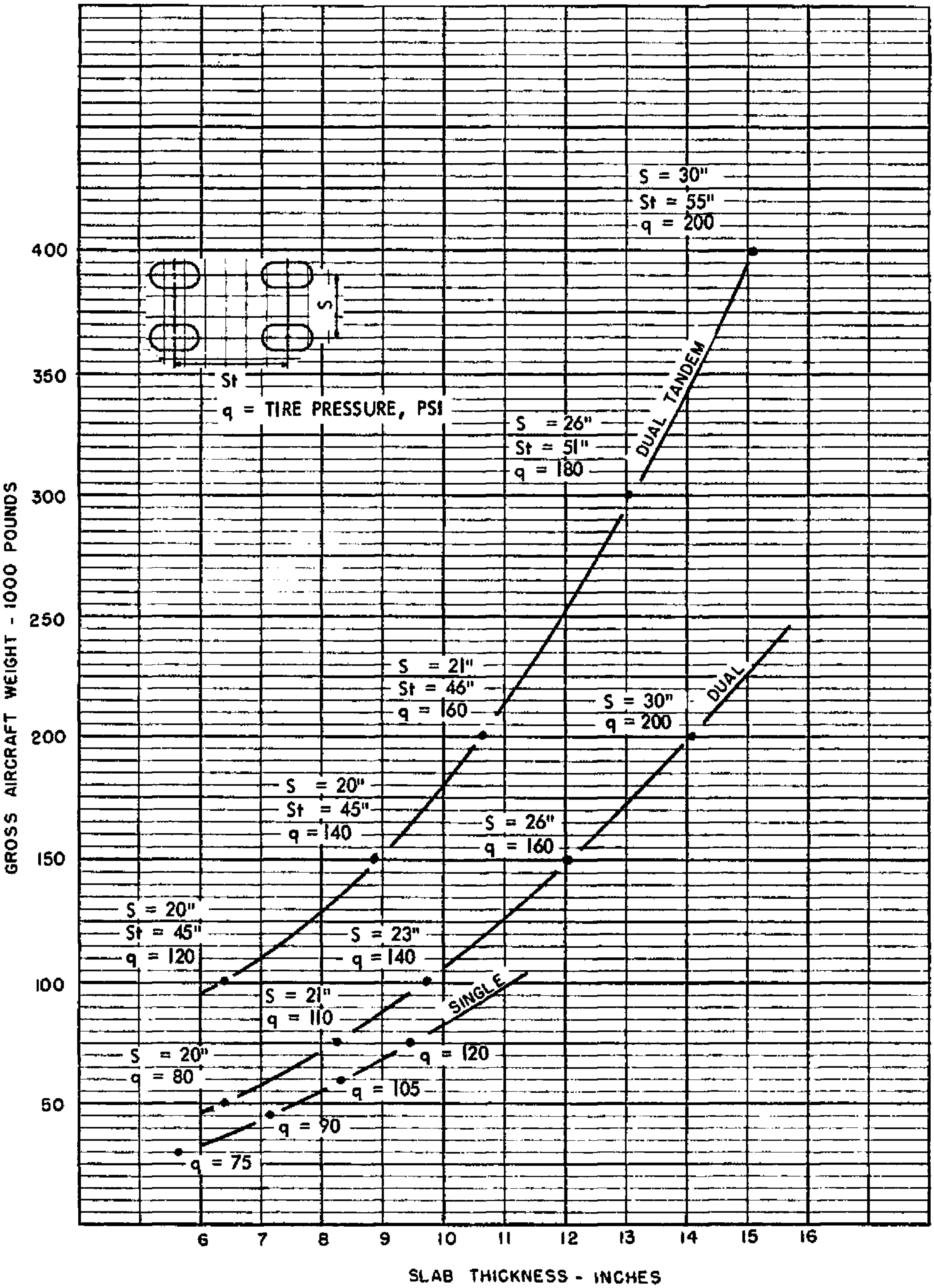

FIGURE 2. DEVELOPMENT OF RIGID PAVEMENT CURVES

* b. Curves have been developed from charts furnished by the Portland Cement Association, which reflect the increased stresses. These charts are shown in Figure 2. They are based also on assumed gear dimensions, tire pressures, and parameters explained in the following paragraphs. *

(1) Single Gear Aircraft - No special assumptions are needed.

(2) Dual Gear Aircraft - A study of the spacing between dual wheels for these aircraft indicated that a dimension of S=20 inches between centerline of tires agreed favorably for the lighter aircraft and a dimension of S=30 inches between centerline of tires agreed favorably for the heavier aircraft, see Figure 1.

