A METHOD OF DESIGN OF NON-RIGID PAVEMENTS FOR HIGHWAYS AND AIRPORT RUNWAYS

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SYNOPSIS

This paper presents a method for arriving at the proper thickness of the non-rigid type of pavement surface to support a given wheel load carried on a given type of tire equipment By means of tests made in the laboratory by the use of a bin 6 ft sq , the manner of distribution of subgrade pressures has been determined under different thicknesses of from 4 to 10 in. of pavement surface Loads were applied by means of a hydraulic jack to elliptical shaped bearing blocks simulating tire imprint areas It is assumed that a non-rigid pavement should be of such thickness that the maximum pressure obtained under the center of the wheel should at no time exceed the bearing value of the subgrade

A method is suggested for determining bearing value, making use of a bearing block of 100 sq in in area Formulas are derived for thickness, first making the arbitrary assumption that the subgrade pressures are confined within an area on the subgrade included within the lines sloping 45 deg. from the tire imprint area The uniform pressure is then expressed in terms of the actual measured pressure, which in turn is assumed to be equal to the subgrade supporting value. Thus, formulas are derived for thickness in terms of wheel load, subgrade supporting value and the dimensions of the imprint area of the tire These dimensions are known for given loads, tire equipment and inflation pressures

As the result of the formulas thus derived, thickness may be determined after a pressure test is made to determine the supporting power of the subgrade For general purposes of design, the pressure tests indicate that the maximum measured pressure under stable, non-rigid surfaces may be taken at from 2 to 2½ times the uniform pressure calculated as above indicated On this basis, curves for the required thickness are shown in terms of wheel-load and subgrade support.

INTRODUCTION

At the outset let it be emphasized that the thoughts expressed in the present article are tentative and may have to be revised as additional knowledge on the design of the non-rigid road becomes available. It is believed, however, that the method of design herein described will enable the practical highway engineer to determine the thickness of a non-rigid road surfacing required to safely, yet economically, support a given wheel-load.

By the non-rigid type of road surfacing is meant that type which ordinarily is not thought capable of developing resistance to bending under load. The present method is a simple generalization of the National Crushed Stone Association subgrade pressure test results into a design theory which may be applied in a practical manner, provided only that a determination be made of the bearing value of the supporting subgrade.

HOW SUBGRADE PRESSURES ARE DISTRIBUTED

In a previous article[1] it was shown that the pressures on the subgrade produced by elliptically shaped bearing blocks, having areas identical with the areas of contact between pneumatic tires and the road surface, are not uniform pressures, but, to the contrary, they are pressures which are of highest intensity directly under the center of application of load and are distributed in accordance with a bell-shaped curve over a considerable area on the subgrade directly under the

[1] A T Goldbeck, Studies of Subgrade Pressures "Under Flexible Road Surfaces," *Proceedings*, Highway Research Board, Vol. 19, p 164 Also *Crushed Stone Journal*, Nov-Dec 1938

load. The longitudinal distribution due to a motor truck wheel-load may extend over a total length of four feet or more with a somewhat lesser distribution laterally because of the elliptical shape of the area of contact. Under a large airplane tire, the pressure distribution is of even wider extent

In Figure 1 are shown typical curves of pressure distribution on the subgrade for 4000, 8000 and 12000 pound, single tire, truck wheel-loads, respectively, as transmitted through 8 inches of very

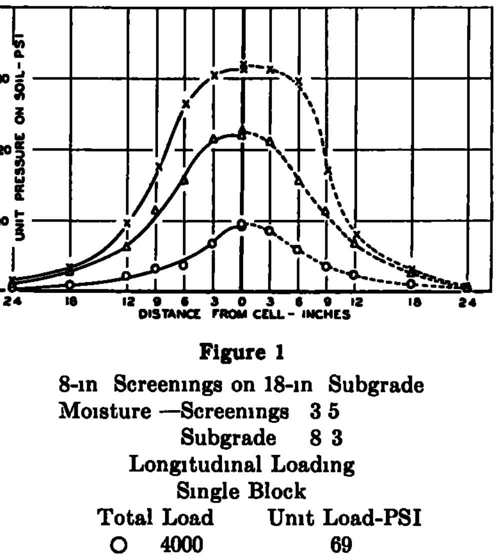

Figure 1

8-in Screenings on 18-in Subgrade
Moisture —Screenings 3 5
Subgrade 8 3
Longitudinal Loading
Single Block

Total Load	Unit Load-PSI
O 4000	69
Δ 8000	82 5
X 12000	92 5

stable limestone screenings The maximum pressure under the center of the wheel will be greater or less than the pressures shown in Fig 1, depending in part on such matters as:

1. The thickness of the non-rigid surface.
2 The stability or rigidity of that surface
3. The magnitude of the wheel load
4. The area of the imprint of the tire.
5. The load-supporting value of the subgrade.

