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STRENGTH OF RUNWAYS

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INTRODUCTION

During the Fifth Session of the Aerodromes, Air Routes and Ground Aids Division, one day of the meeting (30 October 1952) was devoted to Agenda Item 6.2 - Exchange of technical views on "Strength of Runways".

In accordance with Recommendation No. 6 of the Division, which was approved by the Council of ICAO, the following summary of the discussions has been prepared.

The opinions expressed represent the views of the speakers and are not necessarily those of their States or Organizations.

Note. - See also ICAO Circular 25-AN/22 "Runway design methods for Multiple-Wheel Landing Gears".

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CONDUCT OF THE MEETING

The meeting was convened under the chairmanship of Dr. K.N.E. Bradfield of Australia, who called first on M. G.S. Cooper of the United Kingdom to present a paper (AGA V-WP/27). This paper is reproduced in pages 5-12 of this Circular. Dr. F.L. Meara of the United States next addressed the meeting and his statement was published later as AGA V-WP/44 and is reproduced in pages 13-27. Dr. N. McLeod of Canada did not come prepared to make a statement but kindly consented to do so. A summary of his address is given in pages 28-29.

The Chairman then opened the meeting for discussion. General considerations applicable to both flexible and rigid pavements were taken first. A summary is given in pages 30-34. This was followed by a more detailed discussion of Flexible Pavements, summarized in pages 34-36 and of Rigid Pavements, summarized in pages 37-40.

UNITED KINGDOM METHODS

(Presented by Mr. G.S. Cooper)

DESIGN AND CONSTRUCTION

Introduction

Types of Pavement. - It is British practice to build aerodrome pavements either in flexible or in rigid construction. Flexible pavements consist of layers of granular material built up from the natural subgrade, being finally provided with a bitumen-bound wearing coat or coats. It may be of considerable thickness and depends on the load spreading effect to reduce the load from the aircraft wheels sufficiently to make it acceptable on the natural surface. Rigid pavements consist of concrete slabs laid on the natural subgrade after the latter has been prepared to receive the concrete. It depends on the capacity of the concrete to act as a raft to carry the load and spread it over the actual soil on which it rests. Recently, a method of construction has been developed in which concrete is laid as for a rigid pavement, and this is then surfaced (or overlaid) with bitumen or tar bound base and wearing coats. In some cases a cushion course of granular material is laid between the concrete and the surfacing. Sometimes a two-layered system of concrete construction is used.

Choice of Type of Construction. - A number of factors have to be considered when deciding whether to adopt flexible or rigid construction. Generally, a flexible pavement is the more suitable on a granular subgrade such as sand or gravel and a rigid pavement is the more suitable on clay, particularly where the latter is susceptible to considerable moisture movement. In some cases where it is not at once apparent that one or other form of construction is preferable, alternative designs are prepared before a decision is reached. Economic considerations and the availability of suitable materials may considerably influence the decision. The following design methods have been adopted both for military and civil aerodromes in the United Kingdom.

Flexible Pavements

CBR Design System. - The CBR (or California Bearing Ratio) method of design, an empirical system based on experience and developed by the United States Corps of Engineers, is used in British practice with one or two detailed modifications. The CBR is a strength index figure which can be obtained for a particular soil on which the pavement is to be built by performing CBR tests. In the test the resistance given by the soil to the entry of a plunger is measured to give the CBR value. When the CBR value for the soil is known, the thickness of pavement construction required is read off directly from the Corps of Engineers design curves, which are available for single wheel loads at 100 and 200 p.s.i., and for dual and twin-tandem assemblies employing tires with constant contact areas.

British Modifications

Subgrade Moisture Conditions. - The Corps of Engineers design method recommends that the CBR value on which the design is based should be that which obtains when the soil is in a saturated condition. British practice is to estimate the "equilibrium" moisture conditions which will obtain in the subgrade after the pavement has been constructed, and to measure the CBR value of soil samples, compacted at that moisture content, for use as the basis for design.

Tire pressure. - The single wheel design curves for a tire pressure of 100 p.s.i. only are used in British practice. The reason for this is that the British loading criteria for design is expressed in terms of a Load Classification Number (LCN), which represents a combination of wheel load and tire pressure. The corresponding wheel load for the given LCN at a tire pressure of 100 p.s.i. is obtained from the LCN chart (Figure 1), and this is applied to the 100 p.s.i. CBR design curves. As an example, the design LCN might be 65. Figure 1 shows that the wheel load for a tire pressure of 100 p.s.i. is 66 000 lbs. and this figure is applied to the 100 p.s.i. single wheel load CBR design curves.

Rigid Pavements

Westergaard's Theories. - Basically, the theories of concrete pavement design developed by H.M. Westergaard are used in British practice. In the design method, the LCN figure to be used is converted to the load on a 12" diameter contact circle (using Figure 1). With this loading criterion, and knowing the strength of the subgrade, a suitable thickness of concrete is selected and the resulting concrete stress calculated. This stress is the minimum strength to be achieved by the concrete at a certain age, which it must have reached before the pavement is opened to traffic. From this figure the required minimum 28-day strength is calculated, and the concrete mix is designed which, allowing for all possible variations, will not give a strength less than the minimum required. No factor of safety is allowed in runways, but for runway ends and taxiways a factor of 1.25 is included. However, in the runways, the average strength is about 30 per cent more than the minimum strength on account of the allowance made for variation in concrete quality. In addition, as in British practice a load-transfer device is not used to connect the slabs, the design is based upon preventing corner cracking and full allowance is made for stresses caused by temperature. As a result a pavement may have an actual strength as much as twice its design strength when weather conditions are favourable.

Surfaced Rigid Pavements. - In the design of surfaced rigid pavements, i.e., pavements in which the concrete is covered with a bitumen-bound wearing coat, it is assumed that the additional stresses caused by temperature in the concrete slab are reduced or entirely eliminated, depending on the thickness of the surfacing. Also, a small relief of stress is obtained through the load-spreading effects of the surfacing thickness. In general, it is assumed that surfacings of 6" and over in thickness eliminate temperature stressing entirely. This method leads to more economical design, since the strength of the concrete slab is almost doubled by the elimination of temperature stressing. Further, the advantages gained from the better running surface and positive waterproofing, given by the bitumen-bound wearing coat, will at once be apparent.

Double Slab Construction. - Sometimes, on a very bad site, it is necessary to provide a working course of dry lean-mix concrete, compacted by rolling. This can be regarded as a structural slab in a two-layered system, and its load-bearing capacity is considerable on account of the insulation from temperature effects given to it by the upper or surface slab. Joints in the upper and lower slabs are staggered so that all major stressing in the lower slab is central, and the design of the whole is done by applying Westergaard's theories to a consideration of the deflection of both slabs at and under the corners of the top slab. The design system is of particular value where surfaced construction is unsuitable in areas which may be subjected to fuel spillage from jet aircraft, and where the depth of concrete required for a single slab is too great for satisfactory and economical construction.

EVALUATION

Introduction

In Great Britain, it is the practice to test and evaluate all aerodrome pavements after construction. This is considered essential to prove that the design strength has been achieved, and also to benefit from any additional strength which may lie in the pavements over and above the design strength. The specification calls for certain minimum standards to be maintained; it almost invariably happens that these standards are improved upon in construction. Evaluation by "reverse design" methods is considered to be neither accurate nor desirable, and reliable evaluation can only be achieved by performing physical tests on the pavements themselves.

Testing

General Principle. - For testing, loads are applied to the pavements by means of a rigid steel plate, 26" diameter. Different techniques, as will be discussed later, are used for different types of pavements. The reason for the adoption of a plate of this size was that, at the time testing was introduced, it represented the contact area of the single wheel employed on the majority of large four-engined aircraft in operation. The standard testing machine is capable of applying loads of up to 80 000 lbs.: a special large machine can apply loads of up to 200 000 lbs.

Flexible Pavements. - In testing flexible pavements, a number of spots are selected on which to perform the tests. So far as is possible, the areas known to be the weakest parts of the pavements as a whole are chosen so that the results will give the minimum strength figure. Repetitive loading tests are carried out; five repetitions of each of several loads up to a selected maximum. The deflection and residual settlement under each application of load is noted. The results are then plotted so that a figure can be obtained for the load which will result in a settlement of 0.2" after 1 000 repetitions in the case of runways, and 10 000 repetitions in the case of taxiways. Allowance is made for settlement caused by the first application of load, which represents initial compaction. From the various loading figures obtained, a figure is selected to represent the ruling load on a 26" diameter plate.

Rigid Pavements. - In testing rigid pavements, the actual load on a 26" plate which causes cracking is measured, and a ruling load figure selected.

Evaluation

Flexible Pavements. - The ruling load on a 26" plate, as obtained from the tests, is examined and adjusted to allow for the time of year, and weather and temperature conditions obtaining, when the testing was performed. When the final figure is determined, the corresponding load classification number is obtained from the chart shown in Figure 1.

Rigid Pavements. - As in the case of flexible pavements, a final figure is determined for rigid pavements after making allowance for temperature conditions, etc. The latter have a particularly marked effect on rigid pavements and, where the testing is performed in midday heat in summer, the measured failure load may be as much as twice as great as the minimum load which will cause failure under adverse conditions. For runways the final selected figure is used to give the Load Classification Number; for taxiways it is reduced by applying a factor of 1.25 to allow for the additional fatigue effects. In the case of surfaced or overlayed rigid pavements the allowance to be made for temperature effects is considerably reduced and may be eliminated entirely when the overlay thickness is 6" or over in thickness.

The Load Classification Number System

Secretariat Note. - This system was described fully in AGA V-WP/9 which has been revised by the United Kingdom and circulated to States, under cover of letter AN 4/5-604 dated 27 May 1953, for comment. The paper has not therefore been reproduced in this Circular except for Figure which is a copy of Figure 3 of the paper.

Introduction. - Reference has been made several times in this paper to Load Classification Numbers. The Load Classification Number System is the standard British method used in defining airfield loading capacities, both for military and civil use. It is also used by military organizations on the Continent of Europe. It is described in part 4.3 of ICAO Circular 25-AN/22, though it should be noted here that Load Classification Numbers are non-dimensional and so the reference to metric units in part 4.3.1.1 is incorrect. Similarly, in Figure 16 of the same publication, no units should be shown against the central line and the figures on the right hand side of the central line should be ignored.

Principle. - A large number of plate bearing tests carried out in the British Isles with plates of different sizes have shown that a mathematical relationship exists between permissible load and plate size. A wheel-load/tire pressure equation has been developed based on the results of many tests. Accordingly, if a pair of figures for which load and tire pressure are known to represent the safe loading on a particular pavement the various combinations of wheel-load and tire pressure which will also be safe may be determined by applying the equation. A numbering system was developed to give a yard-stick of LCN values combining the two variables of wheel load and tire pressure; this resembles closely the table in Part 7 of Attachment B to Annex 14 to the Convention. For example, Code No. 1 is exactly LCN 100, No. 3 is LCN 60 and No. 5 is LCN 30. From the testing and evaluation of a pavement the LCN for that pavement is determined, using Figure 1, or the alignment chart in Figure 16 in Circular 25-AN/22. The LCN for the aircraft to use the pavement is obtained from the same diagrams, and, by a comparison of the two figures, it is at once possible to decide whether the aircraft may be accepted on the pavement.

Multiple Wheel Undercarriages

Application to the LCN System. - Where aircraft with multiple-wheel undercarriages are concerned it is necessary first to obtain the Equivalent Single-Wheel Load for the aircraft for application to the charts. A major difficulty will be apparent at once; that is that the E.S.W.L. for any multiple-wheel undercarriage aircraft varies with the construction of the pavement. Thus a multiple-wheel undercarriage aircraft has a range of LCN values, but only one value for any particular aerodrome. In dealing with aircraft of this type it is therefore necessary to know not only the LCN of the aerodrome pavement but also its construction.

Calculation of E.S.W.L.

Flexible Pavements. - The only variable is the thickness of the pavement, and the E.S.W.L. varies between the load on one individual wheel of the undercarriage on very thin pavements to the total load on the undercarriage on very thick pavements. The method described, while accurate, involves considerable calculation and it is British practice, for general use, to adopt C.R. Foster's method as described in Part 2.1 of Circular 25-AN/22. Results given by the two methods show a very close measure of agreement. For E.S.W.L. calculation purposes reference is only made to the pavement thickness.

Rigid Pavements. - It is necessary to know a value called the "radius of relative stiffness" of the concrete. For practical purposes it is reasonably accurate to assume that this is approximately equal to four times the thickness of the concrete. Knowing this value, the ratio of the E.S.W.L. to the total load on the undercarriage is obtained and from this ratio the E.S.W.L. is obtained.

