SUB-SECTION VIII b

METHODS OF FLEXIBLE PAVEMENT DESIGN

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THE SHEAR STRENGTH METHOD OF THE DETERMINATION OF PAVEMENT THICKNESS

R. GLOSSOP
B. Sc. A.M. Inst. C.E.
H.Q. GOLDER
M. Eng. A.M. Inst. C. E.

The following method of determining pavement thickness was developed by the authors while engaged on air-field construction in 1942 and 1943, and was originally published in 1944. 1). The method was developed in order to distinguish between failures due to incorrect design, and those due to faulty workmanship. It is based on a comparison of strength with stress, and is thus capable of extension to include more accurate solutions of the stresses in particular cases, and improved methods of measuring strength, as they become available.

The approach to the problem is that of foundation engineering, since the authors' previous experience was in heavy foundations, rather than in road construction. Soft and firm saturated clays of Tertiary or Pleistocene age are widespread in the south of England and the method as originally developed is particularly suited to them, for it ignores the possible effects of consolidation and elastic deformation, and assumes that beneath an impermeable cover no appreciable softening of the sub-soil will occur. Field observation justifies these assumptions, for such soils. In its original form the use of the method is limited to flexible or non-tensile pavements, resting on saturated clay, for which it can be assumed that $\phi = 0$ in immediate shear; but good agreement has also been obtained with failures of unreinforced concrete slabs, and the method has now been extended to frictional soils 2), and a technique developed which allows for the softening of the soil due to rise of ground water or other causes.

It was realised from the first that there existed a large number of factors which might influence the problem, but that to take account of them all would probably make its solution lengthy and exceedingly difficult. It was therefore decided, guided by commonsense and some previous experience of foundation problems, to make several rather drastic simplifying assumptions, and to check their validity by the observation of actual failures. These assumptions were:

1) That the effects of the tensile strength of the pavement in distributing the load on the sub-grade could be ignored, though it could be assumed that the pavement itself would not fail in shear.
2) That the load could be assumed to be applied as a uniform pressure over a circle equal in area to the impress pattern of a type of the largest vehicle for which the pavement is intended.
3) That a Boussinesq distribution of stress could be assumed, both in the pavement and the sub-grade.

From 3) it was obvious that the maximum vertical pressure on the sub-grade would depend on the thickness of the pavement, and the required thickness would be that restricting this maximum pressure to some critical value which would be a function of the shear strength of the soil. Three possible criteria were chosen for this limiting value.

1) $p < \pi s$
Where p is the maximum pressure in the sub-grade, and s the shear strength of the soil
2) $p_m < \pi s$
Where p_m is the mean pressure over the surface of the sub-grade.
3) As a third criterion, Hencky's 3) value for the ultimate bearing capacity ($5.64\,s$) was taken and a factor of safety of 3 applied to the mean pressure over the surface of the sub-grade.

These criteria were then checked against actual failures in the following way. Auger holes were put down at points of failure and on adjacent areas where no failures had occurred, and undisturbed samples of clay 1½" diameter and 3" long were taken. The unconfined compressive strength of the samples was measured in a portable apparatus and the shear strength was assumed to be half this value.

A graticule was drawn with stress as abcissae and depth below, the surface as ordinates, and on it were plotted the curves representing the three criteria, and also the shear strengths of the samples at their correct depths. It was found that the curve for $s = p/\pi$ clearly differentiated between points of failure and points of no failure. Accordingly this expression was adopted for purposes of design.

This method of design has since been checked against many failures, both of roads and runways, by the authors and by other investigators, and has always proved satisfactory. However subsequent experience has led to the adoption of a fourth criterion for design. This is, that the maximum shear stress in the sub - grade shouls not exceed the shearing resistance of the soil. This criterion was first suggested to the authors by L.F. Cooling, and later by G.G. Wilson and A.H.D. Markwick. It is a more logical criterion and gives slightly better agreement with observed failures. It has however a more important advantage, first pointed out by A.W. Skempton, in that the shear strength (modified if necessary to allow for possible softening) can be compared directly with the shear stresses as calculated by any rational method, including the case of layers of material with different Young's Moduli.

