c. **Muskeg.** Muskeg is sometimes encountered in arctic areas. Muskeg is a highly organic soil deposit which is essentially a swamp. Every effort should be made to avoid pavement construction on this material. If construction in areas of muskeg is unavoidable and the soil survey shows the thickness of muskeg is less than 5 feet (1.5 m), the muskeg should be removed and replaced with granular fill. If the thickness of muskeg is too great to warrant removal and replacement, a 5 foot (1.5 m) granular fill should be placed over the muskeg. These thicknesses are based on experience and it should be anticipated that differential settlement will occur and considerable maintenance will be required to maintain a smooth surface. Use of a geotextile between the muskeg surface and the bottom of granular fill is recommended to prevent migration of the muskeg up into the granular till. In this application, the geotextile is considered to perform the function of separation. Additional information on the design and construction of geotextiles performing the separation function within pavement sections is provided in FHWA-HI-90-001 (see Appendix 4).

d. **Permafrost** Design. Design of pavements in areas of permafrost is discussed in Chapter 3. Further information on permafrost can be found in Research Report No. FAA/RD/74/30, see Appendix 4.

CHAPTER 3. PAVEMENT DESIGN

SECTION 1. DESIGN CONSIDERATIONS

300. SCOPE. This chapter covers pavement design for airports serving aircraft with gross weights of 30,000 pounds (13 000 kg) or more. Chapter 5 is devoted to the design of pavements serving lighter aircraft with gross weights under 30,000 pounds (13 000 kg).

301. DESIGN PHILOSOPHY. The FAA policy of treating the design of aircraft landing gear and the design and evaluation of airport pavements as three separate entities is described in the Foreword to this advisory circular. The design of airport pavements is a complex engineering problem which involves a large number of interacting variables. The design curves presented in this chapter are based on the CBR method of design for flexible pavements and a jointed edge stress analysis for rigid pavements. Other design procedures such as those based on layered elastic analysis and those developed by The Asphalt Institute and the Portland Cement Association may be utilized to determine pavement thicknesses when approved by the FAA. These procedures will yield slightly different design thicknesses due to different basic assumptions. All pavement designs should be summarized on FAA Form 5100-1, Airport Pavement Design, which is considered to be part of the Engineer's Report. An Engineer's Report should be prepared for FAA review and approval along with initial plans and specifications. Because of thickness variations, the evaluation of existing pavements should be performed using the same method as was employed in the design. Procedures to be used in evaluating pavements are described in detail in Chapter 6 of this advisory circular. Details on the development of the FAA method of design are as follows:

a. Flexible Pavements. The flexible pavement design curves presented in this chapter are based on the California Bearing Ratio (CBR) method of design. The CBR design method is basically empirical; however, a great deal of research has been done with the method and reliable correlations have been developed. Gear configurations are related using theoretical concepts as well as empirically developed data. The design curves provide the required total thickness of flexible pavement (surface, base, and subbase) needed to support a given weight of aircraft over a particular subgrade. The curves also show the required surface thickness. Minimum base course thicknesses are given in a separate table. A more detailed discussion of CBR design is presented in Appendix 2.

b. Rigid Pavements. The rigid pavement design curves in this chapter are based on the Westergaard analysis of edge loaded slabs. The edge loading analysis has been modified to simulate a jointed edge condition. Pavement stresses are higher at the jointed edge than at the slab interior. Experience shows practically all load induced cracks develop at jointed edges and migrate toward the slab interior. Design curves are furnished for areas where traffic will predominantly follow parallel or perpendicular to joints and for areas where traffic is likely to cross joints at an acute angle. The thickness of pavement determined from the curves is for slab thickness only. Subbase thicknesses are determined separately. A more detailed discussion of the basis for rigid pavement design is presented in Appendix 2.

302. BACKGROUND. An airfield pavement and the operating aircraft represent an interactive system which must be addressed in the pavement design process. Design considerations associated with both the aircraft and the pavement must be recognized in order to produce a satisfactory design. Careful construction control and some degree of maintenance will be required to produce a pavement which will achieve the intended design life. Pavements are designed to provide a finite life and fatigue limits are anticipated. Poor construction and lack of preventative maintenance will usually shorten the service life of even the best designed pavement.

a. Variables. The determination of pavement thickness requirements is a complex engineering problem. Pavements are subject to a wide variety of loadings and climatic effects. The design process involves a large number of interacting variables which are often difficult to quantify. Although a great deal of research work has been completed and more is underway, it has been impossible to arrive at a direct mathematical solution of thickness requirements. For this reason the determination of pavement thickness must be based on the theoretical analysis of load distribution through pavements and soils, the analysis of experimental pavement data, and a study of the performance of pavements under actual service conditions. Pavement thickness curves presented in this chapter have been developed through correlation of the data obtained from these sources. Pavements designed in accordance with these standards are intended to provide a structural life of 20 years that is free of major maintenance if no major changes in forecast traffic are encountered. It is likely that rehabilitation of surface grades and renewal of skid resistant properties will be needed before 20 years due to destructive climatic effects and deteriorating effects of normal usage.

b. Structural Design. The structural design of airport pavements consists of determining both the overall pavement thickness and the thickness 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 and materials comprising the pavement structure.

303. AIRCRAFT CONSIDERATIONS.

a. Load. The pavement design method is based on the gross weight of the aircraft. For design purposes the pavement should be designed for the maximum anticipated takeoff weight of the aircraft. The design procedure assumes 95 percent of the gross weight is carried by the main landing gears and 5 percent is carried by the nose gear. AC 150/5300-13, Airport Design, lists the weight of nearly all civil aircraft. Use of the maximum anticipated takeoff weight is recommended to provide some degree of conservatism in the design and is justified by the fact that changes in operational use can often occur and recognition of the fact that forecast traffic is approximate at best. By ignoring arriving traffic some of the conservatism is offset.

b. Landing Gear Type and Geometry. The gear type and configuration dictate how the aircraft weight is distributed to the pavement and determine pavement response to aircraft loadings. It would have been impractical to develop design curves for each type of aircraft. However, since the thickness of both rigid and flexible pavements is dependent upon the gear dimensions and the type of gear, separate design curves would be necessary unless some valid assumptions could be made to reduce the number of variables. Examination of gear configuration, tire contact areas, and tire pressure in common use indicated that these follow a definite trend related to aircraft gross weight. Reasonable assumptions could therefore be made and design curves constructed from the assumed data. These assumed data are as follows:

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

(2) Dual Gear Aircraft. A study of the spacing between dual wheels for these aircraft indicated that a dimension of 20 inches (0.5 1 m) between the centerline of the tires appeared reasonable for the lighter aircraft and a dimension of 34 inches (0.86 m) between the centerline of the tires appeared reasonable for the heavier aircraft.

(3) Dual Tandem Gear Aircraft. The study indicated a dual wheel spacing of 20 inches (0.51 m) and a tandem spacing of 45 inches (1.14 m) for lighter aircraft, and a dual wheel spacing of 30 inches (0.76 m) and a tandem spacing of 55 inches (1.40 m) for the heavier aircraft are appropriate design values.

(4) Wide Body Aircraft. Wide body aircraft; i.e., B-747, DC-10, and L-101 1 represent a radical departure from the geometry assumed for dual tandem aircraft described in paragraph (c) above. Due to the large differences in gross weights and gear geometries, separate design curves have been prepared for the wide body aircraft.

c. Tire Pressure. Tire pressure varies between 75 and 200 PSI (516 to 1 380 kPa) depending on gear configuration and gross weight. It should be noted that tire pressure asserts less influence on pavement stresses as gross weight increases, and the assumed maximum of 200 PSI (1 380 kPa) may be safely exceeded if other parameters are not exceeded and a high stability surface course is used.

d. Traffic Volume. Forecasts of annual departures by aircraft type are needed for pavement design. Information on aircraft operations is available from Airport Master Plans, Terminal Area Forecasts, the National Plan of Integrated Airport Systems, Airport Activity Statistics and FAA Air Traffic Activity. These publications should be consulted in the development of forecasts of annual departures by aircraft type.

304. DETERMINATION OF DESIGN AIRCRAFT. The forecast of annual departures by aircraft type will result in a list of a number of different aircraft. The design aircraft should be selected on the basis of the one requiring the greatest pavement thickness. Each aircraft type in the forecast should be checked to determine the pavement thickness required by using the appropriate design curve with the forecast number of annual departures for that aircraft. The aircraft type which produces the greatest pavement thickness is the design aircraft. The design aircraft is not necessarily the heaviest aircraft in the forecast.

305. **DETERMINATION OF EQUIVALENT ANNUAL DEPARTURES BY THE DESIGN AIRCRAFT.**

a. Conversions. Since the traffic forecast is a mixture of a variety of aircraft having different landing gear types and different weights, the effects of all traffic must be accounted for in terms of the design aircraft. First, all aircraft must be converted to the same landing gear type as the design aircraft. Factors have been established to accomplish this conversion. These factors are constant and apply to both flexible and rigid pavements. They represent an approximation of the relative fatigue effects of different gear types. Much more precise and theoretically rigorous factors could be developed for different types and thicknesses of pavement. However, such precision would be impractical for hand calculation as numerous iterations and adjustments would be required as the design evolved. At this stage of the design process such precision is not warranted. The following conversion factors should be used to convert from one landing gear type to another:

To Convert From	To	Multiply Departures by
single wheel	dual wheel	0.8
single wheel	dual tandem	0.5
dual wheel	dual tandem	0.6
double dual tandem	dual tandem	1.0
dual tandem	single wheel	2.0
dual tandem	dual wheel	1.7
dual wheel	single wheel	1.3
double dual tandem	dual wheel	1.7

Secondly, after the aircraft have been grouped into the same landing gear configuration, the conversion to equivalent annual departures of the design aircraft should be determined by the following formula:

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

where:
R_1 = equivalent annual departures by the design aircraft
R_2 = annual departures expressed in design aircraft landing gear
W_1 = wheel load of the design aircraft
W_2 = wheel load of the aircraft in question

For this computation 95 percent of the gross weight of the aircraft is assumed to be carried by the main landing gears. Wide body aircraft require special attention in this calculation. The procedure discussed above is a relative rating which compares different aircraft to a common design aircraft. Since wide body aircraft have significantly different landing gear assembly spacings than other aircraft, special considerations are needed to maintain the relative effects. This is done by treating each wide body as a 300,000-pound (136 100 kg) dual tandem aircraft when computing equivalent annual departures. This should be done in every instance even when the design aircraft is a wide body. After the equivalent annual departures are determined, the design should proceed using the appropriate design curve for the design aircraft. For example if a wide body is the design aircraft, all equivalent departures should be calculated as described above; then the design curve for the wide body should be used with the calculated equivalent annual departures.

b. Example: Assume an airport pavement is to be designed for the following forecast traffic:

Aircraft	Gear Type	Average Annual Departures	Maximum Takeoff Weight lbs.	(kg)
727-100	dual	3,760	160,000	(72600)
727-200	dual	9,080	190,500	(86500)
707-320B	dual tandem	3,050	327,000	(148 500)
DC-g-30	dual	5,800	108,000	(49 000)
cv-880	dual tandem	400	184,500	(83 948)
737-200	dual	2,650	115,500	(52 440)
L-101 l-100	dual tandem	1,710	450,000	(204 120)
747-100	double dual tandem	85	700,000	(3 17 800)

(1) **Determine Design Aircraft.** A pavement thickness is determined for each aircraft in the forecast using the appropriate design curves. The pavement input data, CBR, K value, flexural strength, etc., should be the same for all aircraft. Aircraft weights and departure levels must correspond to the particular aircraft in the forecast. In this example the 727-200 requires the greatest pavement thickness and is thus the design aircraft.

(2) **Group Forecast Traffic into Landing Gear of Design Aircraft.** In this example the design aircraft is equipped with a dual wheel landing gear so all traffic must be grouped into the dual wheel configuration.

(3) **Convert Aircraft to Equivalent Annual Departures of the Design Aircraft.** After the aircraft mixture has been grouped into a common landing gear configuration, the equivalent annual departures of the design aircraft can be calculated.

Aircraft	Equi. Dual Gear Departs.	Wheel Load lbs.	Wheel Load (kg)	Wheel Load of Design Aircraft lbs.	Wheel Load of Design Aircraft (kg)	Equi. Annual Departs Design Aircraft
727-100	3,760	38,000	(17 240)	45,240	(20 520)	1,891
727-200	9,080	45,240	(20 520)	45,240	(20 520)	9,080
707-320B	5,185	38,830	(17 610)	45,240	(20 520)	2,764
DC-g-30	5,800	25,650	(11 630)	45,240	(20 520)	682
cv-880	680	21,910	(9 940)	45,240	(20 520)	94
737-200	2,650	27,430	(12,440)	45,240	(20 520)	463
747	145	35,625’	(16 160)	45,240	(20520)	83
L-101 1	2,907	35,625’	(16 160)	45,240	(20,520)	1,184
						Total = 16,241

‘Wheel loads for wide body aircraft will be taken as the wheel load for a 300,000-pound (136 100 kg) aircraft for equivalent annual departure calculations.