Application

Design. - In the design methods described in the first Part of this paper it is necessary, in the case of multiple-wheel undercarriage aircraft, first to determine the equivalent single-wheel load. This necessitates a trial and error process in which an E.S.W.L. value is taken for design purposes for an assumed pavement thickness, and is later checked for accuracy. The most recent Corps of Engineers pavement design curves allow for direct abstraction of design thickness, both for flexible and rigid pavements, for two typical multiple wheel undercarriages.

Evaluation. - For all multiple-wheel undercarriage aircraft, charts have been prepared showing the LCN variation for different types and thickness of construction. It is therefore possible to obtain at once the LCN for any particular aircraft on ahy particular aerodrome. Similarly, on any aerodrome, the LCN's applicable for all aircraft may be known and also, where this is possible, the reduced all-up weight figure which brings the aircraft LCN to a figure less than the LCN of the aerodrome. Therefore, once the initial calculations are made, application becomes relatively simple.

ICAO Method. - It will be appreciated that the arbitrary factors given in Part 7 of Attachment "B" to Annex 14 to the Convention are considered to be misleading and even dangerous in extreme cases. On thin pavements where the equivalent single-wheel load is little more than that of one wheel of the assembly, the arbitrary factors may impose an undue restriction. While the variation of E.S.W.L. may at first sight appear to be a complicated matter, it is not difficult to apply in practice, particularly when linked to the LCN system.

Secretariat Note. - Subsequent to the presentation of this paper the AGA Division, at its Fifth Session, recommended the addition of the following note at the end of Section 7, after the second table:

> "It should be noted, however, that the equivalent single isolated wheel load for a given aircraft will vary depending on the type, thickness and quality of the combination of pavement and subgrade encountered, so that the above assumptions give only approximate figures."

This amendment was approved by the Council of ICAO.

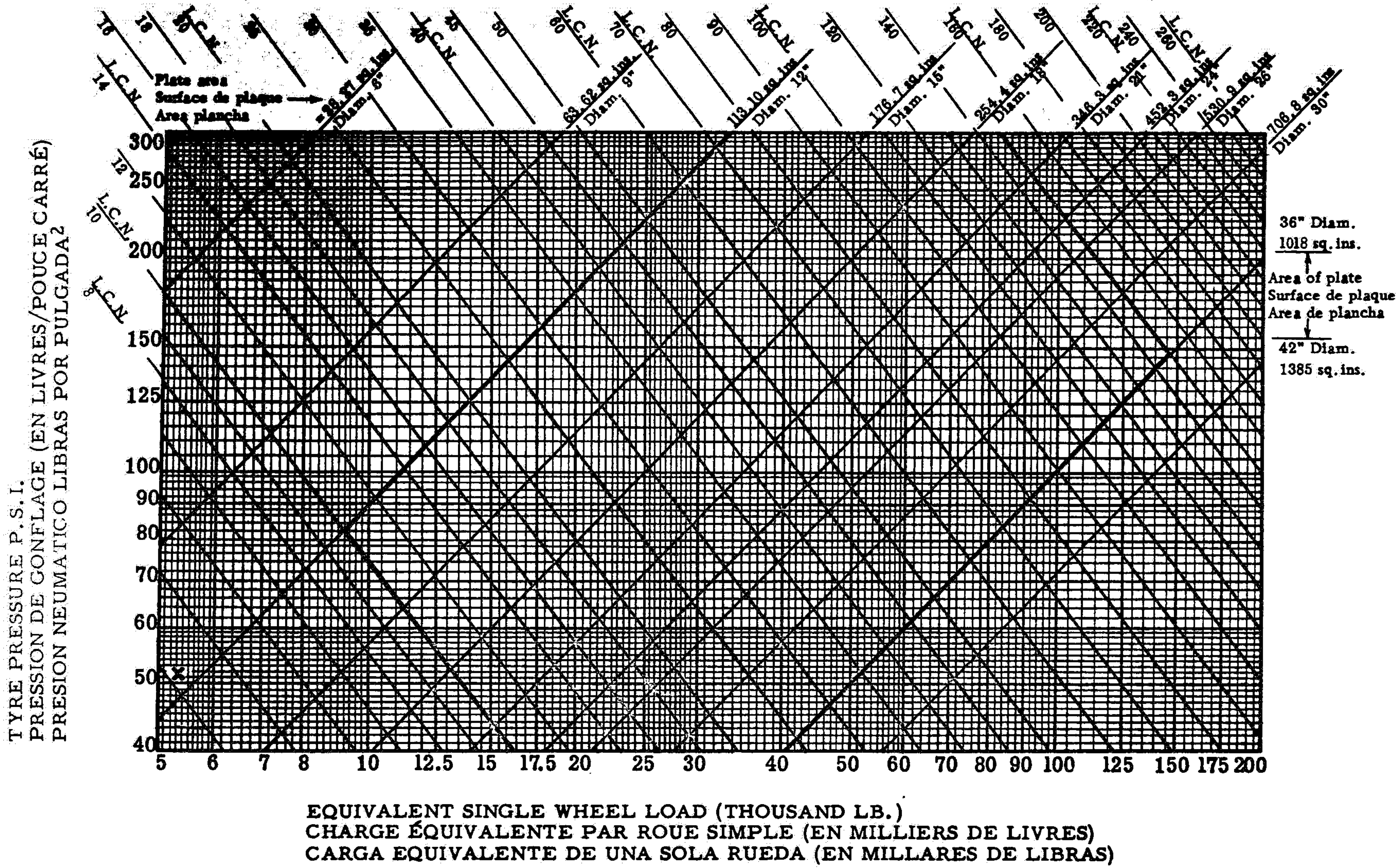


Fig. 3. - L.C.N. TYRE PRESSURE-CONTACT AREA-WHEEL LOAD DIAGRAM

Fig. 3. - ABAQUE NUMERO L.C.N./PRESSION DE GONFLAGE/SURFACE D'APPLICATION/CHARGE PAR ROUE

Fig. 3. - DIAGRAMA CARGA RUEDA/AREA CONTACTO/PRESION NEUMATICO/N.C.C.

UNITED STATES METHOD

(Presented by Dr. F.L. Meara)

DESIGN AND EVALUATION OF RUNWAYS

Introduction

Types of pavements. - Two general types of airfield pavements are constructed namely, rigid pavement built of Portland cement concrete and flexible pavement having an asphalt concrete surface. Either rigid or flexible pavement may have an overlay constructed to increase the strength of the existing pavement. This overlay will generally be of asphaltic concrete.

Rigid Pavements. - The strength of rigid pavements depends primarily on the soil constant of the subgrade and the flexural strength of the concrete. The strength of the subgrade, expressed as a soil modulus (K), is normally determined by means of the plate bearing test. In this test a 30-inch plate is jacked into the subgrade by applying successive loads of 5 p.s.i., 10 p.s.i., 20 p.s.i., etc. A curve is then plotted between the deflection produced and the corresponding load. The pressure of 10 p.s.i. is divided by the deflection produced by this same load and the result, expressed in pounds per cubic inch, is the soil modulus (K). A soil having a (K) value of 40 to 50 is generally considered to be a weak soil whereas one having a (K) value of 400 to 600 is considered to be a strong soil.

A series of design curves for rigid pavements have been produced. In the series, attached (See Figures 2-11 inclusive), separate curves have been drawn for single-wheel loads with 100 p.s.i. tire pressure, single wheel loads with 200 p.s.i tire pressure, twin-wheel loads with 100 p.s.i. tire pressure, twin-wheel and twin-tandem gear loads having a contact area on each tire of 267 square inches. Use of these curves permit design of pavements to meet requirements of existing aircraft. It will be noted from the curves that the variation and thickness of the pavement for any given wheel load such as 100 000 pounds on a dual wheel is only a few inches as we proceed from a weak subgrade with a (K) of 50 to a moderately strong subgrade with a (K) of 300. This brings out the fact that when we have a weak subgrade, it is not economical to build in a base course in order to increase the strength because the base course would be more costly than the small number of additional inches of concrete. Base courses however may be economically dictated for such other purposes as the prevention of pumping, providing proper drainage and because of climatological conditions.

Flexible Pavements. - Design of flexible pavement is predicated upon the use of subsoil strength in terms of California Bearing Ratio (CBR). This ratio is quite different from that used as the basis for the design of rigid pavements. CBR is determined by forcing a piston 3 square inches in area into the soil at a uniform rate of 5/100 inch per minute. A curve is plotted between the penetration and the forces necessary to produce the several penetrations of this piston. A similar curve using well-graded crushed stone has been prepared for use as a standard, the CBR of which is taken as 100. By comparing the force necessary to produce a penetration of 1/10 of an inch in the soil under test with the force necessary to produce the same penetration in the standard sample, we get a ratio which expressed in number of percent, is the CBR of the soil. For example, if the force of a 1/10 inch penetration of the soil under test is 150 pounds and the force for the 1/10 inch penetration on the standard sample is 1 000 pounds, the ratio is 150/1 000 or a CBR of 15.

Flexible pavements are usually constructed of layers of granular material and provided with a wearing or surface course of three or four inches of asphaltic concrete. The required strength of the base course material is specified in terms of CBR. There are attached five designs for flexible pavements for the same wheel loadings as those previously given for rigid pavement. Relative to soil strengths it should be noted that in terms of CBR subgrade strengths generally range from 5 to 30 with very weak subgrades ranging from 3 to 5 while those above 60 are unusually strong subgrades. Pavement thickness in accordance with the design curves and for a wheel load of 100 000 pounds would vary from 45 inches on the soils of CBR 5 to 10 inches on the soils of CBR 35. This variation in thickness demonstrates that the effect of the subgrade on flexible pavement thickness is substantial whereas in the case of rigid pavements it is a question of economy as to whether or not a base course shall be constructed.

The above discussion relates wheel load, thickness of pavement, and CBR of the subgrade. In thick pavements, say 45 inches in thickness, the materials used may be of several types having different CBR values. The material in the lower part of the pavement may have a CBR of 10 while in the central portion, up to within 10 inches of the surface, it may be 35 or 40 while the upper portion must have materials of 80 or more. These CBR values for the various parts of the pavement can be obtained from the same curves which give the total design thickness. This denotes that less costly materials can be used in the lower sections of the pavement.

It was stated previously that we have design curve for five different gear configurations. The question may arise as to why we do not use an equivalent single-wheel load and thus reduce the number of curves required. That approach was tried some years ago but it was found that the equivalent single-wheel load of a multiple-wheeled gear varied with the thickness of the pavement and the spacing of the wheels. Another variable may occur when the base course is the controlling factor rather than the subgrade.

The preceding discussions have been based upon permanent or 25 year life pavements. An interesting variation in pavement construction is the pavement of limited life. Three different types of limited life airfield pavements have been proposed, namely, full operational, minimum operational and emergency.

Limited Life Pavements

Flexible Pavements. - The full operational pavement will have the same thickness as the permanent pavement. In the case of flexible pavements the minimum operational pavement will have 80 per cent of the thickness of the full operational pavement, an assigned life of six months and will require extensive maintenance. The emergency pavement also in the case of the flexible type, will have 50 per cent of the thickness of the full operational pavement, a specified life of only 14 days and will require constant maintenance. In general, the flexible pavement of the limited life type will not have a formal surface as does the normal asphaltic concrete surfaced pavement. The surface will generally be a tack coat or a double surface treatment of asphaltic materials. This surface is expected to provide moisture proofing and serve as a dust palliative. Design curves for the three types of limited life pavements have been prepared.

The design of a flexible pavement without the usual three or four inches of bituminous concrete to carry heavy aircraft utilizing tire pressures from 175 to 195 p.s.i. presents a special problem. In a theoretical study, a consultant for the Air Force found that such tire pressures would require CBR values of 125 to 150. Such high values can only be obtained when a well graded, high quality aggregate is compacted by means of a 50 to 60-ton roller with the tires inflated to 150 p.s.i. The above relationships were based on the shear stresses induced in the pavement and these stresses were correlated by means of some existing data with CBR values. Test sections were also constructed and subjected to traffic tests. The test thus far completed confirmed the principle that the higher tire pressures required high CBR values.

Rigid Pavements. - Limited life type rigid pavements will not generally be constructed but if they are, there probably will be three types as in the case of flexible pavements. The full operational rigid pavement will be 100 per cent of the thickness of the permanent pavement. The minimum operational pavement will be 90 per cent of the thickness of the full operational pavement and the emergency pavement will be 80 per cent of the thickness of the full operational pavement. Design curves for these three types of rigid pavement are now being prepared.

