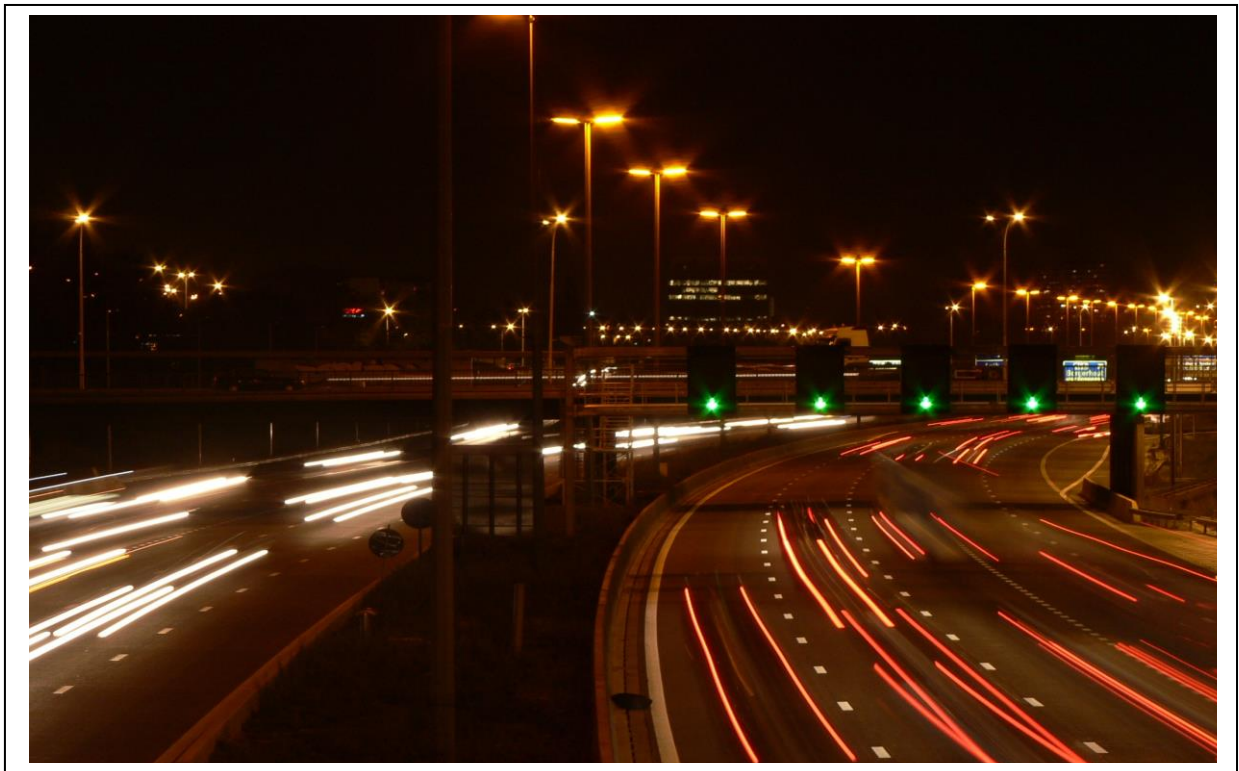




**CE 452**  
**Transportation Engineering Sessional II**  
**(Manual)**



**Department of Civil Engineering**  
**Ahsanullah University of Science and Technology**  
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## **Preface**

This manual covers traffic studies, reinforcement detailing of rigid pavement by road pavement design manual-1999 of Local Government Engineering Department (LGED) according to Road Note 29 developed by Transportation Research Laboratory (TRL) of UK, flexible pavement design by catalogue method of LGED according to Road Note 31 developed by TRL and design of airfield pavement by AC 150/5320-6D developed by Federal Aviation Administration (FAA) of US Department of Transportation (DoT). The road traffic studies are based on collecting field data and in this process students will learn to design, organize and conduct a traffic survey work and also to conduct work simultaneously and quickly.

While preparing the lab manual, different graphs, charts and images are collected from manual developed by LGED, TRL and Federal Aviation Administration (FAA) of US Department of Transportation (DoT).

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# 1. Traffic Volume Studies

## Data Collection

- Observation- Classified Vehicle Counts
- Method- Manual
- Equipment- Hand counter, Tally Sheet, Clip board etc
- Location- Mid-block
- Duration- 30 minute (short count)
- Sampling- Count all vehicles
- Enumerators- 6 nos.
- Group activity- Each enumerator would count a specific vehicle (s) type

## Survey Tips

Before data collection

- Find the suitable site for observation i.e. at what location of the road and from which position (at/above ground)
- Check/calibrate the counters (hand tally)
- Perform a trial survey to familiarize with the job and to find any problem in vehicle counting

## Data Sheet

Location of Survey:

Date of Survey:

Time of survey:

Duration of Survey:

Method:

Enumerators:

*Table: Sample Data Sheet for Volume Study*

<b>Vehicle Classification</b>	<b>Observation in 30 min</b>
Bus (B)	
Car, Jeep, Micro, Taxi	
Auto Rickshaw (AR)	
Motor Cycle (MC)	
NMV	
<b>Total=</b>	

## Data Analysis

- For each direction
  - Determine vehicle composition of traffic stream and show in a Pie-chart
  - Determine service flow rate in PCU/PCE unit
  - Determine directional distribution (DD)
  - Peak hour flow (PHF)
- For whole width of the road
  - Estimate average annual daily traffic AADT based on expansion factors

$$\text{HEF} = \frac{\text{Total volume for 24 hour period}}{\text{Volume for particular hour}}$$

$$\text{DEF} = \frac{\text{Average total volume for a week}}{\text{Average volume for particular day}}$$

$$\text{MEF} = \frac{\text{AADT}}{\text{ADT for particular month}}$$

- Draw flow-fluctuation curve (sharing other groups data)

## 2. Traffic Speed Study

### Data Collection

#### *Spot Speed*

- Observation- Travel time between 88 ft strip (Speed= 60/time in second = speed in mph)
- Method- Manual (Strip Method)
- Equipment- Ranging rods for strip marking, stopwatch, data sheet etc
- Location- Mid-block (free from obstructions)
- Duration- 30 minutes (at least 50 observations for each group)
- Sampling- Random, only free flow vehicles, matching vehicle proportion in the traffic stream
- Enumerators- 6 numbers
- Group activity- Each enumerator would record travel time of a specific vehicle(s) type

#### *Travel Speed*

- Observation- Travel time between two widely separated sections
- Method- Matching registration plate
- Equipment- Ranging rods for marking terminal points, watch, speed recorder etc.
- Location- Suitable points would be where vehicle approach\ -speed is low (near junctions, speed breaker etc)
- Duration- 30 minutes
- Sampling- Record as many vehicle as possible
- Enumerators- 12 numbers (6 numbers at upstream and 6 numbers at downstream)
- Gr. Activity- Each enumerator would record type of vehicle, registration no. and entry/exit time of a specific vehicle(s) type.

### Survey Tips

Before start of the work

- Prepare a data sheet to enter vehicle type, registration number, entry/exit time
- For quick entry
  - Assign vehicle abbreviations
  - Record only the numeric part of registration plate
- Use digital wrist watch to measure travel time in second
- Synchronize enumerators' wrist watches
- To fix starting and ending time of data recording at up & downstream, estimate off-set time between up & downstream points
- To go to the downstream position quickly, rickshaws can be used

## Analysis

### *Spot speed*

- Calculate speeds
- Present data in a tabular form for statistical analysis
- Plot histogram, Frequency Curve and Cumulative frequency curve
- Determine weighted average speed, Pace, modal speed, speed limits, design speed limits, design speed
- Check the speed distribution pattern by a normal distribution curve

### *Travel Speed*

- Find time mean speed and space mean speeds
- Prove that:
  - The space mean speed is lower than the time mean speed (usually  $V_s < V_t$ )
  - The Wardrop relationship between time mean speed and space mean speed is
$$\bar{V}_t = \bar{V}_s + \delta_s^2 / V_s;$$
$$\delta_s = \text{Standard deviation of } V_s$$
$$\delta_s^2 \text{ is the variance about the space mean speed}$$
- Delay for each type of vehicle (assuming free flow spot-speed as the travel speed)
- Find the cost of delay based on present users' value of travel time (VOT), vehicle occupancy rate and vehicles operating cost (VOC)

### *Speed Flow*

- Draw speed (space-mean)-Flow curve based on observed data



### 3. Roadway Condition Survey

#### Data collection

##### *Geometric condition*

###### Observations

- Geometric layout of the roadway (road length, width, no. of lanes, median height, width, shoulder height, width etc.)
- Geometric layout of intersections (geometric measurement and position of channels/islands, corner radius, dimension and location of pedestrian refuge)
- Surface condition
  - ✓ By skid resistance tester or sand-patch method (near high speed location, Zebra crossing, intersection)
  - ✓ By qualitative observation of potholes, elevated/depressed manholes, speed breakers etc.
- Equipment – Tape, Odometer etc.

##### *Operating condition*

###### Observations

- Location and width of side roads
- Road side land-use pattern
- Loss of road width due to parking, passenger loading/unloading, presence of dustbin/construction materials etc.
- Pedestrian crossing facilities
- Location and type of control devices
  - ✓ Road signs, markings
  - ✓ Signal (per approach no. of signal, type of signal heads, special filter signal)
  - ✓ Speed breakers
- Layout of street lighting system (spacing, pattern etc.)

## **Analysis**

- Draw the detailed layout of roadway and intersection
- Show the location of bottlenecks (side road, parking, pedestrian concentrations, dust bins, speed breakers etc.), street light arrangement, control devices etc.
- Determine
  - ✓ Loss of effective width at different locations of road
  - ✓ Average skid resistance value at different locations of road
  - ✓ Density of side roads (access control)
- Identify road traffic problems and suggest improvement measures

## 4. Joint Details of Rigid Pavement

### Main Causes of Failure of Rigid Pavement

- Fatigue
- Rutting
- Differential swelling of sub-grade
- Pore pressure due to poor surface & sub-surface drainage
- Long time submergence
- Construction and design faults etc.

### Stress Inducing Factors of Rigid Pavement

Besides fatigue, rigid pavement slab fails due to distresses caused by:

- Uniform temperature along thickness — which causes
  - **Contraction**
    - Immediately after construction
    - At night especially during winter season
    - Causes
      - at the slab - shrinkage/distributed(random) cracks because of
        - volume change along with frictions developed at the soil-slab interface (due to self wt. of slab)
        - concrete is weaker in tension (about 1/100 of compressive strength)
      - at the edge of expansion joints - excessive stress due to widening of gaps
    - Solutions
      - to minimize immediate shrinkage cracks
        - construction of work should be carried out during winter season
        - should not be constructed when ambient temperature is more than 31°C
        - use of retarder admixture (slow setting)/ice water etc.
        - use of short panel and stabilized subbase
      - to minimize contraction cracks
        - for larger panel size, use of temperature/distributed reinforcement - to hold the crack tightly
        - use of contraction joint (pre-formed crack) - to concentrate random cracks into intended location
        - use of tie bars to prevent construction joints from opening
  - **Expansion**
    - During daytime
    - Causes blowup problems at the slab edges
    - Solution - provision of expansion joints and to reduce load transfer related problems at joints
      - use of skewed joints or
      - use of Dowel bars

- Differential temperature/temp. gradient along thickness of slab — which causes
  - **Warping**
    - During transition of day to night and night to day
    - Causes cracks due to warping of slab
    - Solution - use of distributed reinforcement
- Moisture change — which causes
  - Pumping problems at joints (due to losses of sub-surface materials with water)
  - Solution - use of Dowel bars