(4) **Final Result.** For this example the pavement would be designed for 16,000 annual departures of a dual wheel aircraft weighing 190,500 pounds (86 500 kg). The design should, however, provide for the heaviest aircraft in the traffic mixture, B747-100, when considering depth of compaction, thickness of asphalt surface, drainage structures, etc.

c. **Other Methods.** More refined methods of considering mixed traffic are possible. These refined methods may consider variations in material properties due to climatic effects, take-off versus landing loads, aircraft tread dimensions, etc. Use of these refined methods is allowable under the conditions given in paragraph 301.

306. **TRAFFIC DISTRIBUTION.** Research studies have shown that aircraft traffic is distributed laterally across runways and taxiways according to statistically normal (bell shaped) distribution. FAA Report No. FAA-RD-36, Field Survey and Analysis of Aircraft Distribution on Airport Pavements, dated February 1975, contains the latest research information on traffic distribution. The design procedures presented in this circular incorporate the statistically normal distribution in the departure levels. In addition to the lateral distribution of traffic across pavements, traffic distribution and nature of loadings are considered for aprons, and high speed turnoffs.

307. TYPICAL SECTIONS. Airport pavements are generally constructed in uniform, full width sections. Runways may be constructed with a transversely variable section, if practical. A variable section permits a reduction in the quantity of materials required for the upper paving layers of the runway. However, more complex construction operations are associated with variable sections and are usually more costly. The additional construction costs may negate any savings realized from reduced material quantities. Typical plan and section drawings for transversely variable section runway pavements are shown in Figure 3-1. Deviations from these typical sections will be common due to the change inherent in staged construction projects where runways are extended and the location of taxiways is uncertain. As a general rule-of-thumb the designer should specify full pavement thickness T where departing traffic will be using the pavement; pavement thickness of 0.9T will be specified where traffic will be arrivals such as high speed turnoffs; and pavement thickness of 0.7T will be specified where pavement is required but traffic is unlikely such as along the extreme outer edges of the runway. Note that the full-strength keel section is 50 feet (15 m) on the basis of the research study discussed in paragraph 306a.

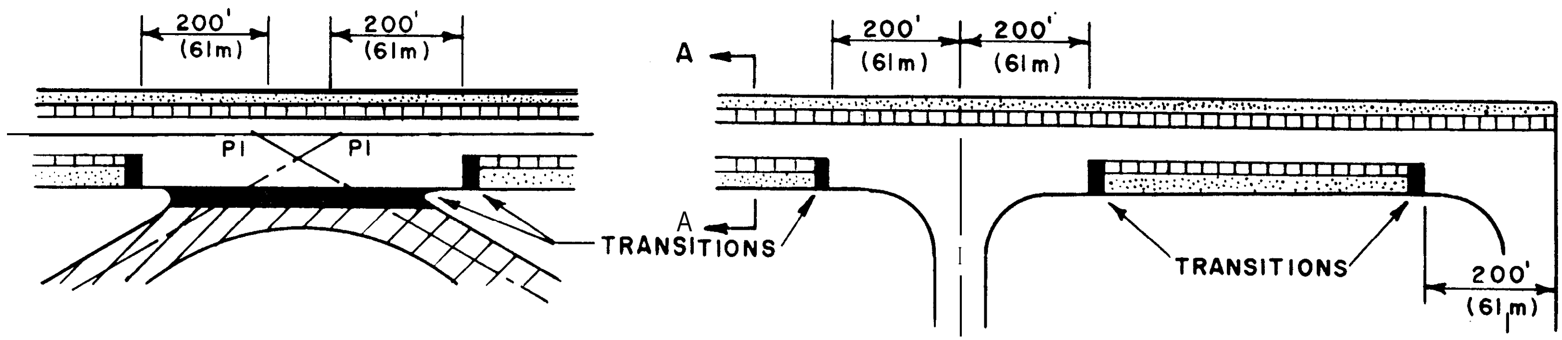
308. FROST AND PERMAFROST DESIGN. The design of an airport pavement must consider the climatic conditions which will act on the pavement during its construction and service life. The protection of pavements from the adverse effects of seasonal frost and permafrost effects are considered in the design of airport pavements as discussed below.

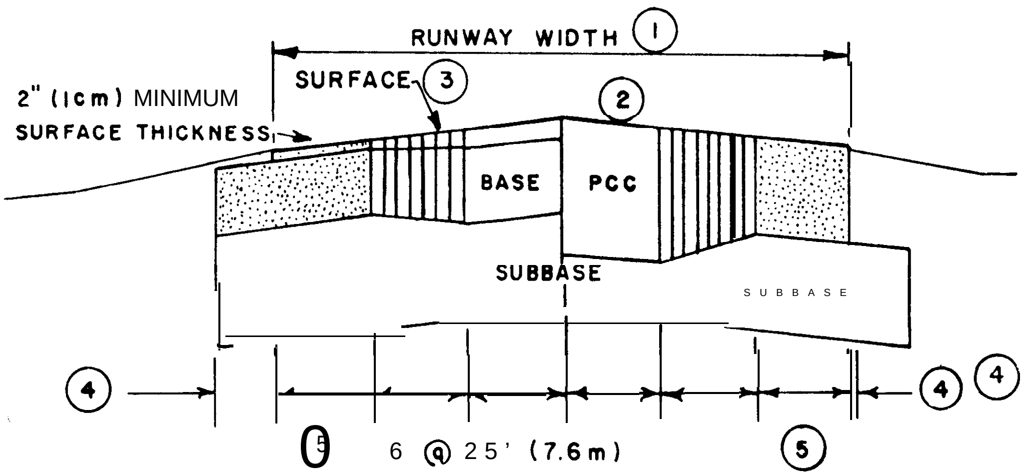
a. Seasonal Frost. The adverse effects of seasonal frost have been discussed in Chapter 2. The design of pavements in seasonal frost areas may be based on either of two approaches. The first approach is based on the control of pavement deformations resulting from frost action. Under this approach, sufficient combined thickness of pavement and non-frost-susceptible material must be provided to eliminate, or limit to an acceptable amount, frost penetration into the subgrade and its adverse effects. The second approach is based on providing adequate pavement load carrying capacity during the critical frost melting period. The second approach provides for the loss of load carrying capacity due to frost melting but ignores the effects of frost heave. Three design procedures have been developed which encompass the above approaches and are discussed below.

(1) Complete Frost Protection. Complete frost protection is accomplished by providing a sufficient thickness of pavement and non-frost-susceptible material to totally contain frost penetration. This method is intended to prevent underlying frost susceptible materials from freezing. To use the complete protection method , the depth of frost penetration is determined by the procedure given in Chapter 2. The thickness of pavement required for structural support is compared with the depth of frost penetration computed. The difference between the pavement thickness required for structural support and the computed depth of frost penetration is made up with non-frost-susceptible material. Depending on grades and other considerations, provision for complete protection may involve removal and replacement of a considerable amount of subgrade material. Complete frost protection is the most positive, and is usually the most costly, method of providing frost protection.

(2) Limited Subgrade Frost Penetration. The limited subgrade frost penetration method is based on holding frost heave to a tolerable level. Frost is allowed to penetrate a limited amount into the underlying frost susceptible subgrade. Sixty five (65%) of the depth of frost penetration is made up with non-frost-susceptible material. Use of the method is similar to the complete protection method. Additional frost protection is required if the thickness of the structural section is less than 65% of the frost penetration. The limited subgrade frost penetration method allows a tolerable (based on experience) amount of frost heave.

(3) Reduced Subgrade Strength. The reduced subgrade strength method is based on the concept of providing a pavement with adequate load carrying capacity during the frost melting period. This method does not consider the effects of frost heave. Use of the reduced subgrade strength method involves assigning a subgrade strength rating to the pavement for the frost melting period. The various soil frost groups as defined in Chapter 2, should be assigned strength ratings as shown below:





NOTES

1. RUNWAY WIDTHS IN ACCORDANCE WITH APPLICABLE ADVISORY CIRCULAR.
2. TRANSVERSE SLOPES IN ACCORDANCE WITH APPLICABLE ADVISORY CIRCULAR.
3. SURFACE, BASE, PCC, ETC., THICKNESS AS INDICATED ON DESIGN CHART.
4. MINIMUM 12" (30cm) UP TO 30" (90cm) ALLOWABLE.
5. FOR RUNWAYS WIDER THAN 150' (45.7m) THIS DIMENSION WILL INCREASE.

LEGEND

THICKNESS = T

THICKNESS TAPERS = T ⟶ 0.7 T

THICKNESS = 0.9 T

THICKNESS = 0.7 T

FIGURE 3-1. TYPICAL PLAN AND CROSS SECTION FOR RUNWAY PAVEMENT

TABLE 3-l. REDUCED SUBGRADE STRENGTH RATINGS

Frost Group	Flexible Pavement CBR Value	Rigid Pavement k-value
FG-1	9	50
FG-2	7	40
FG-3	4	25
FG-4	Reduced Subgrade Strength Method Does Not Apply	

The required pavement thicknesses are determined from the appropriate design curves **using** the reduced subgrade strength ratings. Pavement thicknesses thus established reflect the requirements for the subgrade in its weakened condition due to frost melting.

b. Applications. Due to economic considerations, the maximum practical depth of frost protection that should be provided is normally 72 inches (1.8 m). The recommended applications of the three methods of frost protection discussed above are as follows. In addition to these recommended applications, local experience should be given strong consideration when designing for frost conditions.

(1) Complete Frost Protection. The complete frost protection method applies only to FG-3 and FG-4 soils which are extremely variable in horizontal extent. These soil deposits are characterized by very large, frequent, and abrupt changes in frost heave potential. The variability is such that the use of transition sections is not practical.

(2) Limited Subgrade Frost Penetration. This design method should be used for FG-4 soils except where the conditions require complete protection, see (1) above. The method also applies to soils in frost groups FG-1, FG-2, and FG-3 when the functional requirements of the pavement permit a minor amount of frost heave. Consideration should be given to using transition sections where horizontal variability of frost heave potential permits.

(3) Reduced Subgrade Strength. The reduced subgrade strength method is recommended for FG-1, FG-2, and FG-3 subgrades which are uniform in horizontal extent or where the functional requirements of the pavement will permit some degree of frost heave. the method may also be used for variable FG-1 through FG-3 subgrades for less sensitive pavements which are subject to slow speed traffic and heave can be tolerated.

C. **Permafrost,** The design of pavements in permafrost regions must consider not only the effects of seasonal thawing and refreezing, but also the effects of construction on the existing thermal equilibrium. Changes in the subsurface thermal regime may cause degradation of the permafrost table, resulting in severe differential settlements drastic reduction of pavement load carrying capacity. Gravel surfaced pavements are rather common in permafrost areas and generally will provide satisfactory service. These pavements often exhibit considerable distortion but are rather easily regraded. The absence of a waterproof surface is not a great problem because these areas are usually have low precipitation. Three design methods for asphaltic or concrete surfaced pavements are discussed below.

(1) Complete Protection Method. The objective of the complete protection method is to ensure that the underlying permafrost remains frozen year round. Seasonal thawing is restricted to non-frost-susceptible materials. This method is analogous to the complete frost protection method of design for seasonal frost. The thickness of pavement required for structural support is first determined. The depth of seasonal thaw is then computed as described in Chapter 2 or using information based on local experience. The difference between the depth of seasonal thaw and the thickness needed for structural support is the amount of non-frost-susceptible material which must be provided to fully contain the depth of seasonal thaw. The use of relatively high moisture retaining soils, such as uniformly graded sands, should be considered. If some heaving can be tolerated, the use of frost-susceptible soils in the FG- 1 or FG-2 groups may also be considered. If FG-1 or FG-2 soils are used, they must be placed so as to be as uniform as possible. Normally economic considerations will limit the depth of treatment to a maximum of 6 feet (1.8 m).

(2) Reduced Subgrade Strength Method. If conditions are such that the complete protection method of design is not practical, the design may be based on the reduced subgrade strength method. The use of this method for permafrost design is identical to that presented in paragraph **308b(3)** above. this method should provide a pavement with sufficient structural support during the seasonal permafrost thaw period but will likely result in differential heaving. If practical, it may be advisable to delay paving for 2 or 3 years to allow the embankment to reach equilibrium.

(3) **Insulating Panels.** A third approach which is not as common is the use of insulating panels beneath the pavement structure to protect against degradation of the permafrost. This method can lead to problems if the insulating panels are crushed by the weight of the overburden or by the live loads. Crushing of the cell structure of the insulation results in loss of insulating properties and failure to serve its intended purpose. Pavements using this technique must be very carefully constructed and may be subject to load limitations because of the need to guard against crushing the insulating panels. A significant change in the weight of using aircraft may fail the insulating panels. Since the FAA has no standards or design criteria for the use of insulating panels, their use on federally funded construction requires FAA approval on a case-by-case basis.