Landing Mats. - It is expected that many of the airfield pavements will be surfaced with landing mat where limited life pavements are to be constructed. At present, we have three types of landing mat for such use. All landing mat is of the pierced steel plank type but greatly improved over the type used in World War II. The M-6 mat is a steel mat which weighs 5.4 pounds per square foot; the M-8 mat is a steel mat which weighs 7.3 pounds per square foot; and the M-9 mat is an aluminum mat which weighs 3.7 pounds per square foot and has about the same strength characteristics as the M-8 steel mat. A landing mat, in one sense, is similar to a layer of asphaltic concrete in that it cannot be laid on every soil and be expected to support all the different aircraft loads. A landing mat like asphaltic concrete needs a base course. The thickness of the base course depends again on two factors, namely, the strength of the subgrade and the wheel load to be carried. Design curves for both the M-6 and the M-8 mat for both the emergency and minimum operational type of airfields have been prepared for four different tire pressures ranging from 40 p.s.i. to 300 p.s.i. Since it has been stated that a landing mat requires a base course, the question may arise as to what advantages are obtained from use of the mat. In general, the thickness of the base course, required with the use of a landing mat, is less than required in a flexible pavement. The amount of reduction in thickness depends on the tire pressure. When the tire pressures are low, say 40 pounds, the reduction may be as much as 15 inches, but when the tire pressure is 300, the reduction may be only 6 inches. The second advantage of the landing mat is that the required quality or CBR of the upper layer of the base course is greatly reduced. If we had a 50 000 pound wheel load and a 40 p.s.i. tire pressure, the M-6 mat requires only 8 inches of base course and a CBR of 6. If this same load is used at 300 p.s.i. tire pressure the thickness required in the base course becomes 18 inches and the CBR required is 33.

Surfacing Membrane. - Another type of surfacing that has been used is a membrane called prefabricated bituminous surfacing (PBS). Recently, a new membrane, a vinyl coated duck, has been developed. This is superior to the old PBS, particularly in heat resistant qualities and it is proposed to use this material as a surface for certain emergency runways. This material has no structural strength, and accordingly, the strength of the runway must be built into the base course. The principal merit of the membrane cover is to serve for water proofing and as a dust palliative. Investigations under way at the present time indicate that this type of membrane also can be used under the landing mat for wheel loads in the range from 25 000 pounds to 100 000 pounds with tire pressures ranging from 60 to 180 p.s.i. The twin-tandem gear load varies from about 100 000 pounds to 160 000 pounds.

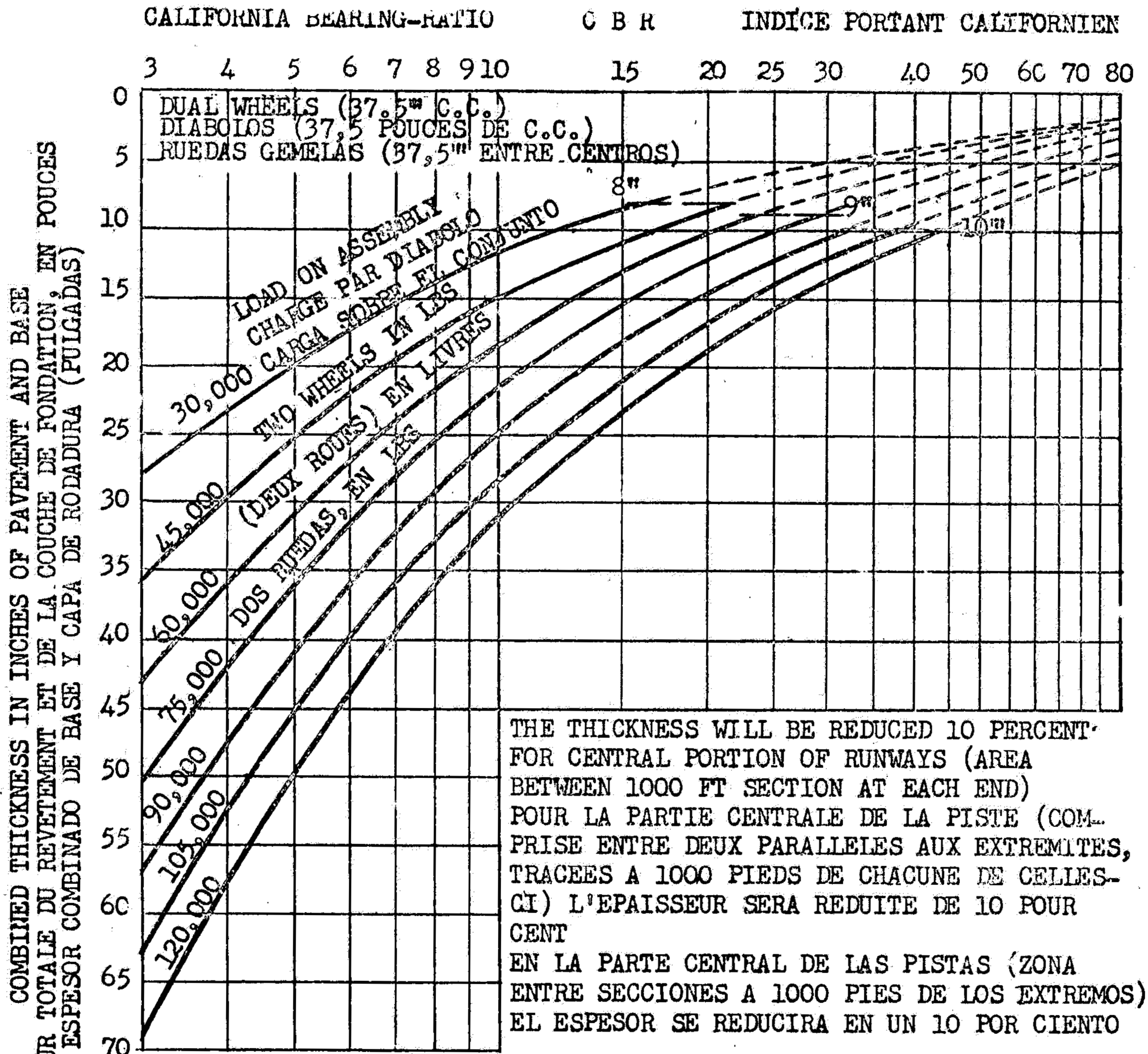
Loads. - Recently, designing engineers for several aircraft companies have predicted that the bombers of the future will decrease in weight while the cargo ships will increase in weight until they eventually reach 400 000 pounds. Existing aircraft physical characteristics, however, include:

Single-wheel loads - 8 000 to 45 000 pounds with tire pressures from 60 to 197 p.s.i.

Twin-wheel loads - 25 000 to 100 000 pounds with tire pressures from 60 to 180 p.s.i.

Twin-tandem gear load - 100 000 pounds to 160 000 pounds with tire pressures corresponding to the twin wheel loads.

From the above discussion, it can be seen that we have firm criteria for the design of pavements for all existing aircraft and the criteria could readily be extended if the need arises.



267 SQ.IN. CONTACT AREA EACH WHEEL
SURFACE DE CONTACT: 267 POUCES CARRES PAR PNEU
AREA DE CONTACTO POR RUEDA 267 PULG. CUADRADAS.

(TENTATIVE) (PROVISOIRE) (PROVISIONAL)

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.
COURBES DE CALCUL DE REVETEMENT SOUPLE POUR VOIES DE CIRCULATION ETC.
CURVAS DE CALCULO DE PAVIMENTO FLEXIBLE PARA CALLES DE RODAJE, ETC.

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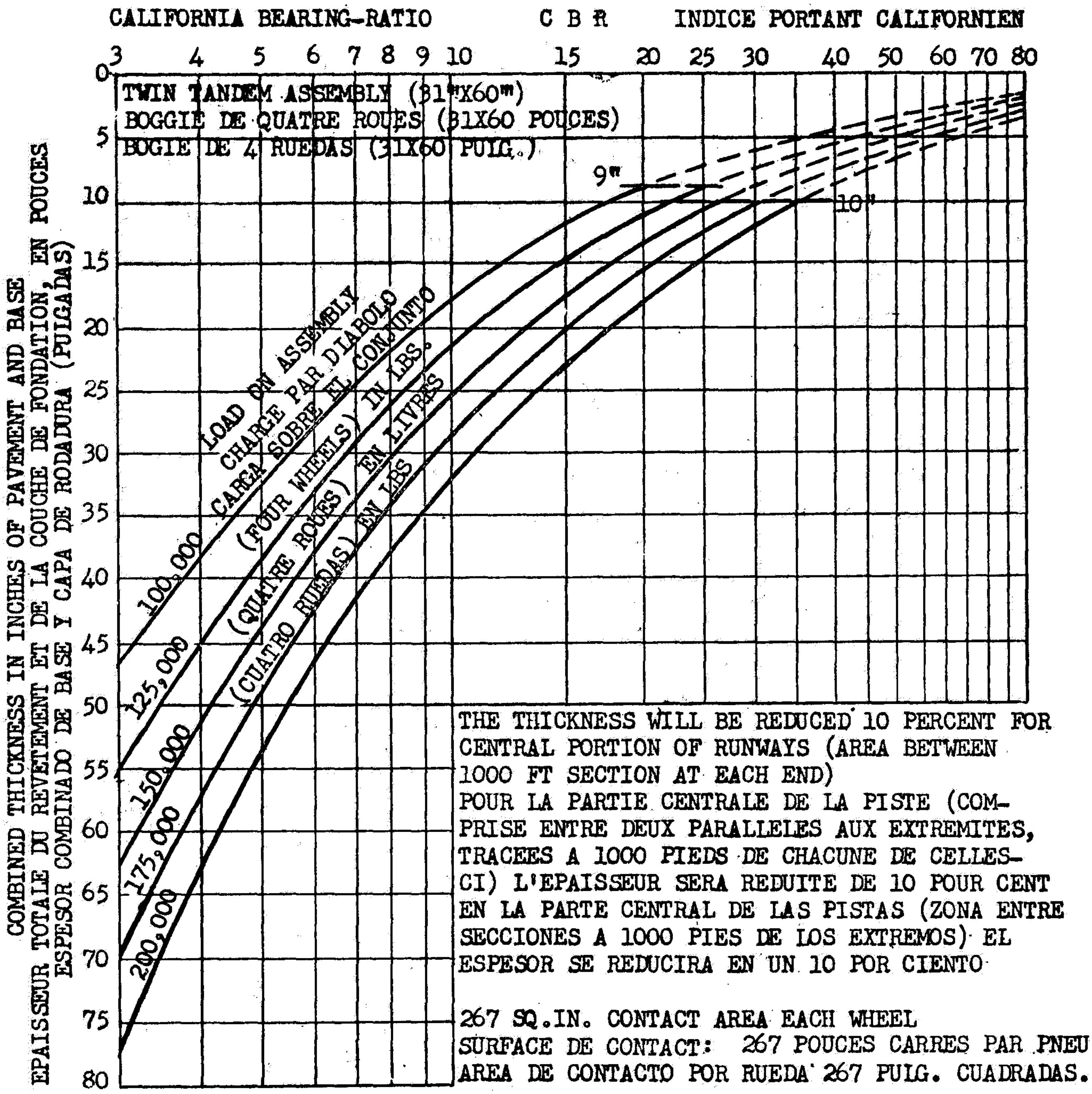
Rev. 6-13-50
Rev. 3-27-50
8-22-49

FIGURE 2



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COURBES DE CALCUL DE REVETEMENT SOUPLE POUR VOIES DE CIRCULATION ETC.
CURVAS DE CALCULO DE PAVIMENTO FLEXIBLE PARA CALLES DE RODAJE, ETC.