### **Joint types**

- Direction-wise
  - **Longitudinal joints**
  - **Transverse joints**
- Function-wise
  - **Contraction joints**
    - are used to prevent irregular shrinkage cracks
    - are used to make sure that cracking will occur at a predetermined desired locations
    - are used to relieve tensile stress resulting from contraction and warping of the concrete
    - constructed by cutting a groove at the pavement surface; groove may be formed by sawing or by placing a metal strip
    - dowel bars are used to transfer load across the joints
    - to permit freedom of movement dowel should be lubricated plain bars
  - **Expansion joints**
    - are used to permit thermal expansion of slab and to prevent blowup at the slab edges
    - are used to relieve compressive stress resulting from expansion of the concrete
    - constructed with a clean break throughout the depth of the slab
    - usually joint opening of 19mm (3/4") to 25mm (1") is used
    - dowel bars are used to transfer load across the joints
    - to permit freedom of movement, dowel bars must be smooth and lubricated on at least one side
    - an expansion cap must also be provided to allow space for dowel bar to move during the expansion process
    - filler (cork/plastic/rubber) and sealant materials are needed to concealed the Joints to reduce infiltration of water or pumping effect and to reduce clogging of joint with hard material or chance of blowup problem
    - expansion joints are susceptible to pumping action
    - periodic maintenance is required

- **Construction joints**

- are used at the transition from old to new construction, such as at the end of a day's pour or at longitudinal joints
- instead of dowel bars, usually key form is used to act as load transferring device and
- deformed or hooked tie bars are used to hold/anchored two adjacent segments firmly to prevent movement

- Layout-wise - w.r.t. direction of travel

- **Perpendicular joints**
- **Skewed joints**

### **Types of Reinforcement**

- Temperature/distributed reinforcements

- used to control the width of the crack opening and not to prohibit the formation of cracks
- not to increase structural capability of the pavements
- smaller in sizes
- applied in the slab, usually in both directions in the form of welded wire-mesh or bar-mat
- amount depend on length of panel & thickness of slab

- Dowel bars

- used as a load transferring device (with high shearing strength i.e. with large x-sectional area)
- used to reduce deflection of slab edge and to control pumping effect
- 25mm (#8) or 32mm (#10) in size, 600mm (2') long and spaced @200mm (8") to 300mm (12") c/c
- applied only in longitudinal direction and across the expansion & contraction joints
- to allow freedom of movement of the slab, dowel bars must be smooth and lubricated
- become necessary for longer span i.e. >12m or 40' (due to excessive movements of expansion joints)
- they are placed at mid-depth of the slab

- Tie bars

- are used to tie two adjacent slabs together
- the bars are not so heavy and are smaller than dowel bars & spaced at greater intervals
- usually 12mm (#4) - 19mm (#5) bars are used
- length of tie bars are determined from bond criterion
- must be deformed or hooked and must be firmly anchored into the concrete to function properly

According to the reinforcement and joints, rigid pavement can be mainly classified in to as follows-

- Jointed reinforced concrete pavement (JRCP): JRCP uses contraction joints and reinforcing steel to control cracking. Transverse joint spacing typically ranges from about 7.6 m (25 ft.) to 15.2 m (50 ft.). Temperature and moisture stresses are expected to cause cracking between joints, hence reinforcing steel or a steel mesh

is used to hold these cracks tightly together. Dowel bars are typically used at transverse joints to assist in load transfer while the reinforcing steel/wire mesh assists in load transfer across cracks.

### Top View

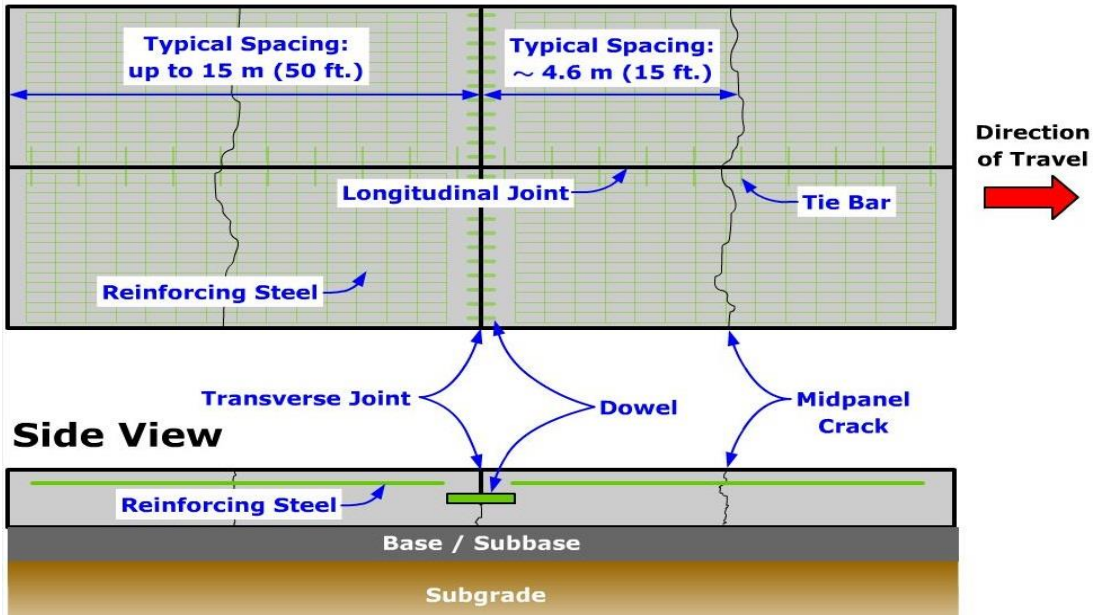


Figure 3.1 Jointed reinforced concrete pavement (JRCP)

- Continuously reinforced concrete pavement (CRCP): CRCP has no active transverse contraction joints. Continuous longitudinal reinforcement is provided that results in tight cracks in the concrete at about 2-ft to 8-ft (0.6 m to 2.4 m) spacing. Sufficient reinforcement is necessary to keep the cracks tight. Unlike dowel bars, reinforcing steel is bonded to the concrete on either side of the crack in order to hold the crack tightly together and provides load transfer across these cracks.

### Top View

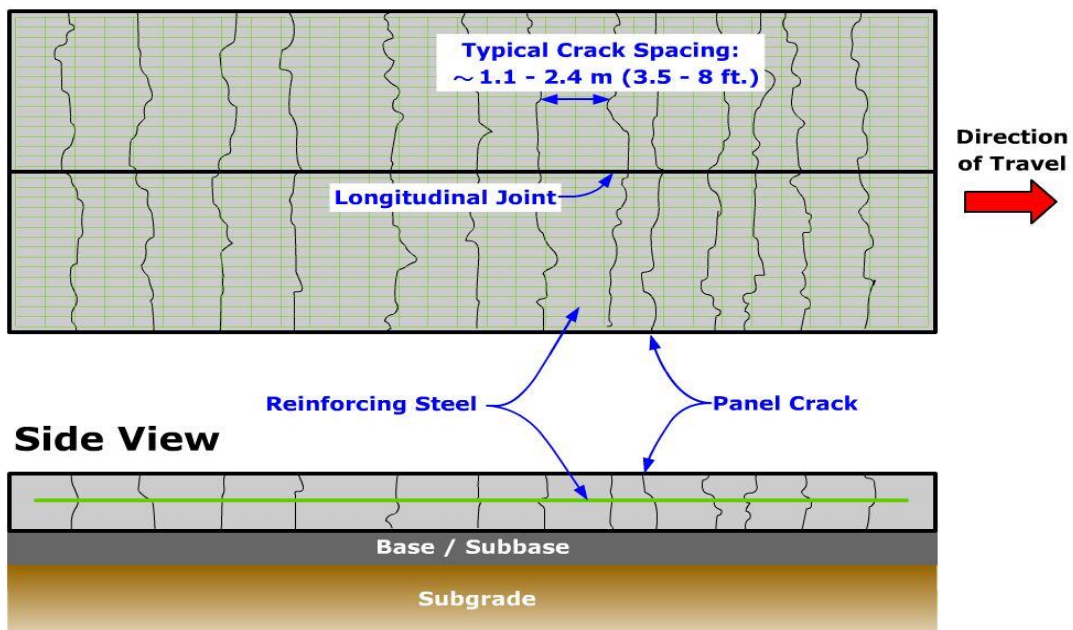


Figure 3.2. Continuously reinforced concrete pavement (CRCP)

- Jointed plain concrete pavement (JPCP): JPCP uses contraction joints to control cracking and does not use any reinforcing steel. Transverse joint spacing is selected such that temperature and moisture stresses do not produce intermediate cracking between joints. This typically results in a spacing no longer than about 6.1 m (20 ft.). Dowel bars are typically used at transverse joints to assist in load transfer. Tie bars are typically used at longitudinal joints.

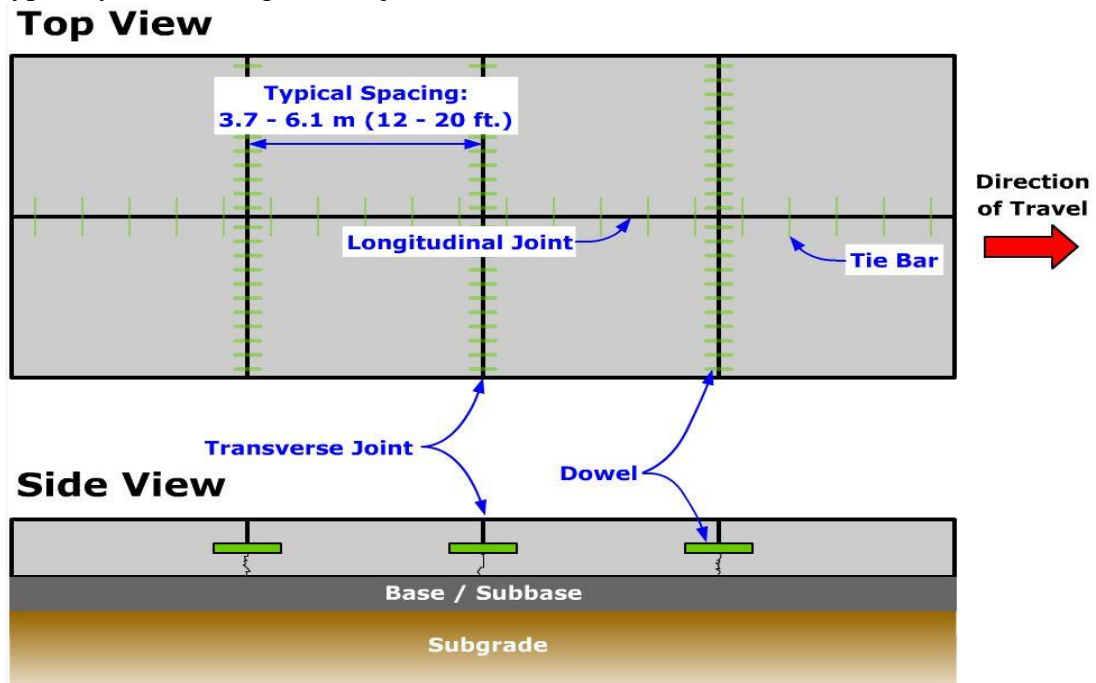


Figure 3.3. Jointed plain concrete pavement (JPCP)

To show the reinforcement and joint detailing of a rigid pavement, an example of Jointed reinforced concrete pavement (JRCP) is provided. The temperature/distribution reinforcement in a JRCP is calculated by Road pavement design manual-1999 of Local Government Engineering Department (LGED), according to Road Note 29 developed by Transportation Research Laboratory (TRL).