FUNDAMENTAL CONCEPTIONS IN DESIGN THEORY

As a fundamental thought in the design theory now presented, it seems reasonable to assume that the thickness of the non-rigid surface should be such that the maximum pressure produced on the subgrade directly under the center of the wheel will not exceed the bearing capacity of the subgrade material in its least stable condition. If the pressure intensity produced by the load does exceed the bearing capacity of the soil, it will yield unduly under the pressure applied and the flexible surface, through lack of sufficient subgrade support, will be subjected to excessive bending and its integrity will be destroyed It is sometimes safe to overstress a material at a given point without danger of failure, whereas failure may occur if the overstress occurs over a wide area It will be considered here that overstress, even at a single point, is undesirable.

Accordingly, let the following rule be set down as a safe one to follow.

The maximum pressure intensity on the subgrade produced by the wheel-load should not exceed the bearing capacity of the soil

BEARING CAPACITY OF SUBGRADE SOIL

This immediately brings up the question, What is meant by "Bearing Capacity"? The soil composing the subgrade acts, in part, elastically and, in part, as a plastic material. It is somewhat elastic in the sense that when a load is applied and again released there is some recovery from the indentation produced by the load On the other hand, it is plastic since, as a rule, even the smallest load will produce a certain amount of permanent indentation or deformation If a bearing block is placed on the subgrade and a small load is applied, that block indents the soil and if that load is retained, the indentation will increase in amount An addition to the load will cause additional indentation and if the load is retained for a short time that indentation will continue to increase. It is known that the indentation produced by a bearing block subjected to load is governed not only by the magnitude of the load applied, but also by the duration of load application and by the size of the bearing block. A large bearing block when subjected to load of a given unit value will indent the soil to a greater degree than a smaller bearing block subjected to that same pressure intensity.[2] All of these matters are important in considering how to determine the bearing capacity of a subgrade for supporting the flexible or non-rigid type of road.

As indicated the pressure intensities on the subgrade are distributed over a restricted area under the non-rigid road and they are distributed over a still wider area under a road of the more rigid type such as concrete. If the bearing capacity of the subgrade under a concrete road were to be determined it would seem reasonable therefore that a larger bearing block be used than in the case of the flexible type. It will be seen from the pressure curve (Fig. 1) that the highest pressures are confined within a relatively small area and to closely approximate the actual subgrade pressure conditions, a bearing block should be used for determining the subgrade bearing capacity which will not deviate too widely from the size of the high pressure area. In the National Crushed Stone Association tests a circular bearing block having 100 square inches is used for determining the bearing capacity of the subgrade and experience with the determination of subgrade resistance in our laboratory has been obtained with a bearing block of that size. A hydraulic jack, frequently calibrated, is used for applying load to the block and dials reading to $\frac{1}{1000}$ in. are used for determining the indentation or movement of the block into the subgrade.

In Fig. 2, Curve A, is shown a pressure-indentation curve made by applying load in increments of 500 lb. total load, or 5 psi. A one-minute time interval elapsed between each load application and this accounts for the stepped appearance of the curve. Having obtained this curve,

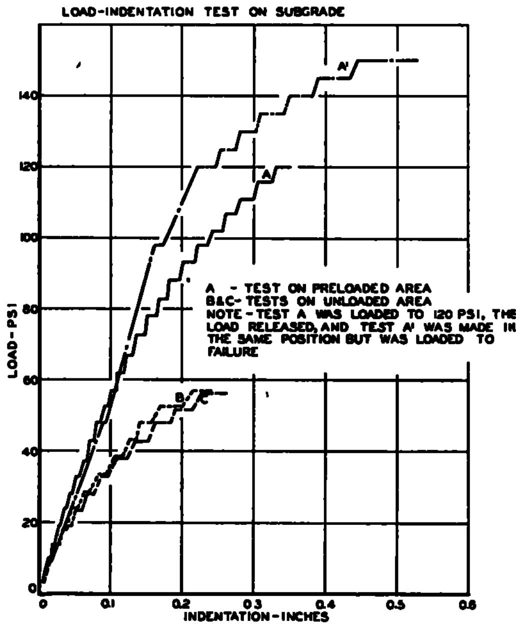

Figure 2

4-in Screenings on 18-in Subgrade
Moisture:—Screenings 3 4
Subgrade 9 4

the question arises, What may be considered a safe bearing value for the soil? It will be noted that the curve starts from the point of zero origin and proceeds more or less in a straight line and at about 60 psi load it begins to deviate from this straight line in the form of a curve. This deviation means that after a pressure of 60 psi is reached, the soil yields more rapidly under the same increment of load and because of this more

[2] A. T. Goldbeck and M. J. Bussard, "The Supporting Value of Soil as Influenced by Bearing Area," *Public Roads*, January, 1925.

rapid yielding, the question arises whether to load that particular soil with a pressure in excess of 60 psi.

