Airport Runway Design and Evaluation in Canada

Dessin et calcul de pistes d'atterrissage au Canada

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Summary

A chart of design curves for the thicknesses of flexible pavement required for aeroplane wheel loads on single tires is presented, based on the design equation $T = K \log P/S$. A method of design for the thicknesses of flexible pavement required for aircraft loads on multi-wheel landing gear assemblies is included, by means of which the equivalent single wheel load can also be determined.

A comparison is made between measured pavement supporting values versus supporting values calculated on the basis of the design equation, and very good agreement is shown.

For rigid pavement design, a method is presented for calculating the subgrade modulus k_b at the surface of any given thickness of granular base, when the subgrade modulus k_s for the underlying subgrade is known.

Sommaire

Se basant sur la formule $T = \log P/S$, l'auteur présente des abaques destinés à déterminer les épaisseurs de dallage flexible requises lorsque la charge de l'avion est répartie sur des roues à pneu unique. Cette communication présente également une méthode de calcul pour déterminer les épaisseurs de dallage flexible requises lorsque la charge de l'avion est répartie sur des trains d'atterrissage à roues multiples. On peut aussi déterminer par cette méthode la charge équivalente sur une seule roue.

La comparaison entre les valeurs mesurées de la résistance du dallage et les valeurs obtenues par les formules proposées montre une bonne correspondance.

Pour le calcul des dallages rigides, une méthode nouvelle permet de déterminer le coefficient d'infrastructure k_b à la surface d'une épaisseur quelconque de fondation granulaire, lorsque le coefficient d'infrastructure k_s est connu.

Flexible Pavement Design for Single Wheel and Multi-Wheel Landing Gear

In a paper for the Second International Conference on Soil Mechanics, an equation for obtaining the thickness of flexible pavement required to carry any wheel load over any subgrade was described (*N. W. McLeod*, 1948). This design equation has resulted from the analysis of many hundreds of plate bearing tests made on the runways at Canadian airports (*N. W. McLeod*, 1947, 1947A, 1948, 1948A, 1948B, 1949). The design equation is:

$$T = K \log P/S \quad \quad (1)$$

where T = required thickness of flexible pavement in inches,
P = the gross single wheel load in pounds to be carried on a runway or taxiway,
S = the total measured subgrade support in pounds for the same contact area, deflection (vertical deformation under load), and the number of repetitions of load that pertain to the design load P,
K = the base course constant, which is an inverse measure of the supporting value of the flexible pavement per unit of thickness, and which varies directly with the size of the contact area.

For the same contact areas, the load applied to a circular bearing plate on the surface of a paved runway, which causes 0.5 inch deflection after 10 repetitions, appears to correspond closely with the heaviest aeroplane wheel loads that the runways at Canadian airports have been supporting in constant service over a period of years. Consequently, this has been adopted as the criterion for the design of flexible pavements for runways for capacity operations.

Fig. 1 is a design chart for required thickness of flexible pavements for airport runways for single wheel loads for capacity operations, utilizing Equation (1). The curves designating required thickness for runways are based upon 0.5 inch deflection, while those for taxiways employ a deflection of 0.35 inch. This is roughly equivalent to designing taxiways, aprons, and the turnaround areas at the ends of runways for 20 per cent greater load than runways.

With slight modifications to account for differences in tire pressures where they occur, the runway design curves of Fig. 1 can be rearranged as shown in Figs. 2 and 3, the tire pressure being 100 p.s.i. for Fig. 2 and 200 p.s.i. for Fig. 3. The curves as shown in Figs. 2 and 3 can be used directly for runway design

