Relationships between applied loads, surface defections, traffic volumes, and thicknesses of flexible pavements / Relations entre les charges appliquées, les fléchissements en surface, les volumes de circulation, et les épaisseurs des revêtements souples

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OTTAWA
JANUARY 1962

PREFACE

The Fifth International Conference on Soil Mechanics and Foundation Engineering was held in Paris, France, from 17 to 22 July 1961. The first such conference was held in 1936 as a part of the tercentenary celebrations of Harvard University, Cambridge, Mass. The incidence of war necessitated the gap of twelve years between the first two meetings. The second conference was held in Rotterdam in 1948, and the third was held in Zurich in 1953. The fourth was held in London in 1957.

Seven Canadians were present at the Harvard meeting. This number has increased over the years and over 25 were present at the conference in Paris. The Associate Committee on Soil and Snow Mechanics of the National Research Council is pleased to publish the reprints of the eleven Canadian papers which were included in the official proceedings.

The International Society of Soil Mechanics and Foundation Engineering is composed of national sections. The executive body for the Canadian Section is the Associate Committee on Soil and Snow Mechanics of the National Research Council. The principal function of the Canadian Section is to assist in the further development and application of soil mechanics throughout Canada. Enquiries with regard to its work will be welcome; they may be addressed to the Secretary, Associate Committee on Soil and Snow Mechanics, National Research Council, Ottawa 2, Canada.

Robert F. Legget,
Chairman.

Ottawa
January 1962

Relationships Between Applied Loads, Surface Deflections, Traffic Volumes, and Thicknesses of Flexible Pavements

Relations entre les charges appliquées, les fléchissements en surface, les volumes de circulation, et les épaisseurs des revêtements souples

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Summary

On the basis of the Canadian Department of Transport's load test data, a method for calculating the surface deflection of an existing flexible pavement under a loaded rigid bearing plate is described. When all other factors are equal, the surface deflection depends upon (a) the thickness of flexible pavement, and (b) the subgrade strength. For any specified traffic volume (less than unlimited) of a given design wheel load and tire inflation pressure, the permissible surface deflection when measured by means of a rigid bearing plate carrying the same total load and unit pressure, must be varied with the strength of the underlying subgrade. This implies that for flexible pavements not strong enough to carry unlimited traffic, a given Benkelman beam deflection under a specified wheel load does not indicate the same ability to carry traffic, if the strengths of the underlying subgrades are different.

Sommaire

Une méthode basée sur les données des essais de chargement du Département des Transports du Canada est décrite. Elle permet de calculer le fléchissement en surface d'un revêtement flexible déjà construit en le soumettant à un essai avec une plaque rigide de chargement. Lorsque tous les autres facteurs sont égaux, le fléchissement en surface dépend (a) de l'épaisseur du revêtement flexible et (b) de la résistance du sol de fondation. Pour n'importe quel volume de circulation spécifié (moindre qu'illimité) d'une roue ayant une certaine charge, le pneu étant gonflé à une pression donnée, le fléchissement admissible en surface change avec la résistance du sol de fondation lorsque ce fléchissement est mesuré au moyen d'une plaque rigide de chargement portant la même charge totale, à la même pression unitaire. Ceci suggère que pour des revêtements flexibles qui ne sont pas assez résistants pour supporter une circulation illimitée, un fléchissement donné, tel qu'indiqué par la poutrelle de Benkelman, sous une charge sur roue spécifiée, n'indique pas la même aptitude à supporter la circulation, si la résistance des sols de fondation est différente

By convention, "*h*" is the symbol ordinarily used to indicate the thickness of a portland cement concrete pavement slab. In this paper therefore, the symbol "*T*" has been used to indicate total thickness of flexible pavement above the subgrade. This includes the thickness of sub-base, base course, and bituminous surface. The symbols "*h*" and "*T*" have been used in this way in the new book by E.J. Yoder, "Principles of Pavement Design", published by John Wiley and Sons Inc.