SECTION 2. FLEXIBLE PAVEMENT DESIGN

309. GENERAL. Flexible pavements consist of a hot mix asphalt wearing surface placed on a base course and, when required by subgrade conditions, a subbase. The entire flexible pavement structure is ultimately supported by the subgrade. Definitions of the function of the various components are given in the following paragraphs. For some aircraft the base and subbase should be constructed of stabilized materials. The requirements for stabilized base and subbase are also discussed in this section.

310. HOT MIX ASPHALT SURFACING. The hot mix asphalt surface or wearing course must prevent the penetration of surface water to the base course; provide a smooth, well-bonded surface free from loose particles which might endanger aircraft or persons; resist the shearing stresses induced by aircraft loads; and furnish a texture of nonskid qualities, yet not cause undue wear on tires. 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 hot mix asphalt concrete such as Item P-401 produced in a central mixing plant will most satisfactorily meet all the above requirements. Whenever a hot mix asphalt surface is subject to spillage of fuel, hydraulic fluid, or other solvents; such as at aircraft fueling positions and maintenance areas, protection should be provided by a solvent resistant surface.

311. BASE COURSE. The base course is the principal structural component of the flexible pavement. It has the major function of distributing the imposed wheel loadings to the pavement foundation, the subbase and/or 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. In the development of pavement thickness requirements, a minimum CBR value of 80 is assumed for the base course. The quality of the base course depends upon composition, physical properties and compaction. Many materials and combinations thereof have proved satisfactory as base courses. They are composed of select, hard, and durable aggregates. Specifications covering the quality of components, gradation, manipulation control, and preparation of various types of base courses for use on airports for aircraft design loads of 30,000 pounds (14 000 kg) or more are as follows:

(1) Item P-208 - Aggregate Base Course[1]
(2) Item P-209 - Crushed Aggregate Base Course
(3) Item P-21 1 - Lime Rock Base Course
(4) Item P-304 - Cement Treated Base Course
(5) Item P-306 - Econocrete Subbase Course
(6) Item P-401 - Plant Mix Bituminous Pavements

[1]The use of Item P-208, Aggregate Base Course, as base course is limited to pavements designed for gross loads of 60,000 Ibs. (27 000 kg) or less. When Item P-208 is used as base course the thickness of the hot mix asphalt surfacing should be increased 1 inch (25 mm) over that shown on the design curves.

312. SUBBASE, A subbase is included as an integral part of the flexible pavement structure in all pavements except those on subgrades with a CBR value of 20 or greater (usually GW or GP type soils). The function of the subbase is similar to that of the base course. However, since it is further removed from the surface and is subjected to lower loading intensities, the material requirements are not as strict as for the base course. In the development of pavement thickness requirements the CBR value of the subbase course is a variable.

a. Quality. Specifications covering the quality of components, gradations, manipulation control, and preparation of various types of subbase courses for use on airports for aircraft design loads of 30,000 pounds (14 000 kg) or more are as follows:

(1) Item P-154 - Subbase Course
(2) Item P-210 - Caliche Base Course
(3) Item P-212 - Shell Base Course

(4) Item P-213 - Sand Clay Base Course'
(5) Item P-301 - Soil Cement Base Course'

'Use of Items P-21 3 and P-301 as subbase course is not recommended where frost penetration into the subbase is anticipated. Any material suitable for use as base course can also be used on subbase if economy and practicality dictate.

b. Sandwich Construction. Pavements should not be configured such that a pervious granular layer is located between two impervious layers. This type of section is often called "sandwich" construction. Problems are often encountered in "sandwich" construction when water becomes trapped in the granular layer causing a dramatic loss of strength and results in poor performance.

313. SUBGRADE. The subgrade soils are subjected to lower stresses than the surface, base, and subbase courses. Subgrade stresses attenuate with depth, and the controlling subgrade stress is usually at the top of the subgrade, unless unusual conditions exist. Unusual conditions such as a layered subgrade or sharply varying water contents or densities can change the location of the controlling stress. The ability of a particular soil to resist shear and deformation vary with its density and moisture content. Such unusual conditions should be revealed during the soils investigation. Specification Item P-152, Excavation and Embankment, covers the construction and density control of subgrade soils. Table 3-2 shows depths below the subgrade surface to which compaction controls apply.

a. Contamination. A loss of structural capacity can result from contamination of base or subbase elements with fines from underlying subgrade soils. This contamination occurs during pavement construction and during pavement loading. Aggregate contamination results in a reduced ability of the aggregate to distribute and reduce stresses applied to the subgrade. Fine grained soils are most likely to contaminate pavement aggregate. This process is not limited to soft subgrade conditions. Problematic soils may be cohesive or noncohesive and usually exhibit poor drainage properties. Chemical and mechanical stabilization of the subbase or subgrade can be effectively used to reduce aggregate contamination (refer to Section 207). Geotextiles have been found to be effective at providing separation between fine-grained soils and overlying pavement aggregates (FHWA-90-001)(see Appendix 4). In this application, the geotextile is not considered to act as a structural element within the pavement. For separation applications the geotextile is designed based on survivability properties. Refer to FHWA-90-001 (see Appendix 4) for additional information regarding design and construction using separation geotextiles.

b. Example. An apron extension is to be built to accommodate a 340,000-pound (154 000 kg) dual tandem geared aircraft, a soils investigation has shown the subgrade will be noncohesive. In-place densities of the 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 (0.3 m) below the existing grade. Depths and densities may be tabulated as follows:

Depth Below Existing Grade	Depth Below Finished Grade	In-Place Density
1' (0.3 m)	2" (50 mm)	70%
2' (0.6 m)	14" (0.36 m)	84%
3' (0.9 m)	26" (0.66 m)	86%
4' (1.2 m)	38" (0.97 m)	90%
5' (1.5 m)	**50" (1.27 m)**	**93%**

Using Table 3-2 values for non-cohesive soils and applying linear interpolation the compaction requirements are as follows:

100%	95%	90%	85%
o-21	21-37	37-52	52-68

Comparison of the tabulations show that for this example in-place density is satisfactory at a depth of 38 inches (0.97 m), being 90 percent within the required 90 percent zone. It will be necessary to compact an additional 1 inch (0.03 m) at 95 percent, and the top 21 inches (0.53 m) of subgrade at 100 percent density.

TABLE 3-2. SUBGRADE COMPACTION REQUIREMENTS FOR FLEXIBLE PAVEMENTS

DESIGN AIRCRAFT	Gross Weight lbs.	NON-COHESIVE SOILS Depth of Compaction In.				COHESIVE SOILS Depth of Compaction In.			
		100%	95%	90%	85%	95%	90%	85%	80%
Single Wheel	30,000	8	8-18	18-32	32-44	6	6-9	9-12	12-17
	50,000	10	10-24	24-36	36-48	6	6-9	9-16	16-20
	75,000	12	12-30	30-40	40-52	6	6-12	12-19	19-25
Dual Wheel (incls. C-130)	50,000	12	12-28	28-38	38-50	6	6-10	10-17	17-22
	100,000	17	17-30	30-42	42-55	6	6-12	12-19	19-25
	150,000	19	19-32	32-46	46-60	7	7-14	14-21	21-28
	200,000	21	21-37	37-53	53-69	9	8-16	16-24	24-32
Dual Tand. (incls. 757, 767, A-300)	100,000	14	14-26	26-38	38-49	6	6-10	10-17	17-22
	200,000	17	17-30	30-43	43-56	6	6-12	12-18	18-26
	300,000	20	20-34	34-48	48-63	7	7-14	14-22	22-29
	400,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36
DC-10	400,000	21	21-36	36-55	55-70	8	8-15	15-20	20-28
L1011	600,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36
747	800,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36

Notes:

1. Noncohesive soils, for the purpose of determining compaction control, are those with a plasticity index (P.I.) of less than 6.
2. Tabulated values denote depths below the finished subgrade above which densities should equal or exceed the indicated percentage of the maximum dry density as specified in Item P-152.
3. The subgrade in cut areas should have natural densities shown or should (a) be compacted from the surface to achieve the required densities, (b) be removed and replaced at the densities shown, 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. For intermediate aircraft weights use linear interpolation.
5. For swelling soils refer to paragraph 314.
6. 1 inch = 25.4 mm
   1 lb. = 0.454 kg

314. SWELLING SOILS. Swelling soils are clayey soils which exhibit significant volume changes brought on by moisture variations. The potential for volumetric change of a soil due to moisture variation is a function of the type of soil and the likelihood of for moisture fluctuation. Airport pavements constructed on these soils are subject to differential movements causing surface roughness and cracking. The design of pavements in areas of swelling soils should incorporate methods that prevent or reduce the effects of soil volume changes.

a. Soil Type. Only clayey soils containing a significant amount of particular clay minerals are prone to swelling. The clay minerals which cause swelling are, in descending order of swelling activity, are: smectite, illite, and kaolinite. These soils usually have liquid limits above 40 and plasticity indexes above 25.

b. Identification. Soils which exhibit a swell of greater than 3 percent when tested for the California Bearing Ratio (CBR), ASTM D 1883, require treatment. Experience with soils in certain locales is often used to determine when treatment is required.

c. **Treatment.** Treatment of swelling soils consist of removal and replacement, stabilization, modified compaction efforts and careful control of compaction moisture. Provisions for adequate drainage is of paramount importance when dealing with swelling soils. Recommended treatments for swelling soils are shown in Table 3-3. Local experience and judgment should be applied in dealing with swelling soils to achieve the best results. Care should be taken to minimize water flow along the contact plane between the stabilized/nonstabilized material.

TABLE 3-3. RECOMMENDED TREATMENT OF SWELLING SOILS

Swell Potential (Based on Experience)	Percent Swell Measured (ASTM D 1883)	Potential for Moisture Fluctuation’	Treatment
Low	3-5	Low	Compact soil on wet side of optimum (+2% to +3%) to not greater than 90% of appropriate maximum density. [2]
		High	Stabilize soil to a depth of at least 6 in. (150 mm)
Medium	6-10	Low	Stabilize soil to a depth of at least 12 in. (300 mm)
		High	Stabilize soil to a depth of at least 12 in. (300 mm)
High	Over 10	Low	Stabilize soil to a depth of at least 12 in. (300 mm)
		High	For uniform soils, i.e., redeposited clays, stabilize soil to a depth of at least 36 in. (900 mm) or raise grade to bury swelling soil at least 36 in. (900 mm) below pavement section or remove and replace with non-swelling soil. For variable soil deposits depth of treatment should be increased to 60 in. (1300 mm).

Notes: ‘Potential for moisture fluctuation is a judgmental determination and should consider proximity of water table, likelihood of variations in water table, as well as other sources of moisture, and thickness of the swelling soil layer.

‘When control of swelling is attempted by compacting on the wet side of optimum and reduced density, the design subgrade strength should be based on the higher moisture content and reduced density.

d. **Additional Information.** Additional information on identifying and handling swelling soils is presented in FAA Reports No. FAA-RD-76-66, Design and Construction of Airport Pavements on Expansive Soils, by R. Gordon McKeen, dated June 1976 and DOT/FAA/PM-85115, Validation of Procedures for Pavement Design on Expansive Soils, by R. Gordon McKeen, dated July 1985. See Appendix 4.

315. SELECTION OF DESIGN CBR VALUE. Subgrade soils are usually rather variable and the selection of a design CBR value requires some judgment. As a general rule of thumb the design CBR value should be equal to or less than 85% of all the subgrade CBR values. This corresponds to a design value of one standard deviation below the mean as recommended in Chapter 2. In some cases subgrade soils which are significantly different in strength occur in different layers. In these instances several designs should be examined to determine the most economical pavement section. It may be more economical to remove and replace a weak layer than designing for it. On the other hand, circumstances may be such that designing for the weakest layer is more economical. Local conditions will dictate which approach should be used.

316. DESIGN CURVES. Due to the differences in stress distribution characteristics, separate flexible pavement design curves for several gear configurations have been prepared and are presented in Figures 3-2 through 3-15, inclusive. The thicknesses determined from these design charts are for untreated granular bases and subbases and do not include frost effects or stabilized materials. Frost effects and stabilized materials must be handled separately.

