PRELIMINARY EXPERIMENTS ON THE DISTRIBUTION OF WHEEL LOADS THROUGH FLEXIBLE PAVEMENTS

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SYNOPSIS

This report describes a type of apparatus for measuring the pressure distribution under static wheel loads on flexible pavements which gives promise of making possible an extensive study of the effects of various characteristics of flexible pavements and subgrades upon pressure distribution

The apparatus consists of a series of stainless steel ribbons arranged to slide between thin stainless steel strips These ribbon assemblies are placed in the plane between the flexible pavement and the subgrade, and are pulled horizontally to measure the total pressure on the ribbons Then the ribbons are shortened by decrements of one inch and the pull measured for each length of ribbon The difference between these pulls is proportional to the difference in pressure on the ribbons at the various lengths, and with the coefficient of friction determined, provides a mechanical differentiation of the pressure

Observations have been made on flexible pavements in which all characteristics were held constant except the thickness, which varied between 3 and 15 in Loads were applied through a pneumatic tire The maximum pressure on the subgrade occurred directly beneath the applied load and distributed laterally in an elongated bell shape The maximum unit pressures accompanying a 3,000 lb load were 65 lb per sq in at 3 in thick, 35 and 44 lb at 5 in , 24 lb at 7½ in , 18 5 lb at 10 in and 13 lb at 15 in thick

The constantly growing demand for the improvement of a vast mileage of light traffic highways by means of low cost types of surfacing has stimulated highway engineers to seek a sound scientific method for designing the flexible or "stabilized" types of pavements The application of scientific principles is essential to the design of this kind of a structure, no less than to other more orthodox structures, in order that economical and durable low cost surfaces may be obtained

The process of designing any structure involves two distinct phases. First the loads to which the structure will be subjected in service and the accompanying stresses in its component parts, including the foundation, need to be determined. Then the structure must be proportioned in such a form and of such dimensions that the materials of which it is made and its foundation will not be subjected to stresses or deformations beyond those which they can safely withstand Very encouraging progress has been made in recent years in soil mechanics relating to development of means for increasing the stress carrying capacity of soils by various methods of stabilization, and the second phase of flexible pavement design has been materially enhanced thereby. On the other hand, although the wheel loads to which flexible pavements will be subjected in service are in general known, there has been relatively little progress made in the advancement of knowledge concerning the distribution of the wheel loads through the pavement and the resulting pressures between the pavement and its subgrade The importance of this matter is emphasized by the realization that the chief function of a flexible pavement is to transmit the super-imposed traffic loads to the subgrade or foundation in such a manner that the deformations of the foundation will not permit bending stress failure of the pavement Unlike rigid pavements, the flexible types are very weak in beam strength, and cannot carry loads over areas of excessive foundation deformation

There are a number of empirical rules in use at present by which the maximum unit pressure between a flexible pavement and the subgrade may be calculated, and a few theoretical studies of the subject have been made, but there are practically no experimental data extant from which the underlying principles governing the distribution of stresses through this type of pavement can be deduced As pointed out by Mr. A C Benkelman[1] in his scholarly review of existing knowledge concerning the design of flexible pavements, "the reason for this probably lies in the difficulty of developing satisfactory apparatus and testing technique rather than any lack of interest in the subject."

The purpose of this paper is to describe a method for measuring the distribution of vertical pressure between a flexible pavement and its subgrade when a wheel load is applied statically to the pavement surface, which is being explored at the Iowa Engineering Experiment Station While only very limited data are available at this time the method appears to be sound in principle and gives promise of providing a means for extensive study of the effect of various characteristics of flexible pavements and their subgrades upon the distribution of wheel loads. A number of details of technique are yet to be worked out satisfactorily, but none of the difficulties appears to be insurmountable The method is presented at this time with the hope that it will be scrutinized carefully by interested engineers and that improvements in technique may be made as a result of their criticisms

Some of the requirements of a device for measuring the pressure between a flexible pavement and the subgrade are

1 It must not impair the continuity of either the pavement or the subgrade

2 It must be flexible enough to permit free and unhampered deflection of both the pavement and the subgrade, under action of the wheel load

3. No movement should be required in the direction of the pressure being measured, to actuate the device

The author[2] has had extensive experience in making pressure measurements on various types of structures by means of stainless steel friction ribbons arranged to slide between suitable surfaces placed in a plane at right angles to the pressure being measured, and has developed considerable confidence in this type of apparatus The pressure on such a ribbon is measured by pulling it in a plane normal to the pressure, and no movement of the ribbon in the direction of the pressure is necessary during the operation The magnitude of this pull is proportional to the total pressure on the ribbon in accordance with the physical law.

$$P = KW \qquad (1)$$

in which P = pull
W = total pressure
K = proportionality factor (coefficient of friction)

This proportionality holds independently of the area of ribbon acted upon by the pressure and of the magnitude of the pressure.