**Calculation of Temperature/Distributed Reinforcement** (according to Road Note 29)

- Assumption - resistance to movement of slab will be overcome by tension in steel
- $A_s = (W * f / f_s) L$   
 Where  $A_s$  = steel per foot of width;  
 $W$  = weight of slab (lb/ft<sup>2</sup>)  
 $f$  = co-efficient of resistance (generally assumed to be 1.5);  
 $f_s$  = allowable stress of steel (psi)  
 $L$  = length of slab (in longitudinal direction  $L$  is  $L/2$  and in transverse direction  $L$  is  $L$ )
- From the equation it is seen that the amount of steel is directly proportional to  $L$ , as such amount of steel can be reduced to zero by shortening the length of the slab
- On the contrary, shorter slab increases no of joints ; as joints are vulnerable and costly to maintain there need to make a trade-off between slab length (cost of reinforcement) and no. of joints (cost of joint construction)

## **Selection Criteria of slab length and its type**

### **a. Stabilized sub-base**

- Cement treated Sub-base/base add to the structural capability of pavement &
- also assist in load transfer across joints without dowel bars
- therefore, use of short slabs (increase no of joints) and a cement-treated sub-base sometimes go hand- in hand

### **b. Plain Versus Reinforced Pavements**

- Plain pavements:
  - no temperature reinforcement is required
  - no contraction joints
  - dowel bars at expansion joints are also omitted if stabilized sub-base is used
  - suitable for
    - pavements that will carry low volume of traffic and
    - slab length is < 6m or 20'
- Simply reinforcement pavements:
  - when slab length lies in between 6m (20') to 23m (75')
  - it became necessary to use
    - some steel for crack control as well as contraction joints
    - dowel bars at the joints to assist with load transfer
  - suitable for pavements that will carry medium volume of traffic
- Continuously reinforced pavements
  - when slab length is > 23m or 75'
  - amount of steel required to hold the cracks become excessive
  - no need for contraction joints



## Reinforcement Detail of Rigid Pavement

### **Problem:**

Design Reinforcement of the following:

Thickness of rigid pavement,  $t = 12$  inch

No. of lanes = 2

Width of pavement,  $w = 24$  ft

Spacing of transverse joint = 45 ft

Allowable Strength of:

Shrinkage steel (bar-mat) = 33000 psi

Tie bars = 27000 psi

Bond = 350 psi (10% comp. strength of concrete)

Draw reinforcement and joint details

### **Solution:**

Amount of shrinkage reinforcement,  $A_s$  (in<sup>2</sup>/ft) =  $(W \cdot f / f_s) \cdot \text{Effective length}$

Wt. of pavement,  $W = 150 \cdot 12 / 12 = 150$  lb/ft<sup>2</sup>

Coefficient of friction,  $f = 1.5$

#### ***Distributed Temperature Reinforcement:***

Longitudinal direction  $A_s = (150 \cdot 1.5 / 33000) \cdot 45 / 2 = 1.03$  in<sup>2</sup>/ft

If #4 bars are used, spacing = Area of bar /  $A_s = 0.2 / 1.03 = 0.194$  ft

Transverse direction,  $A_s = (150 \cdot 1.5 / 33000) \cdot 24 / 2 = 0.54$  in<sup>2</sup>/ft

If #4 bars are used, spacing = Area of bar /  $A_s = 0.2 / 0.54 = 0.37$  ft

#### ***Tie bars along longitudinal construction joints:***

Longitudinal direction,  $A_s = (150 \cdot 1.5 / 27000) \cdot 24 / 2 = 0.4$  in<sup>2</sup>/ft

If #5 bars are used, spacing = Area of bar /  $A_s = 0.31 / 0.4 = 0.775$  ft

Length of tie bars is,  $t(\text{in}) = 0.5 (f_s d) / f_b + 3'' = 0.5 \cdot (27000 \cdot 5/8) / 350 + 3 = 23.5$  inch

(where  $d$  = dia of tie bar in inch)

#### ***Dowel bars across transverse and contraction joints:***

Bar Detail	Transverse Joints	Contraction Joints
Bar Size	No.	No.
Length	ft	ft
Spacing	in c/c	in c/c

Where part of load transferred by interlocking of aggregates

## 5. Catalogue Method of Pavement Design

Considering the behavior of local materials, climatic condition and construction practices, a Catalogue of Pavement Structure is developed

- To simplify design procedure
- To prevent both under design and over design and thereby
- To ensure economical design

The method is designed by LGED (Local Government Engineering Department) as per the Road Note 31 delivered by TRL (Transportation Research Laboratory) of UK Government.

This design method is applicable for –

- Undivided rural road having crest width ranging from 5.6-7.3 m.
- Flexible and semi-rigid pavement (i.e. ratio of modulus between two successive layer is  $<5$ )
- Cumulative traffic 0.5-3.0 MESA (million equivalent standard axle)

This design method is established based on –

- Empirical Analysis – investigating behavior of existing pavement structure and experience gathered in other countries with similar conditions
- Experimental results – laboratory tests of local soil and road construction materials
- Theoretical knowledge – consideration of pavement mechanism i.e. elastic theory of pavement behavior under the effect of traffic
- Finally design catalogue is prepared by checking PADMA (Pavement Design by Mathematical Analysis) software (stress and strain are calculated at the interface of the layers and compared with admissible values as function of expected maximum axle load, cumulative traffic, material characteristics)
- Structures proposed are intended to use materials and construction technique traditionally pertaining in Bangladesh.
- A balancing between geometric and structural design of pavement

**Problem:** Design flexible pavement for an undivided rural highway by using catalogue of pavement structure method for the following data and also determine the construction of a 10 km highway.

**Given:**

The forecast AADT for 2003 the year of opening is assessed as:

Vehicle Types	Two-way AADT vpd
Large Truck	450
Small Truck	90
Large Bus	400
Small Bus	30
Car	200
Autorickshaw	50
Motocycle	30
Bicycle	50
Rickshaw	60
Cart	10

Assume:

Growth Rate,  $r = 7.5\%$  per annum  
 Design Period,  $n = 15$  year  
 CBR of Subgrade = 9.0%

**Solution:**

**(A) Determination of Roadway Geometry**

Vehicle Types	Two-way AADT vpd	PCU Factors	PCU/day at 2003
Large Truck			
Small Truck			
Large Bus			
Small Bus			
Car			
Autorickshaw			
Motocycle			
Bicycle			
Rickshaw			
Cart			
<b>Total =</b>			

$$\begin{aligned} \text{Forecasted design flow in 2018} &= \text{Total PCU/day at 2003 X (1+ growth rate)}^{(\text{design period})} \\ &= X (1.075)^{15} \text{ PCU/day} \end{aligned}$$

From the manuals of geometric design standards the recommended:

$$\begin{aligned} \text{Road Width} &= \text{m} \\ \text{Shoulder Width} &= \text{m} \end{aligned}$$

**(B) Determination of Cumulative ESAL for Pavement Design**

Heavy Vehicle Types	Two-way AADT vpd	ESAL per vehicle	Cumulative ESAL*
Large Truck			
Small Truck			
Large Bus			
Small Bus			
<b>Total =</b>			

$$*\text{Cumulative ESAL} = 365 \times \text{AADT} \times \text{ESAL} \times \frac{[(1+r)^n - 1]}{r}$$

$$\begin{aligned} \text{Total Cumulative ESAL in both direction} &= \\ \text{Total Cumulative ESAL in one direction} &= \text{DD} = 50.0\% \end{aligned}$$

**Determination of Channelization Factor**

The proportion of non-motorized traffic to heavy vehicle is:

$$P = \frac{(\quad + \quad)}{(\quad + \quad + \quad)} =$$

By interpolation Channelization factor from table 3 =

$$\begin{aligned} \text{Design Cumulative Traffic} &= \text{ESA} \\ &= \text{MSA} \end{aligned}$$

**( C ) Determination of Pavement Layer Thickness**

$$\begin{aligned} \text{Traffic Class} &= \text{for MSA} \\ \text{Subgrade Class} &= \text{for 9\% CBR} \end{aligned}$$

Using charts for catalogue propose alternative designs of pavement with varying material types. Then evaluate alternatives based on availability of materials, construction strategy and economy.

**Table 1: PCU factors for rural road**

Vehicle Types	PCU factors
Large Truck	3.0
Small Truck	2.0
Large Bus	2.5
Small Bus	1.5
Car	1.0
Autorickshaw	0.8
Motorcycle	0.5
Bicycle	0.3
Rickshaw	2.0
Other	4.0

**Table 2: ESAL per vehicle**

Vehicle Types	ESAL per veh.
Large Truck	1.5
Smsll Truck	0.5
Large Bus	0.5
Small Bus	0.2

**Table 3: Channelization Factor**

Road Width		Channelization factor depending on the ratio of NMV to be applied to one way flow	
m	ft	Low (<0.5)	High (>= 0.5)
5.6	18.4	2.0	2.0
6.8	22.3	1.0	1.8
7.3	23.9	1.0	1.6

**Table 4: Traffic Definition**

Class	MSA
T0	< 0.5
T1	0.5-1.5
T2	1.5-3.0
T3	3.0-7.5
T4	7.5-20.0
T5	20.0-30.0

**Table 5: Subgrade Definition**

Class	CBR
S1	3-5
S2	5-7
S3	7-10
S4	10-15
S5	>15

## 6. Airport Pavement Design

### SCOPE

All the methodology, charts and table presented below are as per **AC 150/5320-6D** of Federal Aviation Administration (FAA) of US Department of Transportation (DoT). This method covers pavement design for airports serving aircraft with gross weights of 30,000 pounds (13 000 kg) or more.

### 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 here 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.

## **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 (0.51 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 (0.51m) 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-1011 represent a radical departure from the geometry assumed for dual tandem aircraft described in paragraph 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 1380 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 (1380 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, and the National Plan of Integrated Airport Systems.

### **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.

### **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:

Table 6.1: Airport Landing Gear-Configuration Conversion Factors

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

*Source: Federal Aviation Administration*

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:

$$\log R_1 = \log R_2 * (W_2/W_1)^{1/2}$$

where

R<sub>1</sub> = 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 (136100 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	3760	160,000	(72600)
727-200	Dual	9080	190,500	(86500)
707-320B	Dual tandem	3050	327,000	(148500)
DC-g-30	Dual	5800	108,000	(49000)
cv-880	Dual tandem	400	184,500	(83948)
737-200	Dual	2650	115,500	(52440)
L-101 I-100	Dual tandem	1710	450,000	(204120)
747-100	Double dual tandem	85	700,000	(317800)

(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	Equivalent Dual Gear Departures	Wheel load		Wheel load of design aircraft		Equivalent Annual Departs Design Aircraft
		lbs	(kg)	Lbs	(kg)	
727-100	3760	38000	(17240)	45240	(20520)	1891
727-200	9080	45240	(20520)	45240	(20520)	9080
707-320B	5185	38830	(17610)	45240	(20520)	2764
DC-g-30	5800	25650	(11630)	45240	(20520)	682
cv-880	680	21910	(9940)	45240	(20520)	94
737-200	2650	27430	(12440)	45240	(20520)	463
L-101 I-100	145	35625*	(16160)	45240	(20520)	83
747-100	2907	35625*	(16160)	45240	(20520)	1184

Total= 16241

(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.

## Problem

Design a flexible pavement for airport using FAA method for following data:

### Forecast Aircraft Traffic Data for a Typical Airport

<b>Aircraft Type</b>	<b>Forecast Annual Departures</b>	<b>Main Landing Gear Configuration</b>	<b>Gross Take-off Weight, kip</b>
B-727-100	3,000	Dual	160
B-727-200	4,000	Dual	185
B-707-320B	3,000	Dual tandem	327
CV-880	1,000	Dual tandem	185
DC-9-30	1,200	Dual	108
B-737-200	900	Dual	100
L-1011-100	1,300	Dual tandem	510
B-747-100	1,200	Double dual tandem	710
A-340-200	1,000	Dual tandem & Dual	559

Design Pavement Life = 20 years

**Solution:**

*A. Determination of Design Aircraft*

Thickness requirement for each aircraft is determined by using design curves (Fig- 1 to Fig-14, Appendix 1), considering same input data (CBR, k value etc) for all aircraft. Gross weights and no. of departures must correspond to the particular aircraft in the forecast list.