(3) Dual-Tandem Gear Aircraft - The study indicated that dimensions of S=20 inches and ^{S}T=45 inches appeared reasonable for the lighter aircraft, and S=30 inches and ^{S}T=55 inches appeared reasonable for the heavier aircraft, see Figure 1.

* (4) Tire pressure (Q) varies between 75 p.s.i. and 200 p.s.i. depending on gear configuration and gross weight. It should be noted that tire pressure asserts less influence on stress as gross weights increase, and the 200 p.s.i. maximum pressure may be safely exceeded if other parameters are adhered to.

(5) Parameters - The following additional parameters were assumed in developing the rigid pavement thickness.

k = 300 pounds per cubic inch

s = 400 psi working stress

E = 4,000,000 psi

Poisson's Ratio = 0.15

(6) Safety Factor - The curves are based on a 700 psi flexural strength at 90 days (a safety factor of 1.75) and the requirements of critical area pavement.

c. The Figure 2 curves form the basis for the rigid pavement design curves in Figure 9 of Chapter 3, and the evaluation curves in Figures 21, 22, and 23 of Chapter 6. *

*

4. FLEXIBLE PAVEMENT CURVES.

a. As in the case of rigid pavements, it was necessary to make some reasonable compromise on gear dimensions in order to convert from equivalent single wheel loads to gross aircraft weight. Plots of the gear dimensions for civil aircraft indicated a trend of larger spacing for the larger aircraft.

(1) The design curves shown in Figures 3 and 4 were used to develop the present curves. After making the assumptions listed below, it was a simple matter to convert ESWL to gross weight.

(a) Single Gear Aircraft - No special assumptions were needed for the single gear aircraft because the ESWL is independent of depth. All that was necessary was to multiply the ESWL curves by 1/0.475 to convert directly to gross weight. A new gross weight grid was constructed for convenience and the new design curves are shown in Chapter 3, Figure 6.

(b) Dual Gear Aircraft - The plots of the gear dimensions versus ESWL for the dual gear aircraft indicated that a relationship between the d/2 distances and the ESWL's of the aircraft at this depth could be expressed by a straight line on the single wheel load versus pavement thickness curves (Figure 3). This line varied from a d/2 of 5 inches at an ESWL of 15,000 pounds to a d/2 of 10 inches at an ESWL of 50,000 pounds. This line is shown as line "a" in Figure 3. Similarly, these plots also indicated that a straight line could be assumed to express the relationship between the 2S distances and the ESWL's of the aircraft at that depth. This line varied from a 2S of 35 inches at an ESWL of 15,000 pounds to a 2S of 60 inches at an ESWL of 100,000 pounds. This line is shown as line "b" in Figure 3.

(c) Dual-Tandem Gear Aircraft - The plots of the gear dimensions versus ESWL for these aircraft indicated a relationship similar to those discovered for the dual gear aircraft. Plots of the lines expressing these relationships are shown in Figure 4 as lines "a" and "b".

*

* (2) Lines representing dual gear aircraft with gross weights of 50,000, 100,000, and 200,000 pounds are plotted in Figure 3. A new graph is plotted in Chapter 3, Figure 7, with gross aircraft weight on the vertical axis and the total pavement thickness on the horizontal axis. From Figure 3, total pavement thickness requirements for each gross aircraft weight are plotted for each subgrade classification. Connection of the three points for 50,000, 100,000, and 200,000 pounds gross weights for each subgrade classification by a straight line resulted in the reorientation of the subgrade curves. In Chapter 3, Figure 8 for dual-tandem gear aircraft was established by using Figure 4 in a like manner.

(3) The dashed lines in Figures 6, 7, and 8 of Chapter 3 represent the required nonbituminous base course thickness for critical pavement. The area between the two diagonally dashed lines represents the base course requirements for those gross aircraft weights. This base course thickness requirement is indicated along the right edge of the F10 subgrade classification line. *