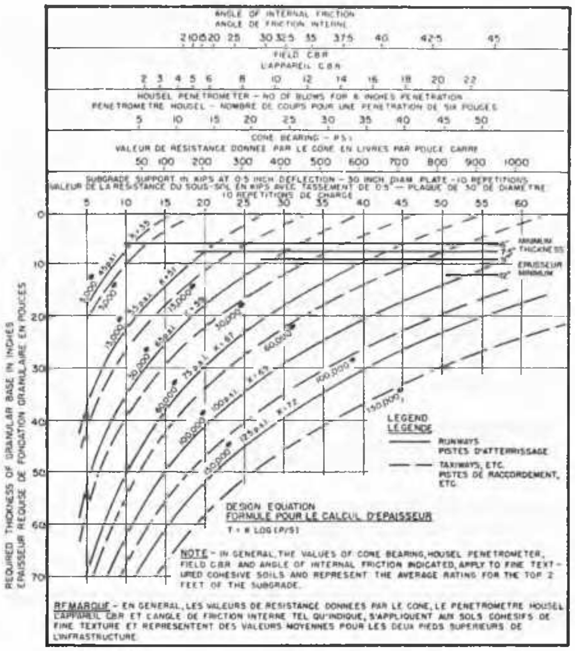

Fig. 1 Design Curves for Flexible Pavements for Runways and Taxiways, etc. for Aeroplane Wheel Loadings (Full Load on Single Tire)
Abaques pour le calcul de revêtements flexibles adaptables aux pistes d'atterrissage, de raccordement, etc., la charge par roue de l'avion étant donnée (charge totale sur pneu unique)

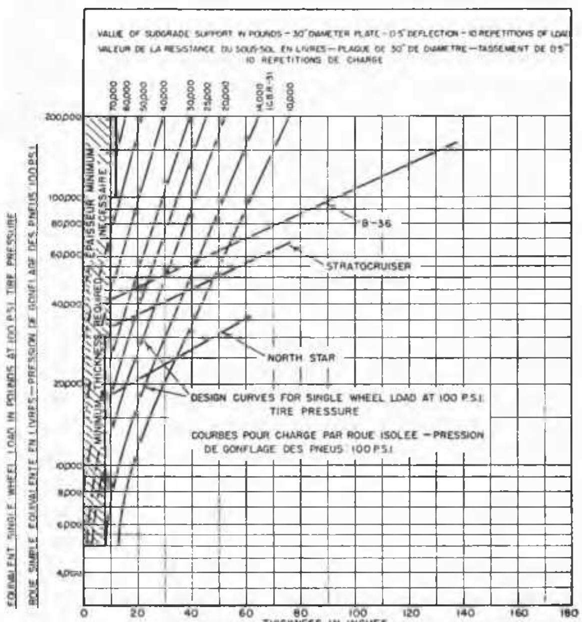

Fig. 2 Flexible Pavement Design and Evaluation Chart for Single-Wheel and Multiple-Wheel Landing Gear Assemblies (Tire Pressure 100 P.S.I.)
Abaques pour détermination de l'épaisseur des pistes pour roue unique ou pour roues multiples (pression de gonflage des pneus 100 P.S.I. = livres par pouce carré

or evaluation for isolated single wheel loads. In addition, Figs. 2 and 3 can be employed for either the evaluation or design of flexible pavements for runways for aircraft with dual tires, dual tandem, or other multi-wheel landing gear. They also enable the single wheel load equivalent to that applied by dual tires or dual tandem wheels to be evaluated. By using a load factor of 1.20, Figs. 2 and 3 can also be employed for the design and evaluation of flexible pavements for taxiways, aprons, and turnarounds for loads applied by either single wheel or multi-wheel landing gear.

The use of Figs. 2 and 3 for runway design and evaluation for multi-wheel landing gear is based upon an approach suggested by *Boyd* and *Foster* (1949), and illustrated by Fig. 4, in which d is the minimum clear distance between the contact areas of dual or dual tandem tires, while s is the spacing between the centres of the contact areas of dual tires, and the diagonal distance between the centres of the contact areas of dual tandem tires. Studies by *Boyd* and *Foster* (1949) have indicated that $d/2$ is the maximum thickness of pavement at