When the method was first developed the Boussinesq solution was the only one known to the authors for the calculation of the stresses in the subgrade. They have since learnt that a solution for the stresses in a largest sustem was published by A.H.R. Hogg in 1938. 4)

Since then L. Fox following Burmister 5) has calculated the shear stresses below the centre of a circular loaded area supported by a two layer elastic system, the two layers having different Moduli of Elasticity. This work is reported in a paper to this Conference. It is now possible therefore to determine more accurately the maximum shear stress in the soil below either a concrete pavement or a compact subgrade of gravel or stabilised soil.

For the original problem, i.e. pavements on saturated clay soils, the unconfined compression test proved satisfactory as a measure of shear strength. But for cases in which it is possible for the soil to soften after the construction of the pavement, due to seasonal variations in the level of the water table, flooding or any other cause, it is obvious that some other technique of measuring shear strength must be used. To meet this need the authors have developed a method of carrying out triaxial compression tests and box shear tests on material which has been allowed to soften before test. The technique can be applied to undisturbed or remoulded soils and is described by A.L. Little in a paper to this conference, Skempton has developed a somewhat similar technique in which undisturbed samples are allowed to soften under different overburden pressures and are then tested in triaxial compression. Using this technique in conjunction with Fox's shear stress curves he found, in designing a runway on clay soils that the authors' method of determining pavement (including sub-base) thickness gave good agreement with the C.B.R. method, which is an empirical method based on experience and tests of actual pavements to destruction.

In the above case, the soil, although a partially saturated clay in its natural state, proved to be a $\phi = 0$ material after softening. The case of frictional materials is more difficult to solve since it is not possible to make a direct comparision between stress and strength, as strength is not a constant, but varies with the effective pressure on the plane of shear. A development of the method to the case of frictional materials has been published 2) and is capable of extension to c,ϕ materials such as unsaturated stabilised subgrades.

The problem is again treated as a foundation problem and the tensile strength of the pavement is neglected. The pavement is assumed to spread the applied load to a mean uniform vertical pressure which acts on the subgrade. The angle of spread θ can be taken as 45° or it can be chosen to conform with the Boussinesq pressure distribution ($26\frac{1}{2}^\circ$), or with the mean pressure given by the stress distribution in a two layer system, if this should become available. This gives an expression for the pressure on the sub-grade in the terms of the thickness of the pavement. This pressure is equated to the ultimate bearing capacity of the sub-grade divided by a factor of safety, the weight of the pavement being treated as a surcharge. An expression is thus obtained which can be solved for t, the thickness of pavement required, the other variables being:

a) the factor of safety of sub-grade (F)
b) size and shape of loaded area and the applied pressure.
c) unit weight of soil in sub-grade γ .
d) unit weight of pavement (assumed as surcharge) γ_p .
e) angle of spread of load in pavement θ .
f) angle of friction of sub-grade, and cohesion if any, (the coefficients N_γ, N_q, N_c, in Terzaghi's Formula).

For example for a rectangular area of width b and length a, loaded with a pressure p the expression is (see figure 2):

$$F=\frac{\frac{1}{2}\gamma N_\gamma(b+2t\tan\theta)+\gamma_p t N_q+cN_c}{pab}(a+2t\tan\theta)(b+2t\tan\theta)$$