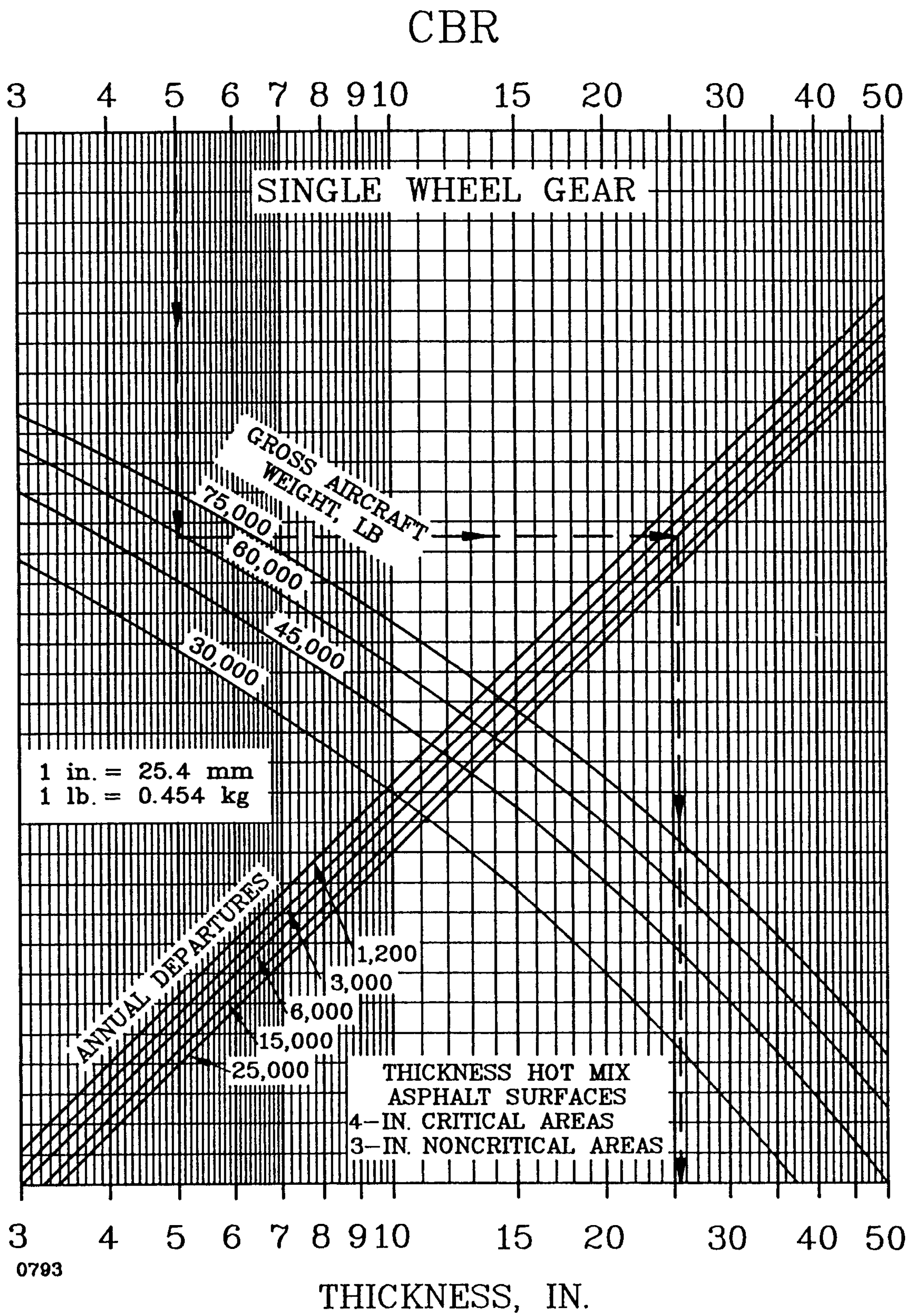


FIGURE 3-2 FLEXIBLE PAVEMENT DESIGN CURVES, SINGLE WHEEL GEAR

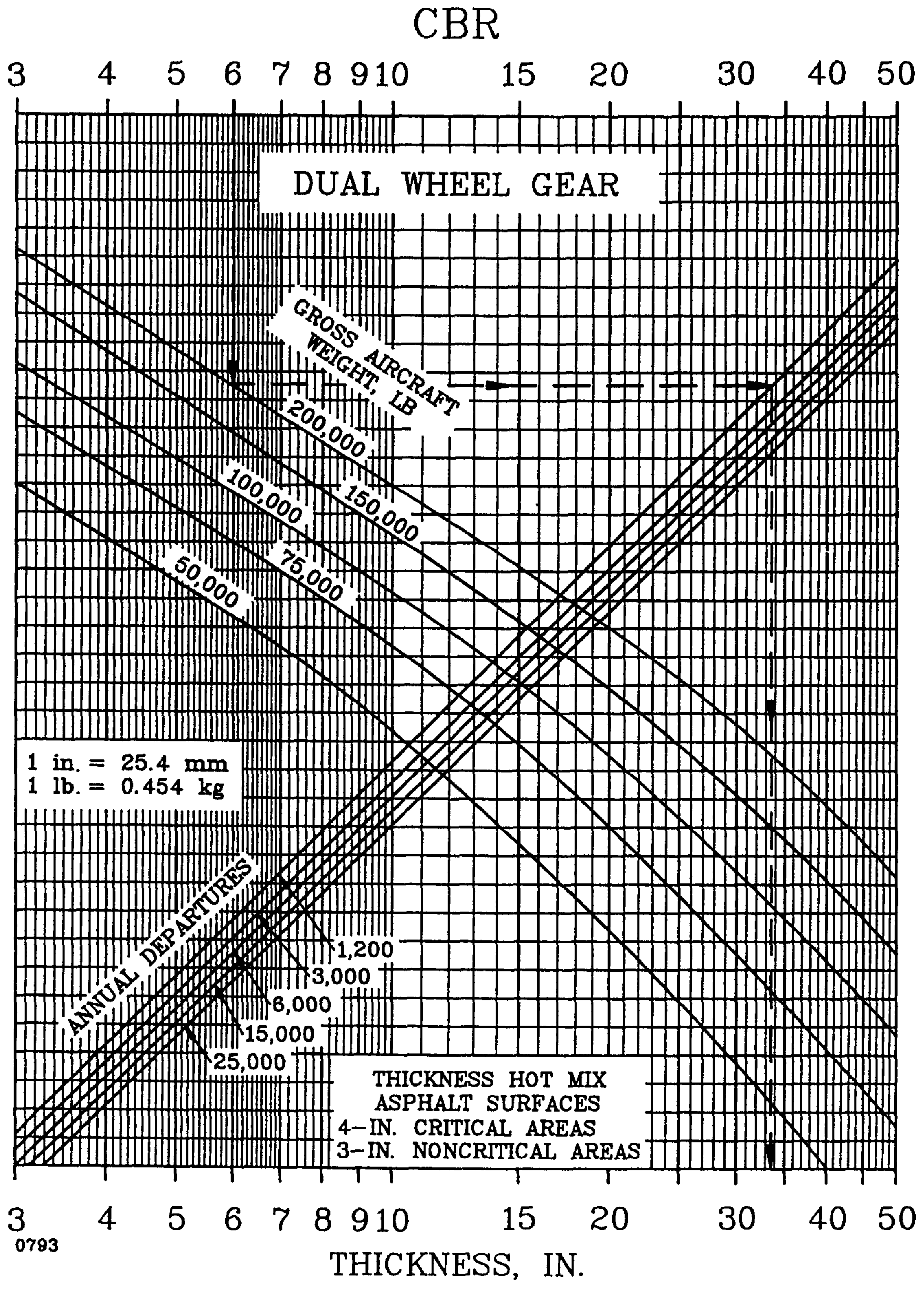


FIGURE 3-3 FLEXIBLE PAVEMENT DESIGN CURVES, DUAL WHEEL GEAR

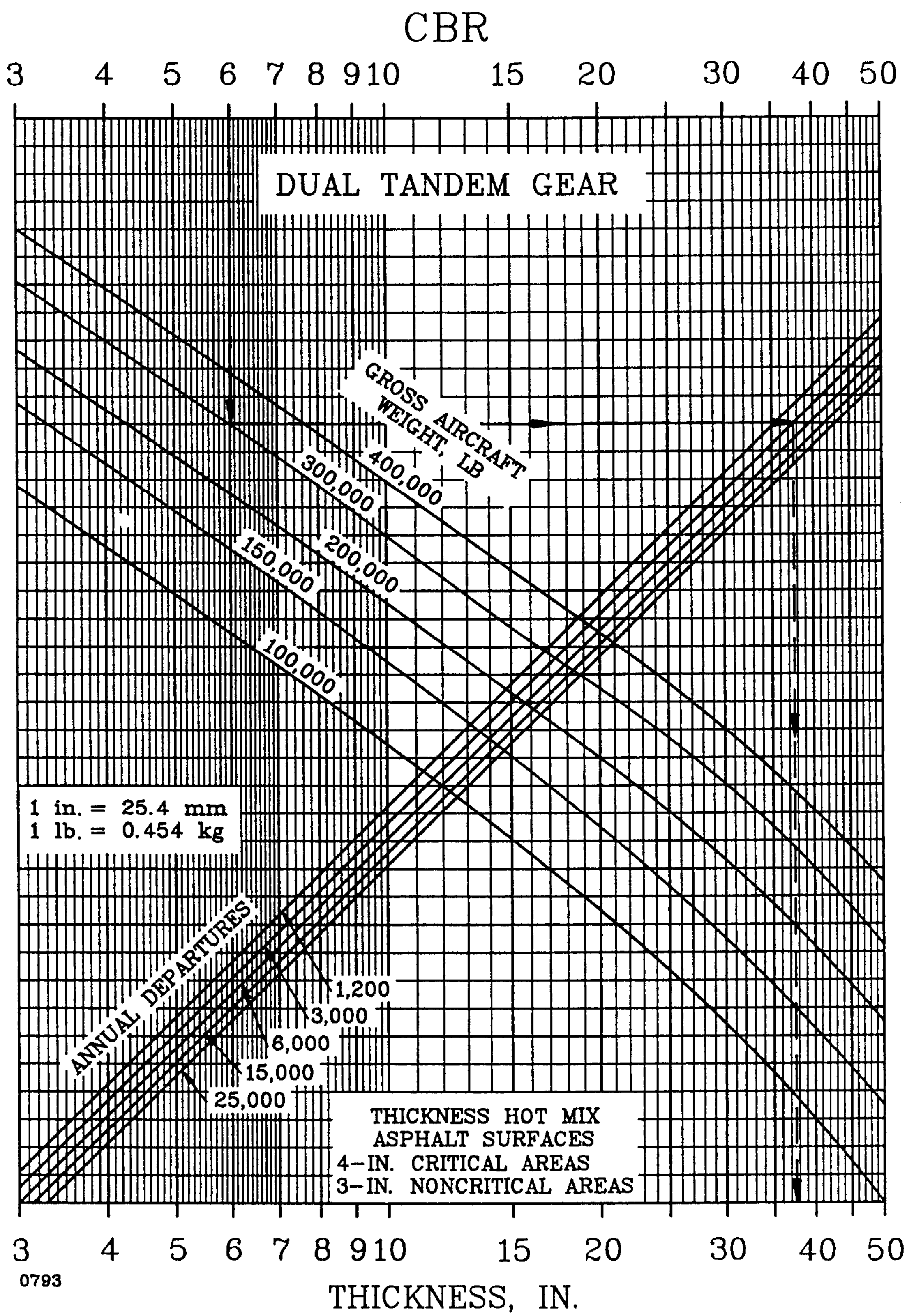


FIGURE 3-4 FLEXIBLE PAVEMENT DESIGN CURVES, DUAL TANDEM GEAR

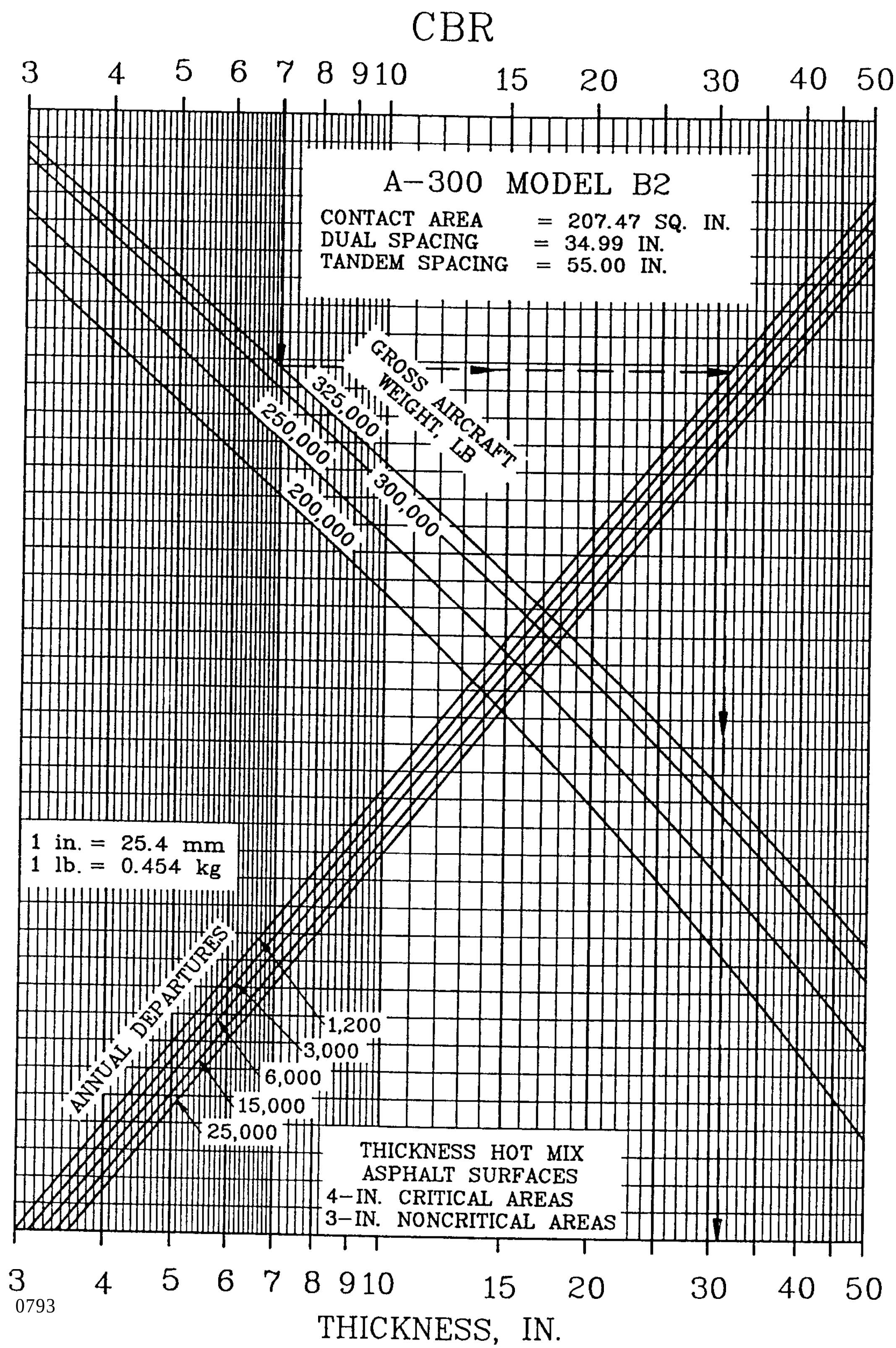


FIGURE 3-5 FLEXIBLE PAVEMENT DESIGN CURVES, A-300 MODEL B2

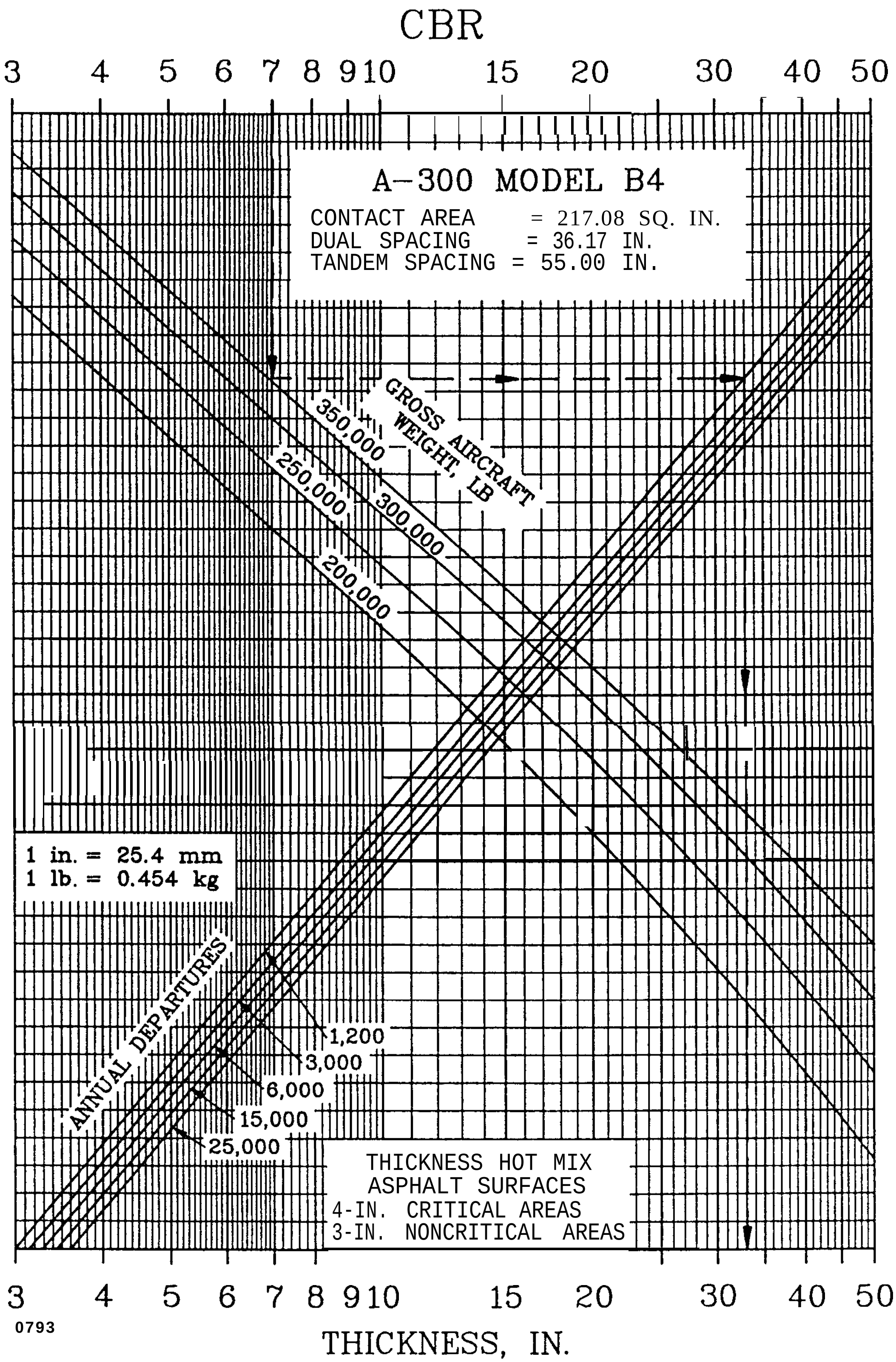


FIGURE 3-6 FLEXIBLE PAVEMENT DESIGN CURVES, A-300 MODEL B4

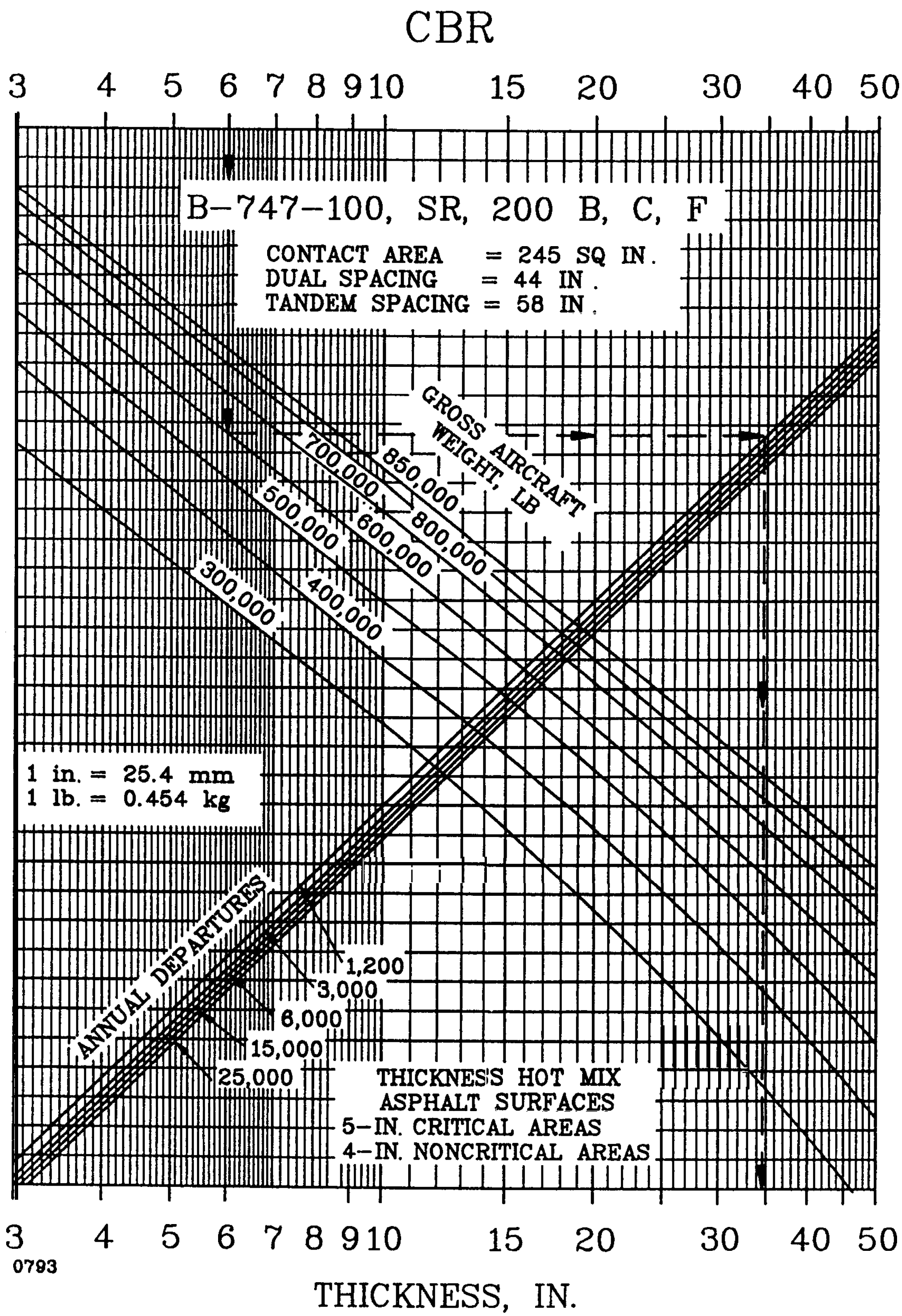


FIGURE 3-7 FLEXIBLE PAVEMENT DESIGN CURVES, B-747-100,SR, 200 B, C, F

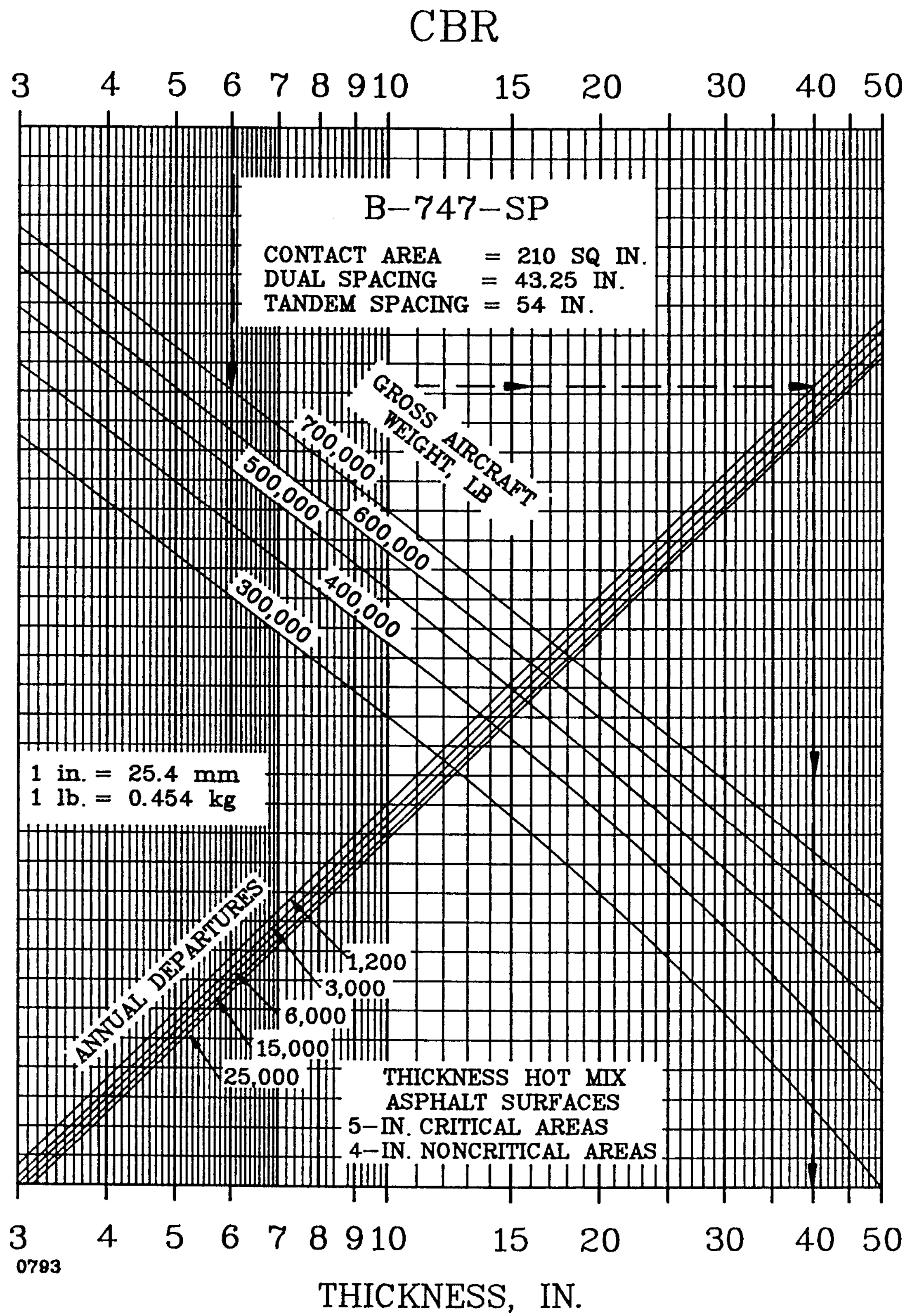


FIGURE 3-8 FLEXIBLE PAVEMENT DESIGN CURVES, B-747-SP

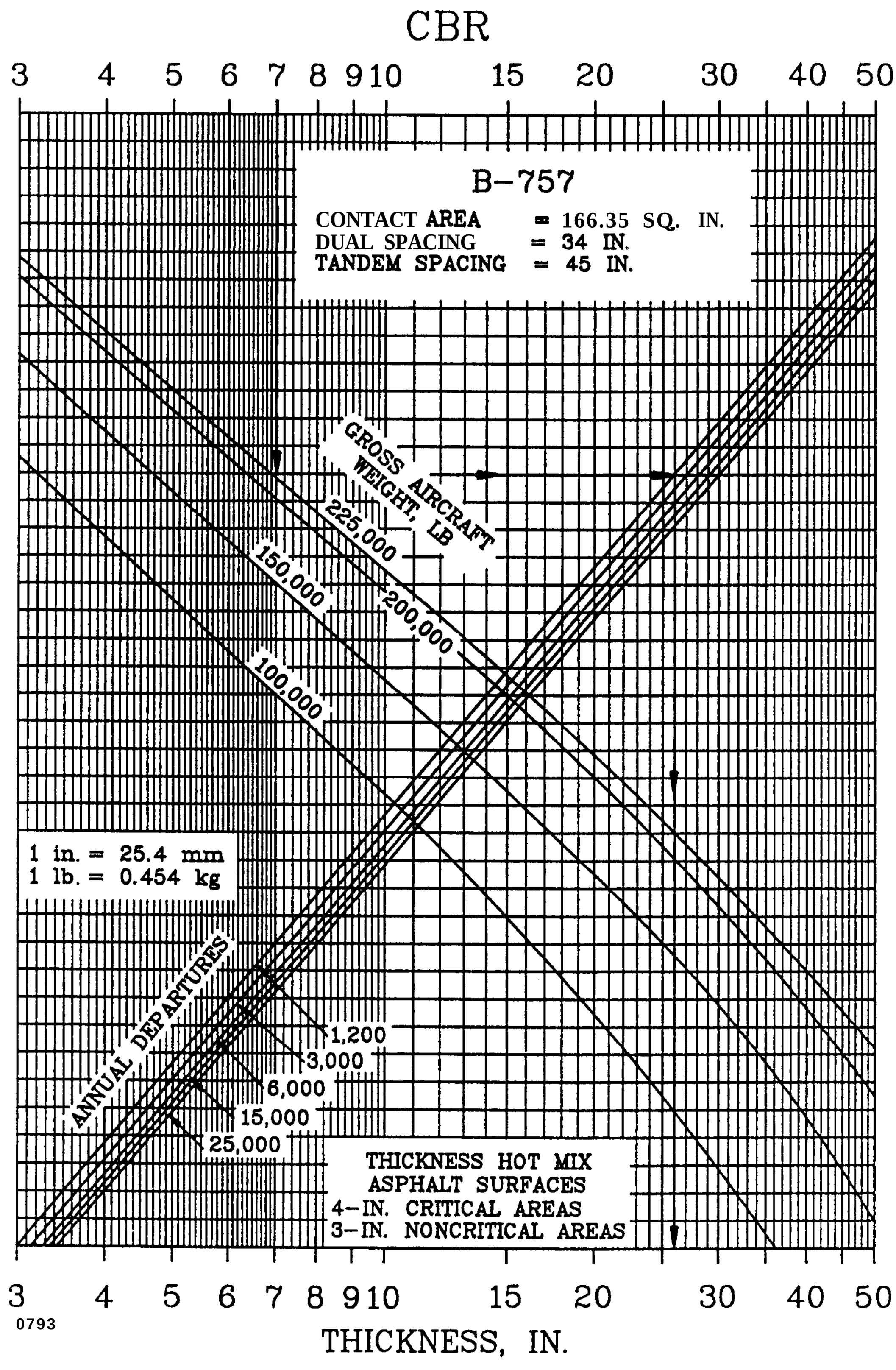


FIGURE 3-9 FLEXIBLE PAVEMENT DESIGN CURVES, B-757

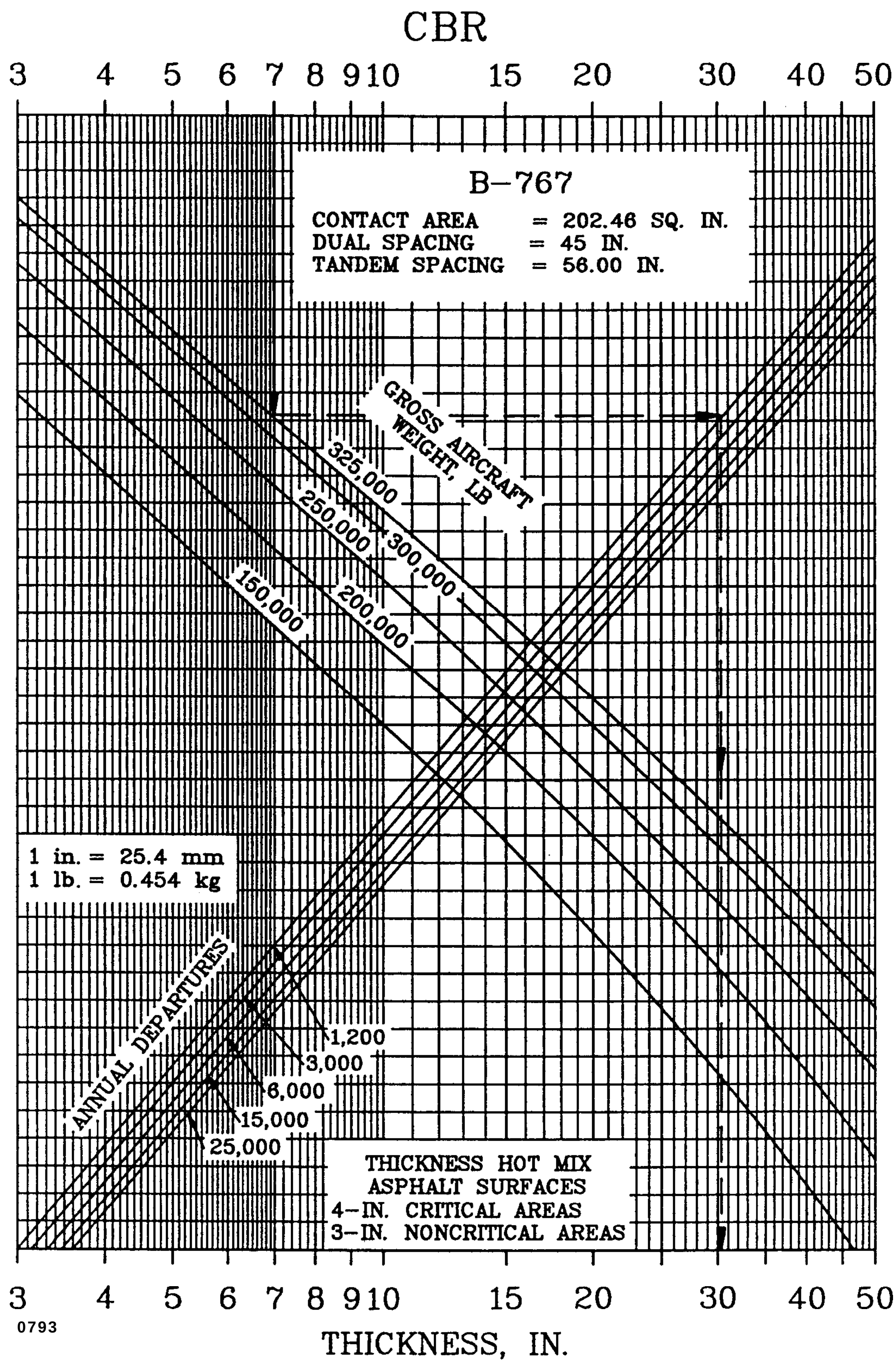


FIGURE 3-10 FLEXIBLE PAVEMENT DESIGN CURVES, B-767

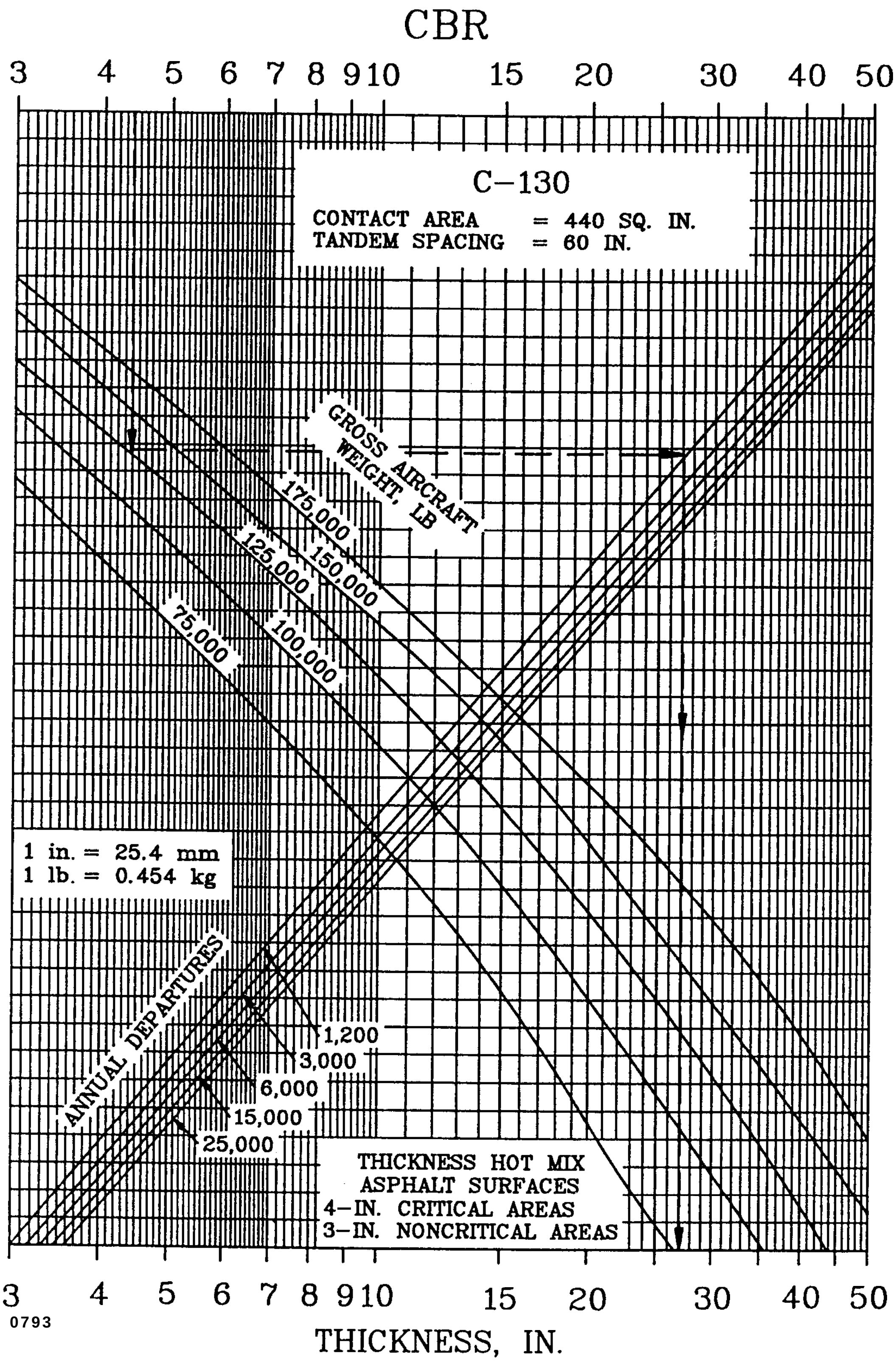


FIGURE 3-11 FLEXIBLE PAVEMENT DESIGN CURVES, C-130

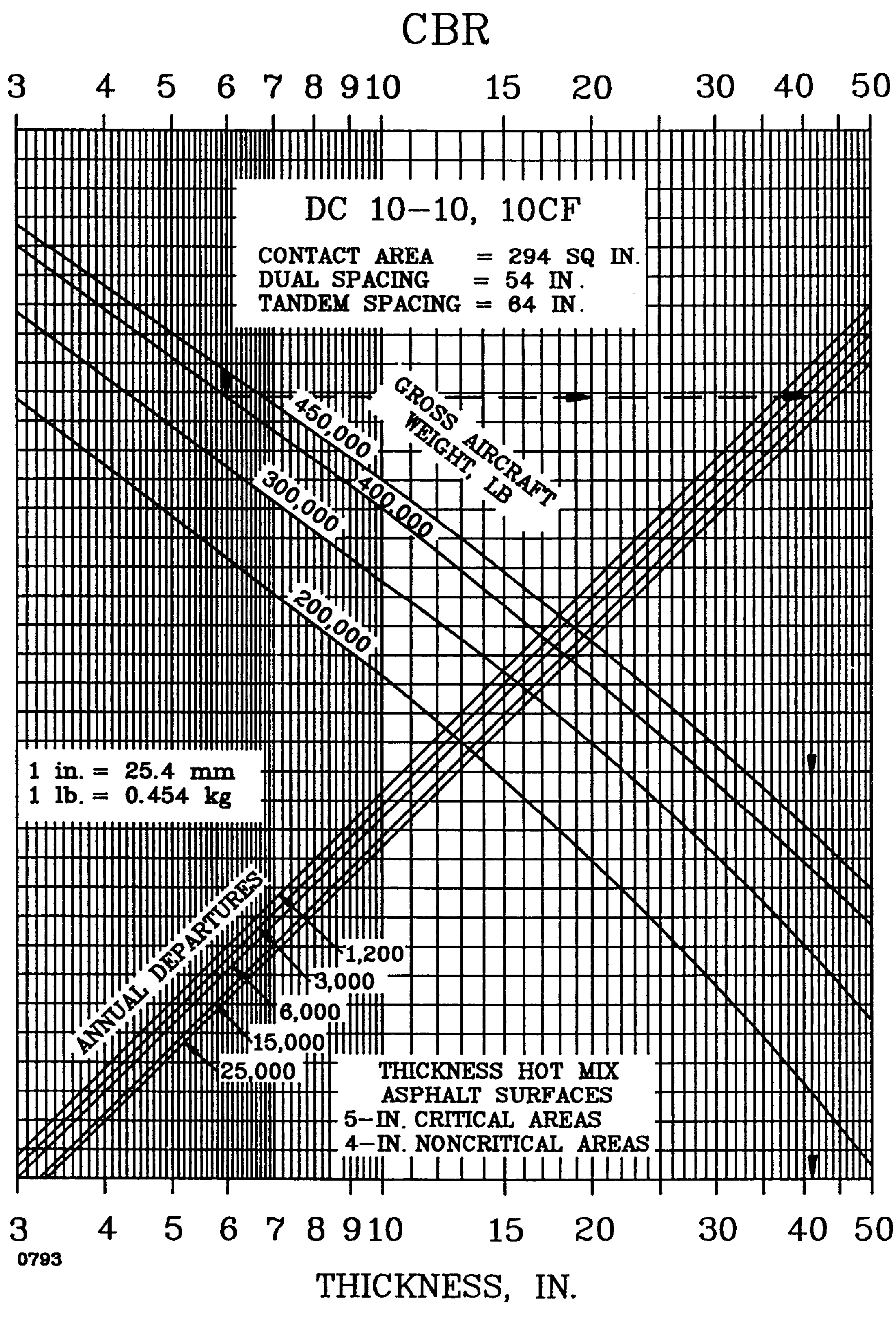


FIGURE 3-12 FLEXIBLE PAVEMENT DESIGN CURVES, DC 10-10, 10CF

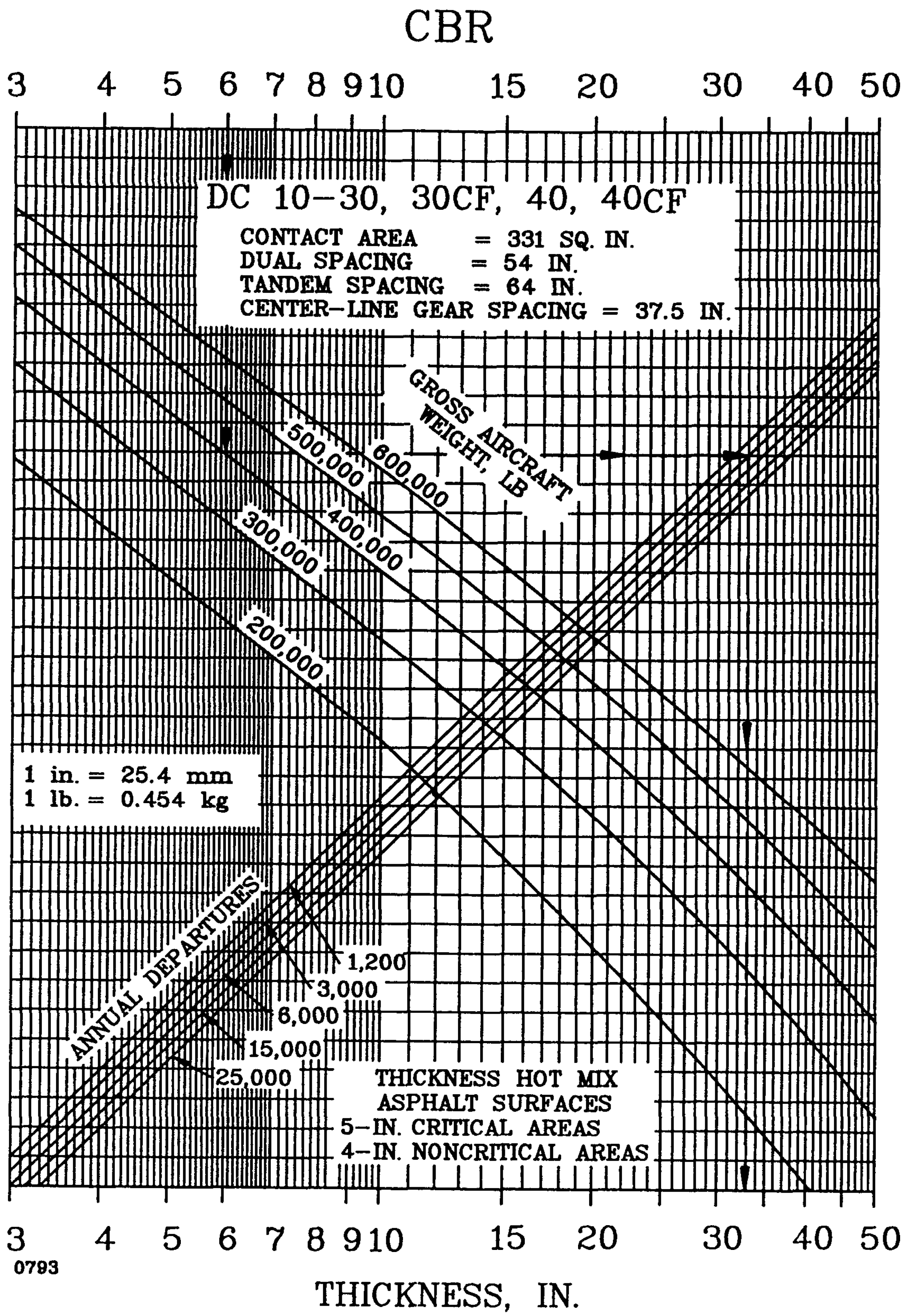


FIGURE 3-13 FLEXIBLE PAVEMENT DESIGN CURVES, DC 10-30, 30CF, 40, 40CF

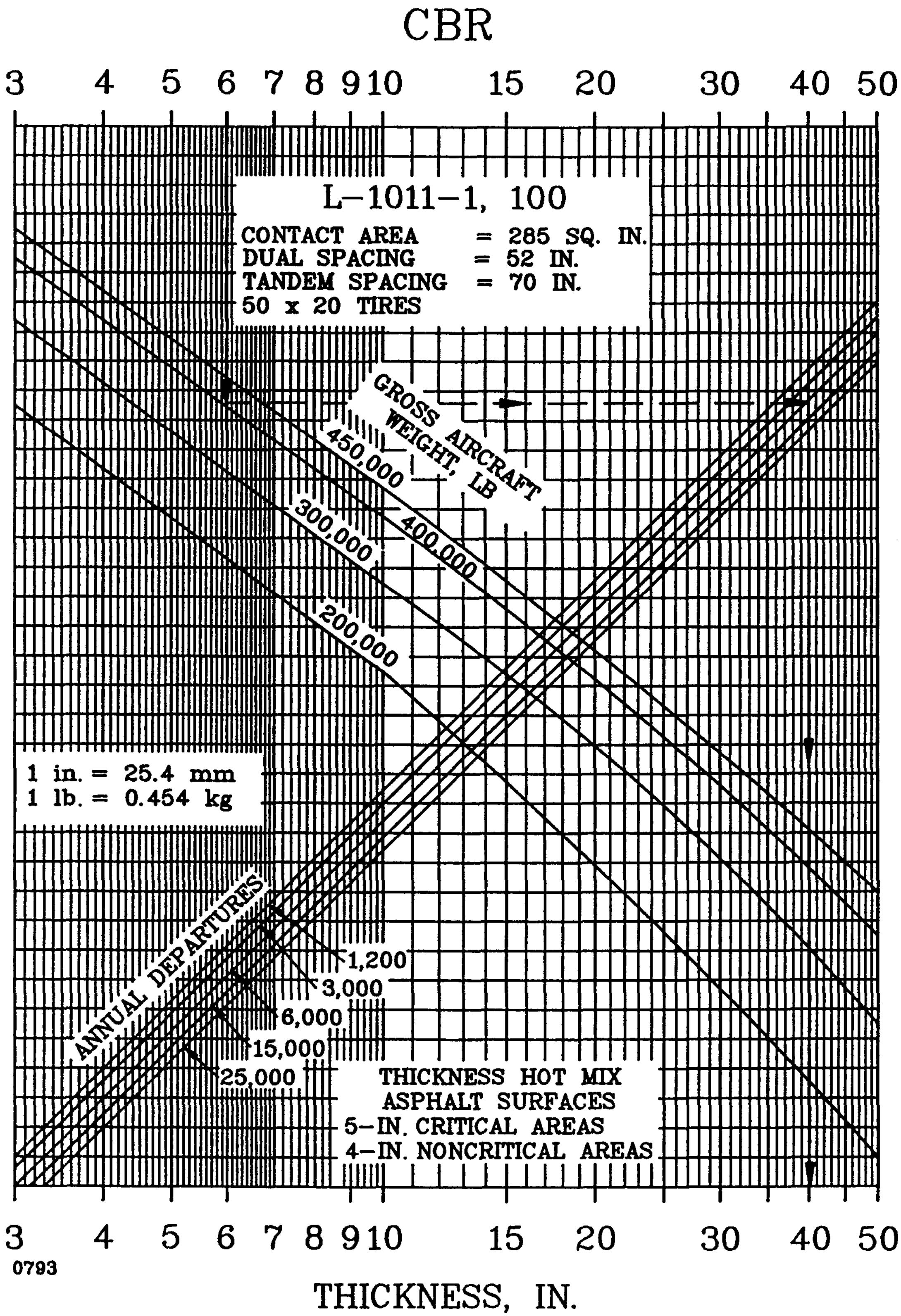


FIGURE 3-14 FLEXIBLE PAVEMENT DESIGN CURVES, L-1011-1,100

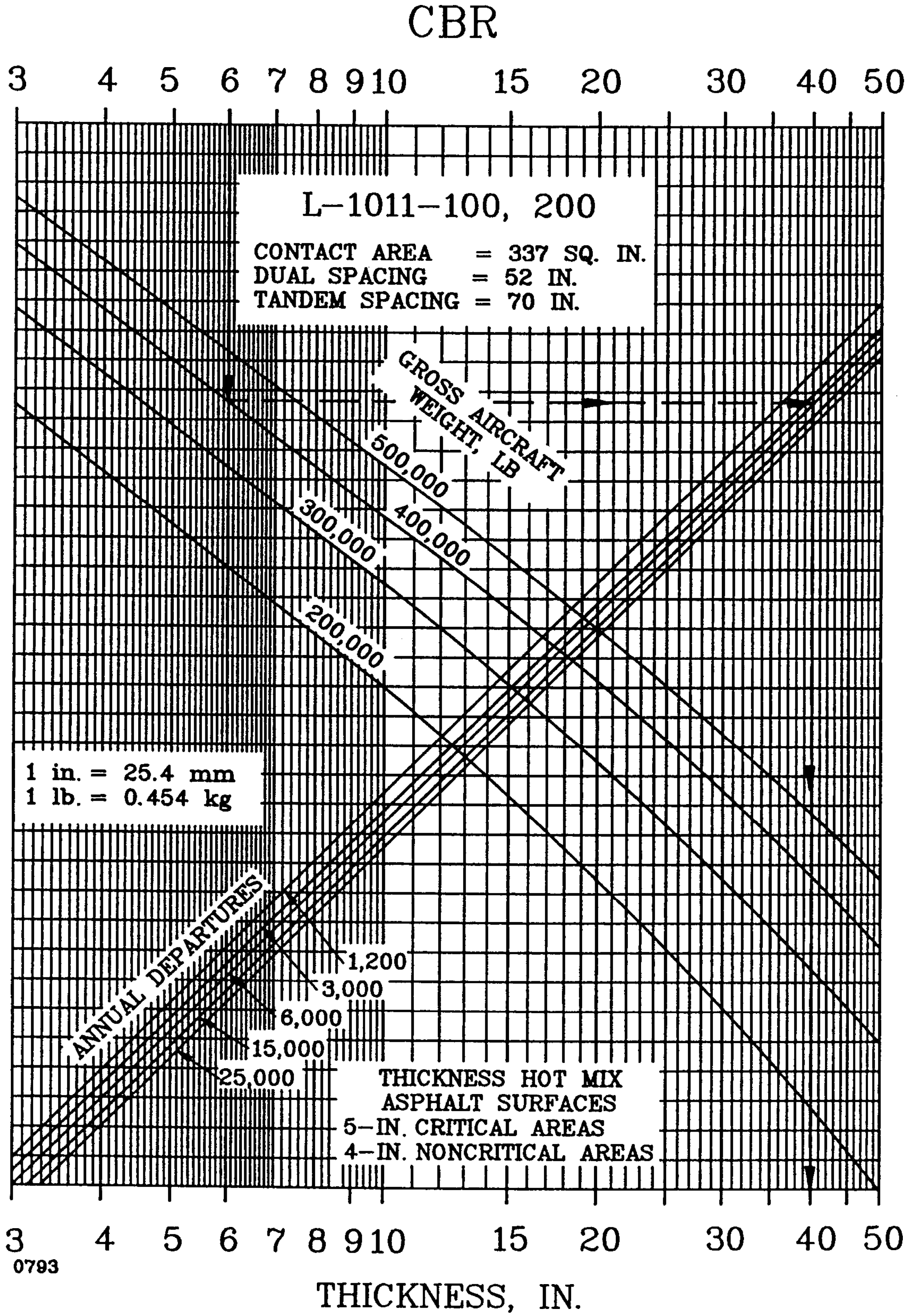


FIGURE 3-15 FLEXIBLE PAVEMENT DESIGN CURVES, L-1011, -100,200

317. DESIGN INPUTS. Use of the design curves for flexible pavements requires a CBR value for the subgrade material, a CBR value for the subbase material, the gross weight of the design aircraft, and the number of annual departures of the design aircraft. The design curves presented in Figures 3-2 through 3-15 indicate the total pavement thickness required and the thickness of hot mix asphalt surfacing. Table 3-4 gives the minimum thicknesses of base course for various materials and design loadings. For annual departures in excess of 25,000 the total pavement thickness should be increased in accordance with Table 3-5. l-inch (25 mm) of the thickness increase should be hot mix asphalt surfacing; the remaining thickness increase should be proportioned between base and subbase.

TABLE 3-4. MINIMUM BASE COURSE THICKNESS

Design Aircraft	Design Load Range		Minimum Base Course Thickness	
	lbs.	(kg)	in.	(mm)
Single Wheel	30,000 - 50,000 50,000 - 75,000	(13600 - 22 700) (22700 - 34 000)	4 6	(100) (150)