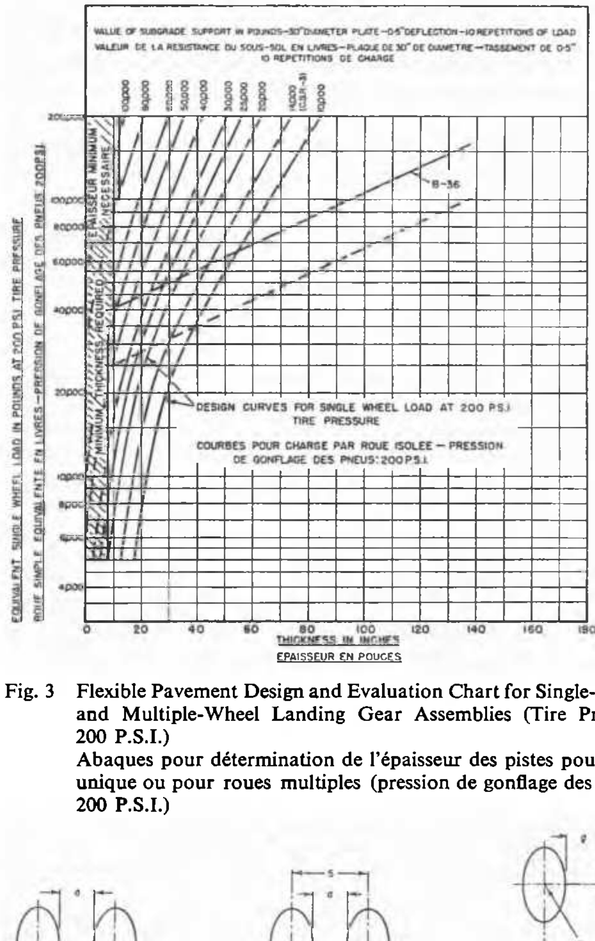

Fig. 3 Flexible Pavement Design and Evaluation Chart for Single-Wheel and Multiple-Wheel Landing Gear Assemblies (Tire Pressure 200 P.S.I.)
Abaques pour détermination de l'épaisseur des pistes pour roue unique ou pour roues multiples (pression de gonflage des pneus 200 P.S.I.)

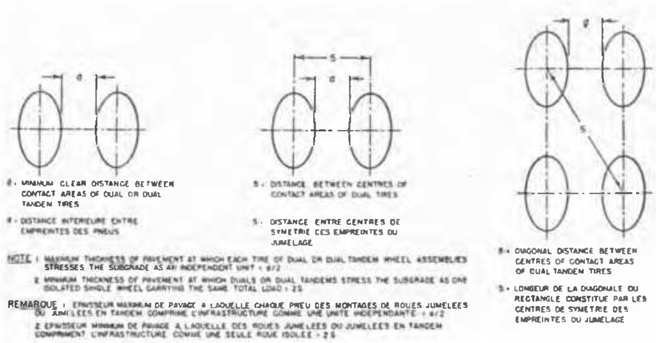

Fig. 4 Diagram Illustrating Dimensions of Contact Areas that Control Thicknesses of Pavements at which Dual or Multiple Wheel Assemblies Stress the Subgrade as Independent Units and as one Isolated Single Wheel Carrying the Same Total Load
Diagramme montrant les dimensions des surfaces de contact sur la base desquelles sont déterminées les épaisseurs des revêtements. Montages de roues jumelées ou multiples sollicitant l'infrastructure, soit en tant qu'unités indépendantes, soit en tant que roue unique portant la même charge totale

which each wheel of dual or dual tandem tires stresses the subgrade as an independent unit, while $2s$ is the minimum thickness of pavement at which either a multi-wheel landing gear or one isolated single wheel carrying the same total load applies equal stress to the underlying subgrade.

In Fig. 2, points having coordinates corresponding to a thickness of $d/2$ and the load carried by each wheel of the multi-wheel landing gear are plotted on the left hand side of the chart for the B-36, Stratocruiser, and Trans-Canada Airlines' North Star. For example, since the North Star applies a load of 36,000 pounds on dual tires, the coordinates of this point are $d/2 =$ 9 inches, wheel load $= \frac{36{,}000}{2} =$ 18,000 lbs. Similarly, the points corresponding to a thickness of $2s$ and the total load carried by the dual or dual tandem, etc. wheel assembly are plotted on the right hand side of the chart for the same aircraft. For the North Star, for example, the coordinates of this point are $2s$ = 61.5 inches, wheel load = 36,000 lbs. These two points for each aircraft are joined by a straight line, as shown in Figs. 2 and 3.