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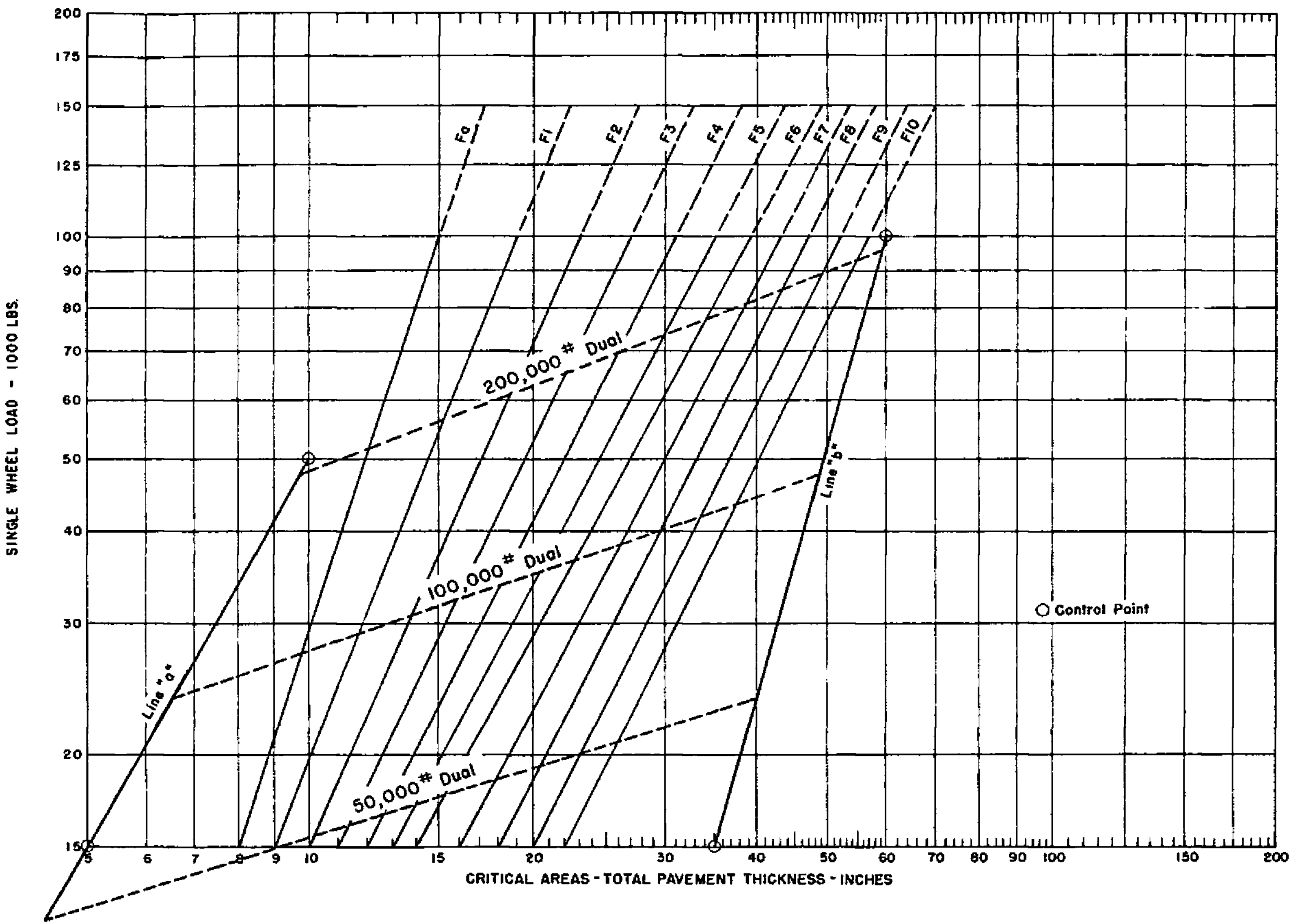