[1] Present knowledge of the design of flexible pavements," by A C Benkelman Proceedings, Highway Research Board vol 17, p 144 Public Roads, Vol 18, No 11, Jan 1938, p 201–212

[2] (a) The Supporting Strength of Rigid Pipe Culverts, Bul 112, Iowa Engineering Experiment Station

(b) The Distribution of Shearing Stresses in Concrete Floor Slabs under Concentrated Loads, Bul 126, Iowa Engineering Experiment Station

(c) Horizontal Pressures on Retaining Walls Due to Concentrated Surface Loads, Bul 140, Iowa Engineering Experiment Station

(d) The Structural Design of Flexible Pipe Culverts Proceedings Highway Research Board, Vol 17, p 235 Public Roads, Vol 18, No 12, Feb , 1938, p 217–231

Although theoretically the proportionality factor K is constant for given surfaces, in practice it has been found to vary between quite wide limits with the result that this type of pressure measuring apparatus cannot at present be considered to be a precision device, but the results of a considerable number of observations must be averaged to obtain reliable values of pressure However, it is believed that greater accuracy of individual measurements can be obtained as optimum types of surfaces are discovered and as improved technique of pulling the ribbons is developed For example, the ribbons were pulled by hand in these experiments and the pull measured by means of a spring balance Better results will probably be obtained if the pulls are applied by gravity Apparatus is being designed at the present time whereby a flexible cable will be attached to the end of a ribbon and passed through 90 degrees over a low friction wheel Lead shot or water will be added to a vessel attached to the cable until the ribbon starts in motion and the starting pull measured by weighing the required amount of such material This will greatly increase the accuracy of individual measurements. It may be advisable to introduce further refinement by constructing an automatic cut-off device to shut off the supply of shot when the ribbon starts to move

It is known that when a solid body is retarded by friction, a larger pull is required to start it in motion than is required to maintain uniform motion Experience at this Station has indicated that the starting pull on friction ribbons is the more reliable index of pressure, perhaps because of the difficulty in obtaining truly uniform motion

Since the coefficient of friction of a ribbon sliding between two surfaces is independent of both its area and the magnitude of the pressure, the starting pull is proportional to the total pressure on the ribbon regardless of its length or the character of the distribution of pressure acting on it Therefore, if a ribbon of any length is pulled, the total pressure on the ribbon is indicated Then if the ribbon is shortened a suitable decrement, and the starting pull again determined, the difference between the two pulls is proportional to the difference in pressure on the ribbon and a measure of the pressure on the decremental area is thus obtained By shortening a ribbon by finite decrements across an area subjected to pressure of varying intensity, an indication of the pressure variation on the strip element of the area covered by the ribbon is obtained This principle is the same as that employed by Teller and Buchanan[3] in their measurements of the distribution of pressure between a pneumatic tire and a rigid pavement surface It is represented graphically in Figure 1 By placing a number of ribbon assemblies at frequent parallel intervals over the area being studied, the distribution of pressure in the normal direction may also be obtained, and the surface representing the pressure distribution over the whole area may be deduced Furthermore, if ordinates to this surface are expressed in terms of lb pull per sq in of area, the volume beneath the surface is proportional to the total pressure, which, in the problem at hand, is known to be equal to the applied wheel load Therefore, the value of K in equation (1) may be determined by dividing the total wheel load into the volume beneath the pressure surface thus expressed, and the ordinates to the surface may be converted to unit pressures