The curved lines in Fig. 2 and 3 illustrate the relationship between subgrade support, pavement thickness, and isolated single wheel load. The straight lines in these charts indicate the thicknesses of flexible pavement required to carry the multi-wheeled landing gear assemblies of the aircraft indicated, for the various degrees of subgrade support represented by the curved lines. For example, for the B-36 with a load of 161,000 pounds on dual tandem tires, at an inflation pressure of 200 p.s.i., Fig. 3, if the subgrade bearing value is 20,000 pounds on a 30-inch diameter plate at 0.5 inch deflection for 10 repetitions of load, the point of intersection of the straight line labelled "B-36" with the curve for subgrade support marked 20,000 pounds shows that a pavement thickness of 34 inches is required.

Fig. 3 also shows that a runway with a subgrade support of 20,000 pounds and a pavement thickness of 34 inches will carry a load of about 52,000 pounds on an isolated single tire inflated to 200 p.s.i. Consequently, a runway with a subgrade bearing value of 20,000 pounds on a 30-inch plate at 0.5 inch deflection after 10 repetitions, and with a flexible pavement thickness of 34 inches, will support either an isolated single wheel load of 52,000 pounds, or a load of 161,000 pounds on the dual tandem tires of the B-36, both at an inflation pressure of 200 p.s.i. For these particular conditions of pavement thickness, subgrade support, and tire inflation pressure, an isolated single wheel load of 52,000 pounds is equivalent to 161,000 pounds on dual tandems.

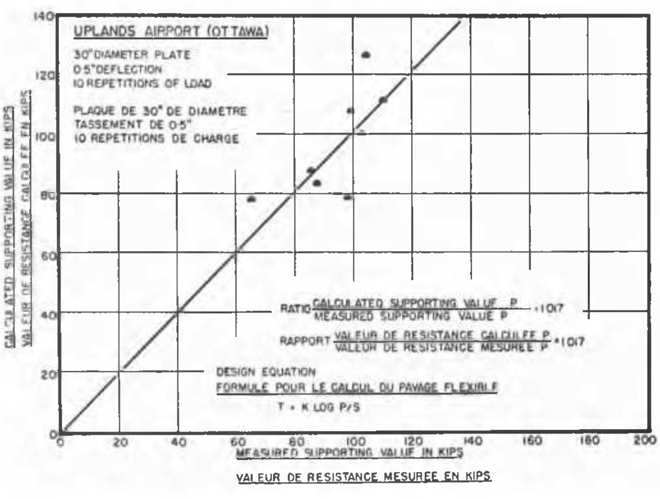

Fig. 5 Uplands Airport (Ottawa). Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation
Aéroport de Upland, Ottawa. Portance mesurée des pistes d'atterrissage comparée à la même valeur calculée selon la formule pour le calcul du revêtement flexible

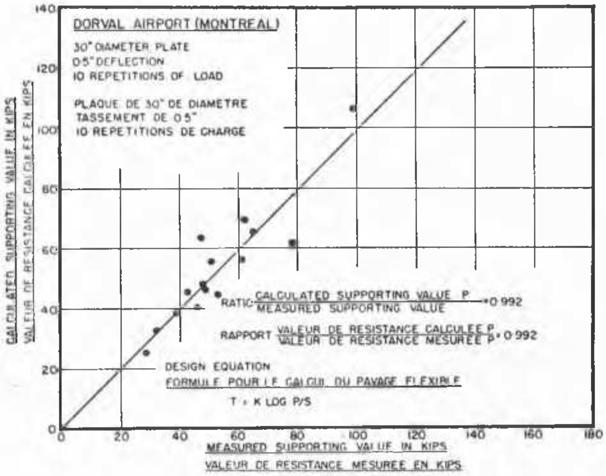

Fig. 6 Dorval Airport (Montreal). Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation
Aéroport de Dorval, Montréal. Portance mesurée des pistes d'atterrissage comparée à la même valeur calculée selon la formule pour le calcul du revêtement flexible