FIGURE 3. DEVELOPMENT OF FLEXIBLE PAVEMENT CURVES - DUAL GEAR

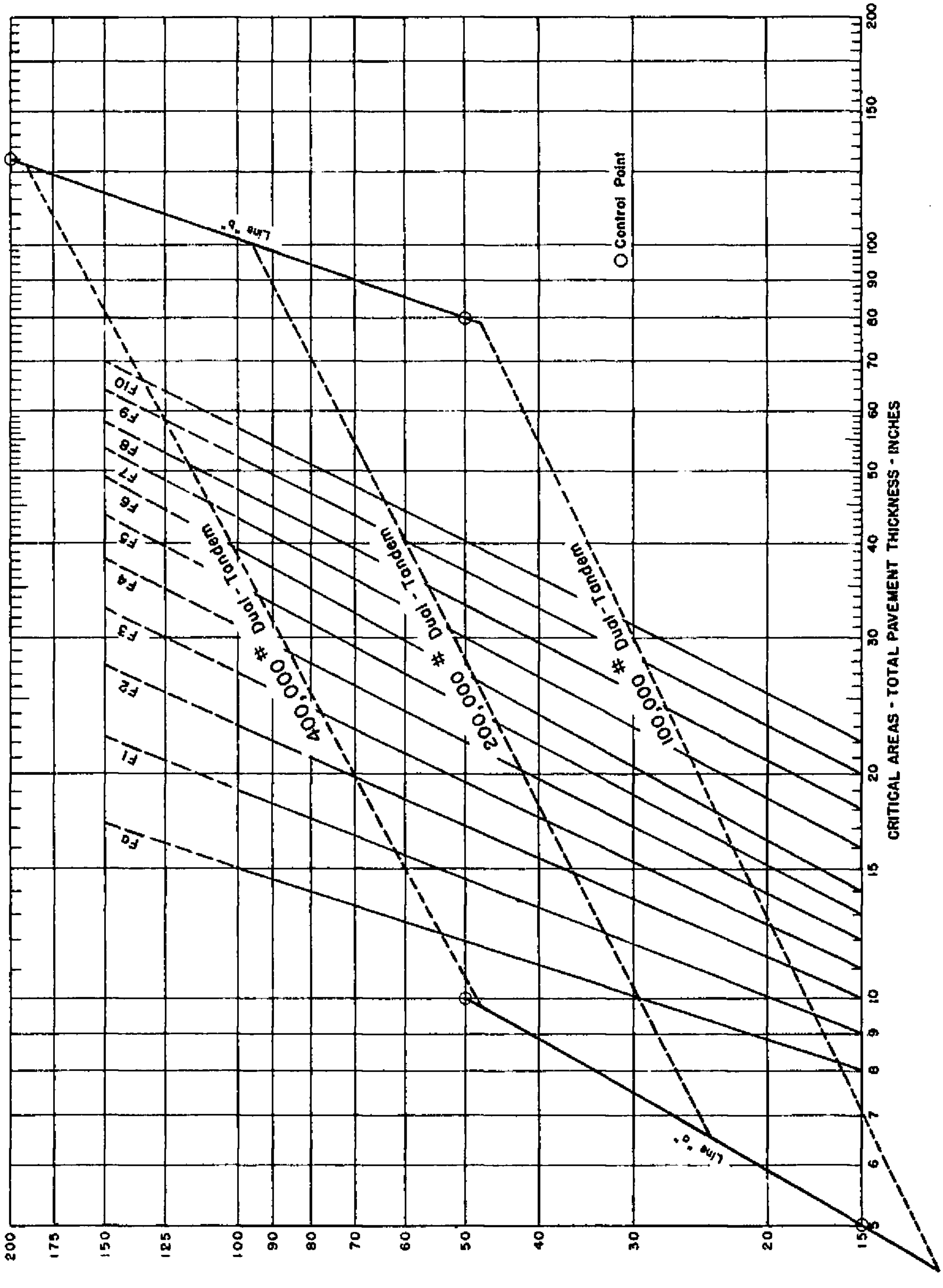

FIGURE 4. DEVELOPMENT OF FLEXIBLE PAVEMENT CURVES - DUAL-TANDEM GEAR

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APPENDIX 2. DESIGN OF PAVEMENTS AND STRUCTURES FOR HEAVY AIRCRAFT

1. BACKGROUND.

a. Aircraft weighing more than 350,000 pounds will soon operate at a number of airports. These include the B-747, DC-10, L-1011, L-500, etc. Other aircraft of lesser weights, but with greater operating frequencies, will impose pavement stresses of large magnitude at these same airports. These include the B-707 (300 and 400 series), DC-8 (20 through 60 series), and B-727 (C, QC, 100C, 200).

b. Traffic forecasts and the predictions of industry associations and airline planners support the supposition that increasingly heavy subsonic aircraft will be developed and utilized within a 10- to 20-year period. A 1-1/2 million pound aircraft appears feasible and reasonably certain to materialize.

c. These data create concern regarding our design practices in the several areas of structures, coverages, heavy loads, stabilized components, and keel sections, as discussed below.