Introduction

A number of methods are currently employed to determine the thicknesses of flexible pavements required to support various wheel loads over subgrades of widely different strengths. Emphasis is usually placed on thickness requirements for unlimited traffic, for example, Fig. 1. However, the Canadian Department of Ttransport [1] has recommended the following thickness reductions for three lesser categories of traffic volume :

(a) light traffic — 50 per cent of the thickness for unlimited traffic.

(b) medium traffic — 75 per cent of the thickness for unlimited traffic

(c) heavy traffic — 90 per cent of the thickness for unlimited traffic.

The Asphalt Institute [2] also employs this method for reducing flexible pavement thickness requirements with respect to traffic volumes. The U.S. Corps of Engineers uses a similar approach [3].

Establishing Relationships Between Load, Thickness, Surface Deflection, and Traffic Volume

Analysis of the data from many hundreds of plate bearing tests conducted by the Department of Fransport, has led to the method to be described in this paper for calculating the deflection of a loaded rigid bearing plate on the surface of a flexible pavement for any combination of load, thickness, and subgrade strength. The required items of information for this purpose are:

(a) The P/A ratio diagram of Fig. 2.

(b) average relationships between loads and deflections for rigid bearing plates, Fig. 3. (Note, due to the uncertainties of extrapolation, Fig. 3 is probably not very accurate for deflections larger than 1·5 inch.)

(c) the thickness design equation $T = K \log \frac{P}{S}$.

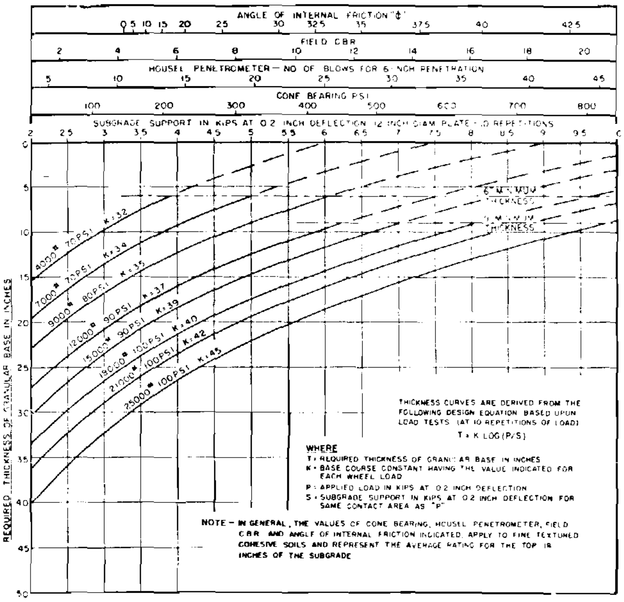

Fig. 1 Design curves for flexible pavements for highway wheel loadings for highest traffic capacity (single wheel).

Abaques donnant l'épaisseur des revêtements flexibles en fonction des charges pour des routes ayant une circulation maximum (une seule roue).

(d) relationship between base course constant K and bearing plate diameter, Fig. 4.

Suppose for example, a flexible pavement is to be designed to just support light traffic (50 per cent of the thickness required for unlimited traffic) by a wheel load of 10,000 lb. at 70 p.s.i. tire inflation pressure. The subgrade strength is 2,800 lb. on a 12-inch bearing plate at 0·2 inch deflection for 10 repetitions of load (in-place C.B.R. = 3). Calculate the surface deflection of this flexible pavement under a rigid bearing plate carrying 10,000 lb. at 70 p.s.i.