Had the soil been softer than that used in this particular test, such, for instance, as was the case in the test shown in Figure 3, the yielding of the soil under increasing load would be much greater than in the first test and this brings up the question, How much yielding of the soil is permissible? If it yields too much, the road surfacing is subjected to excessive bending and disruption may take place. It seems logical to limit the amount of indentation permissible and in soils of a yielding nature, the bearing capacity should be determined for that amount of indentation of the bearing block which is considered the maximum permissible. No very definite information exists on what that maximum indentation might be, but judgment would indicate that ½ in. should not be exceeded, provided that at that amount of indentation, the ratio of increase in unit pressure to increase in indentation is not too low. If this ratio is low there will be a large increase in indentation under a small increase in load and the soil may be close to failure The problem is perplexing and a decision as to what constitutes permissible bearing value needs judgment in interpreting bearing value tests.

It is suggested, tentatively, that for determining the bearing value of the subgrade, the following procedure be used.

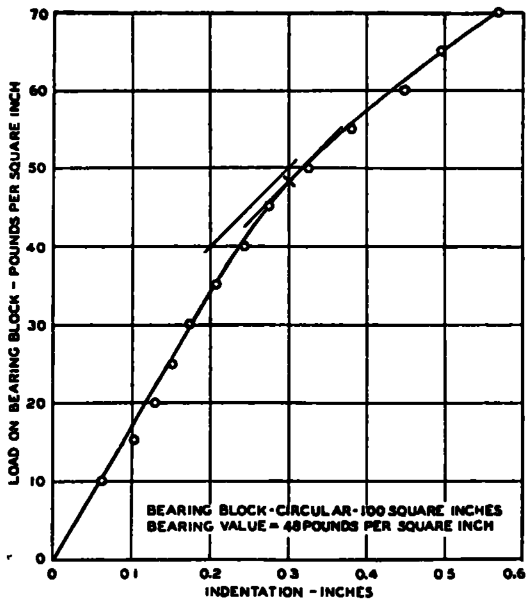

Figure 3. Bearing Value Test on Subgrade

Apply load on a 100 sq in bearing block in increments of 5 psi, allowing one minute to elapse between each increment A calibrated hydraulic jack of 20,000-lb capacity is useful for this purpose By the use of two suitable dials reading to 0 001 in , obtain the average indentation of the bearing block into the soil for each increment of load

The question of condition of moisture or compaction of the subgrade when the test is made must be left to the judgment of the investigator. It would be desirable, if possible, to bring about the most unfavorable conditions which will probably ever exist under the finished surfacing

Plot the load indentation curve thus obtained and from this curve obtain the bearing capacity at the point of ½ in indentation of the bearing block, or at a lesser indentation determined at the point at which the ratio of pressure increase to indentation increase is equal to 100

The foregoing method is suggested in the hope that discussion may develop a simpler one, for use either in the field or in the laboratory. Perhaps the bearing value may be obtained with sufficient accuracy through the interpretation of suitable laboratory tests for other soil properties.

DEVELOPMENT OF FORMULAS FOR THICKNESS

In general, a motor truck or an airplane wheel-load is applied to the surface, either through a single tire or through a dual tire and each case must be considered separately, although the general method of approach in the development of the required formulas for thickness of surfacing in each case will be the same. Static loads will be considered at present, but if it should later develop that impact factors are necessary, this possibility will not present any difficulty It is not believed, however, that impact is any longer very important in its effect on the non-rigid surface, with present-day, low pressure tires. It is true that higher than static loads have been shown to exist under moving motor truck tires and also during the landing of an airplane. However, owing to the rapid forward motion in both cases there is doubt if the impact effect is important in causing damaging increase in subgrade deformation above that produced by static load It has been observed that there is more likelihood of an airplane punching through a too thin surfacing when at rest than when landing. Accordingly, it is believed that the governing loads for design purposes are static wheel loads.