The ribbon assemblies used in these

[3] "Experimental Determination of Variation in Pressure Intensity Over the Contact Area of Tires " Teller, L W and J A Buchanan Proceedings, Highway Research Board, Vol 17, p 240 Public Roads, Vol 18, No 10, Dec , 1937, p 195–198

preliminary experiments consisted of two stainless steel strips, 2 in wide and 0 005 in thick constituting the upper and lower friction surfaces A stainless steel ribbon, ½ in wide and 0 008 in thick was placed between these wider strips and extended beyond one end for pulling The space between the upper and lower surfaces and on each side and back of the measuring ribbons was filled by another 2-inch strip with a slot slightly more than ½ inch in width cut in it Then as plane between a synthetically constructed subgrade and a stabilized gravel flexible pavement with a ¾ in black top wearing surface The subgrade was constructed by tamping yellow clay with optimum moisture content into a bin in layers of about three inches The bin was 5 ft square inside and 2 ft high and was made of 3 x 12-in planks, with a lining of asphalt felt around the inside to retain the moisture in the clay A sheet of pure gum rubber 36 in. wide and $\frac{1}{16}$ in

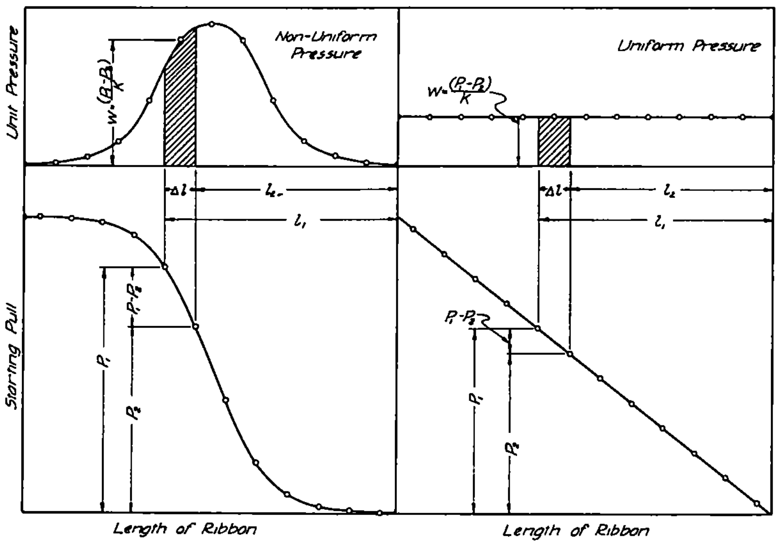

Figure 1

the measuring ribbon was pulled forward in the process of differentiating the pressure, this filler strip was also moved forward the same amount and the space vacated by the measuring ribbon was occupied by the filler strip This arrangement was devised to provide support for the top friction surface of each ribbon assembly throughout its entire area at all times, regardless of the length of the measuring ribbon exposed to pressure

These pressure measuring devices were tried out in the laboratory by placing a series of 17 assemblies in the horizontal thick was spread on top of this subgrade and the ribbon assemblies placed Then another similar sheet of rubber was placed over the top of the ribbons and the whole area of the subgrade covered with light weight asphalt felt The stabilized gravel pavement was then constructed by hand tamping to the desired thickness and the wearing surface placed and rolled, after which the dead load pulls on the measuring ribbons were determined. A load of 3000 lb was applied at the center of the 5-ft square area through a 20 by 7 in 6 ply tire inflated to 70 lb per sq in pressure, at no load The area of contact between the tire and the wearing surface was $10\frac{1}{2}$ in. long and $5\frac{5}{8}$ in. wide and contained 55 sq. in. The tire was placed so that the long axis of the tire imprint was at right angles to the direction of the ribbons. With the load applied, the starting pull on the ribbons was measured. Then each ribbon and its accompanying filler strip was pulled ahead a distance of 1 inch, and the starting pull again determined. This process was repeated until the starting pulls

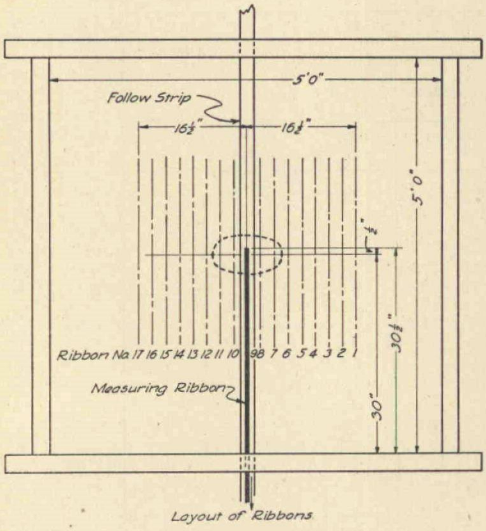

Figure 2. Layout of Ribbons

became substantially equal to the dead load pulls, indicating the distance out from the wheel load at which the foundation pressures vanished. In these pioneer experiments, the ribbons extended from one side of the bin to a point $\frac{1}{2}$ in. beyond the center of the applied load, with the result that the pressure distribution was measured only on one-half of the area of the subgrade subjected to pressure. The layout of the ribbon assemblies is shown in Figure 2 and a photograph of the whole set-up in Figure 3.