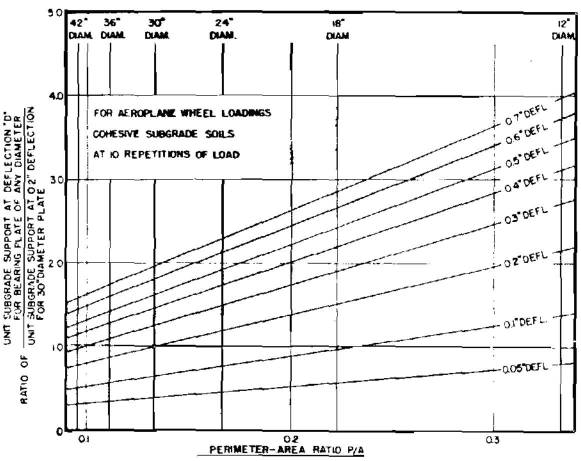

Fig. 2 Ratio of subgrade support at deflection " D " for bearing plates of any diameter over subgrade support at 0·2″ deflection on 30 inch. diameter plate versus perimeter area ratio.

Rapport entre le support du sol de fondation au fléchissement " D " pour des plaques de chargement d'un diamètre quelconque et le support du sol de fondation au fléchissement de 0·2 pouce pour une plaque de 30 pouces de diamètre en fonction du rapport entre le périmètre et la surface.

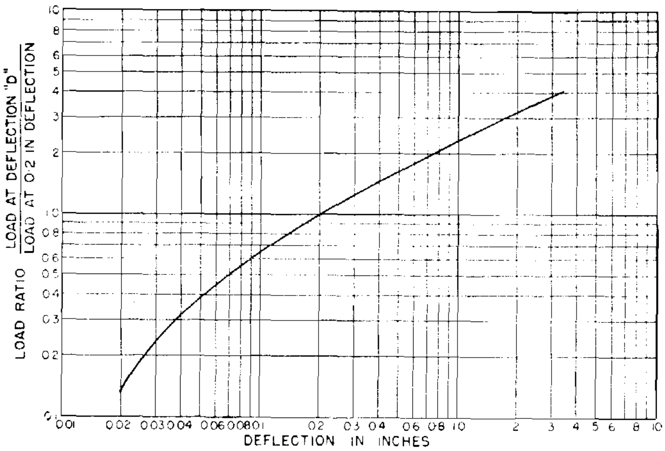

Fig. 3 Average relationship between load and deflection for rigid bearing plates.

Relation moyenne entre la charge et le fléchissement pour des plaques de chargement rigides.

Step 1 The contact area for a wheel load of 10,000 lb. at 70 p.s.i. inflation pressure is approximately equivalent to a circle with a radius of 6·74 inches and a P/A ratio of 0·297, Fig. 2.

Step 2 Subgrade support of 2,800 lb. on a 12-inch bearing plate (P/A ratio = 0·333) corresponds to a unit pressure of 24·7 p.s.i.

Step 3 A unit load of 24·7 p.s.i. for a P/A ratio of 0·333 corresponds to a unit load of 22.5 p.s.i. for a P/A ratio of 0·297, both at 0·2 inch deflection, Fig. 2.

Step 4 For unlimited traffic by a wheel load of 10,000 lb. at 70 p.s.i. tire pressure, and for the subgrade strength given, the thickness requirement is 18 inches, Fig. 1.

Step 5 50 per cent of this thickness requirement is 9 inches, which will just support a light volume of traffic by a 10,000 lb. wheel load over this subgrade.

Step 6 Substituting in the design equation, and solving for P, (K = 37 from Fig. 4), P = 39·4 p.s.i.

Step 7 Therefore, a 13·48 inch diameter rigid bearing plate on a flexible pavement thickness of 9 inches over this subgrade will support only 39·4 p.s.i. at 0·2 inch deflection

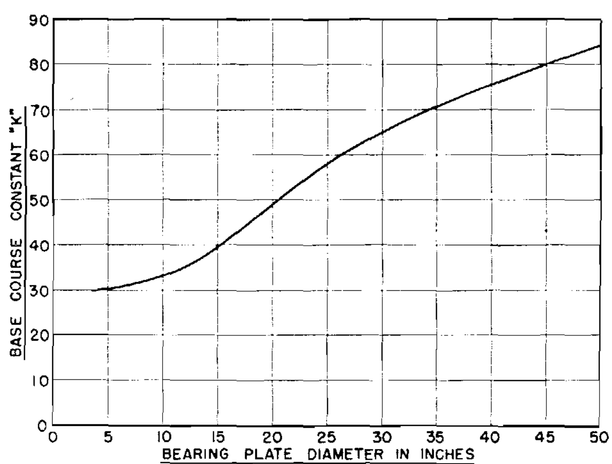

Fig. 4 Influence of bearing plate diameter on value of " K " in flexible pavement design equation.