Design Aircraft <sup>1</sup> Data	
Aircraft Type	
Gear Type	
Gross Wt, $W_g$ (kip)	
Wheel Load, $W_1$ (kip)	

*B. Determination of Equivalent Departures of Design Aircraft*

Aircraft Type	Forecast Annual Departures (R)	Gross Wt. on main landing gears ( $W^2$ )	Total No. of wheels <sup>3</sup>	Load/Wheel ( $W_2$ ) <sup>4</sup>	Gear Conversion Factor, GCF <sup>5</sup>	Equivalent Departures of	
						Design Gear ( $R_2$ ) <sup>5</sup>	Design Wheel Load ( $R_1$ ) <sup>7</sup>
B-727-100	3,000						
B-727-200	4,000						
B-707-320B	3,000						
CV-880	1,000						
DC-9-30	1,200						
B-737-200	900						
L-1011-100	1,300						
B-747-100	1,200						
A-340-200	1,000						

Total Equivalent Annual Departures of Design Aircraft=

Notes:

1. The aircraft which requires greatest pavement thickness
2. 95% of the gross take-off weight is assumed to be carried by the main landing gears. Wide body aircraft is considered as a 300 kip Dual tandem aircraft
3. See Fig 6.1: Landing Gear Configuration
4. Load per wheel=  $W$ /Total no. of wheels
5. For Gear Conversion Factor (GCF) see Table 6.1
6.  $R_2 = R * GCF$

Design Aircraft Data		Design CBR Values	
Aircraft Type		Subgrade	5
Gear Type		Subbase	20
Gross gear wt. (kip)			
Total Equivalent Departures			

*Determination of Pavement Layer Thicknesses for Critical Areas*

Thicknesses from the appropriate design curve	Inputs/Calculations	inch
T <sub>1</sub> = Total thickness above subgrade (i.e. Surface+Base+Subbase)	App 2, Fig: 2 ; CBR= 5	
T <sub>2</sub> = Total thickness above subbase (i.e. Surface+Base)	App 2, Fig: 2 ; CBR= 20	
T <sub>3</sub> = Minimum thickness of untreated base course		
T <sub>4</sub> = Minimum thickness of Surface course	App 2, Fig: 2	
<b>Calculated Thickness of Base and Subbase Course</b>		
T <sub>5</sub> = thickness of untreated subbase	T <sub>1</sub> -T <sub>2</sub>	
T <sub>6</sub> = thickness of untreated base course	T <sub>2</sub> -T <sub>4</sub>	
Check for minimum base course	As T <sub>6</sub> <T <sub>3</sub> , use T <sub>3</sub> instead of T <sub>6</sub>	
<b>Adjusted base and subbase course thicknesses</b>		
T <sub>7</sub> = Due to minimum criterion, the extra thickness of base course would be T <sub>7</sub> This extra thickness need be deducted from the subbase thickness, T <sub>5</sub> instead of adding with the total pavement thickness, T <sub>1</sub>	T <sub>3</sub> -T <sub>6</sub>	
T <sub>8</sub> = So the pavement thickness becomes T <sub>8</sub>	T <sub>5</sub> -T <sub>7</sub>	
<b>Stabilized Subbase and Base Courses</b>		
As the design aircraft Wt.>100 kip, stabilized subbase/base needs to be used		
If soil cement base course materials are used for subbase stabilization then the thickness of stabilized subbase would be	App 3, Table:1 T <sub>8</sub> /Stabilization Factor	
If cement base course materials are used for base stabilization then the thickness of stabilized base would be	App 3, Table:1 T <sub>3</sub> /Stabilization Factor	
<b>Thicknesses for Non-critical areas</b>		
<i>Surface Course</i>		
The minimum thickness of stabilized base would be	App 2; Fig:2	
<i>Base and Subbase Courses</i>		
At high speed areas: The thickness of subbase course would be The thickness of base course would be	0.9 of Critical Thickness 0.9 of Critical Thickness	
At pavement edges: The thickness of base would be	0.7 of critical thickness	
The subbase is not reduced to allow for transverse drainage.		

The final design thickness would be as follows

Pavement Layer	Thickness requirements (rounded to even increments)		
	Critical Areas (in)	Non-critical (in)	
		High Speed Areas	Pavement Edges
Bituminous Surface			
Base Course			
Subbase Course			

## 7. Appendix 1

### Design Curves for Flexible Pavements (Fig: 1 through Fig: 14)

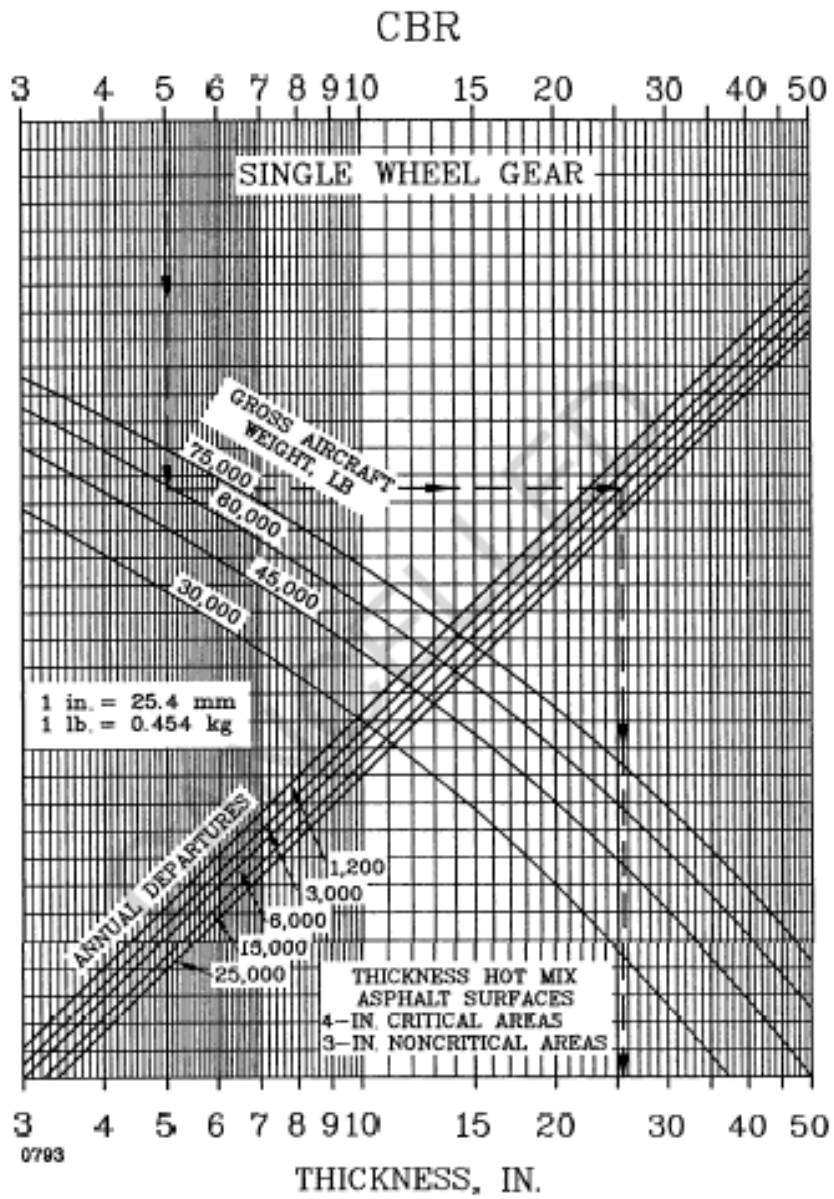


Figure 7.1. Flexible pavement design curves, single wheel gear (Source: FAA)

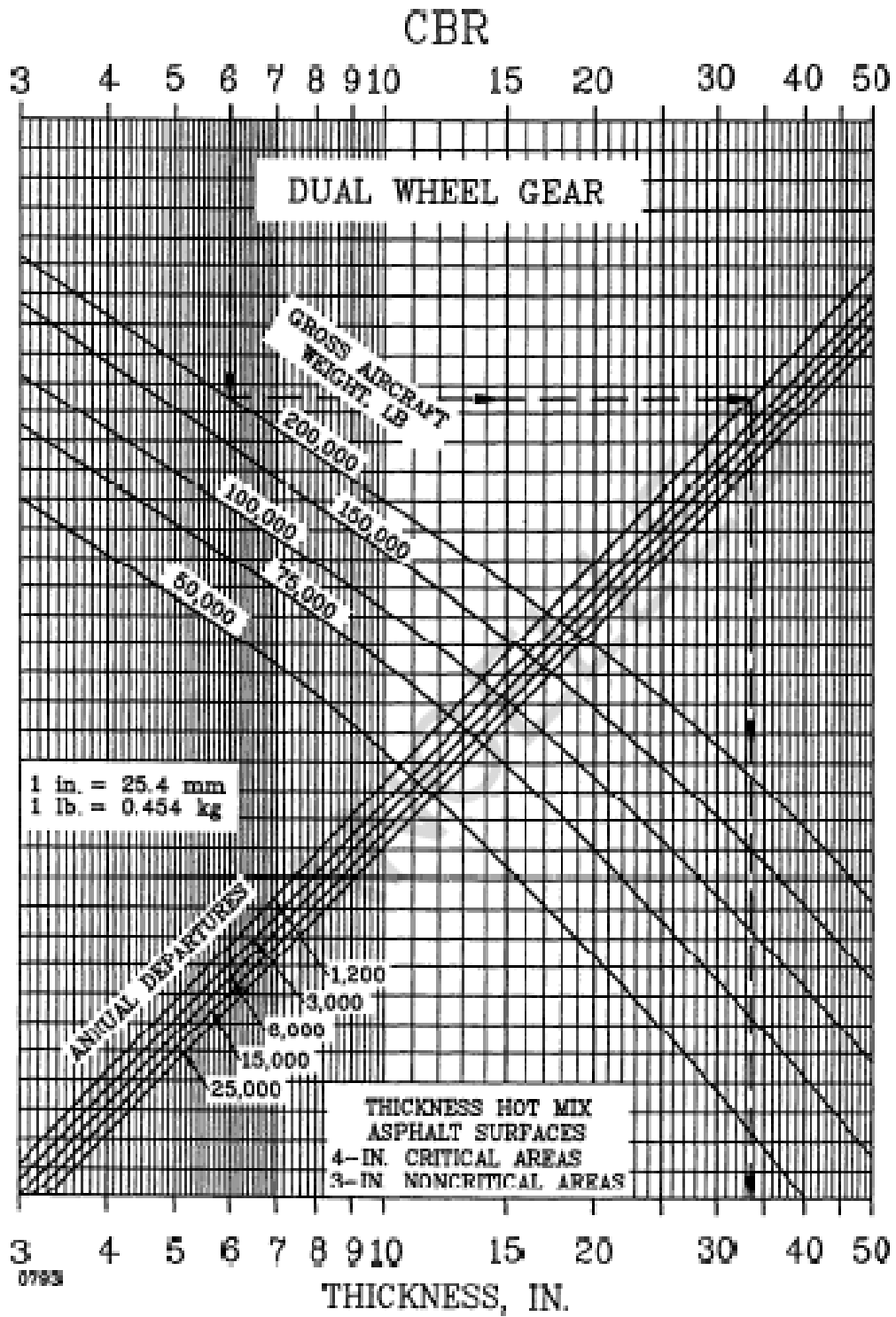


Figure 7.2. Flexible pavement design curves, dual wheel gear (Source: FAA)