Figs. 2 and 3 can also be employed to establish the maximum load on any specified multi-wheel landing gear that any given flexible pavement can support. Suppose, for example, that the pavement thickness is only 23 inches, instead of 34 inches for the same subgrade bearing value of 20,000 pounds for 0.5 inch deflection after 10 repetitions. Fig. 3 shows that this pavement would support an isolated single wheel load of only 29,000 pounds, and that it would not, therefore, sustain capacity operations of the B-36 with a load of 161,000 pounds on dual tandem tires. Through the point of intersection of the curve for a subgrade supporting value of 20,000 pounds for 0.5 inch deflection after 10 repetitions with the ordinate representing a pavement thickness of 23 inches, draw a line parallel to the straight line labelled B-36. This is the broken line in Fig. 3. This broken line intersects the thickness ordinate of 138 inches at a wheel load of 100,000 pounds. This is interpreted to indicate that a runway with a pavement thickness of 23 inches and a subgrade supporting value of 20,000 pounds at 0.5 inch deflection after 10 repetitions would carry the B-36 at capacity operations only if the load on its dual tandem landing gear were reduced from 161,000 pounds to 100,000 pounds.

Verification of the Flexible Pavement Design Equation

The supporting value of the pavement, P, the subgrade supporting value, S, and the overall thickness of base course and surface, T, were measured at test locations at a considerable number of airports, and the base course constant K has been evaluated for various bearing plate sizes (*N. W. McLead*, 1948 A, 1949). Consequently, both measured and calculated data are available for checking the accuracy of Equation (1), $T = K \log P/S$, to determine how closely it represents the actual data, and whether it is likely to lead to either serious overdesign

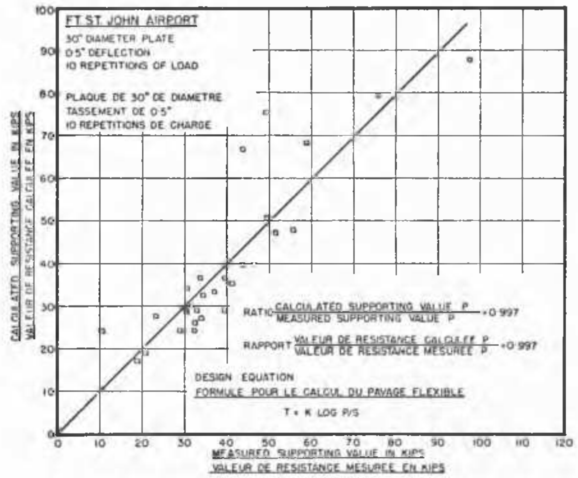

Fig. 7 Fort St. John Airport. Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation
Aéroport de Fort St-John. Portance mesurée des pistes d'atterrissage comparée à la même valeur calculée selon la formule pour le calcul du revêtement flexible

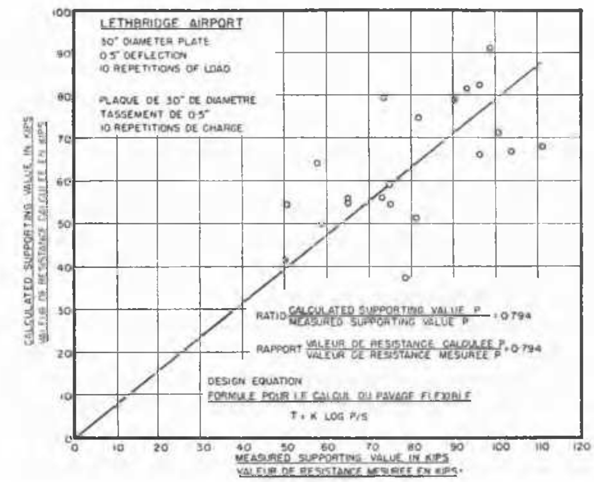

Fig. 9 Lethbridge Airport. Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation
Aéroport de Lethbridge. Portance mesurée des pistes d'atterrissage comparée à la même valeur calculée selon la formule pour le calcul du revêtement flexible