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Rev. 3-27-50
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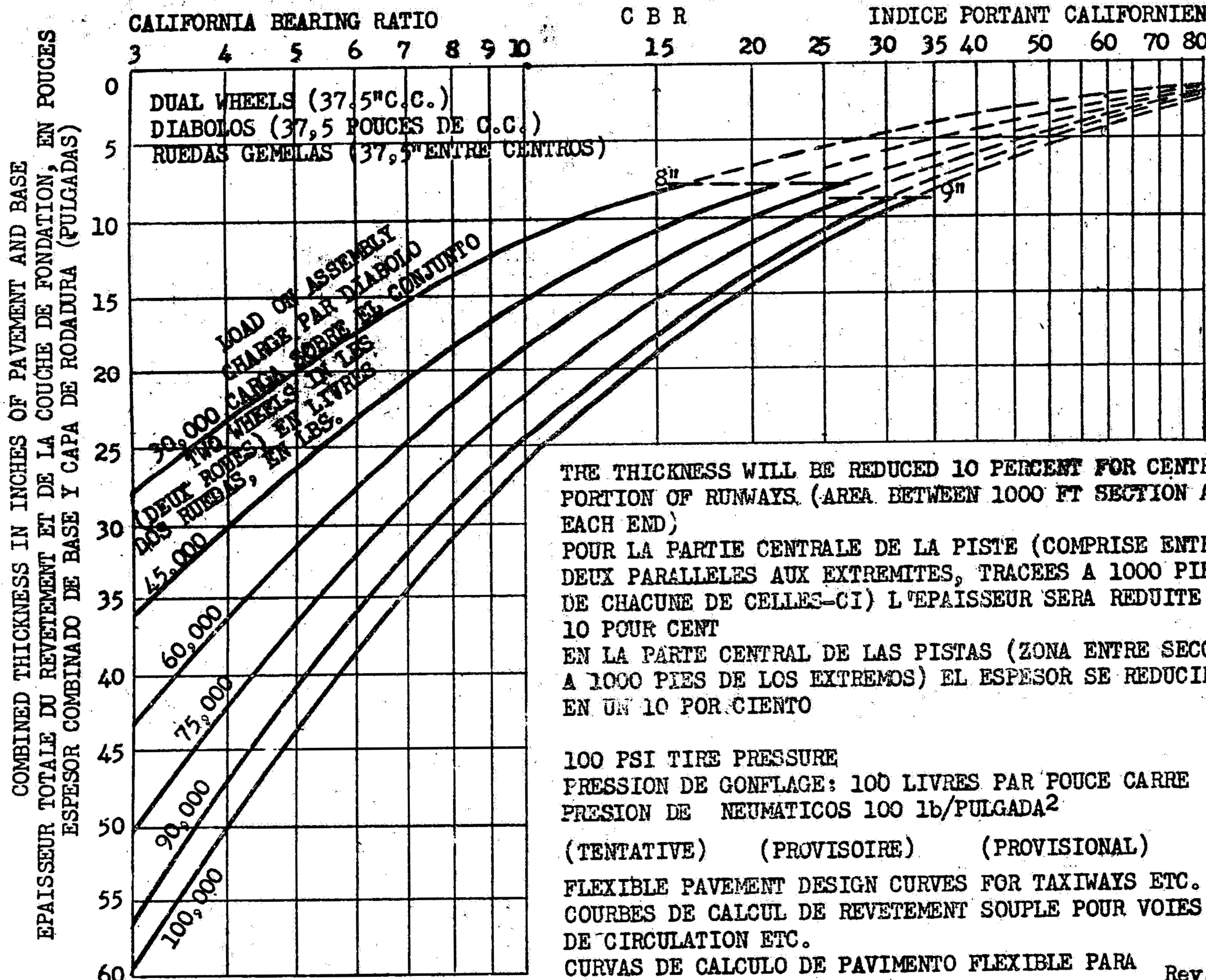
FIGURE 3



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS. (AREA BETWEEN 1000 FT SECTION AT EACH END)

POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI) L'EPAISSEUR SERA REDUITE DE 10 POUR CENT

EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO

100 PSI TIRE PRESSURE
PRESSION DE GONFLAGE: 100 LIVRES PAR POUCE CARRE
PRESION DE NEUMATICOS 100 lb/PULGADA^2

(TENTATIVE) (PROVISOIRE) (PROVISIONAL)

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.
COURBES DE CALCUL DE REVETEMENT SOUPLE POUR VOIES DE CIRCULATION ETC.
CURVAS DE CALCULO DE PAVIMENTO FLEXIBLE PARA CALLES DE RODAJE, ETC.

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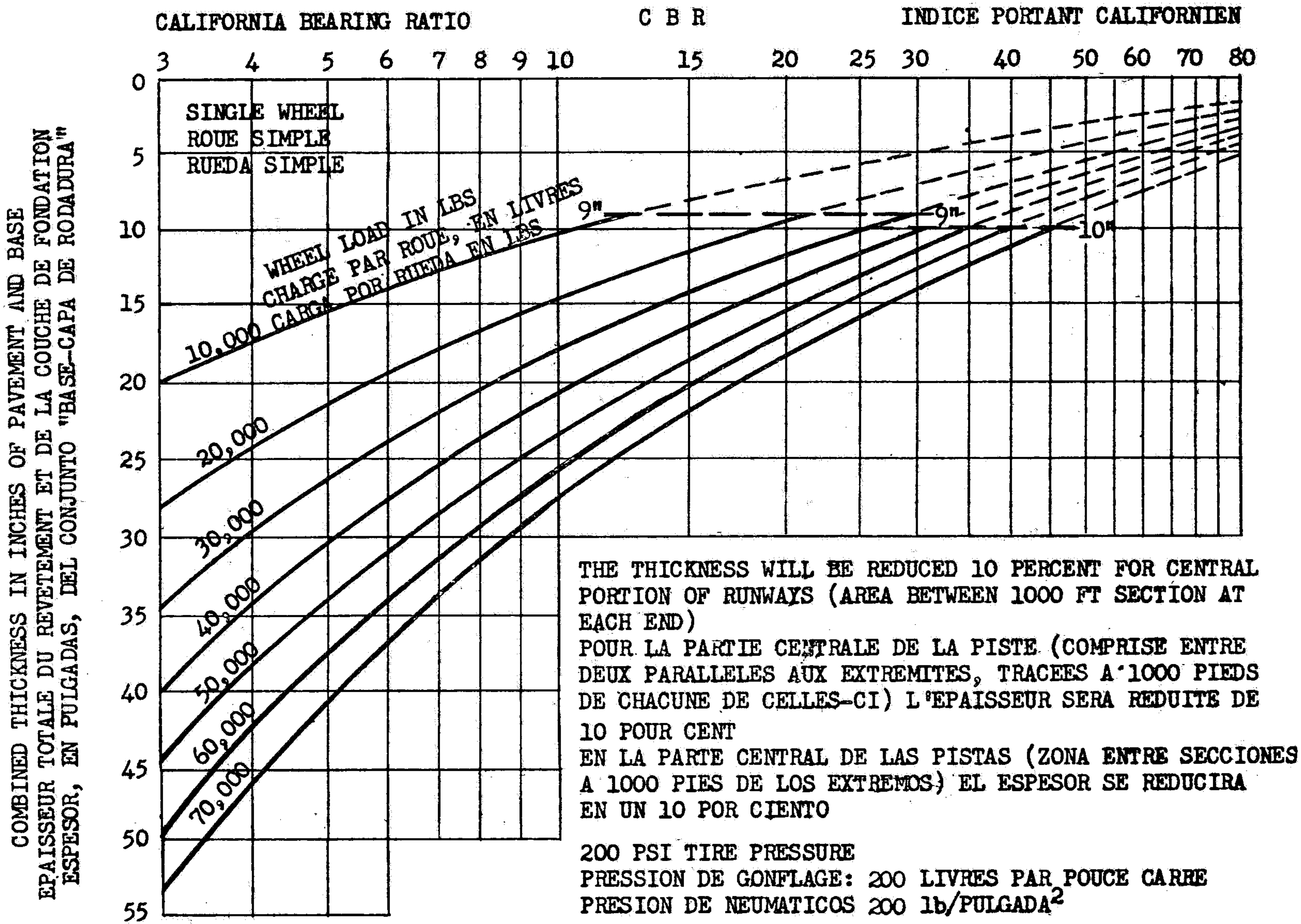
FIGURE 4



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)

POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI) L'EPAISSEUR SERA REDUITE DE 10 POUR CENT

EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO

200 PSI TIRE PRESSURE
PRESSION DE GONFLAGE: 200 LIVRES PAR POUCE CARRE
PRESION DE NEUMATICOS 200 lb/PULGADA^2

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.
COURBES DE CALCUL DE REVETEMENT SOUPLE POUR VOIES DE CIRCULATION ETC.
CURVAS DE CALCULO DE PAVIMENTO FLEXIBLE PARA CALLES DE RODAJE, ETC.

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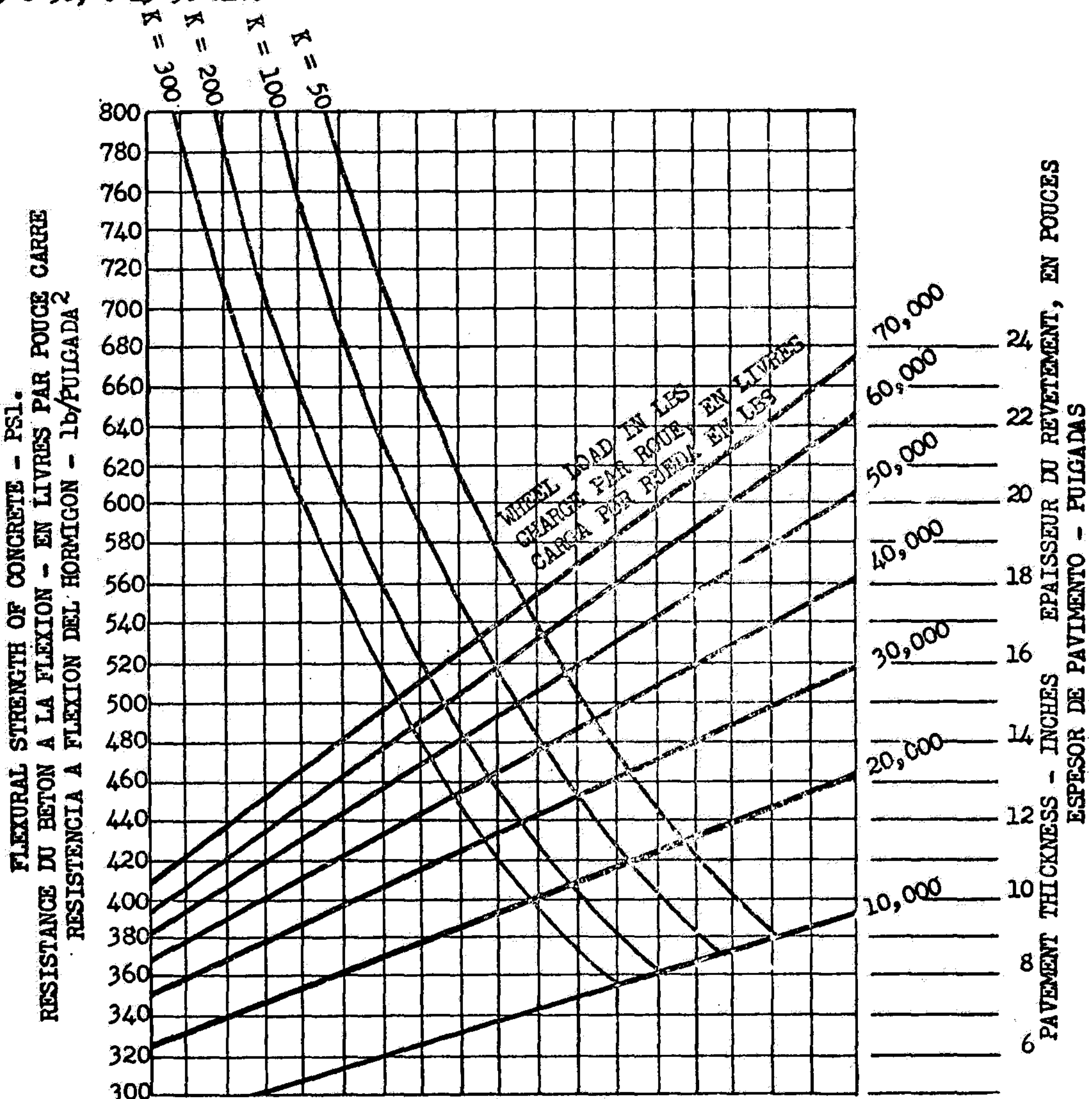
8-18-49