SINGLE TIRE LOADS

As before explained, the pressures measured on the subgrade take the form of a curve of distribution such as shown by the curve labeled "Actual Pressure Distribution" in Figure 4, headed "Case of Single Tire Load." An attempt to use this curve of pressure directly in the development of a practical theory of design might present mathematical difficulties. Consequently, recourse is made to the use of an imaginary equivalent uniform pressure which exists on the subgrade over an elliptical area confined within 45-degree lines drawn from the circumference of the elliptical imprint area of the tire This elliptical area of assumed equivalent uniform pressure on the subgrade equals

$$\pi (L_1 + T) (L_2 + T) \tag{1}$$

and the equivalent uniform pressure, U = the wheel load divided by the area over which this assumed uniform pressure would be distributed or

$$U = \frac{P}{\pi(L_1 + T)(L_2 + T)} \tag{2}$$

From equation (2) the thickness of the pavement is found to be

$$T = \sqrt{\frac{P}{\pi U} + [\tfrac{1}{2}(L_1 + L_2)]^2 - L_1 L_2} - \tfrac{1}{2}(L_1 + L_2) \tag{3}$$

Equation (3) contains the quantity U, but this quantity depends on the thickness of the pavement and consequently in its present form the equation cannot be used for determining thickness. However, a number of subgrade pressure distribution tests have been made by the National Crushed Stone Association laboratory in the manner described in the article previously noted and, as a result of these tests, it becomes possible to compare the actual, measured maximum pressure with the assumed uniform equivalent pressure for a number of different test conditions. This comparison is shown in Table 1

One might expect to find a wide variation in the ratio of maximum measured pressure to the calculated equivalent

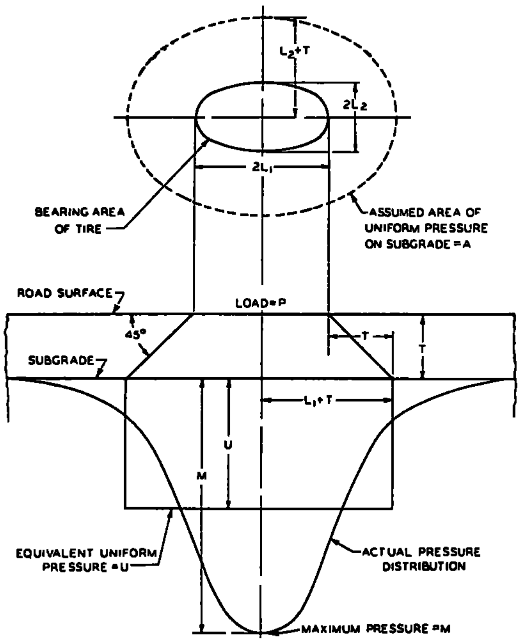

Figure 4 Case of Single Tire Load

uniform pressure, depending on several conditions such as rigidity of the surfacing, its thickness and the resistance or bearing value of the subgrade To be strictly scientific, an appropriate value "k" for this ratio of maximum measured pressure "M" to uniform equivalent pressure "U" should be used for the particular surface and subgrade under consideration If the correct value for k were known for each particular combination of surface and subgrade, then the desired thickness could be calculated from formula (4) derived by substituting for U in equation (3) its value $U = \frac{M}{k}$

$$T = \sqrt{\frac{kP}{\pi M} + [\tfrac{1}{2}(L_1 + L_2)]^2 - L_1 L_2} - \tfrac{1}{2}(L_1 + L_2) \quad (4)$$

Equation 4 can be used for cases in which the wheel load is carried on a single pneumatic tire For convenience of reference, the letters represent the following values

T = thickness of non-rigid surface required

P = maximum wheel load on a single pneumatic tire

k = ratio of $\frac{M}{U}$ = maximum pressure intensity on subgrade (assumed equal to subgrade supporting value) divided by U, the calculated equivalent uniform pressure on subgrade

L_1 = ½ major axis of ellipse of tire contact area

L_2 = ½ minor axis of ellipse of tire contact area

If the tire is a motor truck tire then $L_1 = 2L_2$ and equation (4) becomes

$$T = \sqrt{\frac{kP}{\pi M} + \left(\frac{L_2}{2}\right)^2 - \frac{3L_2}{2}}. \quad (5)$$

In the course of time perhaps additional experiments will permit of stating exactly what value to assign to "k" for each kind of road surfacing material or other influencing variable. If the surfacing material is rigid, k will be smaller than if it is of a material which might at times become softened by water. Thus, a surfacing of well interlocked macadam or well bound bituminous macadam or bituminous concrete may well have a smaller value for k than a sand-clay or a clay-bound gravel base. The former types are unaffected by water; the latter can be so affected as to permit of high pressure intensity on the subgrade.

It should be remembered that certain so-called rational theories for design in other fields of engineering have been devised as the most convenient, though not necessarily the most exact, generalization of the supporting test data. They are justified by their simplicity in application and by the reasonable and safe results they produce. They provide a practical working basis for design which may be refined and corrected as more information becomes available. It is with such thoughts as these in mind that the present design method is proposed,—not as something final and conclusive, but rather as a method which should be immediately useful, and which may need revision in due course.