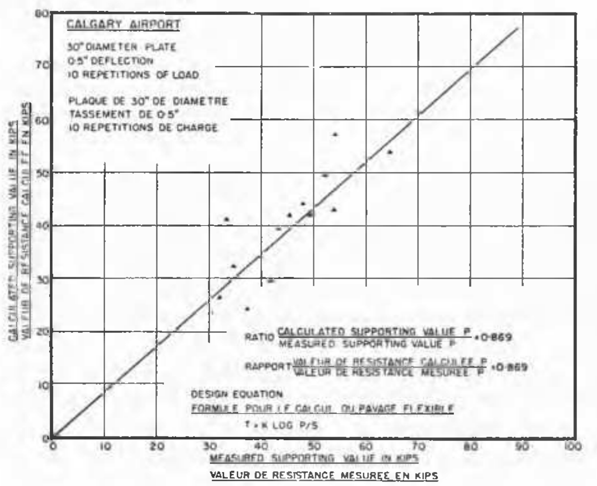

Fig. 8 Calgary Airport. Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation
Aéroport de Calgary. Portance mesurée des pistes d'atterissage comparée à la même valeur calculée selon la formule pour le calcul du revêtement flexible

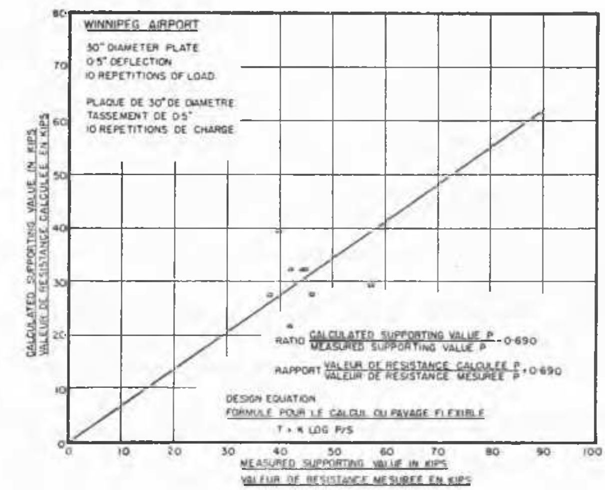

Fig. 10 Winnipeg Airport. Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation
Aéroport de Winnipeg. Portance mesurée des pistes d'atterrissage comparée à la même valeur calculée selon la formule pour le calcul du revêtement flexible

or underdesign. Measured values of P are provided by plate bearing tests on the finished pavement. Calculated values of P are obtained by substituting measured values for S, T, and K in Equation (1) and calculating P which is the only unknown.

Figs. 5 to 11 are employed for this purpose. The comparison of calculated with measured values of P given in these figures is restricted to data obtained with the 30-inch diameter bearing plate, since many more tests have been made with it than with any other bearing plate size. For a 30-inch bearing plate, the value of K to be employed is $K = 65$ (*N. W. McLeod*, 1947A, 1948A, 1948B, 1949). From plate bearing tests on pavement surface, base course, and subgrade, and from the measured thicknesses of pavement and base course, it was determined that 1 inch of asphalt pavement was equivalent in supporting value to 1.5 inches of granular base as a conservatively average ratio, except in the case of Dorval Airport at Montreal, where this ratio was 2.5. For Figs. 5 to 11, the overall measured thickness T of base course and surface was corrected to equivalent thickness of granular base by applying these ratios to the asphalt pavement thickness.

Figs. 5 to 11 represent the extreme range of values found for the ratios of calculated versus measured values for P for the 16 airports for which the necessary information is available. The best straight line drawn through the data of each of Figs. 5 to 11 was obtained by the method of least squares. These figures indicate that the ratio of the calculated values of P versus the actual measured values of P range from a low of 0.69 for Winnipeg to a high of 1.017 for Uplands Airport at Ottawa.

The certain scattering of data in Figs. 5 to 11 is to be expected for several reasons. At each test site on a runway, the plate bearing test on the subgrade was made at a distance of from 10 to 18 feet from the load test on the pavement surface, in order that the former would not be influenced by the latter. As anyone familiar with soil testing is aware, considerable difference in subgrade strength sometimes occurs over this distance, even for subgrades that appear to be homogeneous. Errors in measuring the actual thicknesses of base course and asphalt surface can be made. The thicknesses of base course and surface were measured at the excavation made for the subgrade load test, and were assumed to apply at the location of the corresponding surface load test, but some variation in these thicknesses was possible over the 10 to 18 feet separating the subgrade and surface load test locations. With these various points in mind, the scattering of data in Figs. 5 to 11 is probably less than might have been anticipated.