2. CULVERTS, BRIDGES, AND AIRPORT STRUCTURES SUPPORTING AIRCRAFT.

a. Little, if any, information is available concerning the flotation arrangement which the future heavy aircraft will employ; i.e., whether the primary weight distribution shall be longitudinal along the aircraft fuselage, lateral along the wings, or a combination of both.

b. It may be assumed that sufficient distribution of the imposed aircraft load will be accomplished to permit operation on present runway pavements or, conversely, that strengthening of pavements will not pose extreme problems. Point loading on some structures will be increased; while on overpasses, the entire aircraft weight may be imposed upon a deck span, pier, or footing. For these, strengthening is extremely difficult, costly, and time-consuming.

c. For structures with spans in excess of 10 feet, the slab or deck design, and to some degree, the design of piers and footings, become greatly dependent upon the aircraft gear configuration. Our assessment indicates that three basic configurations, shown in Figure 1, will, if all are considered in the design of the bridge components, provide sufficient support for any aircraft which may be forthcoming. These consist of two areas enclosing eight wheels each, or 16 wheels per aircraft comprising the main gear. Nose gears, as such, are not considered, except as they occur in the Type A bicycle configuration where they support roughly half of the static load. The "area" dimensions are six or eight feet by 20 feet, each supporting half of the aircraft gross weight or 750,000 pounds. Wheel prints are uniformly spaced within their respective areas.

d. Footing design will vary with depth and soil type. No departure from accepted methodology is anticipated; except that for shallow structures, such as inlets and culverts, the concentrated loads may require heavier and wider spread footings than those presently provided by the structures standards in current use.

e. It should be noted that all loads discussed herein are to be considered as live loads, and that braking loads as high as .7G (for no-slip brakes) must be anticipated on bridge decks and considered for other structures subject to direct wheel loads. Where clearances permit, the use of an earth cover over structures shall be used because of the earth's relative insensitivity to increased loadings and to minimize braking thrust and "bridge approach" settlement problems.

f. At airports where operations are occurring or anticipated by aircraft of the type mentioned in paragraph 1a, airport owners shall be encouraged to design decks and covers subject to direct aircraft loadings of this type, such as manhole covers, inlet grates, utility tunnel roofs, bridges, etc., to withstand the following loadings:

(1) For spans of two feet or less in the least direction, a uniform live load of 250 p.s.i.

(2) For spans between two feet and 10 feet in the least direction, a uniform live load varying between 250 p.s.i. and 50 p.s.i., in inverse proportion to the span length.

(3) For spans of 10 feet or greater in the least direction, the design shall be based on the most critical loading condition which may be applied by the gear configurations illustrated in Figure 2.

(4) Special consideration shall be given to structures that will be required to support both in-line and diagonal traffic lanes, such as diagonal taxiways or apron taxi routes. If structures require expansion joints, load transfer may not be possible.

3. PAVEMENT DESIGN AS AFFECTED BY COVERAGES.

a. Historically, the Federal Aviation Administration (FAA) pavement design has provided for "capacity" operations of the critical aircraft; and, based on the Corps of Engineers' criteria from which it was derived, "capacity" is considered as 5,000 coverages. While this is true for flexible pavement, the rigid pavement design changes, incorporated in Change 1 to the Airport Paving Circular, dated 11 June 1968, now provide for approximately 25,000 coverages.

b. The Corps of Engineers' formula for converting aircraft operations to coverages (a coverage occurs when each point of the pavement surface has been subjected to one maximum stress by the operating aircraft) is:

$$C = D \times \frac{0.75 \times N \times W}{T \times 12} \quad \text{where}$$

C = coverages

D = cycles of operations (one landing and one takeoff)

N = number of wheels on one main gear

W = width of tire contact area of one tire in inches

T = traffic width in feet (use 7.5)

c. Using a 13-inch tire width as typical and a 7.5-foot wide traffic lane, 5,000 and 25,000 coverages are achieved by about 12,000 and 60,000 "cycles of operations" by dual tandem gear aircraft. In FAA terminology, this would be expressed as 24,000 and 120,000 operations, respectively, or two D. Further, we consider jet aircraft departures only as being critical, since the maximum landing weight of today's jet is usually 3/4 of the maximum takeoff weight or less, and landings are not critical from a pavement stress standpoint. Accordingly, 24,000 and 120,000 departures are considered to be the design life of flexible and rigid pavements, respectively.

d. Pavement constructed with Federal-aid Airport Program (FAAP) funds should, with normal maintenance, have a life equal at least to the obligation term of the grant agreement or 20 years. Accordingly, pavement constructed to FAA standards now provides for 1,200 and 6,000 departures annually for flexible and rigid pavements, respectively. While this may appear to penalize flexible pavement from an eligibility standpoint, the provisions of this appendix will tend to cancel any discrepancy. We suggest that rather than attempt to provide the 25,000 coverages in original construction, the added thickness be reserved for stage completion at a time when the flexible surface will benefit from a new, dense cover.

e. References 7 and 8, as listed in the masthead page, forecast 1980 level of operations by aircraft such as those mentioned in the background statement. These figures are used as a convenient 20-year mean value.