At present and until more exact values are ascertained, if indeed these are necessary from a practical standpoint, recourse is had to the values for k established by the current National Crushed Stone Association tests and given in Table 1. Although these values show some range depending on the variables in the test, still, for those surfaces which are stable, the average value for k is not far from 2 and it is believed that a universal value of $k = 2$ is sufficiently accurate for general design purposes as applied to most stable surfaces and to loads carried on single tires It is true that values higher than 2.0 are found in the table, but here judgment must be used. Some of the surfaces shown undoubtedly are not so rigid as would be the case with similar surfaces prepared under actual construction conditions. This statement applies to waterbound macadam and to bituminous concrete. Then, too, there are certain questions of laboratory technique involved in the problem, which need not be discussed at present. The laboratory procedure presents many difficulties, but the results obtained are very illuminating and useful when interpreted with judgment and with practical construction conditions in mind. The conditions of the test are apt to make the pressure measurements too high rather than too low.

If, as shown at the bottom of Table 1, the surfacing is somewhat unstable, a higher value for k must be used. This is a case which need not be considered if the surface is designed to retain its stability in spite of the presence of water. Should the surfacing be of a nature which may become unstable when wet, a higher value for k is necessary—perhaps even up to 4 or 5. But there is no reason for permitting conditions which will produce such instability.

Using a value for $k = 2$

$$T = \sqrt{\frac{2P}{\pi M} - \left(\frac{L_2}{2}\right)^2 - \frac{3L_2}{2}} \quad (6)$$

Remembering that the question of the proper value for M, the bearing value of the subgrade material, is difficult to decide, it would be unduly meticulous to insist on strict accuracy in the use of equation (6) and since the quantity $\left(\frac{L_2}{2}\right)^2$ has very little effect on the final thickness, it is reasonable to eliminate this value and finally there results

$$T = \sqrt{\frac{2P}{\pi M} - \frac{3L_2}{2}} \qquad (7)$$

TABLE 1

RATIO (k) OF MAXIMUM SUBGRADE PRESSURE (M) TO CALCULATED UNIFORM PRESSURE (U)

k = M divided by U

Test No	Subgrade		Surface			Single Tire Loads, lb			Dual Tire Load, lb 8000
	Moisture %	Bearing Value psi	Type	Moisture %	Thickness In	4000	8000	12,000	
						Values for k			
Stable Surfaces									
2	9 4	56	Screenings	3 4	4	1 9	2 0	—	2 8
11	9 1	70	Screenings-Emulsion	2 8	4	1 5	1 6	1 7	—
12A	8 8	60	W. B Macadam	2 0	4	1 4	1 8	1 8	2 5
1	9 2	50	Screenings	3 8	6	1 6	1 6	1 9	—
12B	8 2	—	W B. Macadam	1 2	6	1 0	—	—	1 0
14	10 2	48	Sand-Clay-Gr	3 3	6	2 5	2 5	2 7	2 4
13A	9 6	30	W B Macadam	2 0	10	2 3	3 1	2 8	2 6
15	10 3	50	Sand-Clay-Gr	3 7	10	1 6	1 9	2 1	1 8
16	—	40	Hot Bit Conc.	—	4 6	2 0	2 7	2 4	2 6
13B	10 3	44	W B Macadam	2 7	10	1 8	2 0	2 0	2 3
10	10 8	15	Screenings	2 9	4	1 4	1 6	—	—
10A	11 5	10	Screenings	2 1	4	2 1	—	—	—
7	11 0	30	Screenings	2 8	6	—	1 3	1 4	1 4
12	10 4	29[1](−)	W B Macadam	1 1	6	—	2 0	2 2	—
8	10 3	49	Screenings	2 8	8	—	1 2	1 5	1 3
13	10 3	25	W B Macadam	1 5	10	1 6	2 1	2 2	2 2
11A	9 9	42	Screenings-Emulsion	3 8	4	1 9	2 0	2 2	—
6	8 3	100	Screenings	3 5	8	1 3	2 0	2 0	1 6
Ave.						1 7	2 0	2 1	2 0
Unstable Surfaces[2]									
3	10 5	44	Screenings	6 2	4	4 3	—	—	4 4
5	10 4	55	Screenings	7 0	8	4 4	5 3	—	3 2
9	10 0	40	Screenings	6 0	6	4 5	4 1	—	3 8
15B	9 5	50	Sand-Clay-Gr	4 5	10	2 7	3 3	3 6	2 6
Ave.						4 0	4 2	3 6	3 5

[1] At ⅛ in indentation, the ratio of pressure increase to indentation increase is only 55 instead of desired minimum of 100 At no value of indentation was subgrade sufficiently resistant

[2] These surfaces were purposely made unstable by the use of excessive water in their preparation