FIGURE 5

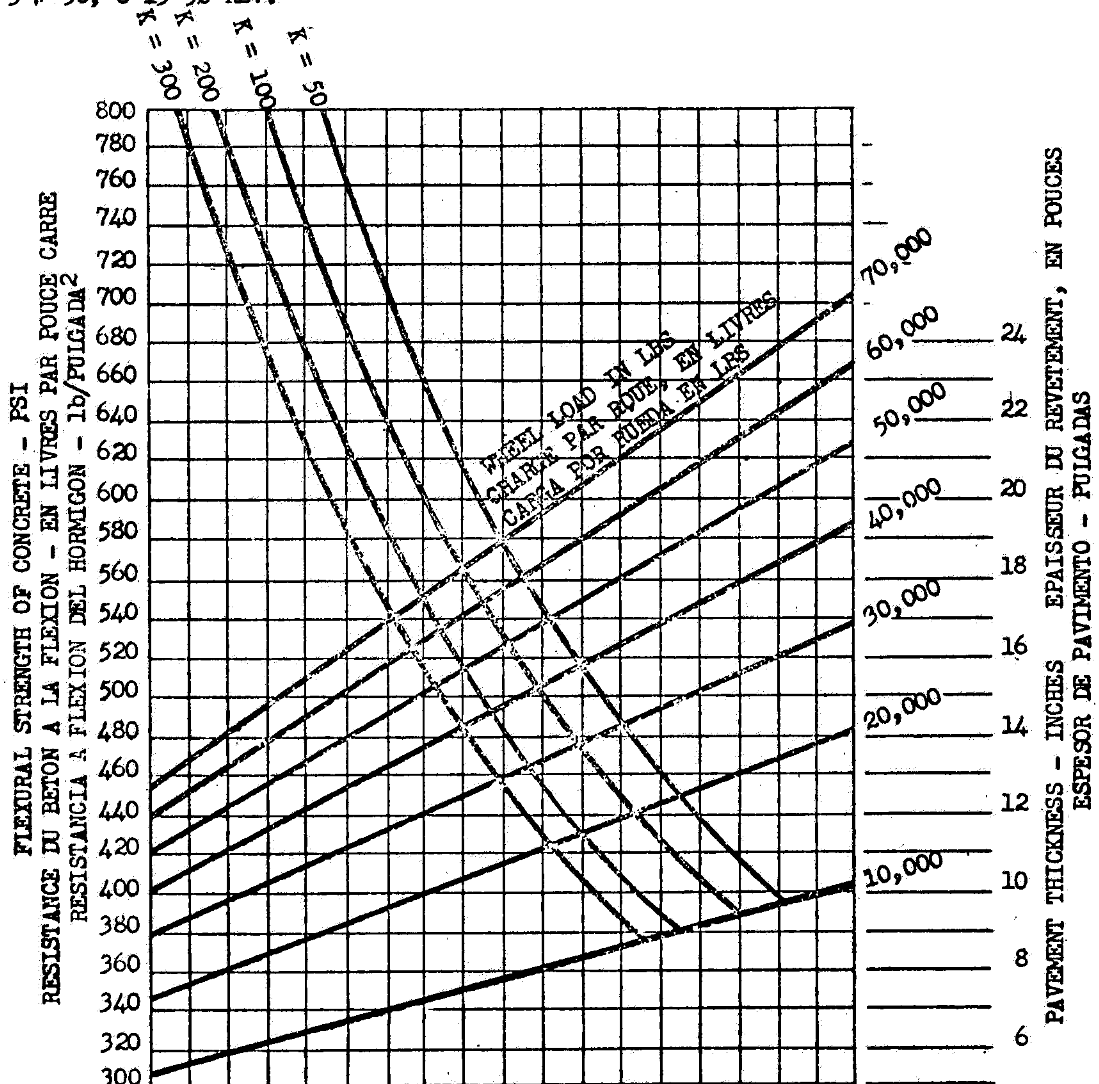
3-6-50, 6-13-50 REV.



THE THICKNESS WILL BE REDUCED 10 PER CENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)
POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI, L'EPAISSEUR SERA REDUITE DE 10 POUR CENT
EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO
PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. SINGLE WHEEL 100 - PSI.
COURBES DE CALCUL DU REVETEMENT EN BETON POUR VOIES DE CIRCULATION, ETC.
ROUE SIMPLE - PRESSION DE GONFLAGE; 100 LIVRES PAR POUCE CARRE
CURVAS DE CALCULO DE PAVIMENTOS DE HORMIGON PARA CALLES DE RODAJE, ETC.
RUEDA SIMPLE - lb/PULGADA^2

FIGURE 6

3-7-50, 6-13-50 REV.



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)

POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI, L'EPAISSEUR SERA REDUITE DE 10 POUR CENT

EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO

PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. SINGLE WHEEL 200 - PSI

COURBES DE CALCUL DU REVETEMENT EN BETON POUR VOIES DE CIRCULATION, ETC.

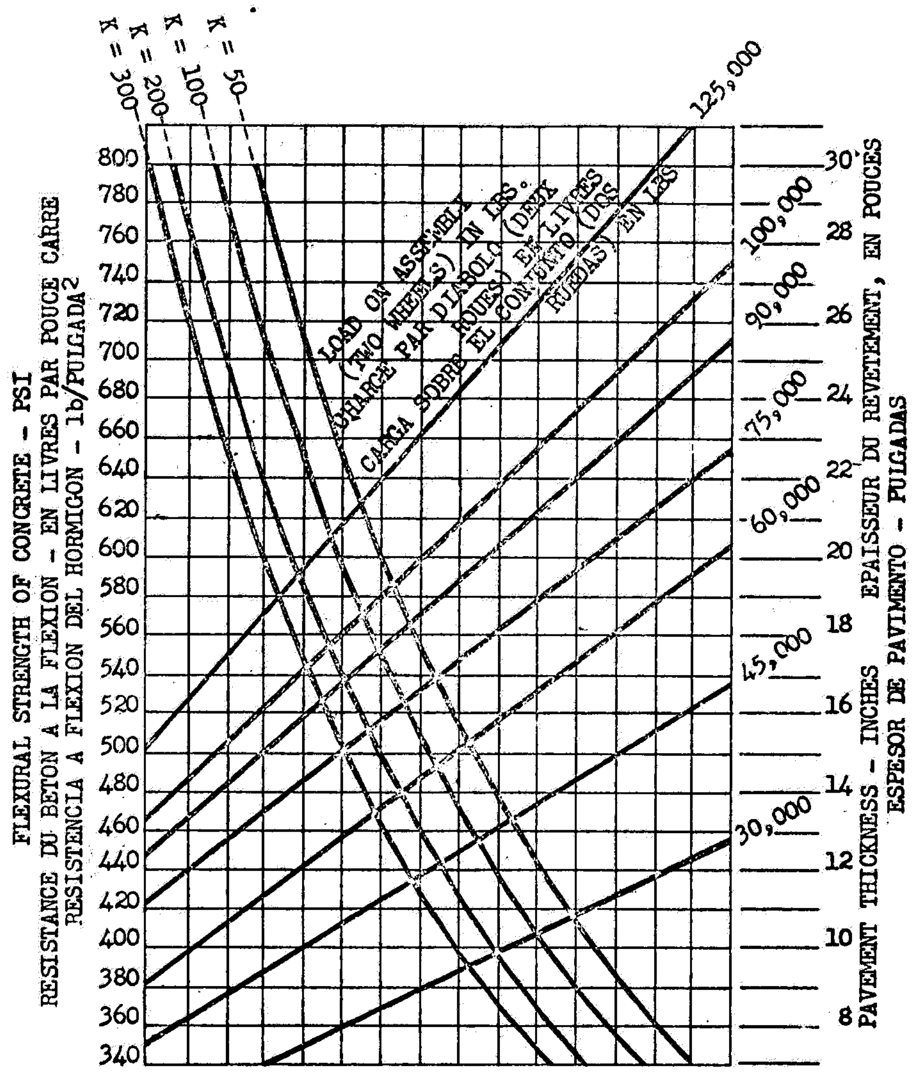
ROUE SIMPLE - PRESSION DE GONFLAGE: 200 LIVRES PAR POUCE CARRE

CURVAS DE CALCULO DE PAVIMENTOS DE HORMIGON PARA CALLES DE RODAJE, ETC.

RUEDA SIMPLE - 2b/PULGADA^2

FIGURE 7

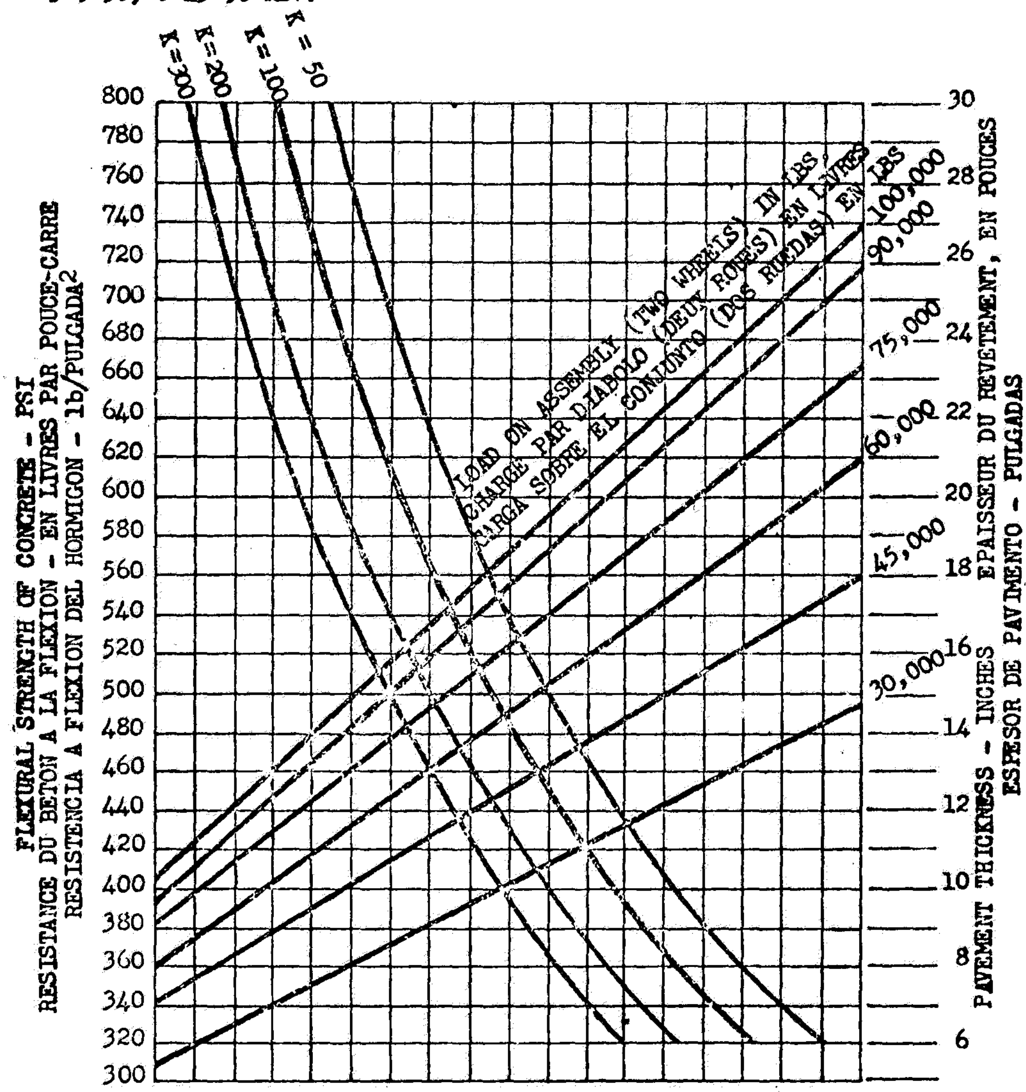
3-10-50, 6-13-50 REV.



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)
POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI) L'EPAISSEUR SERA REDUITE DE 10 POUR CENT
EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO
PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. DUAL WHEELS SPACED 37" C.C. CONTACT AREA 267 SQ. IN. EACH WHEEL
COURBES DE CALCUL DU REVETEMENT EN BETON POUR VOIES DE CIRCULATION, ETC. DIABOLOS, ECARTEMENT: 37 POUCES DE C. AC. SURFACE DE CONTACT: 267 POUCES CARRES PAR PNEU
CURVAS DE CALCULO DE PAVIMENTOS DE HORMIGON PARA CALLES DE RODAJE, ETC. RUEDAS GEMELAS - DISTANCIA ENTRE CENTROS 37 PULG. AREA DE CONTACTO 267 PULGADAS CUADRADAS POR RUEDA

FIGURE 8

3-9-50, 6-13-50 REV.