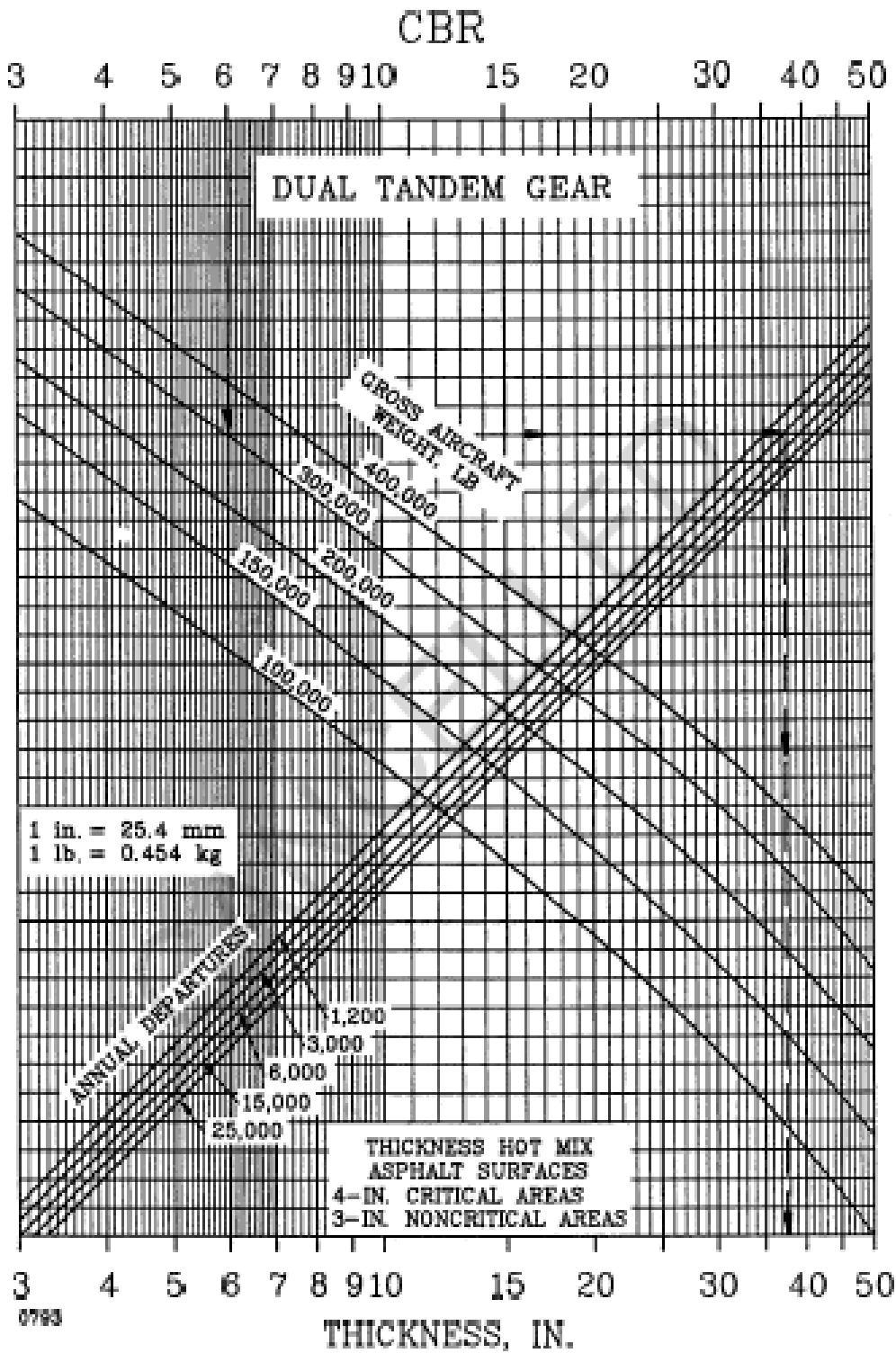


Figure 7.3. Flexible pavement design curves, dual tandem gear (Source: FAA)



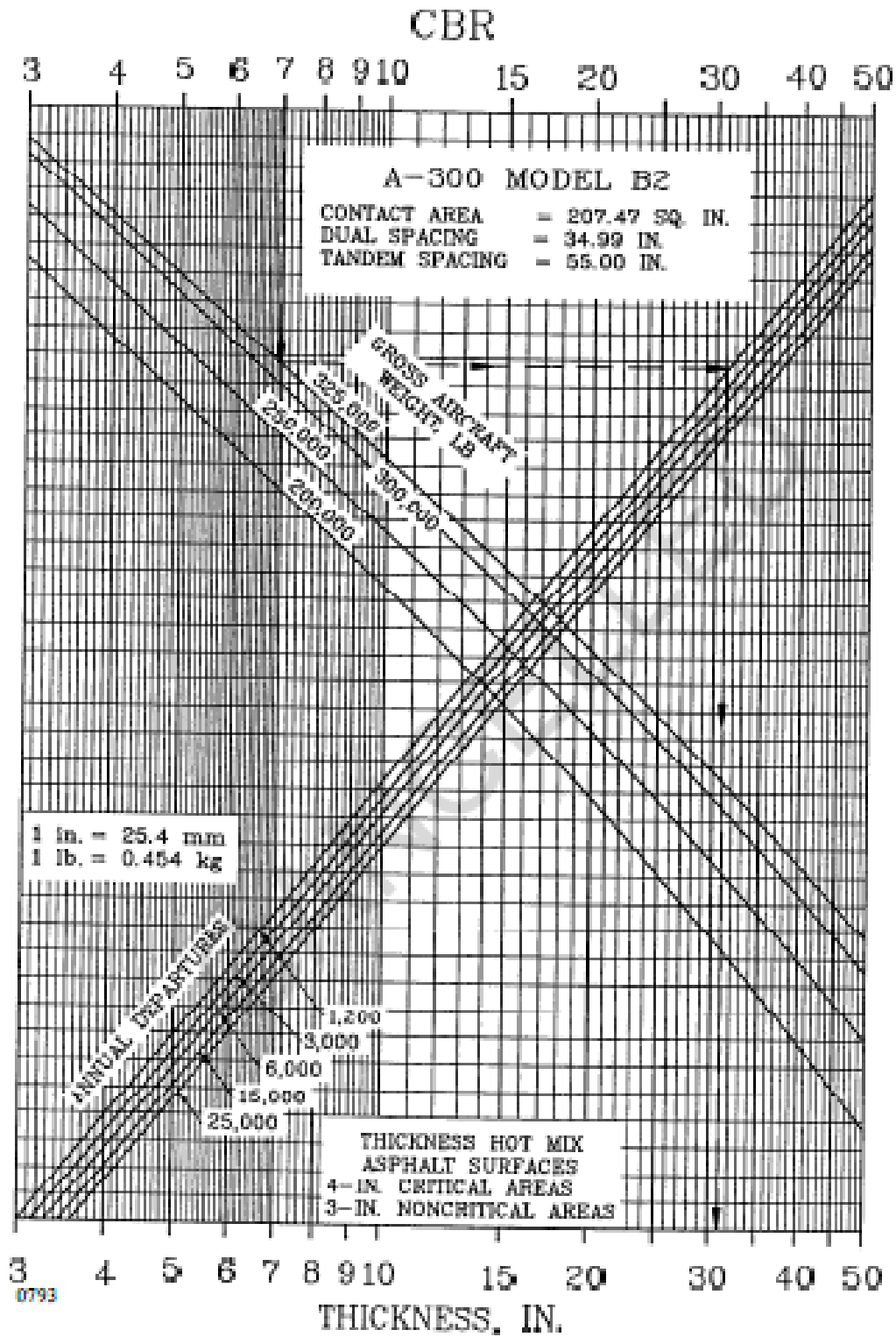


Figure 7.4. Flexible pavement design curves, a-300 model b2 (Source: FAA)

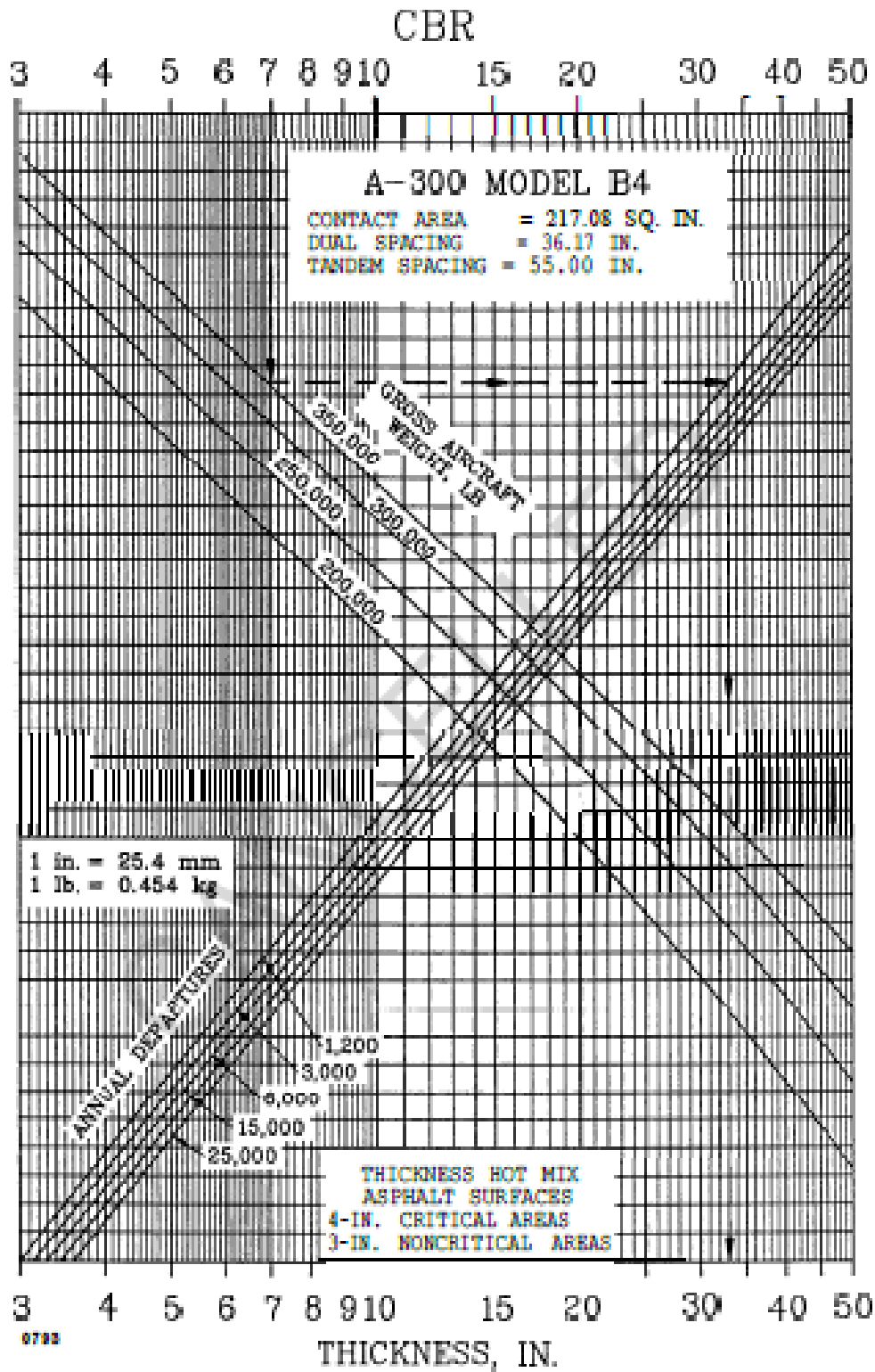


Figure 7.5. Flexible pavement design curves, a-300 model b4 (Source: FAA)