Influence du diamètre de la plaque de chargement sur la valeur de " K " dans l'équation pour le calcul de l'épaisseur d'un revêtement flexible.

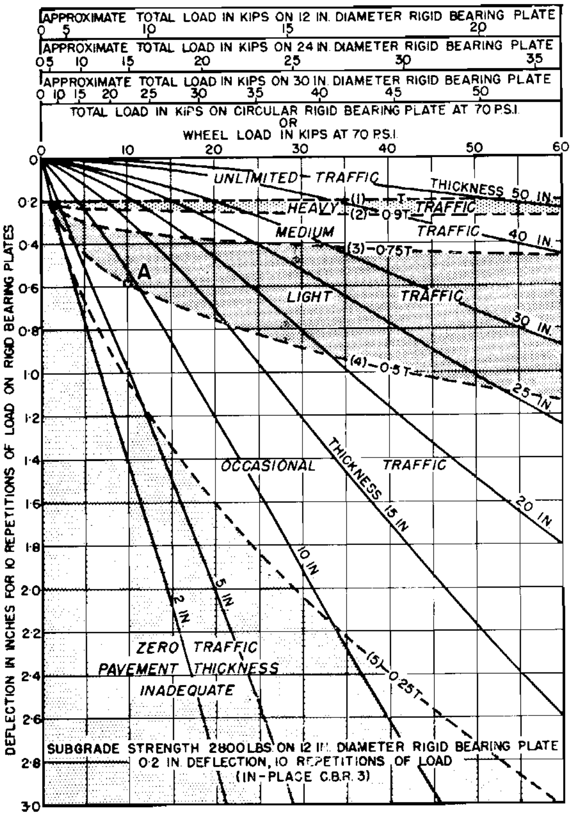

Fig. 5 Interrelationship between load, surface deflection, flexible pavement thickness, and traffic volume category (weak subgrade).

Relations entre la charge, le fléchissement en surface, l'épaisseur du revêtement flexible, et la catégorie de volume de circulation (sol de fondation de faible résistance).

for 10 repetitions of load. However, the deflexion under a unit load of 70 p.s.i. is required.

Step 8 For a load ratio of $\frac{70}{39 \cdot 2} = 1 \cdot 78$, a deflection of 0·59 inch will occur, Fig. 3.

Consequently, on this weak subgrade, for a flexible pavement thickness (9 inches) that is only 50 per cent of that required for unlimited traffic by a wheel load of 10,000 lb. at 70 p.s.i. inflation pressure, the calculated surface deflection under a rigid bearing plate, loaded to 10,000 lb. at 70 p.s.i., is 0·59 inch for 10 repetitions of load, Point *A* in Fig. 5.

Surface deflections can be calculated by this procedure for other applied loads, other categories of traffic volume, and for any specific thickness of flexible pavement. For a relatively weak subgrade supporting only 2,800 lb. on a 12-inch bearing plate at 0.2 inch deflection for 10 repetitions of load (in-place CBR = 3), the chart of Fig. 5 is obtained. Fig. 6 is a similar diagram based upon a subgrade of medium strength capable of supporting 5,600 lb. on a 12-inch bearing plate at 0·2 inch deflection for 10 repetitions of load (in-place CBR = 10).

In Figures 5 and 6, the horizontal line through a surface deflection of 0·2 inch, numbered "1" and labelled "*T*", indicates the thicknesses of flexible pavement required for unlimited traffic by the wheel loads shown. The broken line curves numbered 2, 3, and 4, and labelled 0·9*T*, 0·75 *T*, and 0·5*T*, show the minimum thicknesses needed for the heavy, medium, and light categories of traffic for each wheel load listed along the top of the diagram.