f. There is a logarithmic relationship between cumulative pavement stress due to a given wheel load and repetitions thereof as compared to other wheel loads and repetitions. This relationship can be expressed as:

$$\log R_1 = \log R_2 \times \left(\frac{W_2}{W_1}\right)^{\frac{1}{2}} \quad \text{wherein}$$

R_2 and R_1 are the respective repetitions and W_2 and W_1 are the respective wheel loads. We can, thus, convert operations of an aircraft (or family) of known weight to an equivalent number of 350,000-pound gross weight operations (W_1 = 350,000 pounds) on dual tandem gear. Gross weight is used in this interpretation per the FAA design system.

g. From tabulated FY 1968 air carrier departures, we can tabulate equivalent departures and determine a factor for actual versus equivalent departures on a national basis, as shown below.

AIRCRAFT	MAX. GTW (W_2)	FY '68 DEPS. (R_2)	$\left(\frac{W_2}{W_1}\right)^{\frac{1}{2}}$	EQUIVALENT CRITICAL DEPS. (R_1)
707-300, 300B, 300C	312,000#	74,900	.944	39,950
DC-8 -20, 30, 40, 50	315,000	148,700	.949	81,110
DC-8 -61, 62, F	340,000	23,600	.985	20,290
1/ 727-100, QC, 100C, 200	170,000	900,900	.926	326,600
TOTALS		1,148,100		467,950

NOTE: Ratio of equivalent to actual departures =

$$\frac{467,950}{1,148,100} = .41$$

1/ In order to avoid the cumbersome conversion of the dual gear 727 to coverages relative to dual tandem gear in the balance of the table, the 727 has been assigned a 300,000-pound dual tandem gross weight as determined by the equal pavement thickness requirement incorporated in the Airport Paving Circular, Figures 7, 8, and 9. It is assumed that this provides an equal stress magnitude per aircraft passage.

h. Figure 2 is a listing of locations where the forecast number of departures, after conversion to equivalent critical departures, exceeds 1,200 annually for 1980. For these and for any other location for which FAA planning procedures indicate more than 1,200 equivalent critical departures annually by the aircraft tabulated in paragraph 3g or equivalent, the minimum pavement design section for areas used by the heavy aircraft shall be the FAA 350,000-pound standard contained in Chapter 3. In addition, ground traffic and departure runway use shall be examined and the following design corrections applied to any runway, associated taxiway and terminal apron, when equivalent critical departures (planned by 1980) will exceed the following levels.

(1) For flexible pavements:

(a) For equivalent critical departures in excess of 1,200 annually, both critical and noncritical surface thicknesses shall be increased one inch. In addition, make one of the following adjustments.

(b) For departures between 1,200 and 3,000 annually, increase both base and subbase thicknesses by 10 percent.

(c) For departures between 3,000 and 6,000 annually, increase base and subbase thicknesses by 20 percent.

(d) For departures in excess of 6,000 annually, increase base and subbase thicknesses by 30 percent.

(2) For rigid pavements, when equivalent critical departures exceed 6,000 annually, concrete thickness shall be determined by Figure 23, Chapter 6, using a design safety factor of 2; i.e., for 700 p.s.i. concrete design flexural strength, use a working stress of 350 p.s.i.

4. <u>AIRCRAFT EXCEEDING 350,000 POUNDS IN WEIGHT</u>.

a. Several new aircraft which exceed the 350,000-pound loadings contemplated in FAA design criteria, and for which the flotation systems vary considerably from the assumptions and parameters noted in the Appendix 1 to this circular, are now in the advanced development or production stage. These include the B-747, DC-10, Lockheed L-1011, and L-500. For these, the manufacturers' published aircraft characteristics for airport planning typically include pavement design charts which are based on the PCA-Pickett & Ray-Interior loading design method for rigid pavement and a modified

CBR procedure for flexible pavement. These design methods have been satisfactory for aircraft which do not exceed 350,000 pounds in weight, as the aircraft to which they have been applied were in reasonable conformity to the experimental data from which the design criteria were derived.

b. In each of the large new aircraft, however, the experimental data have required extrapolation and/or additional factors have been introduced, such as the influence of remote wheels and the introduction of meaningful stresses into deeper subgrade strata. These combine to lessen somewhat the relative confidence which can be placed in the present design system as extended to the heavier aircraft. This problem is recognized in the industry, and considerable research is being undertaken to extend the design systems logically. Until such research produces useful criteria, we must make some conservative assumption in our design recommendations for these heavy aircraft.

c. The Figure 1 locations marked by a number sign (#) are considered likely to receive service by aircraft weighing in excess of 350,000 pounds. For these and for other locations designated by FAA planning procedures to receive service by aircraft weighing in excess of 350,000 pounds, the minimum pavement design section for any area on which the heavy aircraft will operate shall be the FAA 350,000-pound standard, regardless of the number of operations anticipated.