Dual Wheel	50,000 - 100,000 100,000 - 200,000	(22700 - 45 000) (45 000 - 90 700)	6 8	(150) (200)
Dual Tandem	100,000 - 250,000 250,000 - 400,000	(45 000 - 113 400) (113400 - 181 000)	6 8	(150) (200)
757 767	200,000 - 400,000	(90700 - 181000)	6	(150)
DC-10 L1011	400,000 - 600,000	(181 000 - 272000)	8	(200)
B-747	400,000 - 600,000 600,000 - 850,000	(181 000 - 272000) (272 000 - 385 700)	6 8	(150) (200)
c-130	75,000 - 125,000 125,000 - 175,000	(34 000 - 56 700) (56700 - 79 400)	4 6	(100) (150)

Note: The calculated base course thicknesses should be compared with the minimum base course thicknesses listed above. The greater thickness, calculated or minimum, should be specified in the design section.

318. CRITICAL AND NONCRITICAL AREAS. The design curves, Figures 3-2 through 3-15, are used to determine the total critical pavement thickness, "T", and the surface course thickness requirements. The 0.9T factor for the noncritical pavement applies to the base and subbase courses; the surface course thickness is as noted on the design curves. For the variable section of the transition section and thinned edge, the reduction applies only to the base course. The 0.7T thickness for base shall be the minimum permitted. The subbase thickness shall be increased or varied to provide positive surface drainage of the subgrade surface. Surface course thicknesses are as shown in Figure 3-l. For fractions of an inch of 0.5 or more, use the next higher whole number; for less than 0.5, use the next lower whole number.

TABLE 3-5. PAVEMENT THICKNESS FOR HIGH DEPARTURE LEVELS

Annual Departure Level	Percent of 25,000 Departure Thickness
50,000	104
100,000	108
150,000	110
200,000	112

Note:
The values given in Table 3-5 are based on extrapolation of research data and observations of in-service pavements. Table 3-5 was developed assuming a logarithmic relationship between percent of thickness and departures.

319. DESIGN EXAMPLE. As an example of the use of the design curves, assume a flexible pavement is to be designed for a dual gear aircraft having a gross weight of 75,000 pounds (34 000 kg) and 6,000 annual equivalent departures of the design aircraft. Design CBR values for the subbase and subgrade are 20 and 6, respectively.

