The Design of Concrete Block Aircraft Pavements

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SUMMARY

This paper provides design guidance for designers of aircraft pavements surfaced with concrete pavers. Both structural design and surface selection are considered. The structural design method presented is based upon the Federal Aviation Authority (FAA) flexible pavement design procedure. Whereas the FAA method assumes that the surface will comprise 4 inches or 5 inches asphalt concrete, this paper assumes 80mm concrete blocks laid into 30mm sharp sand. The background to this change in surfacing materials is explained. The information relating to surfacing is based upon several years' experience of pavers at Luton International Airport. Of particular relevance are the recommendations regarding jointing sand stabilization in areas likely to be subjected to high velocity hot gases. A complete set of modified FAA design charts is presented together with a worked example.

1.0 INTRODUCTION

It has been established at Luton International Airport, UK and elsewhere (Emery 1986) that concrete pavers bedded in sand provide a suitable wearing surface for aircraft pavements. Such pavements have been in use at Luton for aircraft stands, for turning circles at each end of the runway and at various other locations where pavements have been trafficked by aircraft for several years. Plate bearing tests undertaken at Luton have established that concrete pavers increase the strength of an aircraft pavement when compared with alternative surfacing materials. These plate bearing tests are described by Briery (1986) who concludes that it is possible to replace approximately 4 inches of asphalt concrete with concrete pavers with the result that the pavement increases in strength.

In this paper a design method is presented which allows engineers to proportion pavement course thicknesses for aircraft pavement trafficked by commercial airliners. The design method presented relies upon the experience at Luton and also upon the research undertaken in the United Kingdom which has established the structural performance of concrete block paving (Knapton 1976). As well as dealing with pavement course thicknesses this paper also considers those properties which are important to aircraft pavement surfaces. These are durability, strength, surface stability, frictional characteristics, rideability, the removal of surface water, the capability of rapid repair, resistance to both thermal movement and exhaust velocities from jet engines and resistance to de-icing and anti-icing chemicals, fuel and oils.

2.0 BASIS OF DESIGN PROCEDURE

The first published information on the design of concrete block pavements was presented by Knapton (Ref.2) in 1976. This followed his research in which he established that concrete pavers had sufficient load spreading capability to permit the replacement of approximately 6 inches of asphalt concrete with 3 inch thick pavers bedded on 2 inches of sAnd. This research has been incorporated in several highway design procedures (References 3, 4, 5) and has become widely accepted in many parts of the world as the basis of design procedures.

The research was also incorporated in the British Ports Association Heavy Duty Pavement Design Manual which was published in 1982 (Reference 6.). This manual allows designers to proportion pavement course thicknesses for pavements subjected to container handling plant applying wheel loads of up to 30t onto concrete block pavments. In Europe, concrete pavers have been used commonly to surface port pavements for many years and the largest container handling facility in the world, Europe Container Terminus at Rotterdam is entirely surfaced with concrete pavers.

The design method described in this paper takes the experience of port engineers and highway engineers in addition to that at Luton International Airport and by using the research referred to above allows the Federal Aviation Authority (FAA) flexible pavement design method (Ref. 7) to be modified to accommodate concrete pavers. The FAA pavement design method allows the thickness of the pavement courses to be proportioned and assumes that the pavements will be surfaced with either 4 or 5 inches of asphalt concrete. By simply removing the asphalt concrete and substituting concrete pavers plus their sand it can be assumed that the resulting pavement will be at least as strong as the pavement that would have been produced using the unmodified FAA design charts.

In order to use the modified FAA design charts, an assessment of the California Bearing Ratio (CBR) of the subgrade is required. The CBR assessment method is set out below. Firstly the subgrade material is classified into one of 15 types. The standard method of classifying soils for engineering purposes is described in ASTM D-2487, commonly called the Unified system. This system classifies soils on the basis of grain size and plastic con-

The initial division of soils is based on the separation of coarse and fine grained soils and highly organic soils. The distinction between coarse and fine grained soils is determined by the amount of material retained on the No. 200 sieve. Coarse-grained soils are further subdivided into gravels and sands on the basis of the amount of material retained on the No. 4 sieve. Gravels and sands are then classed according to whether or not fine material is present. Fine grain soils are subdivided into two groups on the basis of liquid limit and plasticity index. The chart shown in Figure 1 allows plastic soils to be classified once their Plasticity Index and Liquid Limit are known.

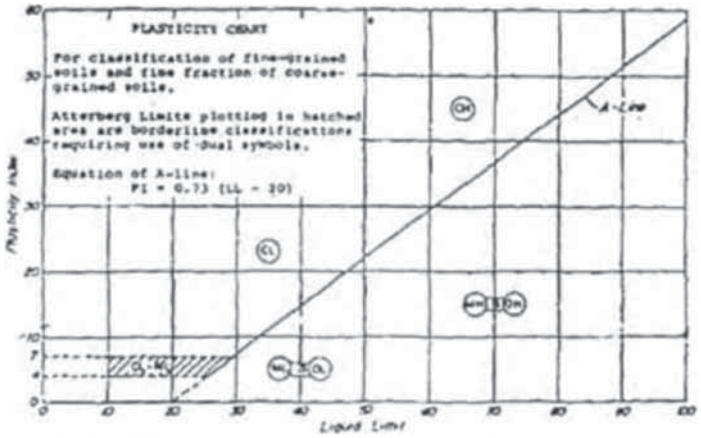


FIGURE 1 Plasticity Chart

The terms in the above chart are explained below:

GW - Well graded gravels and gravel-sand mixtures, little or no fines.

GP - Poorly graded gravels and gravel-sand mixtures, little or no fines.

GM - Silty gravels, gravel-sand-silt mixtures.

GC - Clayey gravels,gravel-sand-clay mixtures.

SW - Well-graded sands and gravelly sands, little or no fines.

SP - Poorly graded sands and gravelly sands, little or no fines.

SC - Clayey sands, sand-clay mixtures.

ML - Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.

CL - Inorganic clays of low to medium plasticity, gravelly clays, silty clays, lean clays.

OL - Organic silts and organic silty clays of low plasticity.

MH - Inorganic silts, micaceous or diatomaceous fine sands or silts, plastic silts.

CH - Inorganic clays or high plasticity fat clays.

OH - Organic clays of medium to high plasticity.

PT - Peat, muck and other highly organic soils.

The flow chart on the next page (Figure 2) describes how soils can be classified fully. Note that some borderline subgrade material are assigned a dual classification. Once the subgrade materials has been classified, Figure 3 can be used to assess the CBR and other relevant CBR information.