In 1950, the Corps of Engineers published a diagram [3] relating flexible pavement thickness to traffic volume for airport runways, which implies that about 18 per cent of the thickness required for unlimited traffic by any specified wheel load will support just one coverage (one trip) of that wheel load without causing pavement failure. Curve 5, labelled 0·25*T*, in Fig. 5 and 6, is somewhat more conservative than the Corps of Engineers' finding, and assumes that 25 per cent of the thickness needed for unlimited traffic by a given wheel load, Fig. 1, will, support just one trip by that wheel load without causing failure of the pavement. Therefore, flexible pavement thicknesses to the left of curve number 5 (0·25*T*) in Figs. 5 and 6, are in the zero traffic category.

The solid line curves crossing the diagrams of Fig. 5 and 6 from upper left toward lower right pertain to specific thicknesses of flexible pavement, and have been labelled 5 inches, 10 inches, etc.

Figs 5 and 6, therefore indicate relationships between total loads at 70 p.s.i. on a rigid bearing plate, deflections for 10 repetitions of load, flexible pavement thicknesses, and categories of traffic volume. It is assumed that the loads on rigid bearing plates in this case are identical with the wheel loads at 70 p.s.i. tire inflation pressure that can be supported for each traffic category shown.

Figs 5 and 6 are restricted to unit pressures of 70 p.s.i. For any given total load, higher and lower unit pressure than 70 p.s.i. will provide higher and lower deflections respectively, than those shown in Fig. 5 and 6, when all other factors are equal.

Along the tops of Figs 5 and 6, corresponding total loads on 12-inch, 24-inch, and 30-inch diameter bearing plates are shown. The relationship is approximate, and the size of

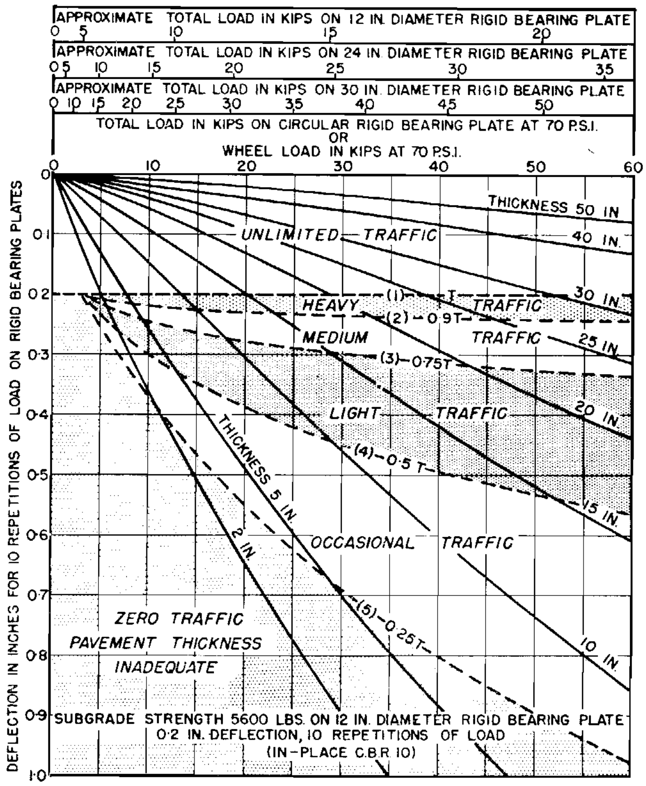

Fig. 6 Interrelationship between load, surface deflection, flexible pavement thickness, and traffic volume category (medium strength subgrade).

Relations entre la charge, le fléchissement en surface, l'épaisseur du revêtement flexible, et la catégorie de volume de circulation (sol de fondation de résistance moyenne).