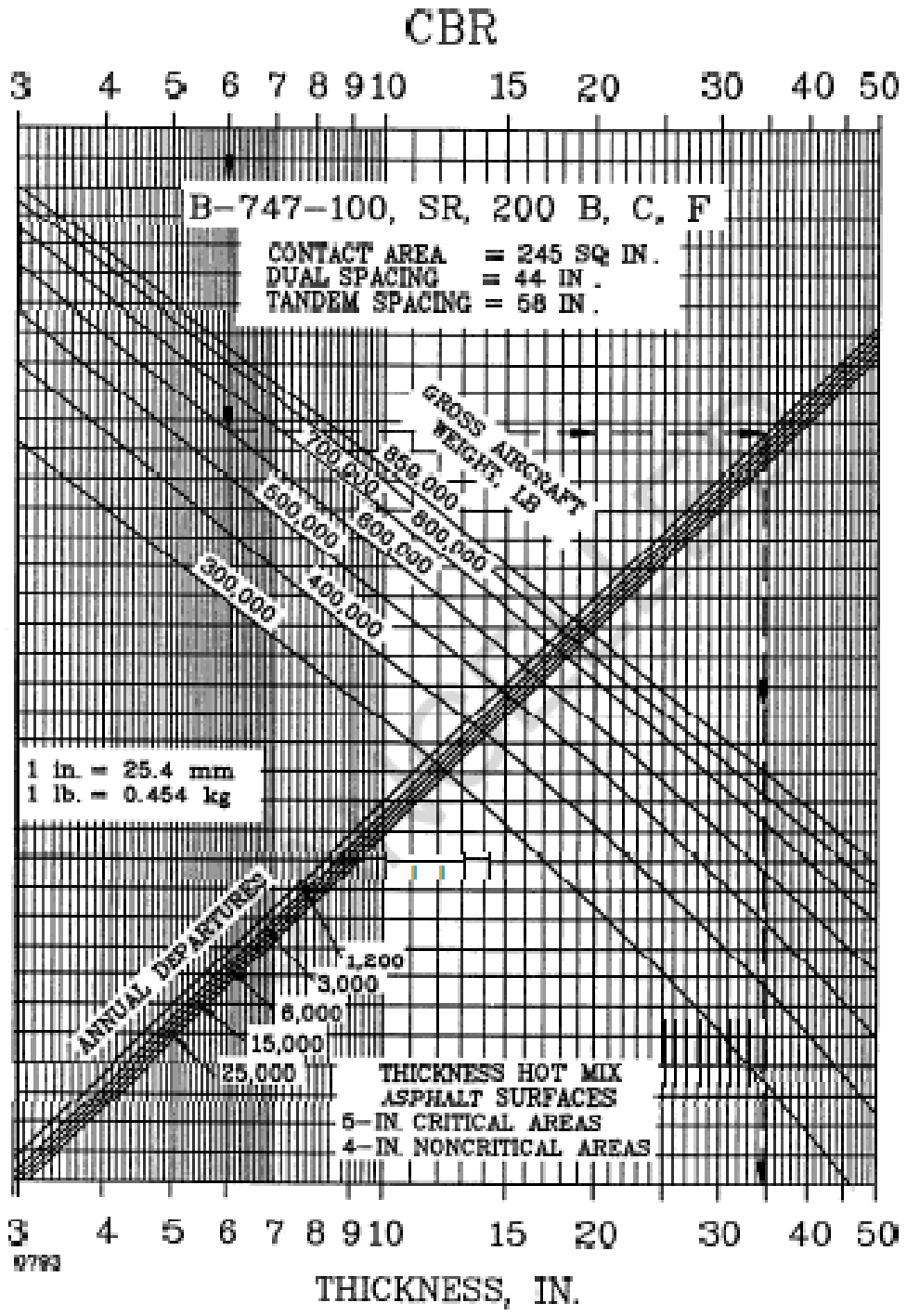


Figure 7.6. Flexible pavement design curves, b-747-100, sr, 200 b, c, f (Source: FAA)

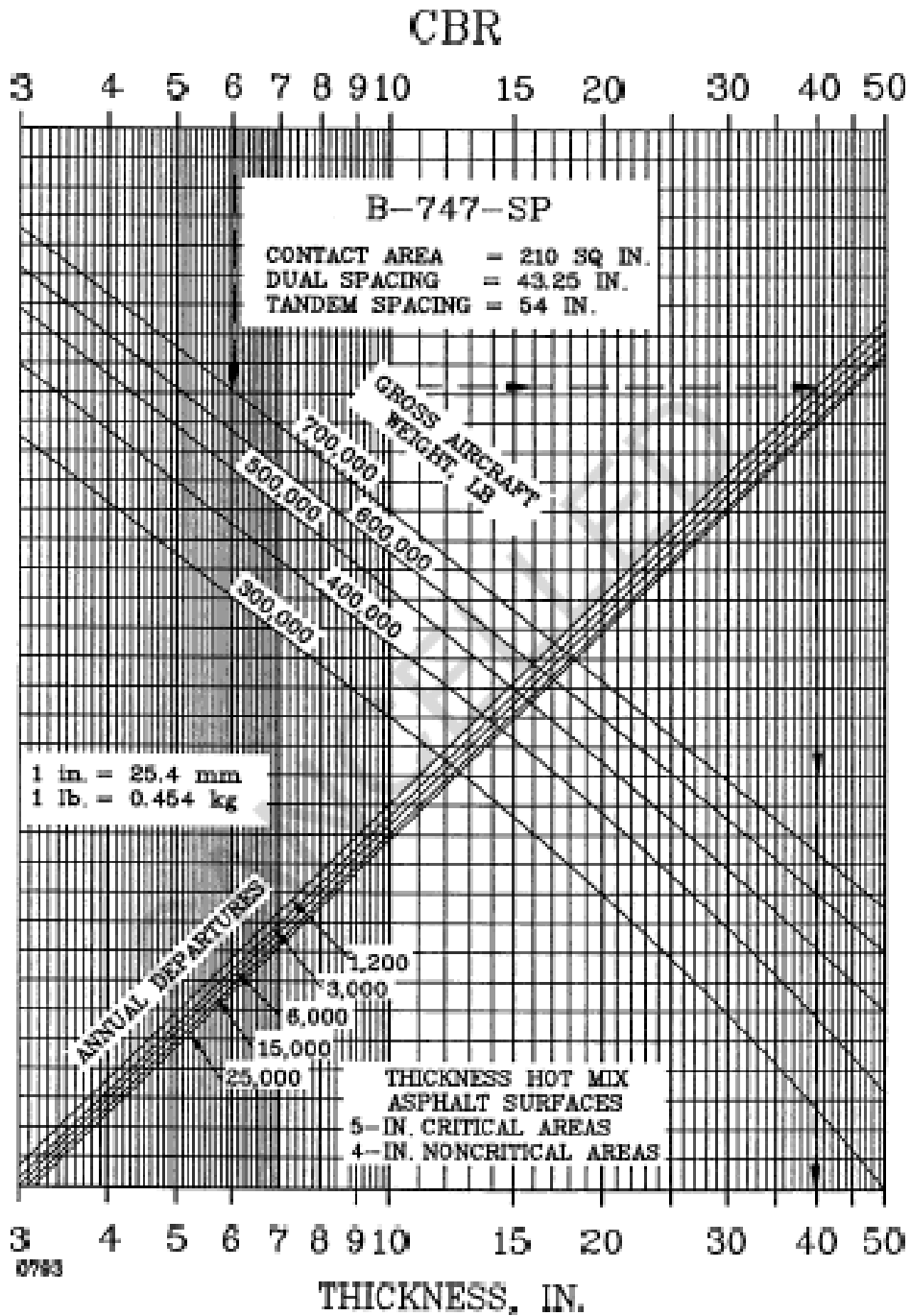


Figure 7.7. Flexible pavement design curves, b-747-sp (Source: FAA)

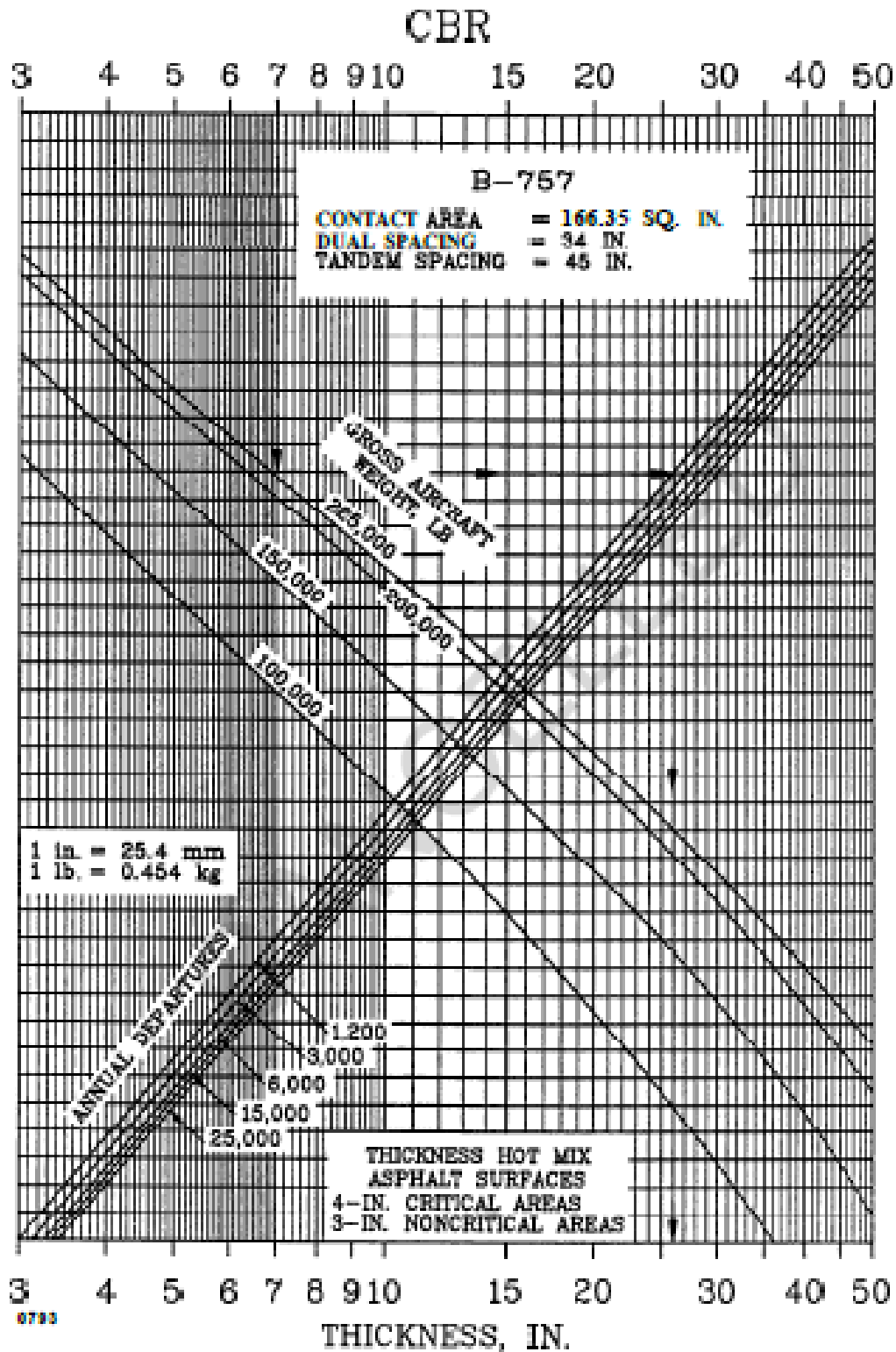


Figure 7.8. Flexible pavement design curves, B-757 (Source: FAA)