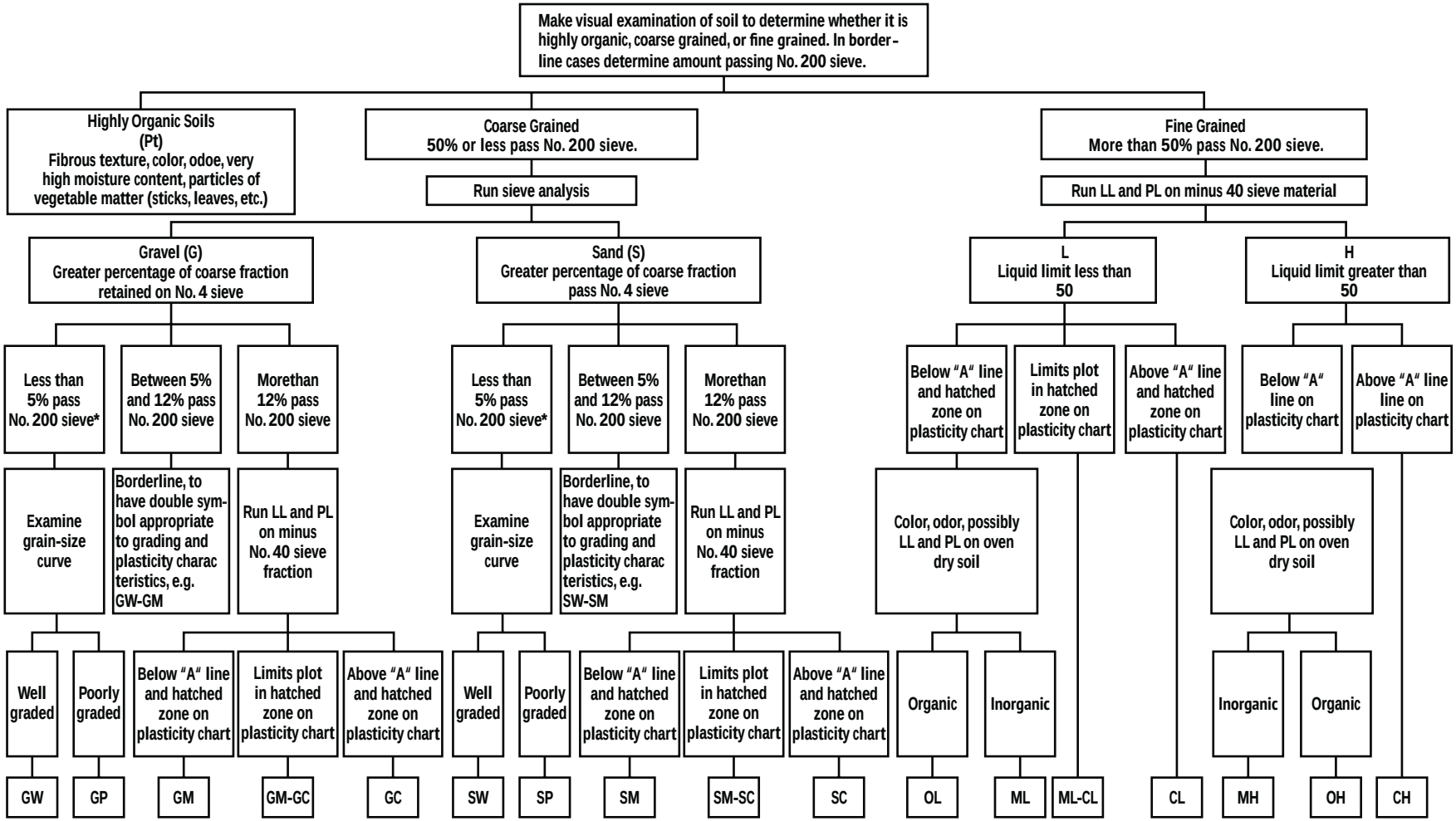
4.0 DESIGN CONSIDERATIONS

This paper covers pavement design for airports serving aircraft with gross weights of 30,000 pounds (13,000kg) or more. The design charts presented (Figures 4 to 12) are based on the California Bearing Ratio (CBR) method of design. Gear configurations are related using theoretical concepts as well as empirically developed data. The design curves provide the required total thickness of flexible pavement (concrete pavers, base and sub-base) needed to support a given weight of aircraft over a particular subgrade. The surfacing comprises

80mm thick concrete blocks
30mm sharp coarse

Minimum base course thicknesses are shown on a separate chart (Figure 13).

The determination' of pavement thickness is 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 paper have been developed through correlation of the data obtained from these sources. The experience at Luton International Airport is particularly inportant as it demonstrates the equivalence of concrete pavers to an equivalent thickness of asphalt.



Note: Sieve sizes are U.S. Standard.

* If fines interfere with free-draining properties use double symbol such as GW-GM, etc.

FIGURE 2 SOIL CLASIFICATIONS

Major (1)	Divisions (2)	Letter (3)	Name (4)	Value as Foundation When Not Subject to Front Action (5)	Value as Base Directly under Wearing Surface (6)	Potential Front Action (7)	Compressi-bility and Expansion (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight (pcf) (11)	Field CBR (12)
Coarse-grained soils	Gravel and gravelly soils	GW	Gravel or sandy gravel, well graded	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rub-ber-tired equipment, steel-wheeled roller	125-140	60-80
		GP	Gravel or sandy gravel, poorly graded	Good to excellent	Poor tn fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rub-ber-tired equipment, steel-wheeled roller	120-130	35-60
		GU	Gravel or sandy gravel, uniformly graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rub-ber-tired equipment	115-125	25-50
		GM	Silly gravel or silty sandy gravel	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller: close control of moisture	130-143	40-80
		GC	Clayey gravel or clayey sandy gravel	Good	Poor	Slight to medium	Slight	Poor to practi-cally impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40
	Sand and sandy soils	SW	Sand or gravelly sand, well graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rub-ber-tired equipment	110-130	20-40
		SP	Sand or gravelly sand, poorly graded	Fair to good	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rub-ber-tired equipment	105-120	15-25
		SU	Sand or gravelly sand, uniformly graded	Fair to good	Not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rub-ber-tired equipment	100-115	10-20
		SM	Silty sand or silty gravelly sand	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller: close control of moisture	120-135	20-40
		SC	Clayey sand or clayey gravelly sand	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practi-cally impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20
Fine-grained soils	Low compresai-bility LL < 50	ML	Silts, sandy silts, gravelly silts, or diatomaceous soils	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller: close control of moisture	100-125	5-13
		CL	Lean clays, sandy clays, or gravelly clays	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15
		OL	Organic silts or lean organic clays	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8
	High compresai-bility LL > 50	MH	Micaceous clays or diatomaceous soils	Poor	Not suitable	Medium to very high	Birth	Fair to poor	Rubber-tired equipment, sheepsfoot roller	80-100	4-8
		CH	Fat clays	Poor to very poor	Not suitable	Medium	Birth	Practically impervious	Rubber-tired equipment, sheepsfoot roller	90-110	3-5
		OH	Fat organic clays	Poor to very	Not suitable	Medium	Birth	Practically impervious	Rubier-tired equipment, sheepsfoot roller	80-105	3-5
Peat and other fibrous organic soils		Pt	Peat, humus, and other	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical		

FIGURE 3 CALIFORNIA BEARING RATIO (CBR) INFORMATION

Emery (References 1,13) undertook plate bearing tests on a bituminous surfaced aircraft pavement. After removing the asphalt concrete, he undertook plate bearing tests directly on the underlying basecourse. He then installed concrete pavers and undertook a third set of plate bearing tests. His reported results indicate a significant increase in strength when asphalt concrete was replaced by concrete pavers. In this paper, this increase is ignored so that the FAA curves can be used safely. In view of the empirical nature of the FAA curves, it would be very difficult to incorporate the additional structural benefit of pavers into the design system. Pavements designed in accordance with this method 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.

Experience in heavy duty concrete block pavements indicates that only minimal surface maintenance will be required during this period.

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 magnitudand character of the aircraft loads to be supported, the volume of the traffic, the concentration of traffic in certain areas and the quality of the subgrade soil and materials comprising the pavement structure.

5.0 MATERIALS

a) Concrete Pavers

In most parts of the world, standards have been developed for concrete pavers and these should be applied. Experience at Luton International Airport indicates that 3in (80mm) thick rectangular pavers are suitable for all categories of aircraft pavements.

b) Base Course

The base course is the principal structural component of a flexible pavement and has the major function of distributing the imposed wheel loads to the sub-base and the subgrade. Because concrete pavers cannot be assumed to be impervious, care has to be taken in basecourse selection and in general, stabilised materials will be required. In this paper, either cement treated or bituminous base courses are assumed. The detailed specifications for these materials should follow conventional aircraft pavement material specifications appropriate to the location of the pavement. In the United States, Reference 8, P-201 and P-304 apply.

c) Sub-Base

A sub-base should be included as an integral part of the pavement in all pavements except those on subgrades classified as GW or GP. Either a granular or a stabilised sub-base can be used and specifications normally used for highway or aircraft pavements are suitable. In the United States, Reference 8, item P-154 applies.

6.0 AIRCRAFT CONSIDERATIONS

The pavement design method is based on the gross weight of the aircraft. For design purposes the pavement should be designed for the maximum takeoff weight of the aircraft. The design procedure assumes 95% of the gross weight is carried by the main landing gears and 5% is carried by the nose gear. The maximum takeoff weight should be used in calculating the pavement thickness required. Use of the maximum 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.

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 pavement thickness 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;

a) Single Gear Aircraft. No special assumptions needed.

b) Dual Gear Aircraft. A study of the spacial between dual wheels for these aircraft indicated that a dimension of 20 inches (0.51m) between the centerline of the tires appeared reasonable for the lighter aircraft and a dimension of 34 inches (0.86m) between the centerline of the tires appeared reasonable for the heavier aircraft.

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

a) 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 (c) earlier. Owing to the large gross weights and gear separate design curves have been for the wide body aircraft.

Tire pressure varies between 75 and 200 psi (0.5 to 1.4 N/mm2) 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 (1.4 N/mm2) may be safely exceeded if other parameters are not exceeded.

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.