5. STABILIZED BASE AND SUBBASE COURSES.

a. A clear majority of pavement difficulties and failures which occurred under heavy aircraft loadings (except in those instances where extreme overloading of the pavement's design capability was at fault) have been attributed to excessive moisture in base and subbase courses. This is especially true for "sandwich" overlays where granular material is used between upper and lower impervious courses.

b. For new pavements to accommodate dual tandem gear aircraft weighing in excess of 200,000 pounds gross aircraft weight and sections of equal thickness for other gear types, it shall be the FAA policy to require that all base and subbase pavement courses be stabilized (P-201, P-304 or equivalent). These shall be substituted for granular base or subbase at the ratio of one inch of stabilized material for 1-1/2 inches of granular material. Exceptions should be based on proven performance of a granular material in a specific location, such as lime rock bases in the State of Florida.

c. Other exceptions may be made on the basis of superior materials being available, such as 100 percent crushed, hard, closely graded stone, or materials modified with cement, lime, or asphalt. These shall meet the present specification requirements, plus the following criteria. For nonfrost areas, base and subbase materials shall exhibit a remolded soaked CBR minimum of 100 and 35, respectively. In addition, where frost may penetrate the base or subbase, the materials must meet such tests as will be satisfactory to the respective regions that the materials used are impermeable or nonfrost susceptible. In no case, however, shall a nonstabilized material be used over a subgrade modified by lime, portland cement, or bituminous material.

d. The minimum combined bituminous surface and stabilized base thickness shall not be less than required by the Fa line in Chapter 3, Figures 7 and 8; nor shall P-201 and P-304 be less than 4" and 6" in thickness, respectively.

6. KEEL SECTION DESIGN.

The advent of heavier aircraft is accompanied by wider gear spacing; and pavement designers must consider the coverage limits in determining acceptable keel and transition section dimensions. Runway design based on the keel sections shown in Chapter 3, Figure 5, is to be encouraged. For runways to serve "X" and "L" category aircraft, as listed in references 7 and 8, the minimum keel width for both critical and noncritical runway areas shall be 100 feet.

(NOT TO SCALE)