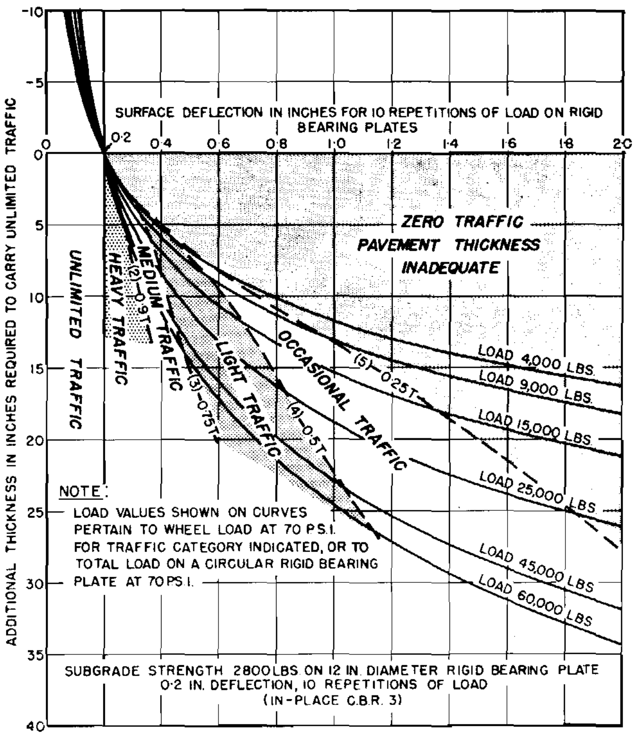

Fig. 7 Interrelationship between load, surface deflection, and additional thickness required to improve an existing flexible pavement from a lower to the unlimited traffic category (weak subgrade).

Relations entre la charge, le fléchissement en surface et l'épaisseur additionnelle requise pour améliorer une route existante de façon à la faire passer d'une circulation réduite à une circulation illimitée (sol de fondation de faible résistance).

bearing plate selected should be that nearest the actual size of the contact area for the design wheel load and tire inflation pressure specified.

For deflections exceeding about 2·0 inches in Fig. 5, the data may not be significant, since the Hybla Valley investigation [4] indicated that deflections larger than these tend to be above those associated with the ultimate strength of the layered system represented by a flexible pavement structure.

Figs 7 and 8, which are derived from Figs 5 and 6 respectively, indicate the additional thickness of flexible pavement required to upgrade the traffic carrying capacity of an existing flexible pavement from a lower traffic volume rating for a specified wheel load to the unlimited category. The change in surface deflection accompanying this improvement in capacity to carry more traffic can also be read off directly from Figures 7 and 8. For example, Fig. 7 shows that to raise the traffic volume category for a 15,000 lb. wheel load at 70 p.s.i., tire inflation pressure from the lower limit of the light traffic category band, to the unlimited rating, an additional thickness of 11·8 inches of granular base or equivalent must be placed on an existing flexible pavement over this weak aubgrade (in-place CBR = 3). At the same time, the surface deflection under a rigid bearing plate loaded to 15,000 lb. at 70 p.s.i. would decrease from 0·68 to 0·2 inch.

The Benkelman beam, which was invented in 1953 (5), or some modification of its principle, is being employed by a number of organizations to investigate the strength of existing flexible pavements. A Benkelman beam deflection in the vicinity of 0·02 to 0·03 inch for the design wheel load (5,6) is believed to indicate that a flexible pavement will carry unlimited traffic of this wheel load or equivalent. Weaker flexible pavements showing higher Benkelman beam deflections for the design wheel load, for example 0·06 inch, are considered adequate for only some smaller traffic volume category.

There is a current tendency to assume that all weaker flexible pavements that exhibit the same Benkelman beam deflection, for example 0·05 inch, have the same traffic volume rating with respect to a specified wheel load.