Since the traffic forecast is a mixture of a variety of aircraft having different land 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. The following conversion factors should be used to convert from one landing gear type to another.

To Convert From	to	Multiply Departures Bv
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:

$$\log R_1 = \log R_2 \times \left(\frac{W2}{W1}\right) 1/2$$

R_1 = equivalent annual departures of 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% 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 radically different landing gear assemblies 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 (136,100kg) 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.

7.0 STABILIZED SUB-BASE AND BABE EQUIVALENCY FACTORS

Stabilized sub-base courses offer some structural benefits to a flexible pavement. The benefits can be expressed in the form of equivalency factors which indicate the substitution thickness ratios applicable to various stabilized layers. The thickness of stabilized material can be computed by dividing the granular sub-base thickness requirement by the equivalency factor. The equivalency factor ranges are presented in Table 1 below.

Material	Equivalency Factor Rance
Bituminous Base Course	1.7-2.3
Cold Laid Bituminous Base Course	1.5-1.7
Mixed In-Place Base Course	1.5-1.7
Cement Treated Base Course	1.6-2.3
Soil Cement Base Course	1.5-2.0
Crushed Aggregate Base Course	1.4-2.0
Sub-Base Course	1.0

TABLE 1 Recommended Equivalency Factor Range Stabilized Sub-base

8.0 FOR AIRCRAFT PAVEMENTS

As well as ensuring that the pavement can withstand the applied loads, consideration must be given to the surfaces of the pavements. Experience at Luton International Airport has shown that in addition to the contribution the pavers make to the strength of the pavement, they provide a surfacing that satisfies the requirements identified below.

a) Durability

Aircraft pavements must have long lasting and hard wearing surfaces because of the abnormally heavy loads which they are required to carry and because of the difficulty in gaining access to these surfaces for maintenance purposes. Experimental work by (Clark, 1980) has shown that strength, by itself, is not an ideal means of predicting durability. Durability is considered more likely if the cement content of the concrete used in manufacturing pavers does not fall below 380 kg/m3 (750 lb/yd3).

b) Strength

The high compressive strength of concrete pavers, (generally in excess of 60 MN/m2 (7000 lb/in2) compared with the 35 MN/m2 (5000 l±>/in2) specified for pavement quality concrete) bedded on coarse sand that is confined at its edges and compacted to refusal, is thought to provide a surface of greater immediate strength than either asphalt concrete or pavement quality concrete.

c) Surface Stability

Modem jet aircraft are susceptible to damage from loose material drawn into engine intakes. It is essential, therefore, that any surface remains coherent and does not produce potentially damaging debris. Pavement quality concrete slabs are prone to spalling, especially along joint edges, and have led to engine ingestion problems. It is thought that concrete pavers with chamfered edges and uniform joint spacing will reduce the probability of this situation developing to unacceptable levels.

d) Good Frictional Characteristics

The frictional characteristics of the runway are measured by means of a 'mu-meter', a machine fitted with a self-wetting attachment capable of depositing a 0.5mm (1/5 in) depth of water beneath the measuring wheels. The device is towed at a steady speed of 130 km/hr (80 m.p.h.). Owing to the relatively small areas involved, it was not possible to carry out these tests. However, it is considered that the concrete pavers should provide excellent frictional resistance, similar to traditional surfacings used.

e) Good Standard of Rideability

This criterion is not considered essential for apron areas and runway turning areas, which are generally subjected to slow moving traffic only. The standard tolerance of 3 mm (1/8 in) under a 3 m (10 ft) straight edge is thought unnecessary and indeed would be difficult to achieve with concrete pavers though not inpossible. Little is known about the performance of aircraft at high spee speed on concrete pavers, and this would provide an interesting topic for future research.

f) Rapid Removal of Surface Water

Experience with concrete pavers at Luton International Airport has shown that rectangular pavers with chamfered edges are capable of rapid removal of surface water and are considered to be as good as, if not better than, the existing bitumen surfacing, in the removal of surface water. Observations have shown that after wetting, concrete pavers dry faster than asphalt surfaces.

Experience has shown (Clark, 1979) that the joints in concrete pavers eventually become 'sealed' with detritus, oil, etc., so reducing the ingress of water into the laying course sand. However the addition of bentonite to the jointing sand provides an immediate means of sealing joints. This has been established at Luton.

g) Capability of Rapid Repair

The use of concrete pavers has one major advantage over traditional surfacings for aircraft pavements. It can be rapidly laid and repaired even in sub-zero temperatures. Once laid and compacted it can be put into immediate use.

h) Resistance to Thermal Movements

Differential thermal movements in the underlying pavement quality concrete appear not to have produced any visible movement in the concrete pavers. This is due to the fact that the pavers act as a flexible surface and individual pavers articulate without significant opening of the joints. Another advantage of concrete pavers is their lighter colour, which reduces the amount of heat absorbed into the underlying concrete, so reducing thermal movement.

i) Resistance to Jet Engine Exhaust Velocities and Thermal Shock

Concrete is generally preferred where jet efflux gases are likely to induce thermal shock to pavement surfaces. On take-off, the exhaust velocities from the jet engines of conroercial aircraft can be in the order of

160 km/hour (100 m.p.h.). Temperatures of approximately 100 degrees C. can occur where the jet efflux impinges on the pavement surface approximately 10 m (30 ft) beyond the rear of the aircraft. Tests carried out on concrete pavers by British Aerospace PLC (1985) during investigations to the feasibility of landing vertical take-off military aircraft (Harriers) on various surfaces have shown that concrete pavers are capable of withstanding temperatures of up to 520 degrees C.

The high exhaust velocities from jet aircraft can cause some loss of jointing sand. Experience at Luton Airport has shown that this is generally confined to the top 1/2 in (10 mm) of the joints and is not considered to affect the integrity of the concrete pavers. Nonetheless, for areas subjected to high jet exhaust velocities, it as recommended that liquid polymer is applied to the surface of the pavers and allowed to penetrate the jointing sand. Trials are in progress at Luton to assess the performance of various polymers and to determine their cost of application. Some information on these trials is given in Emery (1987).

j) Resistance to De-icing and Anti-icing Chemicals Avaiation Fuels and Hydraulic Oils

Aircraft pavements, perhaps more than any others must be capable of surviving an exceptionally harsh environment. Runways in particular are generally located in exposed areas and are subject to low temperatures, down to say -30 degree C.

At Luton International Airport, urea is used as an anti-icing agent, and glycol mixtures are used for de-icing purposes. These two materials have been known to have a damaging effect upon concrete, owing to the very rapid cooling effect within the surface of the pavement, which can freeze any moisture present. An immediate volume increase of approximately 9% in the interstices holding moisture can lead to an almost immediate disintegration of some concrete surfaces.

The UK Canent and Concrete Association have carried out a series of tests on concrete pavers to measure their freeze-thaw resistance when urea and glycol mixtures are used. The test method adopted was the freeze thaw (RILEM 1977).

Basically, this consists of subjecting sample pavers to 25 freeze-thaw cycles between the temperature range of -18 degrees C. and + 20 degrees C. and treasuring the loss of mass per unit area. Tests so far carried out indicate that the weight loss, when urea is used is less than that found with a 3% salt solution and would not lead to ingestion of small pieces of surface aggregate into aircraft jet engines.

Portland canent concrete has generally been found to be resistant to aviation fuels and hydraulic oils, but these fluids have been found to have a deleterious effect on joint sealing compounds, even on those which are claimed to be resistant to these materials. This danger is averted by using concrete pavers, which do not require the use of expansion joints.

Fears of concentration of aviation fuel accumulating in the sand layer under the pavers appear to be unfounded. Tests carried out under the supervision of the County Petroleum Officer indicated that no explosive vapours are present when sample pavers are removed from an area heavily contaminated with aviation fuel.

9.0 USE OF DESIGN CHARTS

Firstly select one of the following 9 design charts according to the aircraft gear configuration (Figure 4 to 12). On each chart, start with the subgrade CBR on the upper horizontal axis. From this position, project a line down to the appropriate gross aircraft weight curve. From here, project a line horizontally to the appropriate annual departures line. Finally project a line down to the lower horizontal axis and read off the total thickness of the pavement.

This thickness is then used in Figure 13 to determine the base thickness. Figure 13 is used by starting with the total pavement thickness on the left vertical axis. Project a line horizontally to meet the appropriate subgrade CBR curve. Fran this point, project a line vertically up or down and read off the base thickness.