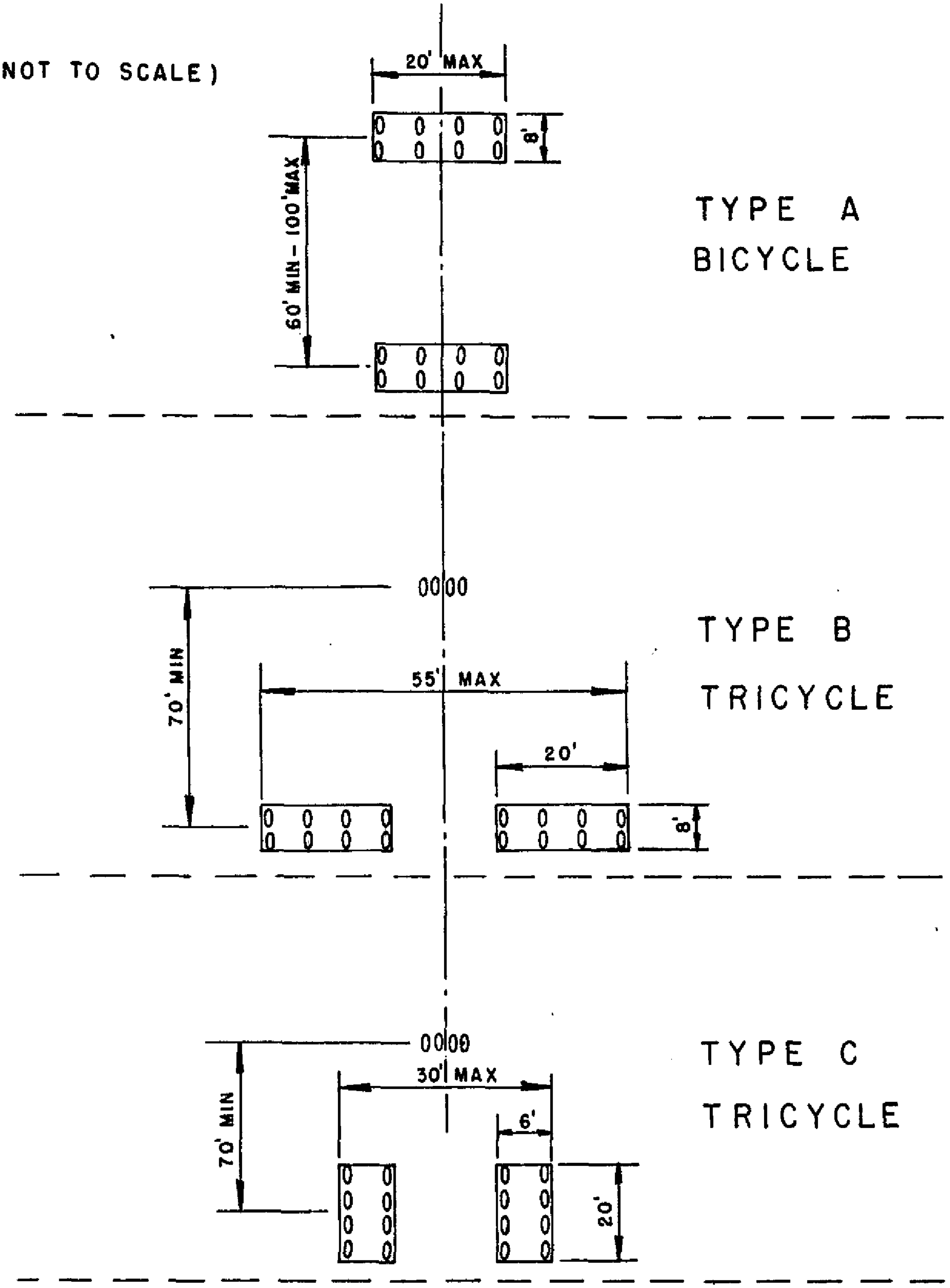

FIGURE 1. TYPICAL GEAR CONFIGURATIONS FOR DESIGN OF STRUCTURES

FIGURE 2. ESTIMATED 1980 EQUIVALENT CRITICAL DEPARTURES

The number sign (#) shows locations where service by aircraft exceeding 350,000 pounds is anticipated.

LOCATION	EQUIVALENT NO. OF DEPARTURES BY CRITICAL AIRCRAFT
Albany, N.Y.	3,050
#Albuquerque	5,300
#Anchorage, Alaska	1,636 (1)
#Atlanta	51,630
#Baltimore	26,400
Birmingham, Ala.	1,735
#Boston	43,775
#Buffalo	7,500
Charlotte, N.C.	1,200
#Chicago - O'Hare	108,200
Chicago - Midway	27,050
#Cincinnati	18,525
#Cleveland	29,650
#Columbus, Ohio	6,835
#Dallas	51,200
Dayton	2,250
#Denver	28,175
#Detroit	40,500
#El Paso	5,080
#Fort Lauderdale, Fla.	11,150
Hartford, Conn. (Bradley)	4,365
#Honolulu, Hawaii	12,978 (1)
#Houston	27,175
#Indianapolis	2,020
#Jacksonville, Fla.	7,710
#Kansas City	14,280
#Las Vegas	17,550
#Los Angeles	111,300
#Louisville	6,140
#Memphis	3,775
#Miami	60,425
#Milwaukee	7,240
#Minneapolis	21,215
Nashville	2,960
#New Orleans	26,600
#Newark	46,690
#New York (JFK)	83,905
#New York (La Guardia)	56,220
#Oakland	6,145

LOCATION	EQUIVALANT NO. OF DEPARTURES BY CRITICAL AIRCRAFT
#Oklahoma City	4,120
Omaha	1,940
Orlando	5,630
#Philadelphia	36,990
#Phoenix	13,830
#Pittsburg	26,600
#Portland, Oregon	17,015
#Rochester, N.Y.	4,900
Sacramento	2,850
#Salt Lake City	9,365
#San Antonio	8,445
#San Diego	15,690
#San Francisco	64,900
#San Juan, Puerto Rico	8,806 (1)
#Seattle-Tacoma	31,620
#St. Louis	25,680
Syracuse	3,040
#Tampa	26,480
#Tucson	3,980
#Tulsa	3,960
#Washington (Dulles)	13,730
Washington (National)	65,605
#West Palm Beach, Fla.	7,013 (1)

(1) Forecast data are not available for these locations in references 7 and 8, so individual calculations were made using hub growth factors.