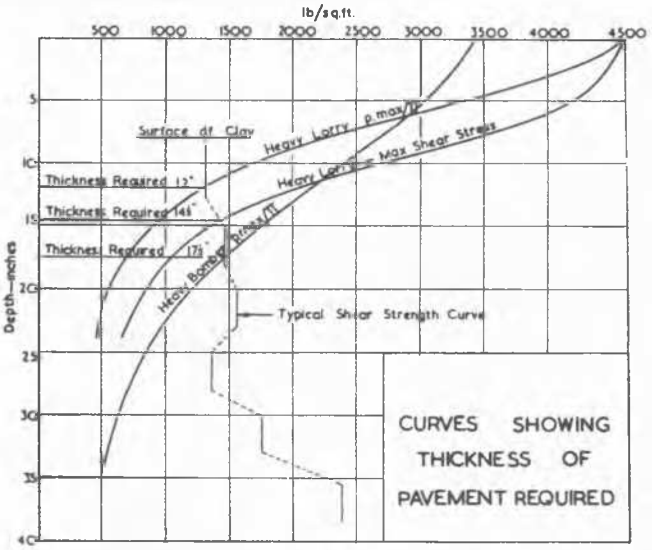
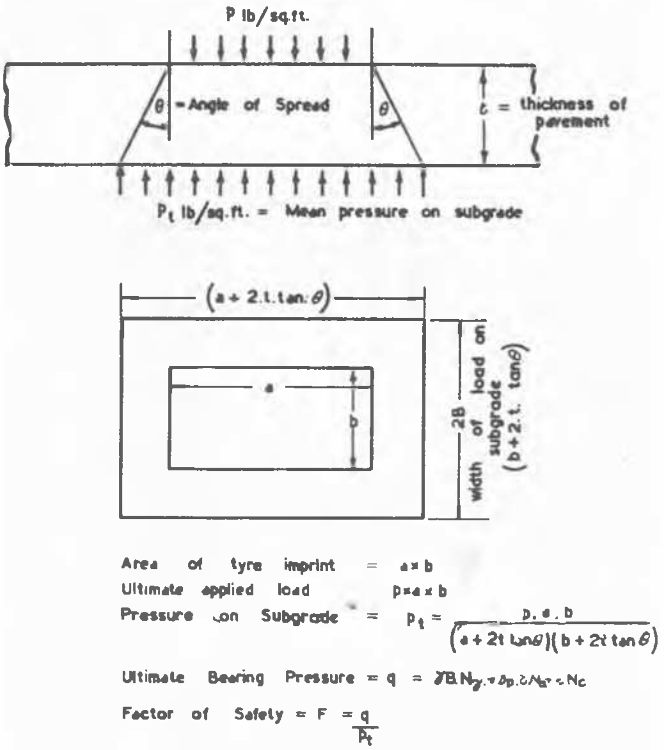


FIG. 1



Spread of load through pavement

FIG. 2

From this expression a curve can be drawn relating F & t for any given conditions of loading and soil properties.

The ultimate bearing capacity of the sub-grade was calculated from Terzaghi's formula 6) which was checked by loading tests on footings 1 ft. and 2 ft. square on sand, and found to give good agreement. Any other formula for bearing capacity can of course be used if desired.

Using the Boussinesq pressure distribution and Terzaghi's formula for bearing capacity the method gives very interesting results, but unfortunately it has not been possible to check it against failures of pavements on frictional sub-grades, as such failures are rare.

TABLE I

Thickness of Pavement Required. - Comparison of Methods.

Methods.

I. Westergaard.
II. California Bearing Ratio.
III. Glossop & Golder - clays.
IV. Golder - sands.

Soils

1. Soft clay s = 400 k = 100 C.B.R. 3
2. Stiff clay s = 2000 k = 500 C.B.R. 5 - 15
3. Loose sand φ = 32° k = 200 C.B.R. 8 - 15
4. Dense sand φ = 38° k = 700 C.B.R. 40 - 80
5. Firm sandy clay.
(c, φ) c = 500 φ = 25° k = 300 C.B.R. 20 - 30

Loads. International Loadings - Ottawa Conferences.