By subtracting the base thickness and the concrete paver and sand thickness (4 1/2 in or 110mm) from the total thickness, the sub-base thickness can be determined. This is the thickness required for a granular sub-base. For a stabilised sub-base, reduce the thickness by dividing by the factors in Table 1.

10.0 DESIGN EXAMPLE

Assume an airport pavement is to be designed for the following mix of aircraft;

Aircraft	Type	Annual Departure	Maximum Takeoff Weight (lb)
727-200	dual	3000	190,500
737-200	dual	1200	115,500
747-100	double dual tandem	1200	600,000

Subgrade CBR - 6%

First, the design aircraft has to be determined. This is the one requiring the thickest pavement for the appropriate number of departures of the aircraft. Using the design charts, the following overall pavement thicknesses are required:

Aircraft	Annual Departures	Overall Pavement Thickness (in)
727-200	3000	36 (Fig 5)
737-200	1200	24 (Fig 5)
747-100	1200	35 (Fig 7)

The 727-200 requires the greatest pavement thickness and is therefore the design aircraft. This aircraft has dual wheel landing gear so all traffic must be grouped into the dual wheel configuration. The equivalent number of annual departures is calculated as follows:

Aircraft	Equivalent Dual Gear Departures	Wheel (lb)	Design Wheel Load (lb)	Equivalent Annual Departures Design Aircraft
727-200	3000	45,240	45,240	3000
737-200	1200	27,430	45,240	250
747-100	2040	35/625	45,240	365
			Total	4115

The dual wheel gear design chart, Figure 5 shows that the total pavement thickness required is 37in. Fran the base thickness design chart, Figure 13, the minimum base course thickness is 12in. Therefore, the pavement section required is;

3 l/4in. (80mm) pavers
1 l/4in. (30mm) sharp sand
12in. base
20 l/2in. granular sub-base

Alternatively, the sub-base could be replaced with a stabilised material, if a soil cement sub-base course were used, the factor by which sub-base thickness should be divided is shown as 1.5 to 2.0 (say 1.7) in Table 1. Therefore, the following alternative pavement could be provided:

3 l/2in. (80mm) pavers
1 l/4in. (30mm) sharp sand
12in. base
12in. soil cement sub-base

REFERENCES

1) EMERY J.A. (1986) "The Use Of Concrete Blocks For Aircraft Pavements" Proc ICE 80 451-464

2) KNAPTON J. (1976) "The Design Of Concrete Block Roads" Cement and Concrete Association, Wexham Springs, UK. Technical Report No. TRA42.515

3) LILLEY A.A & KNAPTON J. (1976) "Concrete Block. Paving for Roads" Cement and and Concrete Association, Wexham Springs, UK. Technical Report No. 46.021

4) KNAPTON J & MAVIN K.C. (1987) "Clay Segemental Pavements - A Design and Construction Guide" The Brick Development Research Institute, Carlton, South Victoria, Australia.

5) ROLLINGS R.S. (1984) "Corps Of Engineers Design method For Concrete Block Pavement" Proc. 2nd International Conference Concrete Block Paving, Delft, Pp 147-151

6) KNAPTON J. (1982) "The Structural Design of Heavy Duty Pavements for Ports and Other Industries" British Ports Association, London.

7) FEDERAL AVIATION ADMINISTRATIS (1978) "Advisory Circular Airport Pavement Design and Evaluation" Department of Transportation, Washington, D.C.

8) FEDERAL AVIATION ADMINISTRATION AND CORPS OF ENGINEERS (1977) Standards for Specifying Construction of Airports. AC No. 150/5370-10 Department of Transporta tion Washington D.C.

9) CLARK, A.J. (1980) "Freeze-Thaw Durability Tests Upon Concrete Block Speciments". First International Conference on Concrete Block Paving, Newcastle Upon Tyne.

10) CLARK A.J. (1979) "Water Penetration Through Newly Laid Concrete Block Pavements" Technical Report No. 529, Cement and Concrete Associates, Wexham Springs, Slough, UK.

11) FEDERAL AVIATION ADMINISTRATION AND CORPS OF ENGINEERS (1977) "Airport Pavement Design and Evaluation", Advisory-Circular AC 150/5320-6C, includes design charts and technical aircraft footprint data.

12) RILEM (1977) "Methods of Carrying Out and Reporting Freeze-Thaw Test on Concrete with De-icing Chemicals" International Union of Testing and Research Laboratories for Materials and Structures (RILEM) Recommendation CDC2.

13) MERY J.A.(1987) "A Evaluation of the Performance of Concrete Blocks on Aircraft Pavements at Luton Airport". Proc. 3rd International Conference on Concrete Block Paving, University of Rome.

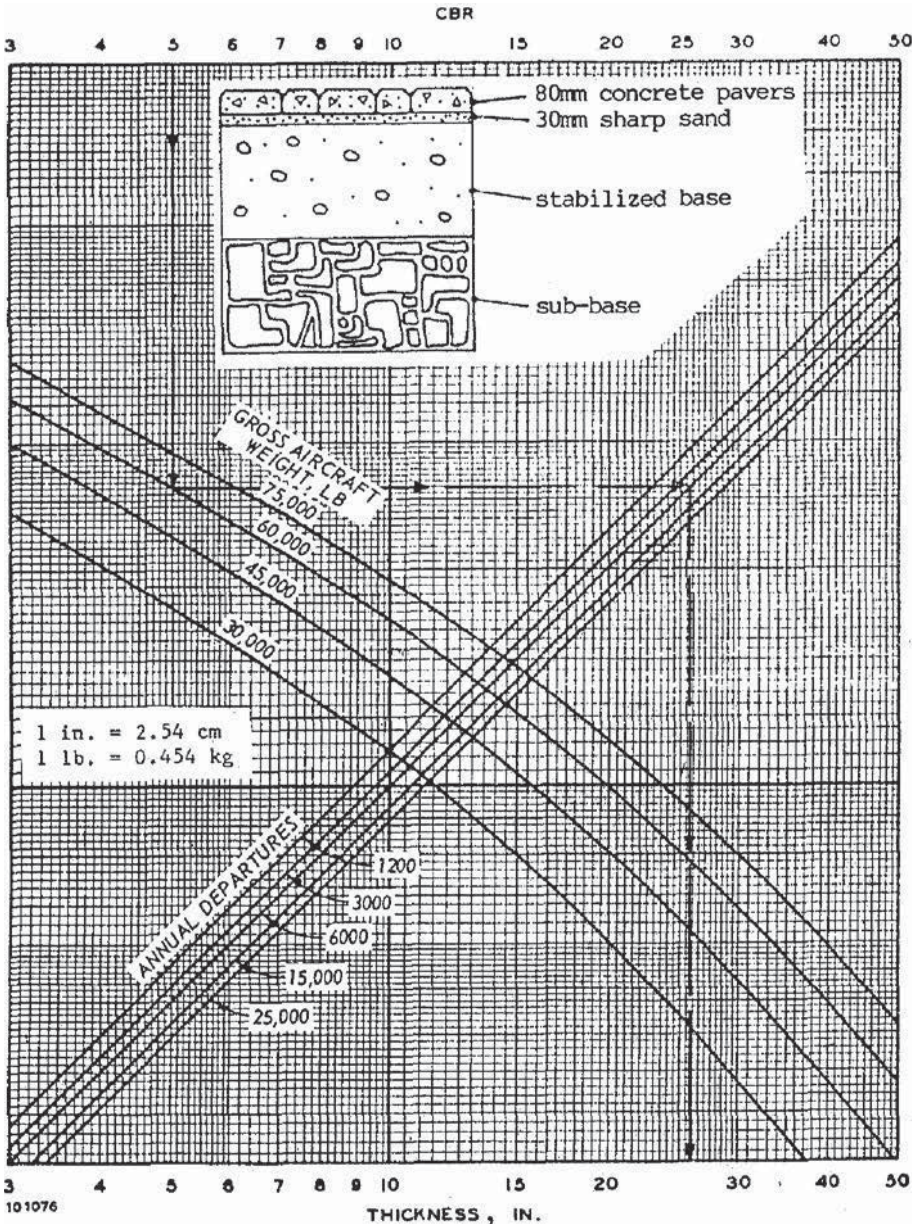


FIGURE 4 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, SINGLE WHEEL GEAR