Equation 7 is applicable to single truck tires. For the benefit of those who might feel safer through the use of an impact factor, this can be introduced merely by increasing the value for P by the desired percentage

For airplane tires it is best to use equation (4) making k = 2 and calculating the values for L_1 and L_2 from the known wheel-load and tire pressure. It is not strictly accurate to equate the wheel-load to the tire contact area multiplied by the tire pressure because each tire has a "supporting factor" which results in a reduced area of contact. This supporting factor varies but can be taken as 1.10 and equals—

$$\frac{\text{Actual Tire Load}}{\text{Inflation Pressure x Contact Area}}$$

However, it is probable that the use of the tire supporting factor for calculating tire contact area would savor of straining for accuracy beyond what seems possible in a problem of the nature under consideration. Hence, it will be considered sufficiently accurate to ignore the existence of a "supporting factor." This factor is mentioned, however, for those who may wish to use it for more accurately calculating the contact area.

The width of the elliptical imprint or contact area of an airplane tire may be taken as equal to the nominal overall width of the tire ($2L_2$); then, since the tire contact area $= \pi L_1L_2$,

$$\pi L_1L_2 \text{ x inflation pressure} = \text{Actual Tire Load} \qquad (8)$$

From equation (8), L_1 may be obtained and equation (4) may then be used to obtain the required thickness of the runway if the subgrade supporting value (M) has been determined using the methods described.

DUAL TIRE LOADS

Most heavy wheel loads on motor trucks are carried on dual tires rather than on single tires and in the design of non-rigid pavements, the influence of dual tires is very important. A given wheel load when carried on dual tires is less severe than when carried on a single tire because:

(1) The load is spread over a wider area on the subgrade, and
(2) The tire pressure is less in the smaller tires used together.

To develop the theory of design making use of dual tires, refer to Figure 5. The pressures, by measurement, are found to be distributed transversely much as shown by the curve labeled, "Actual Pressure Distribution." Here, as in the

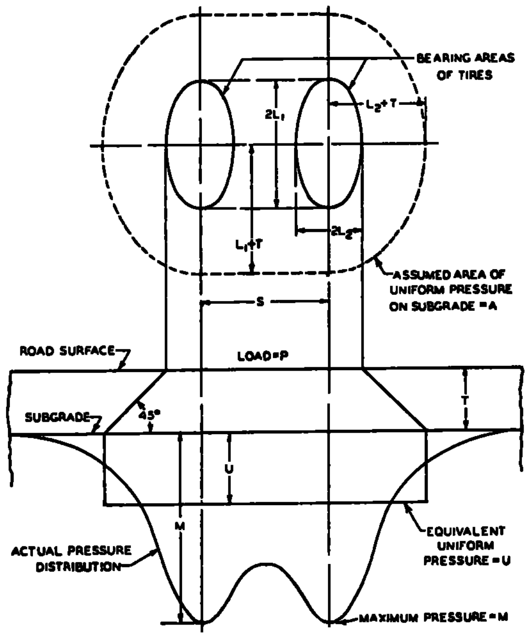

Figure 5. Case of Dual Tire Load

case of the single tire, it is desirable that the maximum pressure on the subgrade never exceed the bearing capacity of the subgrade and, for economy, it seems logical to make the design such that the maximum pressure approach the subgrade supporting value as determined by the method previously described

Since mathematical complications would ensue in attempts to use the actual curve of pressure distribution, let it be assumed that the pressures are confined within an area defined by 45-degree lines sloping from the sides of the tire imprint areas and from the straight lines connecting the ends of the major axes of these areas, and shown in Figure 5 by dotted lines Over this area the subgrade pressures will be assumed as uniform Had some other method of arriving at the assumed area of equivalent uniform pressures been used, the final calculated road thickness would not be altered The use of confining lines of 45 degrees makes for a simple form of calculation and this is the sole reason for their use