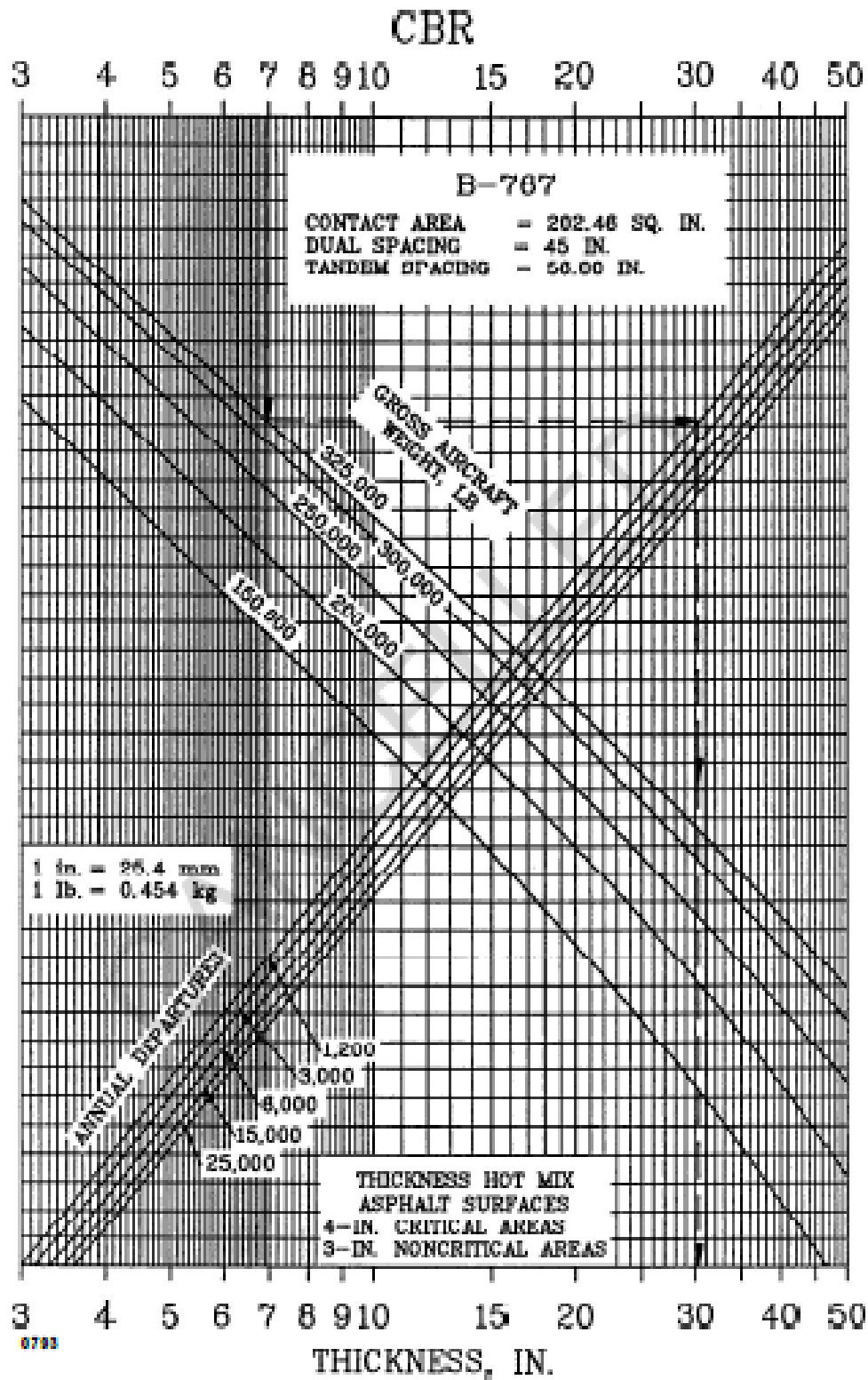


Figure 7.9. Flexible pavement design curves, B-767 (Source: FAA)

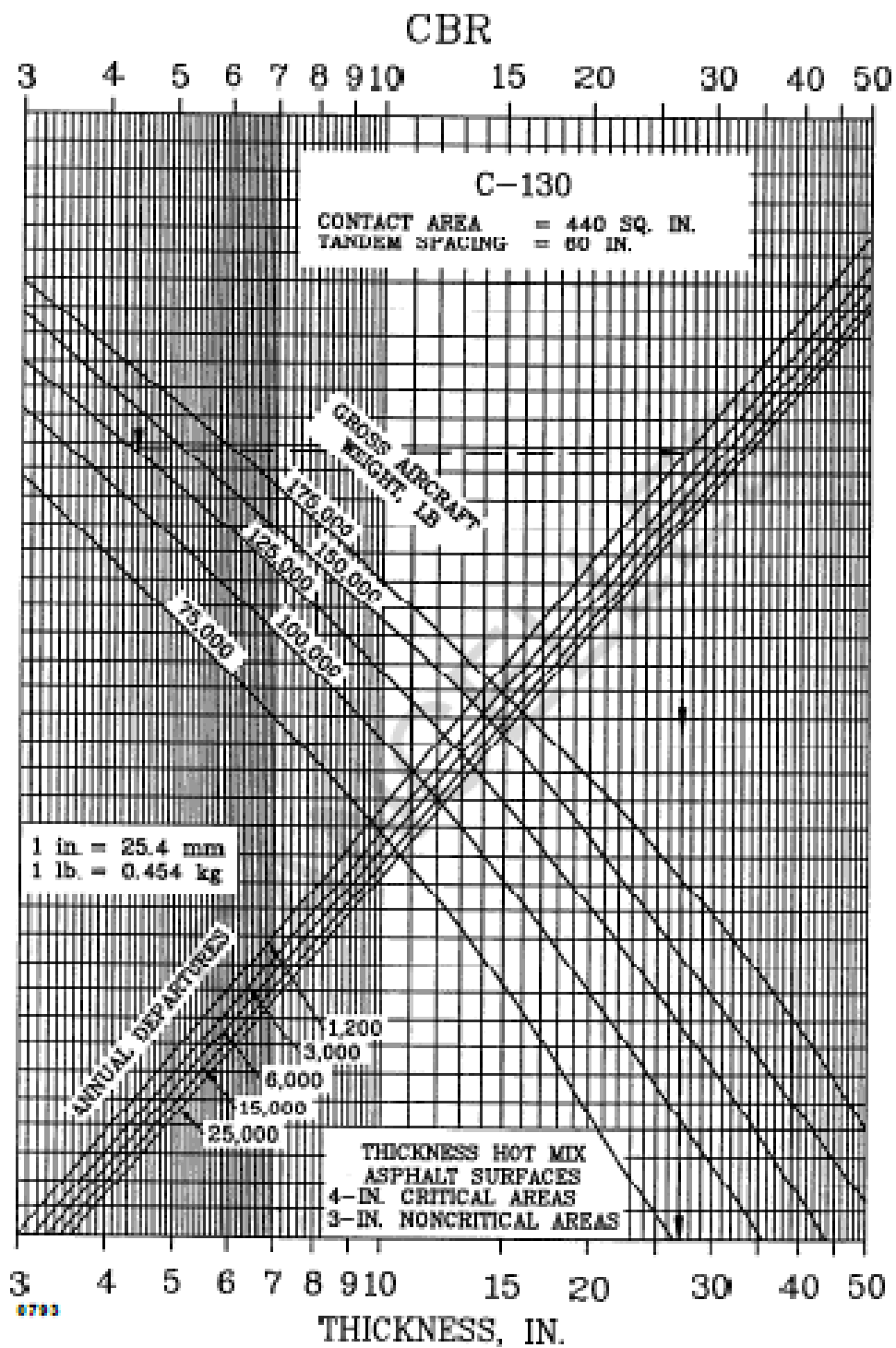


Figure 7.10. Flexible pavement design curves, C-130 (Source: FAA)

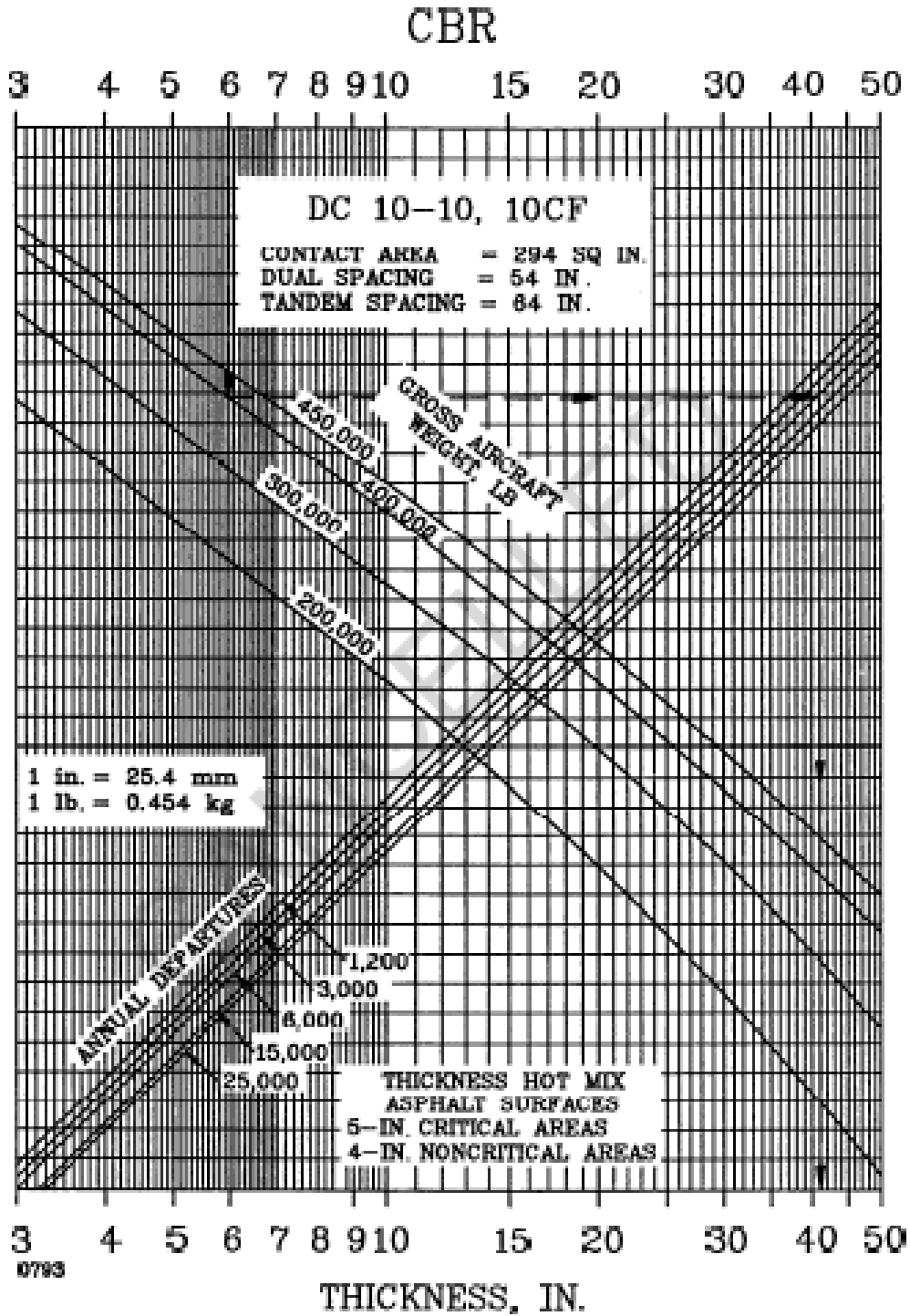


Figure 7.11. Flexible pavement design curves, DC 10-10, 10CF (Source: FAA)