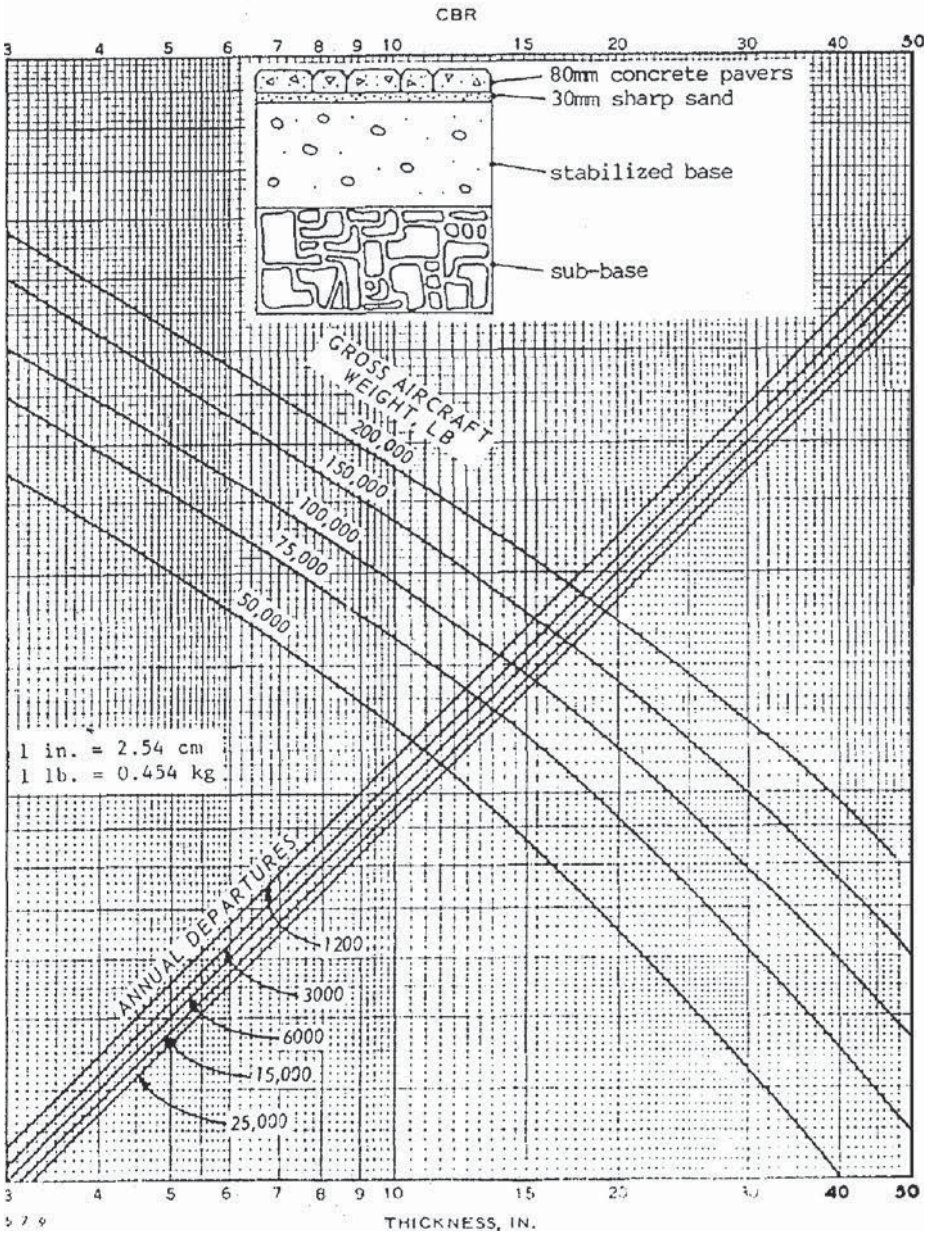


FIGURE 5 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, DUAL WHEEL GEAR

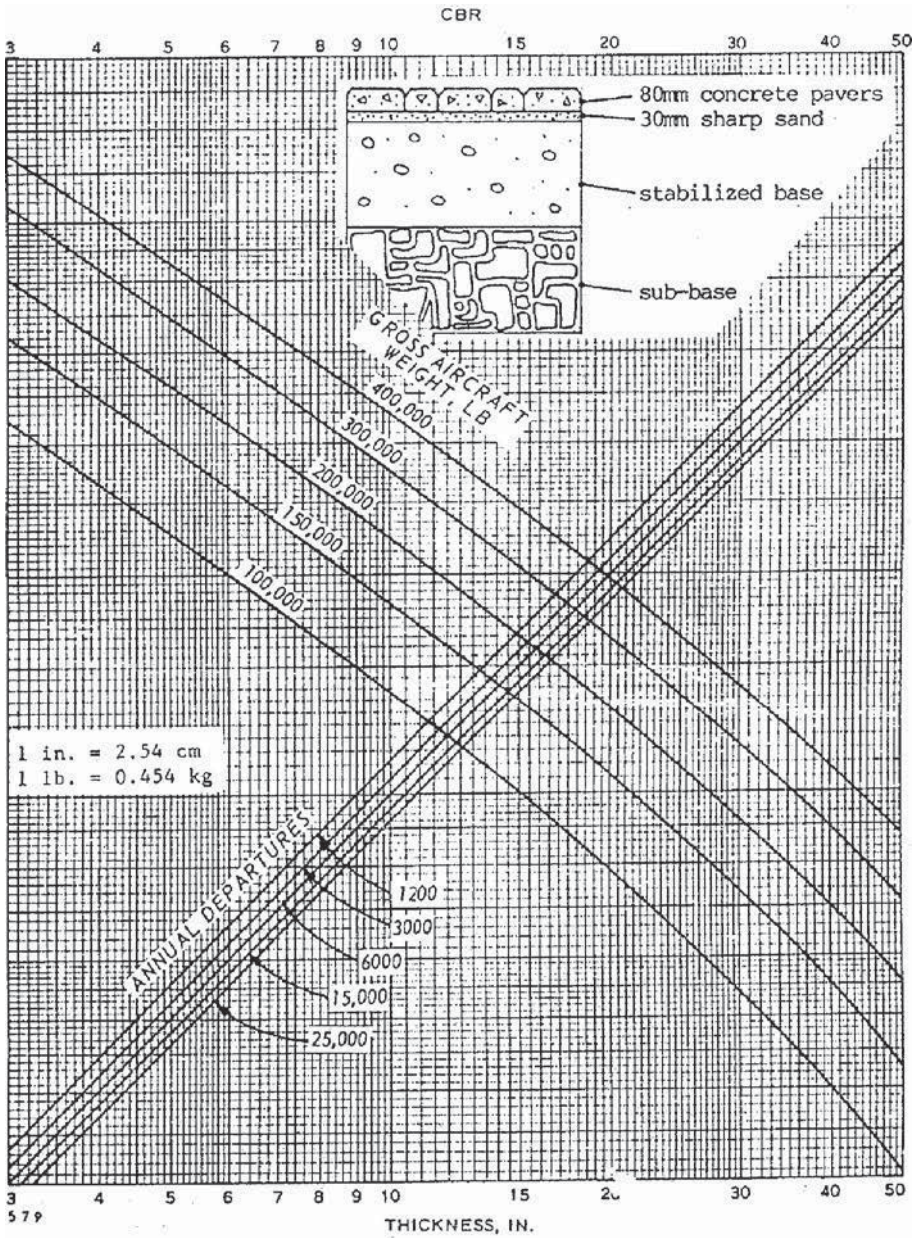