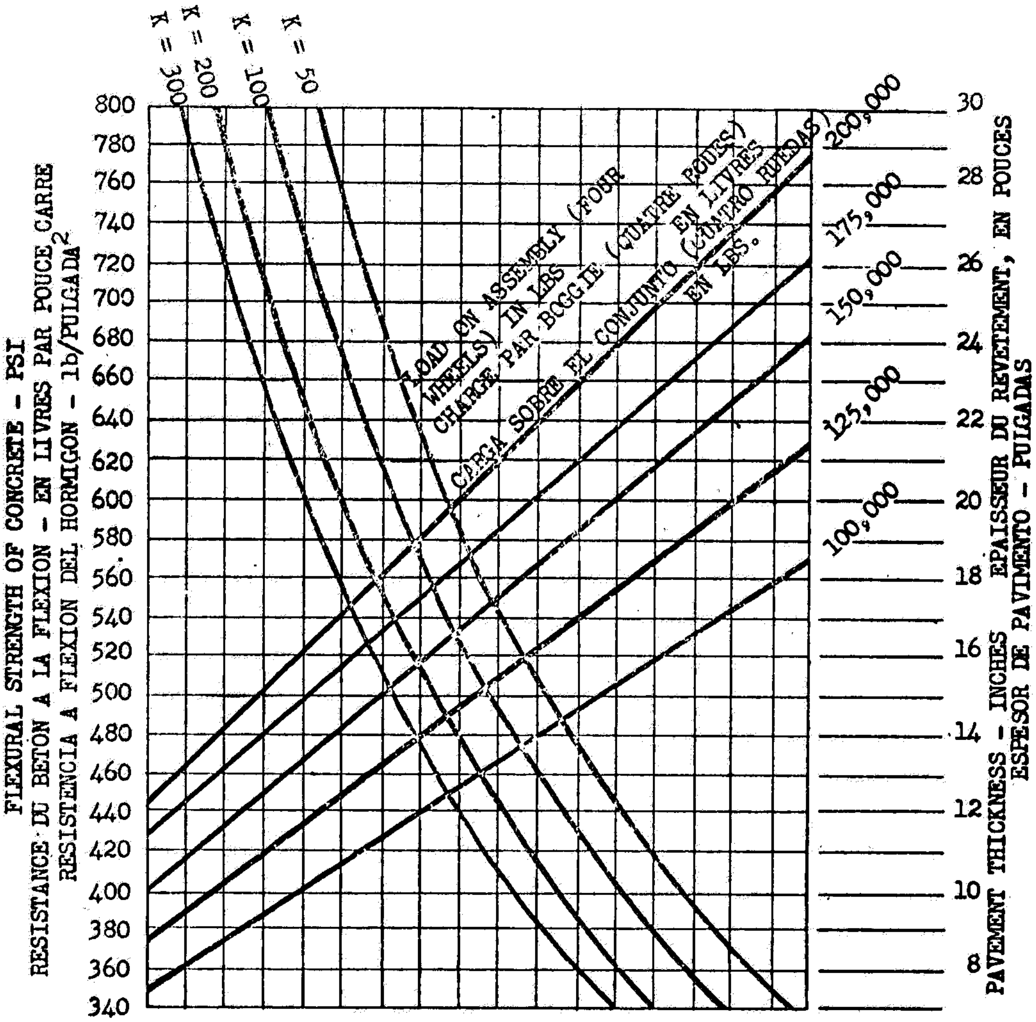
THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)

POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI) L'EPAISSEUR SERA REDUITE DE 10 POUR CENT

EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO

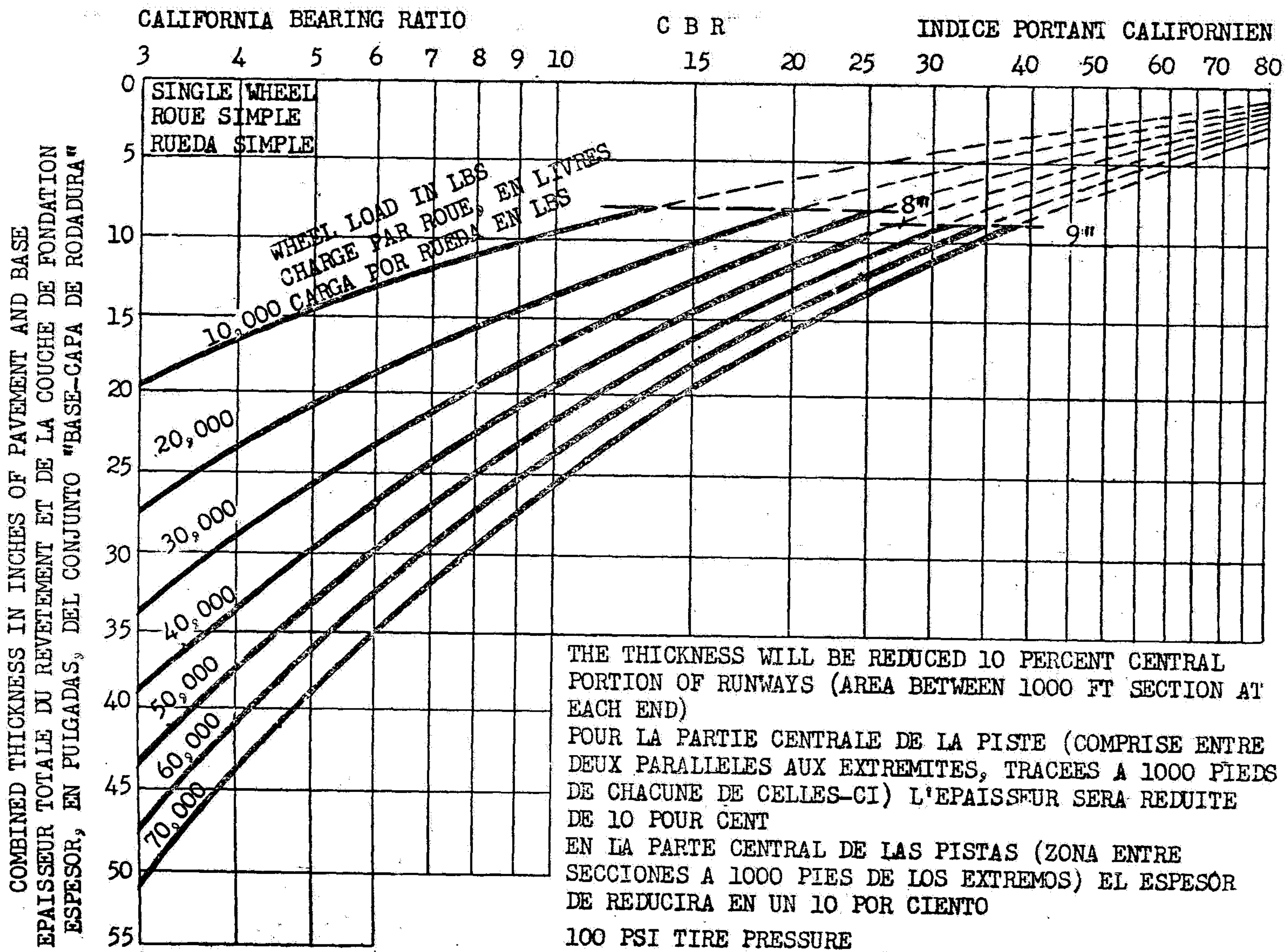
PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. DUAL WHEELS SPACED 37" C.C. TIRE PRESSURE 100 PSI
COURBES DE CALCUL DU REVETEMENT EN BETON POUR VOIES DE CIRCULATION, ETC. DIABOLOS, ECARTEMENT: 37 POUCES DE C. A C. PRESSION DE GONFLAGE: 100 LIVRES PAR POUCE CARRE
CURVAS DE CALCULO DE PAVIMENTOS DE HORMIGON PARA CALLES DE RODAJE, ETC. RUEDAS GEMELAS - DISTANCIA ENTRE CENTROS 37 PULG. PRESION DE NEUMATICOS 100 lb/PULGADA^2

FIGURE 9



PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. TWIN TANDEM GEAR - SPACING 31"X60" CONTACT AREA 267 SQ. IN. EACH WHEEL
COURBES DE CALCUL DU REVETEMENT EN BETON POUR VOIES DE CIRCULATION, ETC., BOGGIE - ECARTEMENTS: 31 POUCES X 60 POUCES SURFACE DE CONTACT: 267 POUCES CARRES PAR PNEU
CURVAS DE CALCULO DE PAVIMENTOS DE HORMIGON PARA CALLES DE RADAJE, ETC. BOGIE DE 4 RUEDAS - SEPARADAS 31X60 PULG. AREA DE CONTACTO 267 PULGADAS CUADRADAS POR RUEDA
THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)
POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI) L'EPAISSEUR SERA REDUITE DE 10 POUR CENT
EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR SE REDUCIRA EN UN 10 POR CIENTO

FIGURE 10



THE THICKNESS WILL BE REDUCED 10 PERCENT CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)

POUR LA PARTIE CENTRALE DE LA PISTE (COMPRISE ENTRE DEUX PARALLELES AUX EXTREMITES, TRACEES A 1000 PIEDS DE CHACUNE DE CELLES-CI) L'EPAISSEUR SERA REDUITE DE 10 POUR CENT

EN LA PARTE CENTRAL DE LAS PISTAS (ZONA ENTRE SECCIONES A 1000 PIES DE LOS EXTREMOS) EL ESPESOR DE REDUCIRA EN UN 10 POR CIENTO

100 PSI TIRE PRESSURE
PRESSION DE GONFLAGE: 100 LIVRES PAR POUCE CARRE
PRESION DE NEUMATICOS 100 lb/PULGADA²

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.
COURBES DE CALCUL DE REVETEMENT SOUPLE POUR VOIES DE CIRCULATION ETC.
CURVAS DE CALCULO DE PAVIMENTO FLEXIBLE PARA CALLES DE RODAJE, ETC.

FIGURE 11

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CANADIAN METHODS

(Presented by Dr. N. McLeod)

General

Dr. McLeod stated that both flexible and rigid types of pavement were used in Canada. To assist in determining the type of pavement best suited to a particular location, design studies were normally made for both types of pavement on the basis of the anticipated loads and the subgrade conditions at the site. If the estimated difference in cost was slight, alternative bids were requested from contractors.

Rigid Pavements

Design. - Rigid pavement design in Canada was commonly based on methods described in a booklet entitled "Design of Concrete Airport Pavement" published by the Portland Cement Association, 1950. In those design specifications, it is assumed that the concrete itself has a certain structural strength and calculations of the thickness required are based on Westergaard's formula. The subgrade modulus is determined by means of the common plate bearing test using a 30-inch diameter plate.

Later experience in Canada has seemed to indicate, however, that the required thickness of rigid pavement, if determined on the basis of this publication was greater than was thought necessary in practice. The thicknesses have therefore been scaled down to conform more closely with earlier specifications recommended by the Portland Cement Association (1942). The reduction in thickness is roughly 5 cms (2 inches) for pavements designed for lighter wheel loadings and may be as much as 7.5 cms (3 inches) for heavier wheel loadings.

Evaluation. - For the evaluation of rigid pavements of existing runways, taxiways or aprons, the following procedure is followed: a section of pavement is cut out and used as a standard beam for determining the structural strength of the concrete. Enough concrete pavement is removed to make a plate-bearing test with a 30-inch diameter plate on the underlying subgrade. From this test the subgrade modulus K, required by the Westergaard analysis, can be calculated. From the subgrade modulus K and from the actual structural strength of the concrete that has been cut out, it is then possible by using curves given in the above-mentioned specifications to determine the wheel load that it will support.

Flexible Pavements

Design. - In 1945, the Department of Transport started an extensive load-testing programme of existing flexible runway pavements. Plate-bearing tests were made with bearing plates of various diameters. The load-test data obtained was carefully analyzed and from it an "overall perimeter area ratio diagram" was developed. Using this diagram and a single-load test on a given subgrade it is now possible to calculate the subgrade strength for any other size of bearing plate and for any deflection from 0.13 cms (0.05 inch) to about 1.78 cms (0.7 inch). The diagram is useful since it would be a difficult procedure to make plate-bearing tests corresponding to every size of contact area of aircraft tires that might possibly be used on the runways. On the basis of these load-test data a design formula has been derived, which is the basis of the design charts used in Canada. The original design chart was established for single isolated wheel loads on flexible pavement but has been changed, as proposed by the U.S. Corps of Engineers, so that the equivalent single-wheel load for any desired multiple tire assembly arrangement can be determined (see diagrams on pages 45 and 47 of ICAO Circular 25-AN/22.

Evaluation

To determine the strength of existing pavements, the Department of Transport uses the following test procedure: Plate-bearing tests are first made on the pavement surface. By using the perimeter area ratio diagram it is possible to establish the single isolated wheel load that the pavement will carry and by means of the two diagrams in ICAO Circular 25-AN/22 it is possible to determine the total wheel load, for either a dual tire assembly or a dual tandem tire assembly that the pavement will support.

During the past three years, the Department of Transport has been designing flexible pavements for a minimum tire pressure of 14 kgs./sq.cm (200 p.s.i.). The gross weights of aircraft were increasing and runways built in the early 1940s were too weak to carry present-day aircraft. The Department of Transport has therefore strengthened many of these runways utilizing the existing flexible pavement as a subgrade and treating it as such in the design equation to determine the additional thickness of flexible pavement required to carry greater wheel loads.

In conclusion, Dr. McLeod said that while Canada has available at the present time methods for designing and evaluating rigid and flexible pavements for both single isolated wheel loads and multiple wheel landing gears these solutions were not considered to be final. The Department of Transport intends to modify, as necessary, the present findings as further test data are obtained.

SUMMARY OF DISCUSSIONS

The meeting was then opened for discussion.

GENERAL CONSIDERATIONS

The effect of weather on pavement. - The question was asked if weather conditions might influence the choice of the type of pavement to be adopted. Both Mr. Cooper and Dr. McLeod expressed the opinion that economic considerations such as the availability and cost of materials and the quality of the subgrade were the predominant factors effecting the choice of the pavement to be used. In Canada, where the temperature ranges from 50° Centigrade (60°F) below zero in winter to a maximum of 43-45° Centigrade (110°-115°F) above in summertime, the only major consideration in the choice of either flexible or rigid pavement is an economic one i.e., which can be built and maintained to carry the load most economically.