A	150,000 lb.	(wheel load	120 lb/in²
B	100,000 lb.	"	100 "
C	60,000 lb.	"	100 "
D	30,000 lb.	"	85 "
E	15,000 lb.	"	70 "
F	10,000 lb.	"	60 "

Method	Load A. Soil					Load B. Soil					Load C. Soil					Load D. Soil					Load E. Soil					Load F. Soil				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
I	14½"	13½"	14"	13"	14"	12½"	9½"	11½"	8½"	11"	10½"	8"	9½"	7½"	9"	7½"	5½"	7"	5"	6½"	5"	4"	5"	3½"	4½"	4½"	3"	4"	3"	3½"
II	70"	50" -20"	35" -20"	11" -7"	18" -13"	59"	42" -20"	31" -20"	11" -7"	16" -13"	47"	34" -17"	25" -17"	9" -6"	14" -11"	35"	25" -13"	19" -13"	8" -4"	11" -9"	25"	19" -10"	14" -10"	6" -4"	9" -7"	21"	18" -9"	12" -9"	5" -3"	8" -6"
III	95"	35"	-	-	-	78"	28"	-	-	-	60"	22"	-	-	-	39"	14"	-	-	-	27"	8½"	-	-	-	22"	6"	-	-	-
IV	-	-	18½"	7½"	10½"	-	-	14½"	6½"	7"	-	-	14½"	7"	6"	-	12"	12"	5½"	3"	-	-	10"	5"	1½"	-	-	8½"	4"	½"

NOTES.

1. k = Modulus of Sub-grade Reaction in Method I in lb/in³
2. Thicknesses for Method I are for the centre of the slab and are obtained from Tables published by the U.S. Portland Cement Association, Chicago. Dec. 1941.

In Table I the thicknesses given by this method are compared with those given by other methods for a range of soils and loads. The results are of the same order as those obtained by the Westergaard method, but the method bases on bearing capacity is much more sensitive to the effect of soil properties.

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AN INVESTIGATION OF AIRPORT RUNWAYS IN CANADA

NORMAN W. McLEOD
Engineering Consultant
Department of Transport,
Ottawa, Canada

1. INTRODUCTION.

The design and construction of airports and highways in Canada is materially influenced by the airport and highway engineering practice of our great neighbour to the south. However, the experience of the principal engineers of Canada's Department of Transport during the past ten years, has indicated that the methods for determining pavement thicknesses for airport runways, which are being currently advocated by some of the principal organizations in the U.S.A., are unnecessarily conservative. In particular, it is felt that pavement thickness design based upon the California Bearing Ratio (C.B.R.) rating of soaked subgrade samples could not ordinarily be justified for airport runway construction in Canada. That airports with relatively thin pavements throughout Canada, have for several years successfully carried wheel loads that are several times their safe carrying capacity according to some U.S.A. designs, is indicated in Table I for representative airfields. Because of the publicity that was given to their method of airport runway design during the World War just concluded, and their published reports on the large scale investigations which they have made in this field, it is common practice to compare runway experience and design elsewhere with that which is advocated by the U.S. Corps of Engineers. It is for this reason that their design requirements are listed in Table I as the yardstick for comparison with Canadian experience.

TABLE I

Traffic data for Montreal, Toronto, Winnipeg and Lethbridge Airports.
From January 1. 1941 to January 31, 1947.

Airport	Overall thickness pavement and base Inches	Average C.B.R. value Soaked subgrade samples	Wheel load rating U.S. Corps of Engineers design curves	Actual traffic data to nearest full thousand Number of operations of aircraft weighing more than				
				7,500 lbs.	15,000 lbs.	25,000 lbs.	50,000 lbs.	64,000 lbs.
Montreal x)	14	3.1	5000			211.000	89,000	23,000
Toronto	8 to 10	3.5	2000 (approx)	299,000	79,000	41,000	3.400	3,000
Winnipeg	(8"-2 rwys. (14"-1 rwy.	3.3	2000) 5000)	319,000	96,000	25,000	several	hundred
Lethbridge x)	6 to 8	4.6	2000 (approx.)	229,000	35,000	4,400	several	hundred

x) Traffic data for period January 1, 1942 to January 31, 1947.