In Fig. 11, an overall comparison between calculated and measured values for P is listed for over two hundred test locations for the 16 airports for which the necessary data have been obtained. It should be particularly noted that the data of Fig. 11 cover pavement supporting values ranging from about 10,000 pounds to over 100,000 pounds; that is, from quite weak to very strong runways. The actual flexible pavement thicknesses (base course plus asphalt surface) to which the data of Fig. 11 pertain varied from about 5 to about 30 inches. The overall average ratio of 0.899 for calculated versus measured values for P provided by Fig. 11 indicates that on the average Equation (1) leads to 10.1 per cent overdesign. Consequently, Fig. 11 seems to provide satisfactory verification of the overall accuracy and general utility of Equation (1) for airport runway design and evaluation.

Figs. 5 to 11 illustrate two particularly instructive facts. First, if only the subgrade supporting value S had been available for each of these airports, the use of Equation (1), $T = K \log P/S$, would not have led to underdesigning any one of the 16 airports for which data are available by more than 1.7 per cent, Fig. 5 for Uplands Airport at Ottawa, while the maximum degree of overdesign would have been 31 per cent, Fig. 10 for Winnipeg Airport.

Secondly, Figs. 9 and 10, for which the ratio of calculated to actual supporting value is considerably less than unity, indicate the advantage of developing construction techniques that

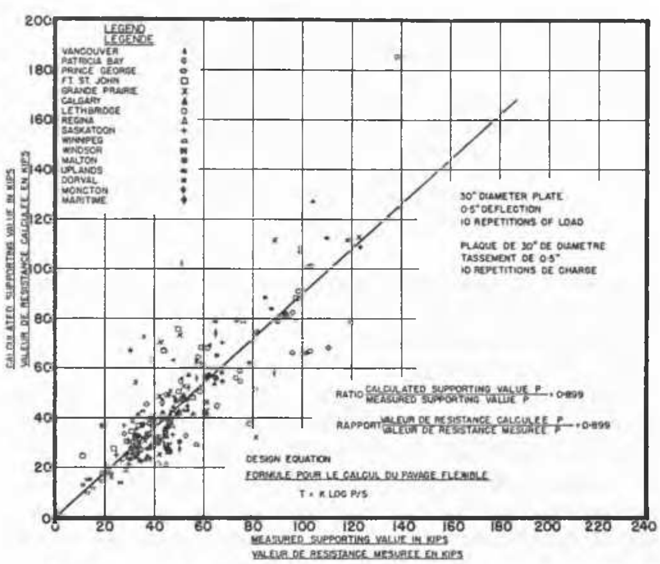

Fig. 11 Measured Runway Supporting Values Versus the Supporting Values Calculated by Means of the Flexible Pavement Design Equation for the Sixteen Airports for which these Data are Available
Portance mesurée des pistes d'atterrissage de seize aéroports comparée à la même valeur calculée selon les formules de calcul pour revêtements flexibles

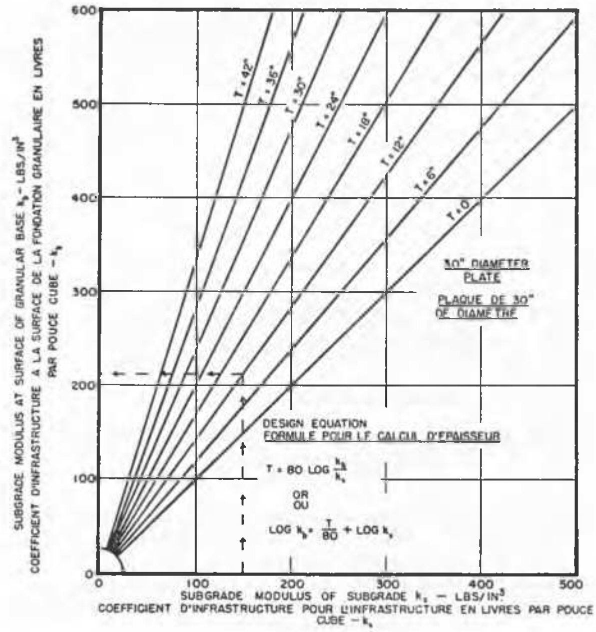

Fig. 12 Design Curves Giving the Value of the Subgrade Modulus k_b at the Surface of a Well Compacted Granular Base Course, when the Subgrade Modulus k_s of the Underlying Subgrade has been Measured
Courbes donnant la valeur du coefficient d'infrastructure k_b à la surface d'une couche de fondation granulaire bien consolidée, le coefficient d'infrastructure k_s pour l'assise ayant été mesuré