a. Total Pavement Thickness. The total pavement thickness required is determined from Figure 3-3. Enter the upper abscissa with the subgrade CBR value, 6. Project vertically downward to the gross weight of the design aircraft, 75,000 pounds (34 000 kg). At the point of intersection of the vertical projection and the aircraft gross weight, make a horizontal projection to the equivalent annual departures, 6000. From the point of intersection of the horizontal projection and the annual departure level, make a vertical projection down to the lower abscissa and read the total pavement thickness; in this example - 23 inches (584 mm).

b. Thickness of Subbase Course. The thickness of the subbase course is determined in a manner similar to the total pavement thickness. Using Figure 3-3, enter the upper abscissa with the design CBR value for the subbase, 20. The chart is used in the same manner as described in "a" above, i.e., vertical projection to aircraft gross weight, horizontal projection to annual departures, and vertical projection to lower abscissa. In this example the thickness obtained is 9.5 inches (241 mm). This means that the combined thickness of hot mix asphalt surface and base course needed over a 20 CBR subbase is 9.5 inches (241 mm), thus leaving a subbase thickness of 23 - 9.5 = 13.5 inches (343 mm).

c. Thickness of Hot Mix Asphalt Surface. As indicated by the note in Figure 3-3, the thickness of hot mix asphalt surface for critical areas is 4 inches (100 mm) and for noncritical, 3 inches (76 mm).

a. **Thickness of Base Course.** The thickness of base course can be computed by subtracting the thickness of hot mix asphalt surface from the combined thickness of surface and base determined in "b" above; in this example 9.5 - 4.0 = 5.5 (150 mm) of base course. The thickness of base course thus calculated should be compared with the minimum base course thickness required as shown in Table 3-4. Note that the minimum base course thickness is 6 inches (150 mm) from Table 3-4. Therefore the minimum base course thickness from Table 3-4, 6 inches (152 mm), would control. If the minimum base course thickness from Table 3-4 had been less than the calculated thickness, the calculated thickness would have controlled. Note also that use of Item P-208, Aggregate Base Course, as base course is not permissible since the weight of the design aircraft exceeds 60,000 Ibs. (27 000 kg).

e. Thickness of Noncritical Areas. The total pavement thickness for noncritical areas is obtained by taking 0.9 of the critical pavement base and subbase thicknesses plus the required hot mix asphalt surface thickness given on the design charts. For the thinned edge portion of the critical and noncritical pavements, the 0.7T factor applies only to the base course because the subbase should allow for transverse drainage. The transition section and surface course requirements are as noted in Figure 3- 1.