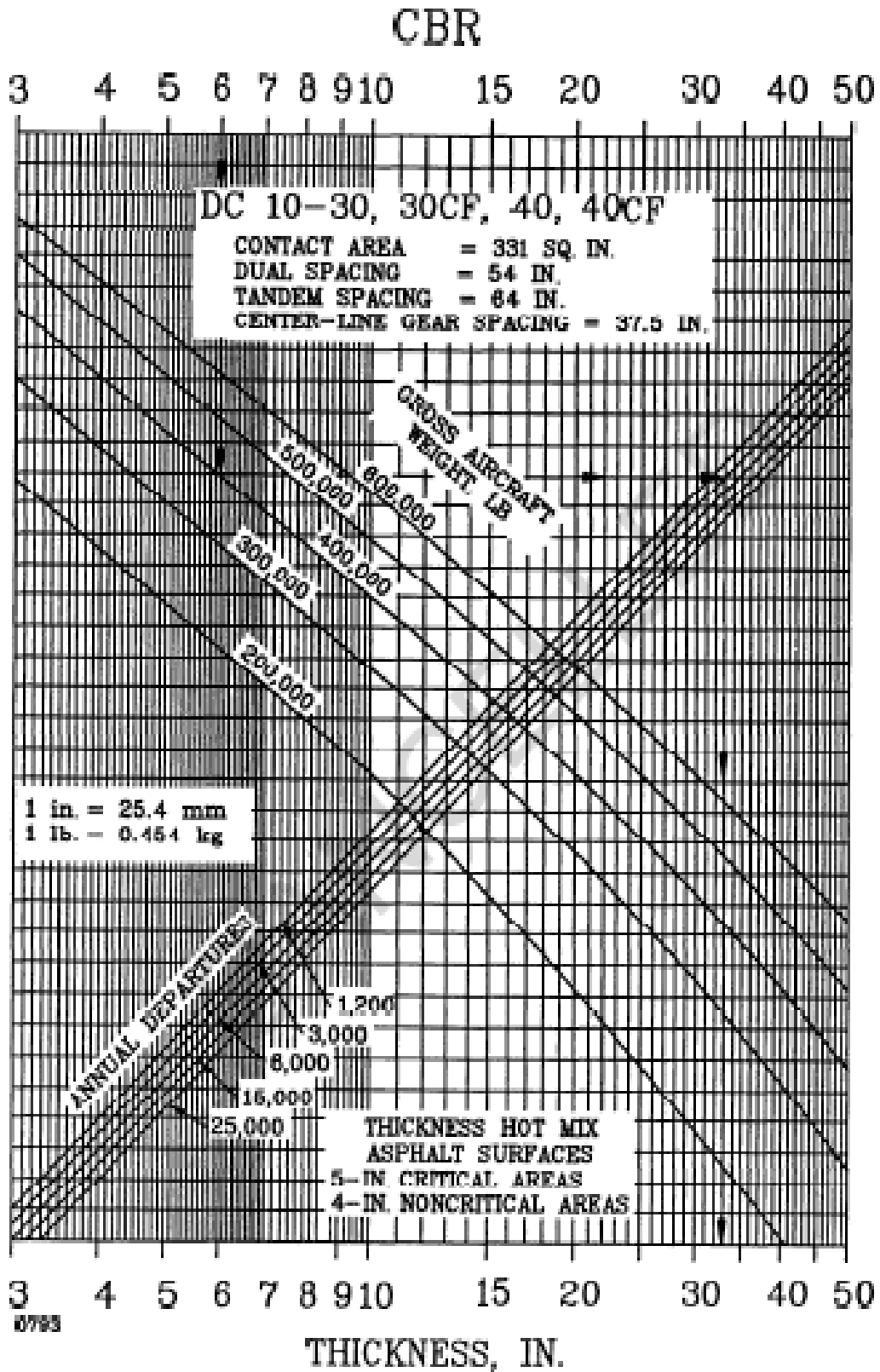


Figure 7.12. Flexible pavement design curves, DC 10-30,30CF, 40,40CF (Source: FAA)

# CBR

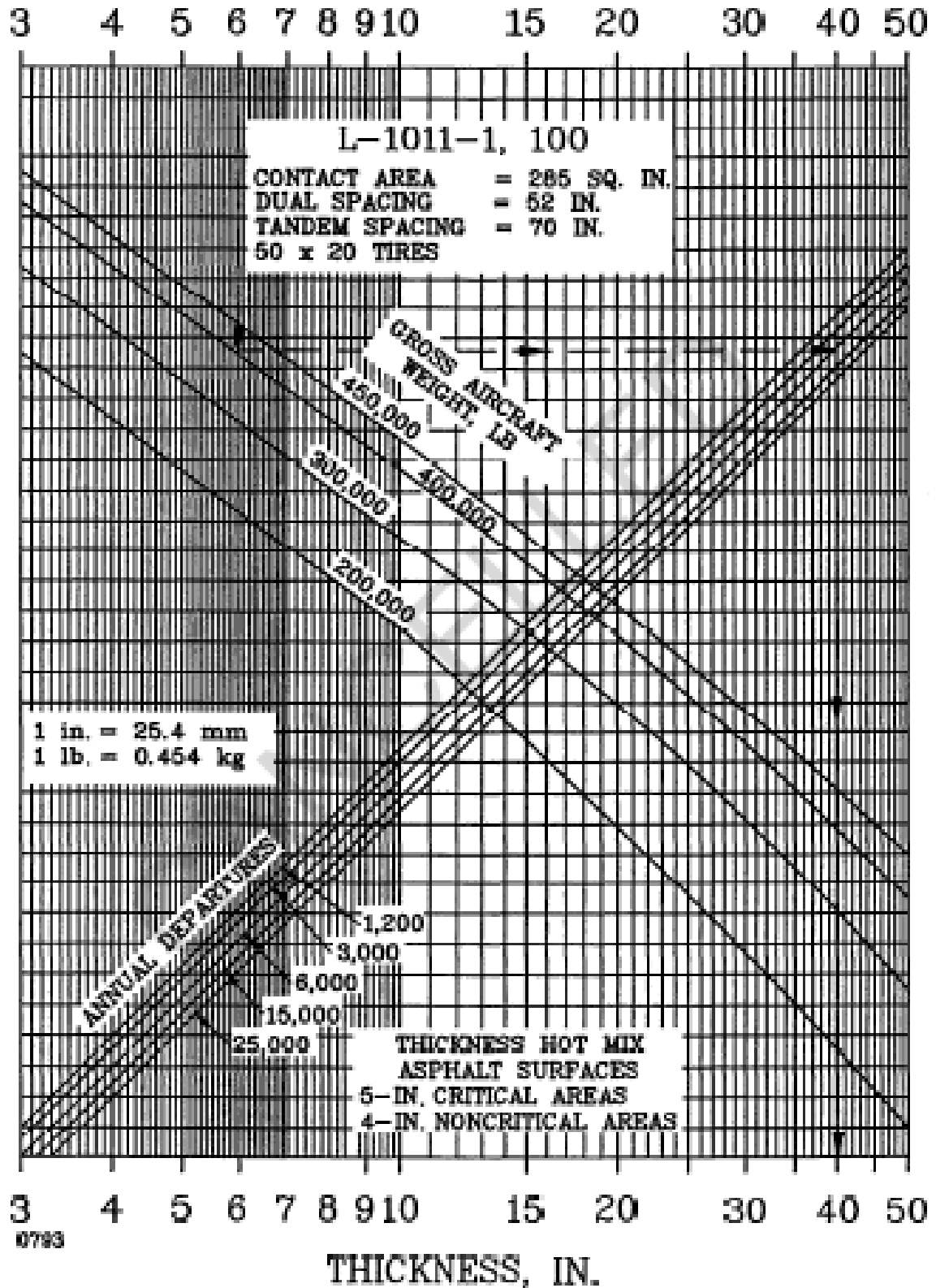


Figure 7.13. Flexible pavement design curves, L-1011-1,100 (Source: FAA)

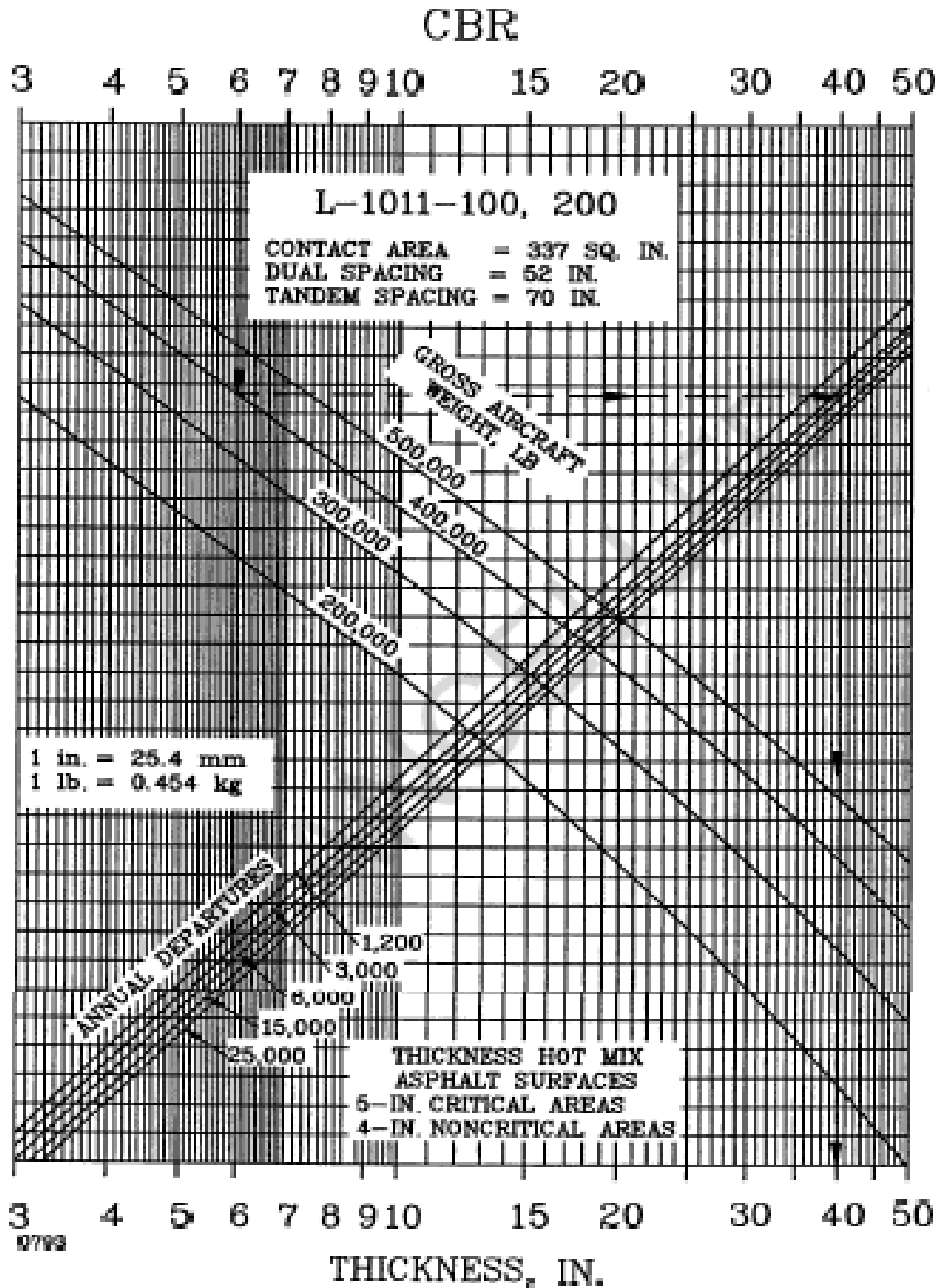


Figure 7.14. Flexible pavement design curves, L-1011-1,200 (Source: FAA)

## 8. Appendix 2

Table 1: Recommended Equivalent Factors for Stabilized Subbase Course

Material Used	Equivalency Factor	
	Subbase	Base
Bituminous Surface Course	1.7-2.3	1.2-1.6
Bituminous base course	1.7-2.3	1.2-1.6
Cold laid bituminous base course	1.5-1.7	1.0-1.2
Mixed in-place base course	1.5-1.7	1.0-1.2
Cement treated base course	1.6-2.3	1.2-1.6
Soil cement base course	1.5-2.0	N/A
Crushed aggregate base course	1.4-2.0	1
Gravel subbase course	1	N/A

## **9. Reference**

1. Local Government Engineering Division, 2003. Road Pavement Design Manual.
2. Road Note 29 by Transportation Research Laboratory (TRL)
3. AC 150/5320-6D, Federal Aviation Administration (FAA) of US Department of Transportation (DoT)