Experiments have been conducted on three stabilized base courses, having thicknesses of 5, 10, and 15 in., respectively and each carrying a $\frac{3}{4}$-in. black top wearing surface. The material in the base courses was an arbitrary mix composed of pit run gravel passing a $1\frac{1}{2}$-in. sieve, plus clay. The gradation curve of the combined material is shown in Figure 4. The material passing the No. 40 sieve had a plastic limit of 13.3 per cent, a liquid limit of 21.0 per cent

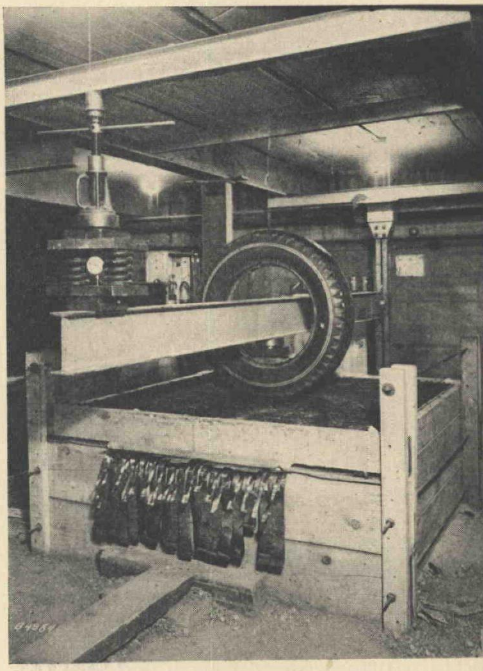

Figure 3. Laboratory Apparatus for Measuring Distribution of Wheel Loads through a Flexible Pavement.

and a plastic index of 7.7 per cent. The optimum moisture content for maximum density was 9.12 per cent which gave a maximum dry density of 130.96 lb. per cu. ft. The moisture content of the three base courses as constructed in the experiments was approximately 5 to $5\frac{1}{2}$ per cent. The material was hand mixed and hand tamped in layers about two inches thick and showed an average dry density in place of about 126 to 127 lb per cu ft