FIGURE 6 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, DUAL TANDEM GEAR

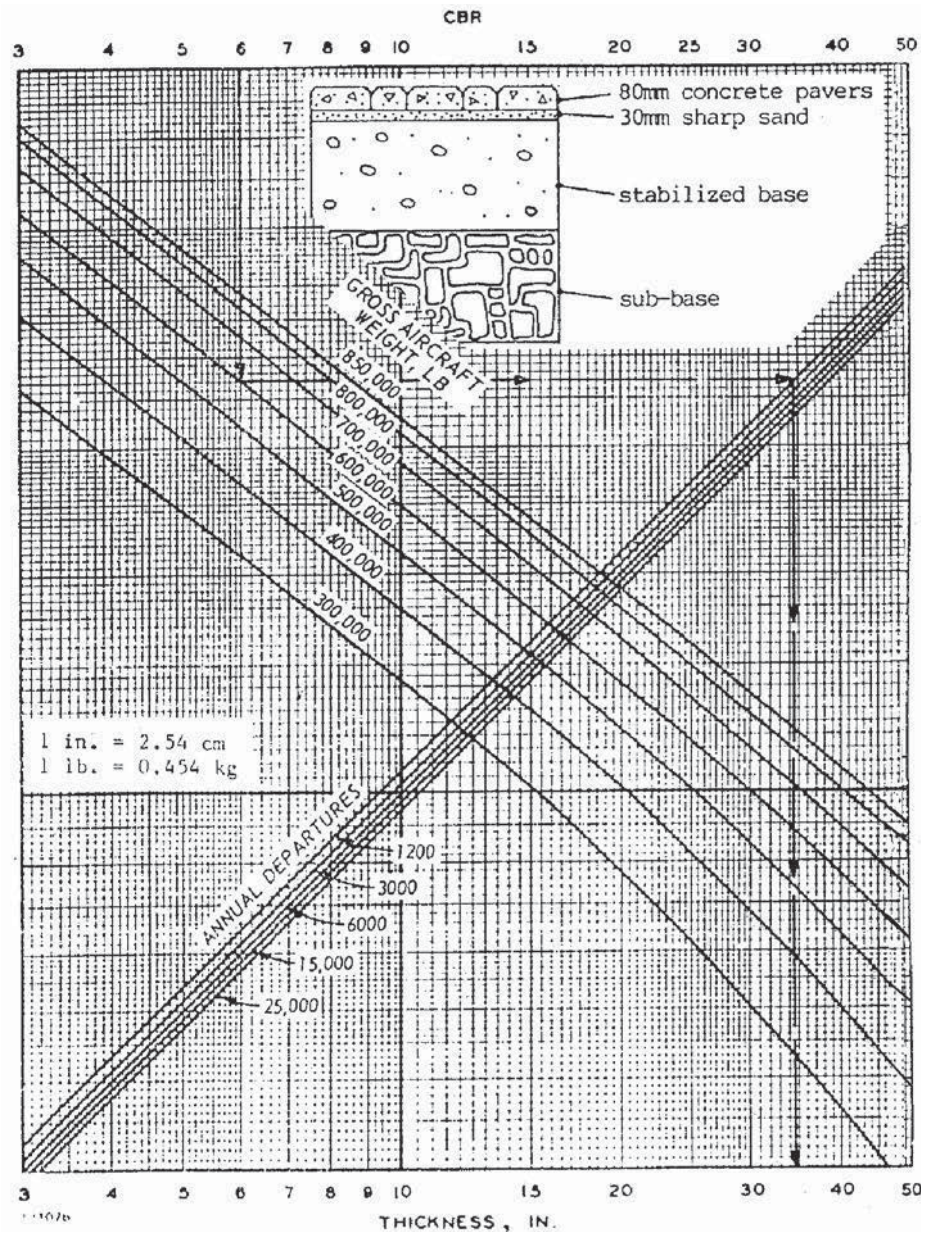


FIGURE 7 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, B-747-100, SR, 200 B, C, F