Wheel loads. - It was questioned whether an equivalent single isolated wheel load of 45 000 kgs (100 000 pounds) which was the maximum indicated in the present ICAO Annex 14 and which has been regarded as the limiting load for the past few years, was likely to be exceeded with future types of aircraft. Dr. Meara suggested that a gross weight of approximately 180 000 kgs (400 000 pounds) might be anticipated for air cargo aircraft within a few years but that as far as he could determine this load was likely to be distributed in such a manner that the equivalent single isolated wheel load would not exceed 45 000 kgs (100 000 pounds).

Tire Pressures. - The Chairman noted that mention had been made of tire pressures of 14 kgs/sq. cm. (200 lbs/sq. in) and pointed out that the maximum pressure indicated in Annex 14, Attachment "B", Page 76 was 8.5 kgs/sq. cm. (120 lbs/sq. in). He asked for views as to whether or not there was any possibility or thought of going beyond the limit of 14 kgs/sq. cm. (200 lbs/sq. in). Dr. McLeod stated that in Canada they were using this figure for design purposes on the assumption that it would be the normal maximum for the immediate future. He had noted, however, that at a U.S. Navy Symposium in 1952 there was an indication that tire pressure may reach higher values. Mr. Cooper thought it was important to differentiate between civil and military requirements. He felt that manufacturers of civil aircraft would attempt to find the widest possible market for their products and would try to avoid excluding potential purchasers by keeping tire pressures and equivalent single isolated wheel loads within acceptable limits for a large number of aerodromes. He added that in the United Kingdom there was very close liaison between the aircraft manufacturer and the aerodrome constructor through the medium of the Ministries of Supply and Civil Aviation. They had found it possible to keep tire pressure down and also to increase the number of wheels per undercarriage leg since the latest aircraft including both the Comet and Delta wing aircraft provided ample stowage space for accommodating bogey-type wheel arrangements. He mentioned that the tire pressure of the

Comet was not likely to go above 10 kgs/sq. cm (140 lbs/sq. in). Mr. Pascal stated that this was the figure used for design purposes for major aerodromes in France. Dr. Meara stated that several years ago there had been talk of tyre pressures exceeding 21 kgs/sq. cm (300 lbs/sq. in) but that during the war, when a proposal was made to increase tyre pressure by 3.5 kgs/sq. cm (50 lbs/sq. in) to 7 kgs/sq. cm (100 lbs/sq. in), it was found that this change would have added many weeks, or even months, to the time required to construct aerodromes. He believed, therefore, that although it was possible and perhaps desirable from the aircraft manufacturers point of view to construct tyres with higher pressures, considerations such as those mentioned by Mr. Cooper may mitigate against this.

The question was then asked as to what was meant by "tyre pressure", whether it was the actual pressure on the pavement or the pressure in the tyre itself, and how the pressure was affected by the tyre becoming hot due to rolling. Replies indicated that the pressure on the pavement varied from zero at the edge of the tyre tread to a maximum a short distance in from the edge and decreased toward the centre of the contact area. It appeared to be general practice, however, to assume for design purposes, that the tyre pressure as measured by a tyre gauge represented the average pressure on the pavement. No data was available on the changes in pressure due to heating but the opinion was expressed that the rolling time was normally of sufficiently short duration not to cause any appreciable increase in pressure.

Traffic. - It was asked whether the advice given in Annex 14 to design taxiways and aprons to accommodate a single isolated wheel load equal to 125% of that used in designing the main runway was still applicable. The replies indicated that it was, but that States employed different design methods that achieved approximately similar results. Guidance was sought regarding the margin of overload that could be accepted with safety on both flexible and rigid pavements and whether there was any point beyond which aircraft imposing greater stresses should not be accepted. Mr. Hargraves said that, in answer to the last part of the question, it had been decided in the U.K. that under no circumstances should an aircraft in flight be prevented from landing, (irrespective of its weight) and that Air Traffic Control Officers had received instructions to this effect. He said that no attempt had been made to indicate any sort of margin over the declared strength of a runway. Dr. Meara said that some indication of the overload capacity of a runway might be gained from their experience in military airfield construction. It had been found that if a pavement withstood 6 000 specified coverages of the critical aircraft for which it was designed it would stand up indefinitely and was regarded as a permanent pavement. In the case of a flexible pavement, if the thickness is reduced to 80% of the full design thickness it will stand up to approximately 700 coverages. If it is reduced to 50% it will stand 50 coverages and in this case would be regarded as an emergency airfield only.

The term "coverage" was not used to refer to a single operation but represented the following:

4 operations of a large dual tandem wheel heavy bomber
8 operations of a medium bomber
16 operations of a light bomber
25 operations of a light fighter

Mr. Cooper said that in England a flexible pavement that could withstand 1 000 repetitions of the equivalent single isolated wheel load of a particular aircraft was regarded as having unlimited life for all aircraft up to and including that aircraft.

Since the movement of aircraft is spread to some extent over the pavement, the figure of 1 000 could be multiplied by a certain factor to arrive at the probable number of aircraft movements that could be accepted. For example, a factor of about 20 might be applied in the case of an average transport aircraft giving a figure of approximately 20 000 movements for that type of aircraft.

Tests had indicated that higher loads could be accepted for a lower number of repetitions of that load. As an example the U.K, Handbook on the subject indicated that a pavement assessed as LCN 27 i.e., 27 000 pounds E.S.W.L. for unlimited use, would take an aircraft of LCN 72 for a very limited number of applications. In the case of rigid pavements it was a different matter as it was a question of whether the concrete would break or not. It was asked whether any indication could be given of the criteria that could be used to indicate the point at which a runway would become unsuitable for the traffic intending to use it i.e., when the degree of maintenance would become unacceptable. Dr. McLeod said that he was unable to give any quantitative information on the subject but that at a limited number of aerodromes in Canada some difficulties had been encountered during the Spring "break-up" period when the loss of pavement strength was as high as 50% of the normal late Summer or Fall strength. Pending strengthening of the runway, in cases where this was found to be necessary, certain load limitations had been established but it was not the policy of the Canadian Government to impose load limitations. Every effort was made to meet the requirements of year-round operations for all types of aircraft the aerodromes were intended to serve. In the isolated cases where load restrictions had been applied two criteria were used to determine the maximum load that should be permitted on the runway. The first was to prevent the pavement being seriously damaged or destroyed and the second was to avoid danger to aircraft that might break through the surface.

<u>Testing.</u> - It was asked whether any States had developed a very simple method of testing subgrade strength that gave good correlation with the standard but more elaborate tests. Dr. McLeod said that the Canadian Department of Transport had been particularly concerned with the difficulty of transporting heavy testing equipment to aerodromes in inaccessible areas. It therefore decided that, wherever subgrade strength was measured by means of a plate bearing test, four other tests of the same subgrade would be made with lighter equipment in an attempt to establish some correlation between these tests. The four tests were:

(a) The in-place value of the California bearing ratio.

(b) The North Dakota cone bearing test, in which the penetration of a cone into the subgrade, was measured for a series of smaller loads.

(c) The Housel penetrometer test which is based on the load required to drive a sharpened pipe 3.2 centimetres (1-1/4") in diameter, 15.2 centimetres (6") into the subgrade.

(d) The triaxial test made on specimens from the subgrade.

The results showed that a reasonable correlation did exist between all these tests particularly in the case of fine textured soils of the silt and clay types and fine sandy loam types of soil. The correlation was not good in gravel or very stony types of soil. He believed that any of these alternatives could be used in the former types of soils but that the accuracy for a given number of tests would be considerably less than that achieved by a plate-bearing test.

Mr. Cooper said that similar tests had been carried out in England using:

(a) A plate-bearing test with a 66 centimetre (26 inches) diameter plate.

(b) A CBR test.

(c) A small plate-bearing test using a 7.6 centimetre (3 inches) diameter plate.

(d) A cone penetrometer test similar to the North Dakota type.

It had been found, as might be expected, that many more tests were necessary with the smaller equipment to achieve satisfactory mean values. Good correlation had been found between plate-bearing tests and cone penetrometer tests at certain fixed deflections, but as plate-bearing tests were normally carried to failure, it was difficult to establish any correlation between these two tests. Similarly, little correlation could be found between the CBR tests which were made for a fixed penetration value and plate-bearing tests carried to failure. More recent experiments had indicated, however, that there appeared to be a close correlation between these two types of tests when both were carried to failure but further testing was being carried out in an attempt to confirm this.

Subgrade Water Content. - An enquiry was made as to whether measurements had been taken of the water pressure in subgrades at various sites. Mr. Cooper replied that one of the most difficult problems in runway design was to estimate the moisture content likely to exist in the subgrade when the pavement was built. He said that a method had been developed in the U.K. whereby the moisture content of the soil was measured at intervals of 15.2 centimetres (6 inches) from the natural surface down to approximately 3 metres (10 feet) and after taking into account the water table level it was possible to estimate both the moisture content and the water pressure in the subgrade when the pavement was built. He indicated that the method was extremely intricate and that further study of this subject was necessary. He added that some soils were relatively unaffected by changes in moisture content and others - notably of the clay type - were considerably affected. In the case of the latter a very small change in moisture content would produce large variations in the CBR value. Mr. Pascal said that in a limited number of tests in France, it had been found that with subgrades having a high proportion of clay the subgrade appeared to be at or near its plastic limit under pavements that ranged in age from a few months to 18 years. He wondered whether these findings had been confirmed elsewhere. Mr. Cooper replied that this condition had been found in many cases but that further investigation had shown that this was generally due to a break-down in the water proofing of the pavement. He stressed the importance of maintaining an effective seal and indicated that where this had been achieved the estimate of the equilibrium moisture content had been found to be reasonably accurate. The Chairman indicated that tests conducted in Australia had given results similar to those found in France. Dr. McLeod said that tests on a number of airports in Canada had indicated a range of moisture content in the subgrade from 65% to 114% of the plastic limit. Of 11 airports tested 2 of them were above the 100% and the others were 100% or less.

FLEXIBLE PAVEMENTS

California Bearing Ratio. - Turning to the subject of flexible pavements it was noted that the CBR method was used in the design of flexible pavements in Australia, Canada, France, the United Kingdom and the United States and that apparently in Australia, Canada and the United Kingdom it had been found that this method had lead to slightly generous results for pavement thickness. Mr. Cooper was asked whether he could indicate what percentage of saturation had been found in subgrades under existing runways in England. Mr. Cooper replied that it varied greatly and was particularly critical in the case of clay. Small variations in the type of clay appeared to have a greater effect than did the height of the water table. Dr. Meara stated that in recent years in the United States thorough investigations had been made to determine the actual water content of subsoils under runways and that particularly in the case of arid regions, full saturation was no longer assumed.

Mr. Hogan said that in Ireland the CBR method had been used for road work, but not for airports since rigid pavements were normally used in his country. He thought the system was originally developed for highway design purposes as a result of a correlation between these tests and of assessments of highway failures with different subgrades in California.

He believed that at that stage it was valid for loads up to about 3 600 kgms. (8 000 pounds), but that during the war the curves were extended on the basis of accelerated traffic tests to permit of its application to very much larger aircraft loads. He asked whether the curves had been modified since that time or whether, as a result of further experience, it was likely that they may be modified. Dr. Meara said that the curves had been modified as a result of tests carried out subsequent to 1941. Mr. Haan added that in recent years in the United States more attention was being given to soil analysis and particularly to mechanical analysis and to the determination of the plastic index and liquid limits. Separate curves had been developed for subgrade, base and surface design. An evaluation survey of many airports in the United States has recently been completed and it had been found that the curves showed close correlation with the tests. He believed that, as a result of this work, it may be possible in future to reduce sub-base and pavement thicknesses. Mr. Cooper said that in the United Kingdom they had not found the CBR method of design to be unduly conservative provided that the equilibrium moisture content was used. It was standard practice to carry out plate-bearing tests on every new runway constructed in order to measure load classification numbers and the tests had shown a very high measure of agreement with the design figures.