f. Summary. The thickness calculated in the above paragraphs should be rounded off to even increments as discussed in paragraph 3 18. If conditions for detrimental frost action exist, another analysis is required. The final design thicknesses for this example would be as follows:

THICKNESS REQUIREMENTS

	Critical in. (mm)	Non-Critical in. (mm)	Edge in. (mm)
Hot Mix Asphalt Surface (P-209 Base)	4 (100)	3 (75)	2 (50)
Base Course (P-209, or P-21 1)	6 (200)	5 (1'25)	4 (100)
Subbase Course (P-154)	14 (355)	13 (330)	10 (255)
Transverse Drainage Course (if needed)	0 (0)	3 (75)	8 (205)

320. **STABILIZED BASE AND SUBBASE.** Stabilized base and subbase courses are necessary for new pavements designed to accommodate jet aircraft weighing 100,000 pounds (45 350 kg) or more. These stabilized courses may be substituted for granular courses using the equivalency factors discussed in paragraph 322. These equivalency factors are based on research studies which measured pavement performance. See FAA Report No. FAA-RD-73-198, Volumes I, II, and III. Comparative Performance of Structural Layers in Pavement Systems. See Appendix 3. A range of equivalency factors is given because the factor is sensitive to a number of variables such as layer thickness, stabilizing agent type and quantity, location of stabilized layer in the pavement structure, etc. Exceptions to the policy requiring stabilized base and subbase may be made on the basis of superior materials being available, such as 100 percent crushed, hard, closely graded stone. These materials should exhibit a remolded soaked CBR minimum of 100 for base and 35 for subbase. In areas subject to frost penetration, the materials should meet permeability and nonfrost susceptibility tests in addition to the CBR requirements. Other exceptions to the policy requiring stabilized base and subbase should be based on proven performance of a granular material such as lime rock in the State of Florida. Proven performance in this instance means a history of satisfactory airport pavements using the materials. This history of satisfactory performance should be under aircraft loadings and climatic conditions comparable to those anticipated.