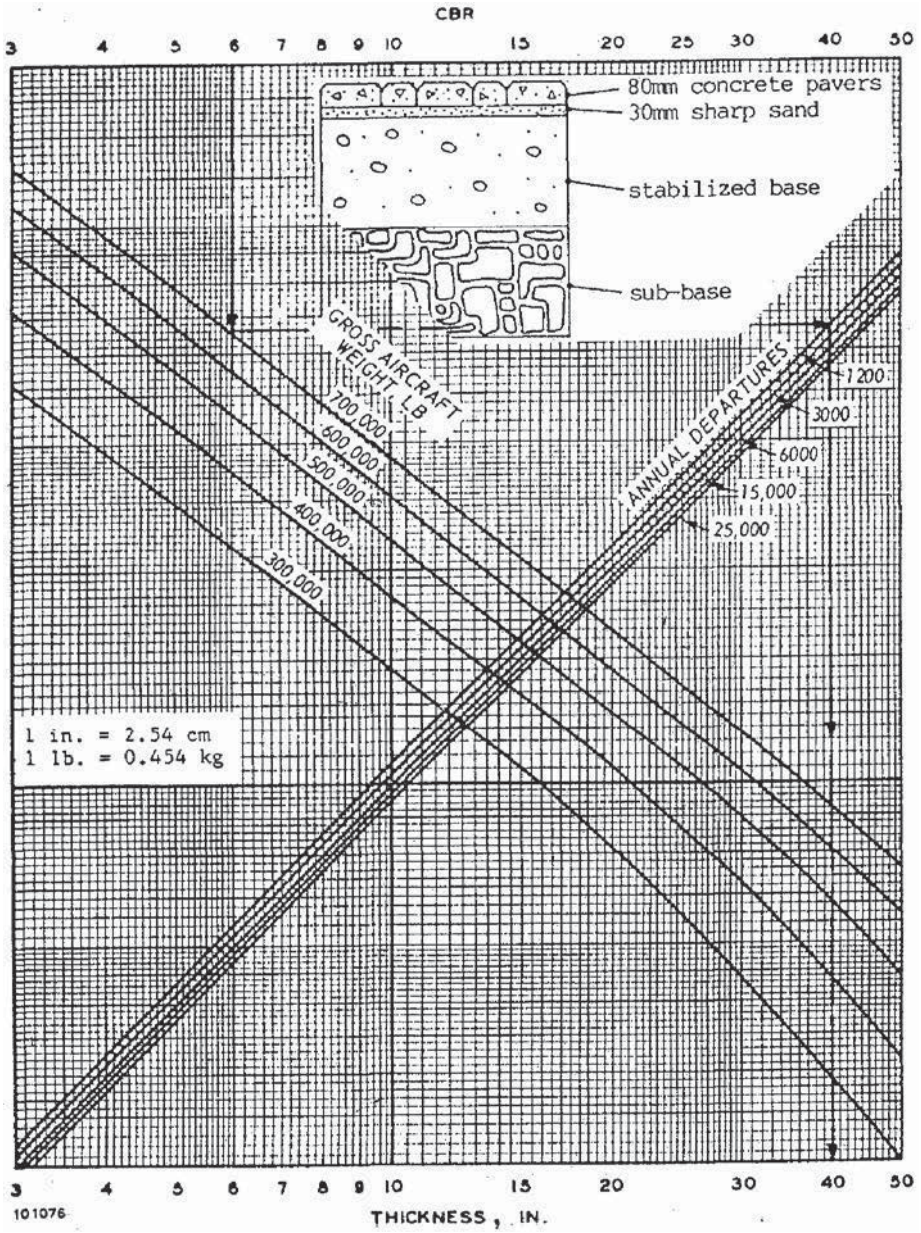


FIGURE 8 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, B-747-SP

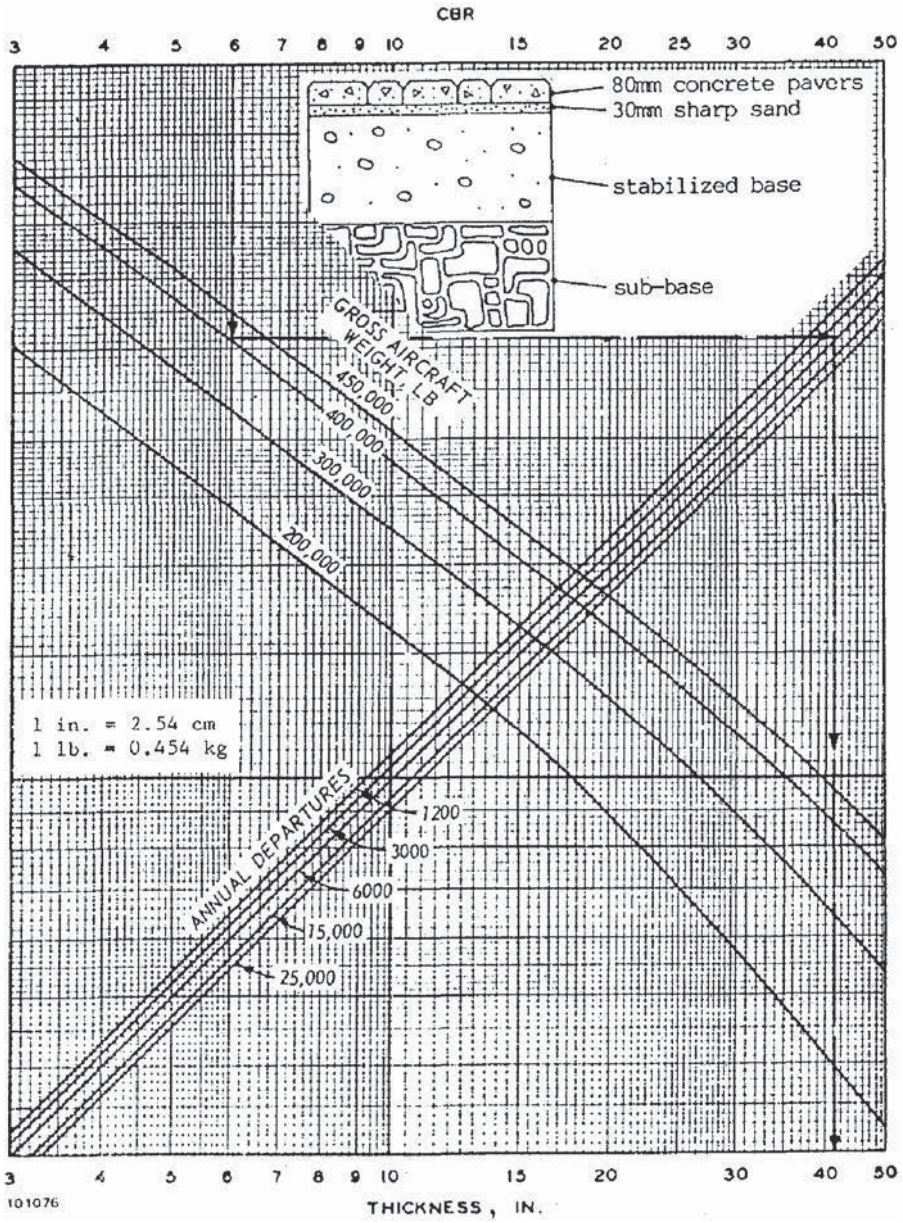


FIGURE 9 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, DC 10-10, 10CF

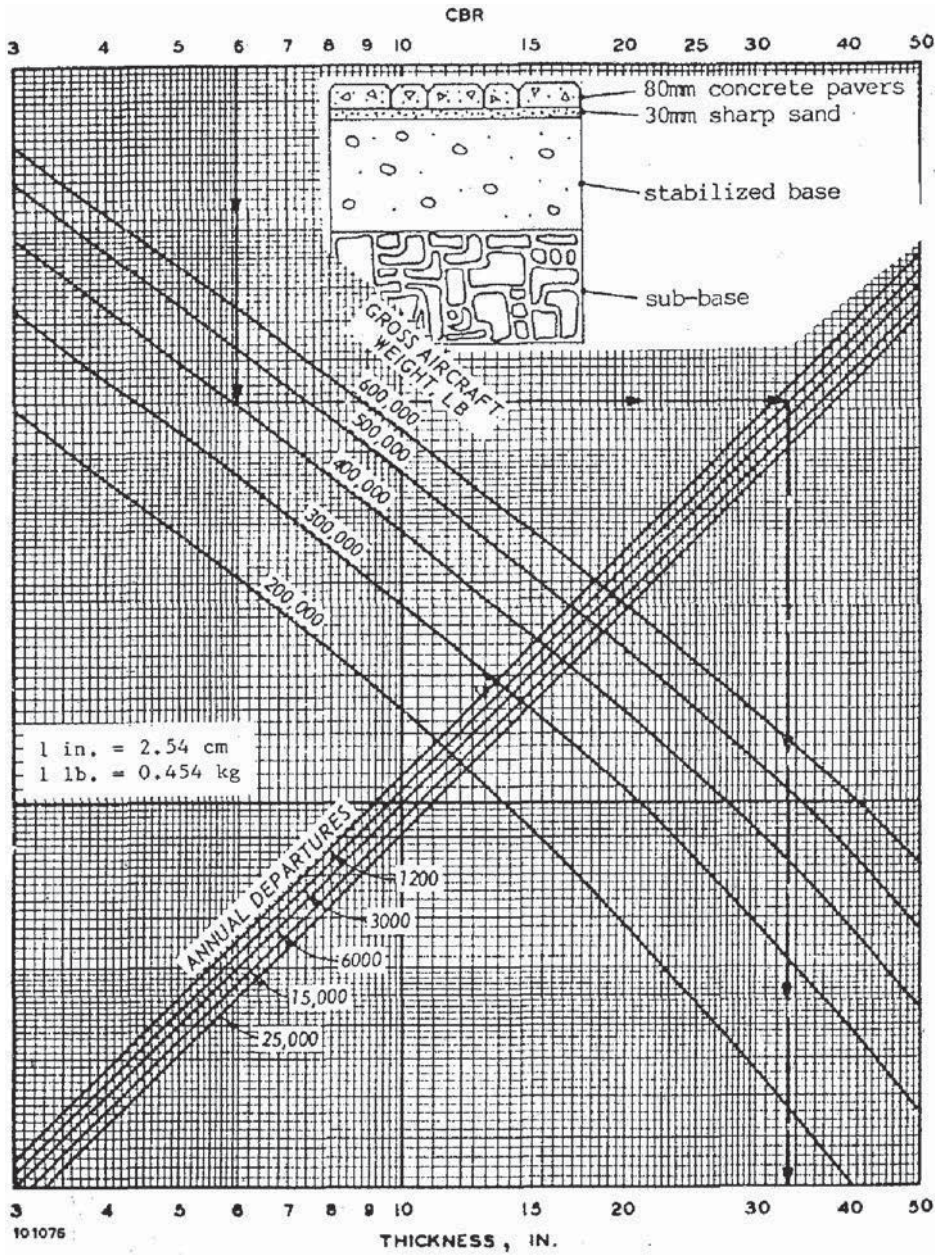


FIGURE 10 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, DC 10-30, 30CF, 40, 40CF