will result in base courses with greater supporting value per unit thickness. It is believed that the ratio of calculated versus actual supporting values is appreciably less than unity for Figs. 9 and 10, because the supporting value of the granular base per unit thickness is higher than normal due to greater density resulting from better compaction, or to the use of base course materials of higher stability, etc.; that is, the value of the base course constant K employed for these two figures should be less than 65. As a matter of fact, if a value of $K = 40$ were employed in Equation (1), and applied to the data of Fig. 10, the ratio of calculated to actual supporting value P would be unity. Since the value of K is an inverse measure of the supporting value of the base course per unit thickness, a value of $K = 40$ represents a base course of considerably higher strength per unit thickness than does a value of $K = 65$. Higher strength in this case probably means greater ability to spread the applied load over the subgrade. Greater compactive effort applied to the base course during construction may be the simplest, least expensive, and most effective method of lowering the K value of the base course in many cases.

For a general design equation a conservative value for K must be employed to avoid underdesign on those projects where only average base course materials are employed, or where only average care may be taken in base course construction. Fig. 5 to 11 indicate that $K = 65$ appears to be sufficiently conservative for this purpose based upon data obtained with a bearing plate 30 inches in diameter. It should be noted that the value of K varies with plate diameter and a value of $K = 35$, for example, has been determined for a 12-inch bearing plate (*N. W. McLeod*, 1948 A).

Subgrade Modulus for Rigid Pavement Design

For the design and evaluation of rigid pavements for runways for single and multi-wheel aircraft landing gear, the Department of Transport is guided by the recent publication of the Portland Cement Association on this subject (*PCA*, 1950). However, since the slab thicknesses recommended in this brochure are considered to be greater than necessary, they are reduced to more nearly conform with the lesser thickness requirements of earlier publications of the Portland Cement Association (*PCA*, 1942).

In rigid pavement construction, a granular base course is frequently placed between a cohesive subgrade and the pavement slab. This raises the problem of determining what the subgrade modulus k_b at the top of any given thickness of granular base course will be, if the subgrade modulus k_s for the underlying subgrade has been measured. The subgrade modulus k_b or k_s is usually expressed in units of pounds per square inch per inch of vertical deformation, and is calculated from the load supported by a 30-inch diameter bearing plate at 0.05 inch deflection.

Graphs of actual data obtained with a 30-inch bearing plate at 0.05 inch deflection after 10 repetitions of load on the subgrade and on the surface of 7, 14, and 21 inches of granular base course are given in an earlier publication (*N. W. McLeod*, 1948 A). These data provide the following relationship between the thickness of granular base T, k_b, and k_s,

$$T = 80 \log k_b/k_s \qquad (2)$$

The similarity between Equation (2) and Equation (1) is quite apparent.

Fig. 12 is a graph of Equation (2) and it provides the value of the subgrade modulus k_b at the surface of any given thickness T of well compacted granular base, if the value of the subgrade modulus k_s for the underlying subgrade has been measured. For example, if the measured subgrade modulus for the subgrade $k_s = 150$ lbs./in²/in., the dashed lines and arrows on Fig. 12 indicate that the construction of a granular base course 12 inches thick will increase the value of the subgrade modulus to $k_b = 212$ lbs./in²/in.

If a loose, poorly compacted granular base course is employed, the supporting value, k_b, furnished for a rigid pavement by any given thickness of granular base course, may be even smaller than that of the underlying subgrade, k_s. It cannot be too strongly emphasized, therefore, that Equation (2) and Fig. 12 will only apply to a granular base course that has been thoroughly compacted.

Acknowledgments

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