Referring to Fig 5

Let P = wheel load

A = area of equivalent subgrade pressure

U = equivalent uniform pressure over area A

M = maximum subgrade pressure, also equal to bearing value of subgrade

S = center to center spacing of dual tires

L_1 = half major axis of tire contact area

L_2 = half minor axis of tire contact area

$$k = \frac{M}{U}$$

$$A = 2S(L_1 + T) + \pi(L_1 + T)(L_2 + T)$$

$$P = AU = \frac{AM}{k}$$

$$= [2S(L_1 + T) + \pi(L_1 + T)(L_2 + T]\,\frac{M}{k}$$

from which

$$T = -\frac{B}{2\pi} + \sqrt{\left(\frac{B}{2\pi}\right)^2 + C} \qquad (9)$$

where $B = 2S + \pi(L_2 + L_1)$

$$C = \frac{Pk}{M\pi} - \frac{2SL_1}{\pi} - L_1 L_2$$

Referring to Table 1 under "Dual Tires" there will be found values for $k = \frac{M}{U}$ determined from tests by the use of the National Crushed Stone Association test bin These results thus far are rather meager and are seen to have considerable variation depending on the various conditions At the present time it seems safest to be somewhat conservative in selecting any one value for k for general use Although the average value for k obtained with stable surfaces is about 2 0 there is one value as high as 2 8 Judgment must be used in selection of the proper value to use for any particular kind of non-rigid surface Some of the non-rigid types might permit of small values while less rigid surfaces would necessitate the use of higher values It would seem, however, that 2 5 might be selected as a suitable value for general design use This value is conservative and is higher than the average value of 2 0, thus far secured by pressure tests

SOME EXAMPLES OF DESIGN

Example I

Let it be required to design a non-rigid road type to carry a motor truck with a load of 8000 lb on a single tire

P = 8000 lb.

Tire pressure = 82 5 psi

Contact area = 97 sq in

$2L_1$ = 16 in , $2L_2$ = 8 in

M = subgrade bearing value = 40 psi

$$T = \sqrt{\frac{2P}{\pi M}} - \frac{3L_2}{2} = \sqrt{\frac{2 \times 8000}{\pi \times 40}} - \frac{3}{2} \times 4 = 11.3 - 6 = 5\ 3 \text{ in , say } 6 \text{ in.}$$

Example II

Let the 8000-lb. wheel load be carried on dual tires then—

$P = 8000$ lb.

Tire pressure $= 69.0$ psi

$2L_1 = 12$ in., $2L_2 = 6$ in.

$S = 12$ in.

$M = 40$ psi

$k = 2.5$

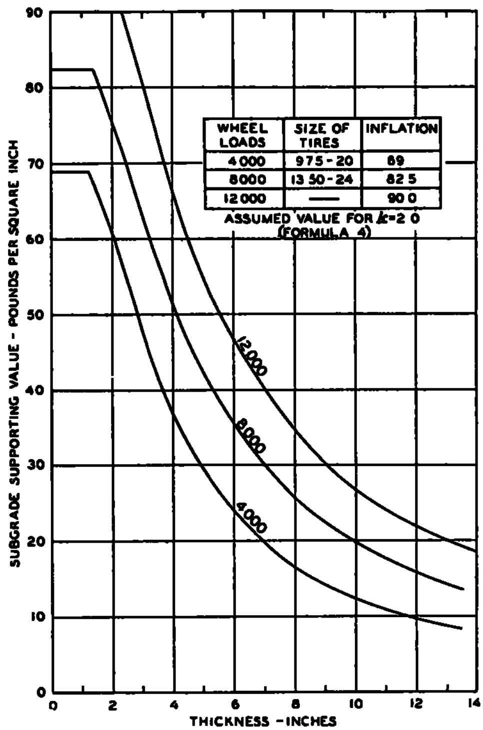

Figure 6. Calculated Thickness Required for Truck Wheel Loads on Single Tires

$$B = 2S + \pi(L_2 + L_1) =$$

$$2 \times 12 + \pi(3 + 6) = 24 + 28.2 = 52.2$$

$$C = \frac{Pk}{M\pi} - \frac{2SL_1}{\pi} - L_1L_2 =$$

$$\frac{8000 \times 2.5}{40 \times \pi} - \frac{2 \times 12 \times 6}{\pi} - 6 \times 3 =$$