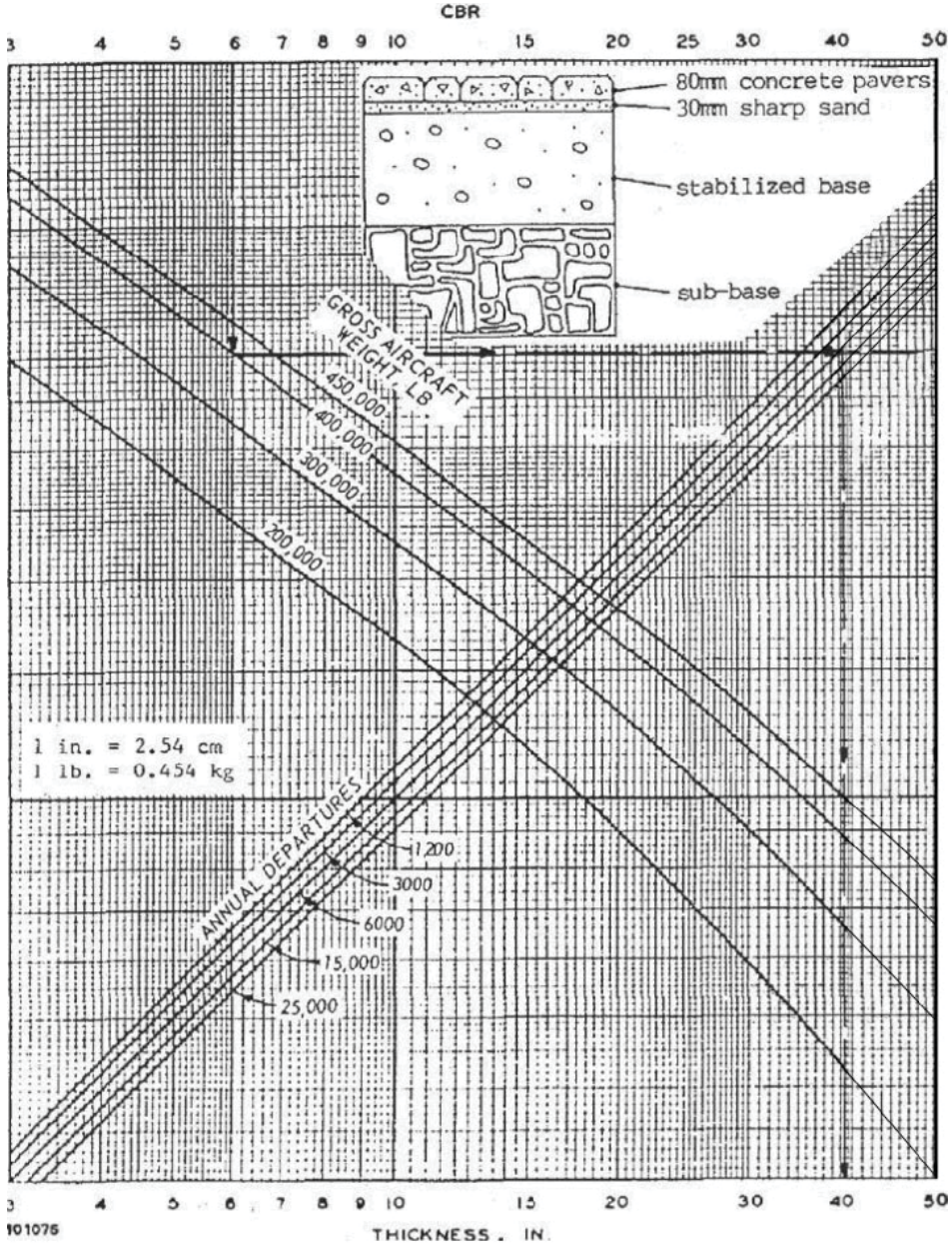


FIGURE 11 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS L-1011-1, 100

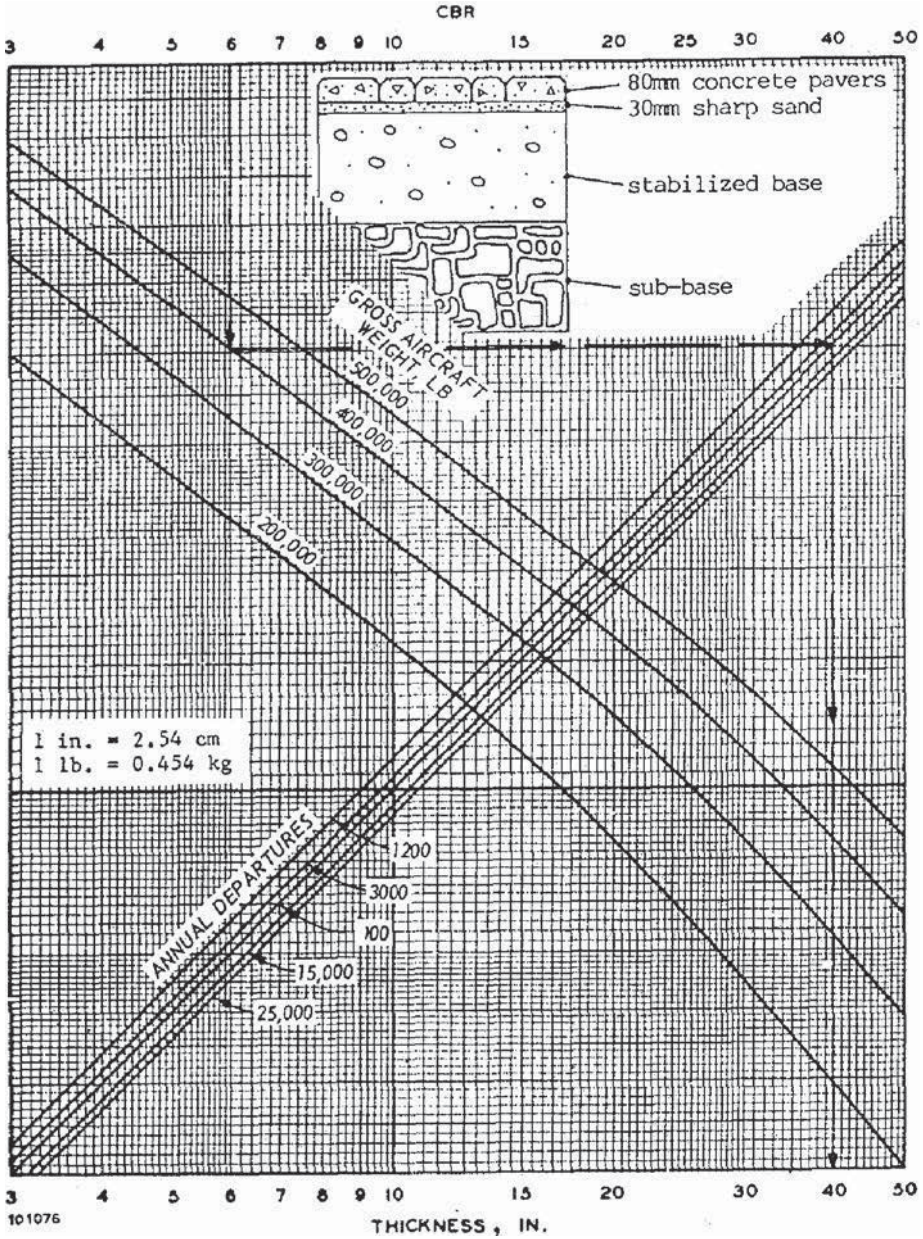


FIGURE 12 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, L-1011-100, 200

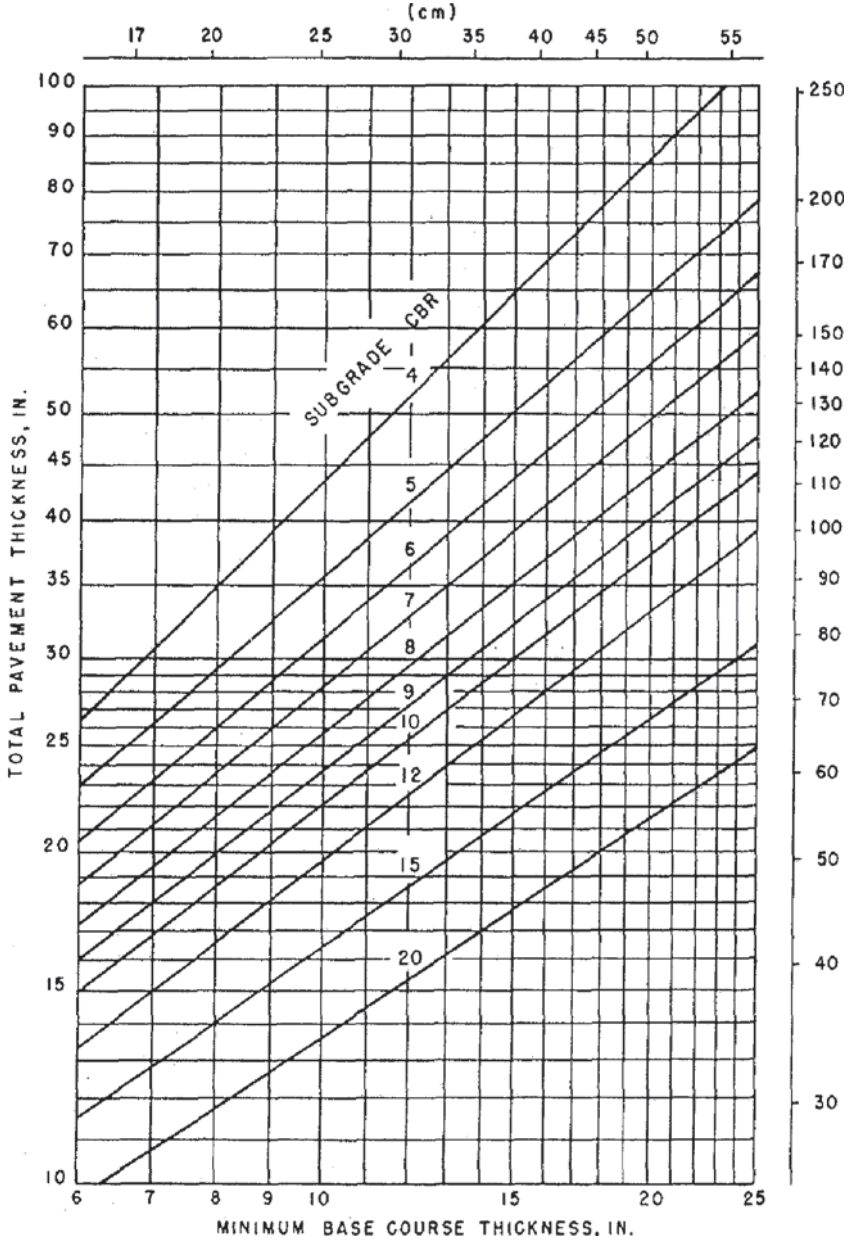


FIGURE 13 MINIMUM BASE COURSE THICKNESS REQUIREMENTS