Overlays. - Information was sought on the experience gained with the use of asphaltic concrete as an overlay on existing flexible and rigid pavements. Dr. Meara said that overlay requirements for increasing the bearing capacity of old pavements were being studied in the United States with the intention of developing design curves for this particular application. The new curves would probably be similar to the existing flexible pavement design curves and it was to be expected that the required overlay thickness would vary between 5 cms and 38 cms (2 inches and 15 inches). Tests indicated that, even if the underlying concrete slab was loaded to failure, the top surface may still be in reasonably good condition and able to withstand traffic. This phenomena may result from the decrease in temperature effect on underlying pavement or from the fact that asphalt concrete may, in some cases, have a surprisingly high modulus of elasticity. However, it was not advisable to use very thin overlays, since a gravel base of a certain thickness with a 5 cms to 7.6 cms (2 inches to 3 inches) thick asphaltic concrete layer on the top has better ability to increase the bearing strength of the pavement. It was possible to strengthen even a flexible type of pavement by use of a top layer. For instance, a hot mixed asphaltic concrete layer 5 cm (2 inches) thick will considerably increase the bearing strength of an old 10 cm (4 inches) thick "mixed in place" pavement.

Mr. Cooper said that investigations over the past two years in the United Kingdom had revealed that an overlay of approximately 15 cms (6 inches) practically eliminated temperature effect on the underlying slab, but if the overlay was only 2.5 cms (1 inch) thick, the heat absorbing properties of the black surface increased temperature stresses in the slab. If the overlay was too thin (7.6 cms - 3 inches) or less, thermal expansion and contraction can cause cracking in the overlay surface. This had been significant especially over joints in the underlying pavement. To avoid this a separating layer of 0.3 cms (1/8 inch) of sand or roofing material between the surface itself and the overlay and wide enough to provide isolation for 30 cms (12 inches) on either side of the joint had been used with success.

Permeability. - Information was requested regarding permeability tests on bituminous concrete and whether specifications for bituminous concrete in various countries set limits for permeability or whether it was considered sufficient to specify the degree of compaction. Dr. Meara said that in the United States specifications do not cover permeability, but from experience it had been found that, if the voids can be kept down to about 5% asphaltic concrete was very impermeable and seemed to provide a large measure of protection from the penetration of jet fuel. In the United States stability tests were made to determine strength and density measurements, the degree of impermeability. Mr. Cooper said that from his experience only sand mixes provided a completely impermeable or waterproof asphalt surfacing, but since it was necessary to use a proportion of stone to achieve stability and an acceptable coefficient of surface friction, it was not reasonable to expect 100% impermeability in practice. He added that experiments were being conducted in the United Kingdom with a view to defining a standard degree of permeability which would in fact give a measure of the compaction achieved. Mr. Pascal said that tests in France had indicated that some samples of bituminous concrete with less than 4% of voids had been found to possess a high degree of permeability. Mr. Cooper said that this had also been found to be the case in the United Kingdom in tests made on new surfaces, but that with the kneading action of traffic coupled with particles of clay and dirt being worked into the surface, it had been found that the pavement became much more impermeable after use. There was thus a critical period with a new pavement when there was a possibility of water seeping through it. He believed that the best method of avoiding this was to use a heavy pneumatic-tired roller. Good results had been achieved in the United Kingdom with a 60-ton roller with a tire pressure of 7 kgs/sq.cm (100 lbs/sq.in).

Torsional effects. - It was asked whether aircraft with multi-wheeled undercarriages caused damage to flexible surfaces when such aircraft were turned sharply. Mr. Cooper said that some "gouging-up" of surfaces up to 6-weeks old had occurred with aircraft with undercarriages with four or more wheels, but that the risk of damage from torsional effects seemed to disappear when the surface was more than 3-4 months old.

RIGID PAVEMENTS

Westergaard's Method. - Values of "E" and "k". It was asked whether the Westergaard's Method for pavement design was more or less in general use. Replies indicated that Canada, France, Ireland, Spain, the United Kingdom and the United States used this method with certain modifications. In reply to an enquiry as to whether determination of the "k" value used in this formula was based on a particular moisture content value of the soil, Dr. Meara said that field tests were necessarily carried out at the "in-place" moisture content but that further laboratory tests were made on soaked samples of the soil and the determination of the "k" value took into consideration the selected moisture content of the soil. Mr. Cooper suggested that the "k" value obtained from tests in the United Kingdom normally ranged between 100 and 200 and that this variation had less effect on the final thickness to be chosen for the pavement than did the width of the standard forms available. Mr. Mazen noted that the "k" value was associated with the value of "E" - the modulus of elasticity in Westergaard's formula. He asked for information regarding the values selected for "E" in various countries. Mr. Cooper said that the value of "E" generally varied between 3×10^6 and 6×10^6 pounds per square inch and that very great care was taken in designing the mix to ensure that its strength was at least equal to the design strength based on the assumed value of "E". Dr. Meara felt that the "k" value at times could be significant. Since with a "k" value of 50 and a load of 45 000 kgs (100 000 pounds) on dual wheels 43 cms (17 inches) of concrete would be required and that with a "k" value of 300 and a similar load only 37 cms (14-1/2 inches) of concrete would be needed. Mr. Cooper agreed that the "k" value might be significant in extreme cases but still felt that in general it was relatively insignificant, compared with other factors.

Design cases. - Information was sought regarding which of the following three design cases were normally used (a) the wheel load at the centre of the slab (b) the wheel load at the edge of the slab (c) the wheel load at the corner of the slab and whether any provision was made for the transfer of stress from one slab to the next. Mr. Cooper said that in the United Kingdom the corner case was used and that Tether and Sutherland's modification of Westergaard's formula had been found by tests to give good results. Dr. Meara noted that the United Kingdom used the corner case, the United States Corps of engineers used the edge case and the Portland Cement Association the centre case and that as far as he could determine each of these methods produced from similar results. When asked whether, in the United States, load transfer devices were still used between pavement slabs, Dr. Meara said that they were using them less and less as tests seemed to indicate that most of these devices gave only about a 25% transfer of load which was of the same order as that given by projecting stones etc., normally present in the joints.

Temperature. - Mr. Hogan noted that in Westergaard's theory, the distribution of temperature stress was assumed to be linear and that in certain cases this gave very high values of stress. He asked whether States were using this or some other assumption for the distribution of temperature stresses. Mr. Cooper said that a considerable number of tests had been carried out in the United Kingdom to determine the temperature gradient through concrete pavements under different temperature conditions and to determine the magnitude of deflection of the corners of slabs under such conditions. It had been found that for the temperature conditions in the United Kingdom the maximum temperature gradient from the top to the bottom of the pavement was 1°C per 4.5 cms (1°F per 1 inch) of thickness. The maximum deflection or curling up of the corners of a slab was 0.18 cms (0.07 inch). When a load was applied to a curled up corner of a slab, deflection was considered to occur in two stages. In the first stage, no subbase support was assumed and the slab was considered to act as a pure cantilever. The load necessary to restore it to a level condition was calculated on this basis. The second stage was to calculate, using Westergaard's theory as modified by Tether and Sutherland, the load necessary to deflect the slab to the limiting stress condition assuming it received the full support of the subbase. It had been found that the slab corners normally break at a deflection of about 0.3 cms (0.12 inch). Tests performed in the midday heat of summer (i.e., when the top of the pavement was hottest and the corners had curled down) had indicated load bearing capacities up to twice that obtained under less favourable conditions (i.e., on a cool night after the pavement had been hot and the top had cooled rapidly causing the corners of the slab to curl upwards). In the United Kingdom the bearing values quoted for pavements were normally based on the minimum value assuming the worst combination of temperature and subgrade conditions.

Testing. - In reply to a question regarding the number of tests considered necessary to determine the bearing value of a runway, Mr. Cooper said that in the case of a new pavement where it was known that the control had been good, it was only necessary to carry out tests at intervals of 300 to 400 metres (1 000 to 1 300 feet) along a runway together with additional tests on areas which, for some reason, were suspected of being weak. In the case of older pavements, tests were usually carried out on all areas where there were any indications of cracking, as these areas were usually found to be weakest.

Differential movement of slabs. - Information was sought as to whether States had experienced difficulties due to the differential movement of slabs and whether this had given rise to complaints. Replies indicated that, although a certain amount of differential movement between slabs was relatively common, no complaints had been received. This was probably due to the fact that aircraft were not affected to the same extent by pavement irregularities as were automobiles.

Transfer of stresses. - Mr. Weibel said that in Switzerland every effort was made to transfer loads by means of dowels from one slab to another to prevent differential movement of the slabs. He was interested to know whether experience in other countries had indicated a reduction in the efficiency of the dowels with the passing of time and rusting of the dowels. Dr. Meara said that no such cases had come to his notice. Mr. Cooper said that the main reason why dowels were not used in concrete pavements in the United Kingdom was that concrete was cheaper than steel and it was, therefore, more economical to achieve the acquired strength by increasing the thickness of the slab than to use dowels. It was asked whether any experience had been obtained with special types of joints designed to transfer stresses and whether such devices tended to cause cracking of the slabs with temperature changes. Dr. Meara said that his experience had been limited to highway practice. He had found that it was possible to design a joint which was 100% effective in transfering stresses but that it tended to introduce high stresses due to the restraint imposed against warping.

Prestressing. - Information was sought regarding experiments with prestressed concrete pavement. Mr. Pascal described briefly tests that had been undertaken several years previously at Orly, France, but as full details of these tests have been widely published they have not been repeated in this Circular. Mr. Mazen added that the main object of the tests was to attempt to achieve greater economies by developing a material which was more susceptible to deformation than ordinary concrete and which could, therefore, make greater use of the bearing capacity of the subgrade. He believed that it was a first step towards finding new materials which would solve some of the problems associated with ordinary concrete pavements. Mr. Cooper said that with ordinary concrete pavements he believed there was little purpose in constructing elaborate granular base courses since, to develop its maximum strength, the flexible base course had to be deflected as much as 1.25 cm (1/2 inch) while the concrete slab would break if it was deflected more than about 1/5 of that amount.

Double slab construction. - Reference was made to the double slab construction mentioned by Mr. Cooper in his paper and further information was requested on this type of construction. Mr. Cooper said that it was more expensive than single slab construction and that it was only used in special cases such as where concrete had to be used and where more than 30 cms (12 inches) of concrete were needed and existing forms were not suitable. He pointed out that it did not eliminate the problem of joints and that, under certain conditions, such as in the heat of midday when the top slab was arched upwards in the centre and rested on its four corners on the rigid base, loads applied to the centre of the top slab tended to break it into four quarters. A method of overcoming this was to provide dummy joints of the contraction type to allow cracks to form naturally. Mr. Cooper added that it had been found necessary, in order to avoid sympathetic cracking of the top slab over joints in the lower slab, to separate the top slab from the bottom slab by means of building paper in addition to a layer of bitumen. This provided for the necessary freedom of movement between the slabs. Mr. Pascal added that this type of construction had also been used with success on two runways in France.

Tire wear and co-efficient of friction. - Information was sought regarding any special measures that had been taken to reduce tire wear. Mr. Meara said that experience in the United States had indicated that coarse aggregate in the surface tended to cause rapid tire wear but that moderately smooth surfaces did not create this problem. Mr. Mazen said that experience in France had indicated that, provided that the runway surface was not exceptionally rough, the greatest cause of tire wear was loose debris on the runway and differences in elevations of adjoining slabs in rigid pavements. Mr. Cooper added that experience in the United Kingdom was very similar and that the majority of tires became unserviceable due to cuts rather than to wear. He believed, that runways should be as rough as practicable, consistent with not causing excessive tire wear, in order to provide an adequate co-efficient of friction for braking purposes. The minimum co-efficient of friction accepted in the United Kingdom was 0.5% under wet conditions. This was achieved with a standard top -wearing coat 2.5 cms (1 inch) thick and composed of 50% of stone aggregate ranging from 1.25 cms to 0.47 cms (1/2 to 3/16 inch), and the remainder of sand from 0.47 cms (3/16 inch) down. With concrete the same co-efficient of friction was achieved by allowing the surface to remain as it was left behind the finishing screed. Dr. Meara asked whether any equipment had been developed in the United Kingdom for measuring the co-efficient of friction of the surface of runways. Mr. Cooper said that there was a large amount of data available from tests made on highways by means of a motor bicycle with a side-car attachment in which the wheel of the side car was set at a slight angle to the direction of travel and the skidding resistance was measured. This machine was, however, only capable of travelling at speeds up to 48 kilometres per hour (30 miles per hour). Mr. Cooper was of the opinion that the co-efficient of friction might decrease at higher speeds particularly under wet conditions due to planing action over the water. A form of motor car with a central offset wheel was being developed and it was hoped that data would soon be available indicating the effect, if any, of speed on the co-efficient of friction. Mr. Weibel enquired about the practice used in Canada to reduce the dangers of skidding on frozen surfaces. Dr. McLeod replied that the normal practice was to apply sand to the centre third of the runway throughout its length and that no salts were used.

In closing the meeting the Chairman expressed his thanks to all who participated in the meeting and in particular to Mr. Cooper, Dr. Meara and Dr. McLeod. He felt that, despite early opposition to a discussion of this type at a Divisional Meeting, this experiment had proved successfull.

- END -

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