321. **SUBBASE AND BASE EQUIVALENCY FACTORS.** It is sometimes advantageous to substitute higher quality materials for subbase and base course than the standard FAA subbase and base material. The structural benefits of using a higher quality material is expressed in the form of equivalency factors. Equivalency factors indicate the substitution thickness ratios applicable to various higher quality layers. Stabilized subbase and base courses are designed in this way. Note that substitution of lesser quality materials for higher quality materials, regardless of thickness, is not permitted. The designer is reminded that even though structural considerations for flexible pavements with high quality subbase and base may result in thinner flexible pavements; frost effects must still be considered and could require thicknesses greater than the thickness for structural considerations.

a. Minimum Total Pavement Thickness. The minimum total pavement thickness calculated, after all substitutions and equivalencies have been made, should not be less than the total pavement thickness required by a 20 CBR subgrade on the appropriate design curve.

b. Granular Subbase. The FAA standard for granular subbase is Item P-154, Subbase Course. In some instances it may be advantageous to utilize nonstabilized granular material of higher quality than P-154 as subbase course. Since these materials possess higher strength than P-154, equivalency factor ranges are established whereby a lesser thickness of high quality granular may be used in lieu of the required thickness of P-154. In developing the equivalency factors the standard granular subbase course, P-154, was used as the basis. Thicknesses computed from the design curves assume P-154 will be used as the subbase. If a granular material of higher quality is substituted for Item P-154, the thickness of the higher quality layer should be less than P-154. The lesser thickness is computed by dividing the required thickness of granular subbase, P-154, by the appropriate equivalency factor. In establishing the equivalency factors the CBR of the standard granular subbase, P-154, was assumed to be 20. The equivalency factor ranges are given below in Table 3-6:

TABLE 3-6. RECOMMENDED EQUIVALENCY FACTOR RANGES FOR HIGH QUALITY GRANULAR SUBBASE

Material	Equivalency Factor Range
P-208, Aggregate Base Course	1.0 - 1.5
P-209, Crushed Aggregate Base Course	1.2 - 1.8
P-2 I 1, Lime Rock Base Course	1.0 - 1.5