Figs 7 and 8 warn that this assumption may be in serious error. For example, Fig. 7 indicates that for a surface deflection of 0·4 inch under a rigid bearing plate loaded to 9,000 lb. at 70 p.s.i., an existing flexible pavement over a weak subgrade (in-place CBR = 3) will support light traffic by a wheel load of 9,000 lb. at 70 p.s.i. tire inflation pressure. On the other hand, Fig. 8 shows that for a surface deflection of 0·4 inch under a rigid bearing plate loaded to 9,000 lb. at 70 p.s.i., a flexible pavement over a subgrade of medium strength (in-place CBR = 10) will support less than one coverage of a wheel load of 9,000 lb. at 70 p.s.i. tire inflation pressure, that is, its traffic category is zero for this wheel load. This difference in traffic volume ratings for weaker flexible pavements having the same surface deflection is much greater for wider differences in the strength of the underlying subgrades.

Figs 7 and 8 suggest that for a given design wheel load, *the permissible Benkelman beam deflection* at the surface of an existing flexible pavement for any specified traffic volume category less than unlimited *must be varied with the strength of the underlying subgrade.*

Figs 7 and 8 indicate that all weak flexible pavements having the same surface deflection under a given loaded rigid bearing plate, require the same additional thickness of granular material or equivalent to upgrade them to the unlimited traffic category for the same wheel load. This

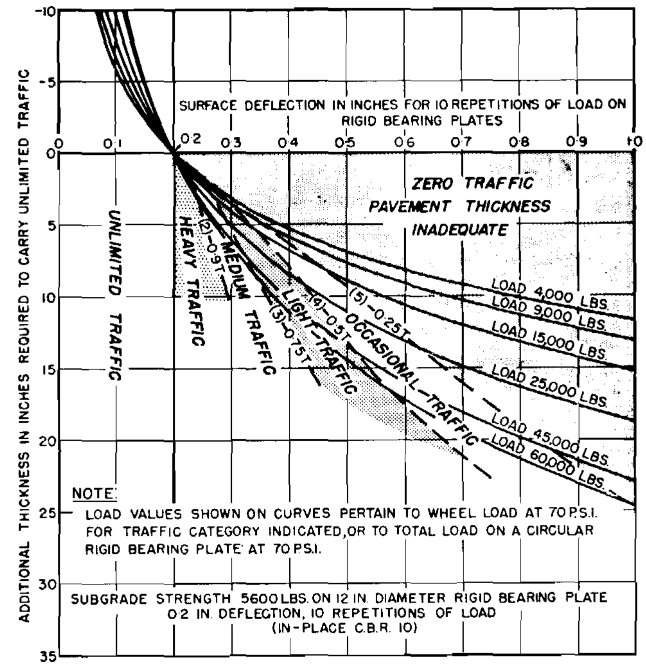

Fig. 8 Interrelationship between load, surface deflection, and additional thickness required to improve an existing flexible pavement from a lower to the unlimited traffic category (medium strength subgrade).

Relations entre la charge, le fléchissement en surface et l'épaisseur additionnelle requise pour améliorer une route existante de façon à la faire passer d'une circulation réduite à une circulation illimitée (sol de fondation de résistance moyenne).

implies that this can also be expected for existing weak flexible pavements that show the same Benkelman beam deflections.

Figs 5, 6, 7, and 8 pertain to highway traffic. Similar diagrams can be prepared for airport runway design. Furthermore, Figs 1 to 8 are based on load test data for Canadian soils, and somewhat different relationships may be found elsewhere.

Limitations of space prevent additional comments on Figs 5, 6, 7, and 8.

Acknowledgments

This paper represents part of an extensive investigation of airports in Canada that was begun by the Canadian Department of Transport in 1945. Air Vice-Marshall A. de Niverville, Director-General Air Services, has the general administration of this investigation. It comes under the direct administration of Mr. Harold J. Connolly, Director, Air Services Construction, and Mr. George W. Smith, Chief Engineer. In their respective territories, the investigation is carried on with the cooperation of Regional Construction Engineers G. T. Chilcott, V. E. Currie, L. Millidge, R. A. Bradley, R. L. Davies, and W. G. D. Stratton.

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