$$159 - 45.8 - 18 = 95.2$$

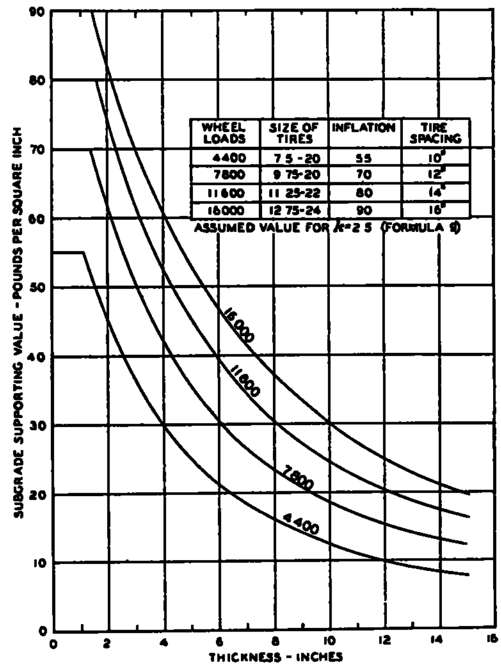

Figure 7. Calculated Thickness Required for Truck Wheel Loads on Dual Tires

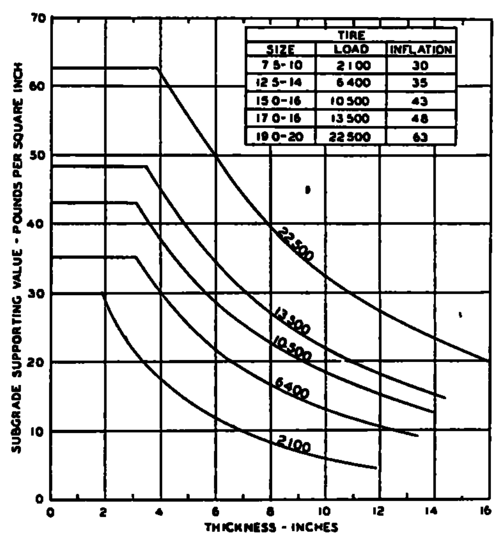

Figure 8. Calculated Thickness Required for Airport Runways

TABLE 2

SERVICE LOAD AND INFLATION TABLE FOR TRUCK AND BUS BALLOON TIRES BASED ON TIRE AND RIM ASSOCIATION STANDARD, TABLE TB-2

Tire Size	Loads at Various Inflation Pressures											
	40	45	50	55	60	65	70	75	80	85	90	95
5 50-20		1225										
6 00-20		1400										
6 50-18			1550									
7 00-18				1800								
7 50-20				2200								
8 25-22					2850							
9 00-20						3250						
9 75-20							3900					
10 50-22								5000				
11 25-22									5800			
12 00-24										6950		
12 75-24											8000	
13 50-24												9100

$$T = \frac{-B}{2\pi} + \sqrt{\left(\frac{B}{2\pi}\right)^2 + C}$$

$$= \frac{-52.2}{2\pi} + \sqrt{\left(\frac{52\ 2}{2\pi}\right)^2 + 95\ 2}$$

$$= -8\ 3 + \sqrt{69 + 95.2}$$

$$= -8.3 + 12.8 = 4.5 \text{ in., say } 5 \text{ in.}$$

Example III

Assume an airplane runway is to be designed for a plane having a gross weight of 45,000 lb.; tire size 19.00 x 23, inflation pressure 63 psi; Let the subgrade resistance equal 40 psi.

The tire imprint area is approximately equal to $\frac{22{,}500}{63} = 357$ sq. in. Actually the imprint area is known to be somewhat smaller due to the "supporting factor" of the tire, but this refinement in the calculations is not warranted. The width of the ellipse of contact is approximately equal to the tire width which is 19 in.

$$\pi \times \frac{19}{2} \times L_1 = 357 \text{ sq. in.}$$

$$L_1 = 2 \times \frac{357}{\pi \times 19} = 12 \text{ in.};\ L_2 = 9.5 \text{ in.}$$

TABLE 3

SPACING OF DUAL TIRES FOR TRUCKS AND BUSSES

Tire Size, Nominal Cross-Section	Dual Spacing, Center to Center, in
Balloon Tires	
5 50	7¼
6 00	7¾
6 50	8¼
7 00	9
7 50	10
8 25	10½
9 00	11½
9 75	12
9 75	12¾
10 50	13¼
11 25	14
12 00	15¼
12 75	16
13 50	16
High Pressure Tires	
in	in
5	7¾
6	9
7	10
8	11½
9	12¾
10	12¾

Using equation (4)

$$T = \sqrt{\frac{kP}{\pi M} + [\tfrac{1}{2}(L_1 + L_2)]^2 - L_1 L_2} - \tfrac{1}{2}(L_1 + L_2)$$

$$= \sqrt{\frac{2 \times 22{,}500}{\pi \times 40} + [\tfrac{1}{2}(12 + 9.5)]^2 - 12 \times 9.5} - \tfrac{1}{2}(12 + 9.5) = \text{about } 8 \text{ in.}$$

Similarly, calculations have been made for various truck wheel loads carried on single and on dual tires and for various airplane wheel loadings on single tires. The results of these calculations are shown in Figs. 6, 7 and 8. Tables 2 and 3, taken from the Year Book of the Tire and Rim Association, are included for the convenience of those who may wish to make special calculations.

CONCLUSION

In conclusion, let it again be stated that the present method of design is tentative and will need correction as better information becomes available. Admittedly somewhat crude and not wholly scientific, still it compares not unfavorably in that respect with other so-called rational design theories which are found useful to engineers. A truly rational theory for non-rigid road design may never be entirely possible and even if attained would still involve many variables which would have to be evaluated for each application. At best, the non-rigid road, and to an almost equal extent the rigid road surface as well, involve uncertainties in their design, but the method now suggested, at least is founded on subgrade pressure tests and gives an approximation to the truth. For these reasons its publication seems to be justified.