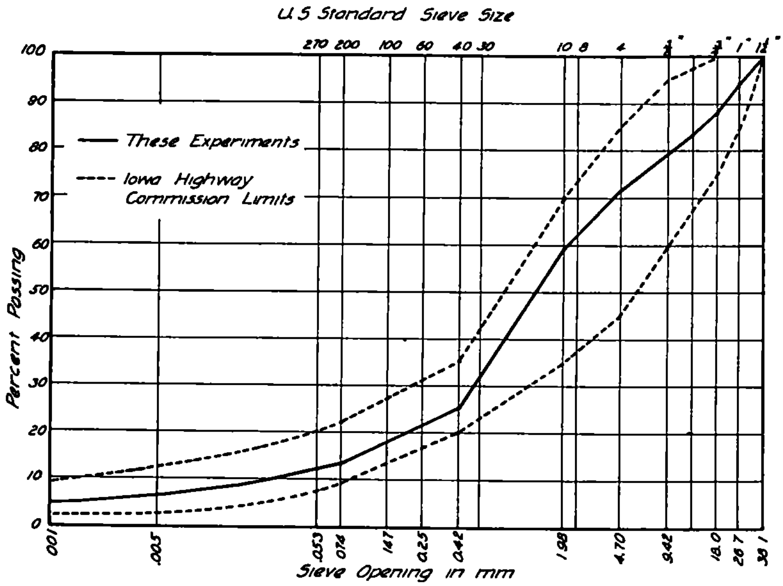

Figure 4. Gradation Curve—Base Course

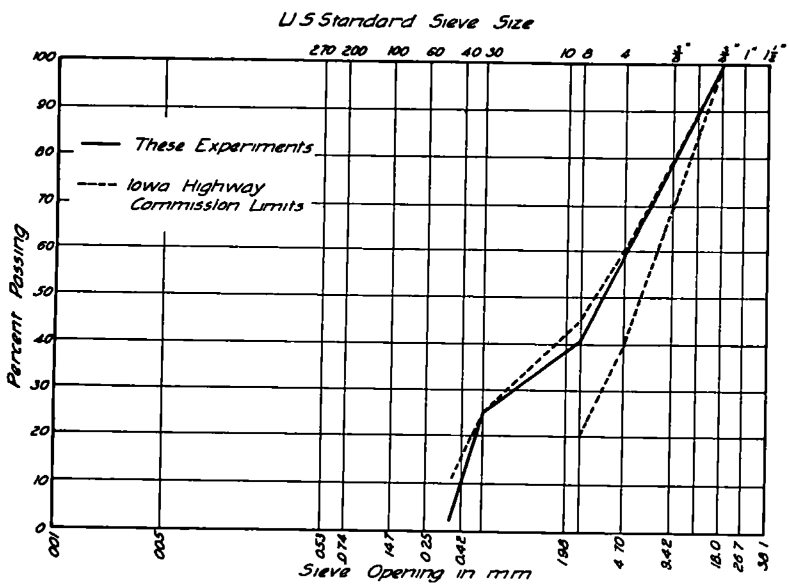

Figure 5 Gradation Curve—Wearing Course

The wearing surface used in the experiments consisted of an arbitrary mix of washed gravel passing a ¾-in sieve, and having the gradation shown in Figure 5 It was applied to the base course at the rate of 60 lb per sq. yd The SC-7 bituminous binder was applied at the rate of about 0 6 gal per sq yd. of surface or 0 1 gal per 10 lb. of aggregate. The wearing surface material was spread evenly over the base course and rolled with a small lawn roller after which it was hand tamped. It was not subjected to any wheel traffic prior to application of the test load

The test measurements was carried out as follows first the no load pulls on the measuring ribbons were determined with various lengths of ribbon exposed to pressure These data for the 5-in base course are shown in Figure 6 Then the measuring ribbons and the filler strips were moved back to their original position, the wheel load applied, and the starting pull on each of the 17 ribbons measured Since the movement required to determine the starting pull of a ribbon is not more than about $\frac{1}{16}$ in, at least three pulls can be made without creating a seriously large open space between the end of the ribbon and the filler strip. After these three starting pulls were determined, each ribbon and its filler strip were moved ahead one inch and three more pulls taken. It was found necessary to release about two thirds to three fourths of the load when the filler strips were moved forward, but the tire was not moved during the process It is believed that the use of heavier strips having a greater tensile strength will eliminate the necessity for this in future experiments The process of pulling the ribbons and shortening them by one inch decrements was repeated until the area affected by the wheel load was traversed

On completion of one run, the load was removed and the ribbons and filler strips were returned to their original position and the whole process repeated In this manner, three complete runs were obtained after which the wearing surface was removed, the 5-in base course scarified about one inch deep and then built up to 10 in thick, and another wearing course added

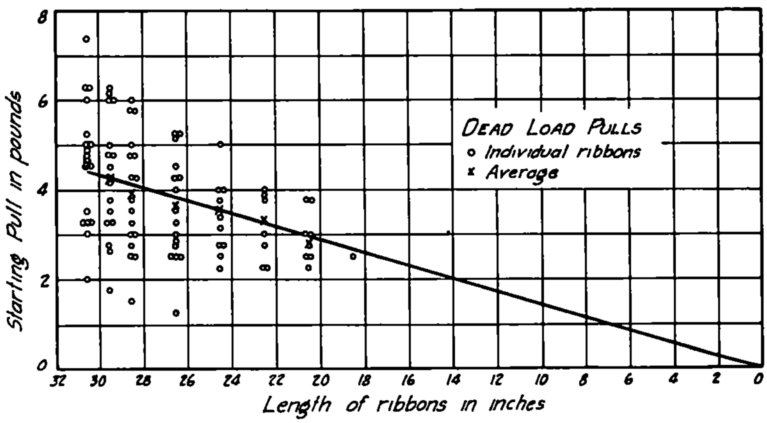

Figure 6. Dead Load Pulls, 5-in Base Course

The data for the three runs conducted on the 5-in base course are shown graphically in Figures 7 to 10 The net pulls due to the applied wheel load were obtained by subtracting the dead load pulls from the total load pulls and they are shown in the figures by the curves labeled "wheel load" These curves were then differentiated arithmetically to obtain the pressure distribution on the various ribbons in terms of lb pull per sq in and a contour diagram constructed showing the pressure distribution over the whole area of the subgrade. The volume beneath this pressure surface

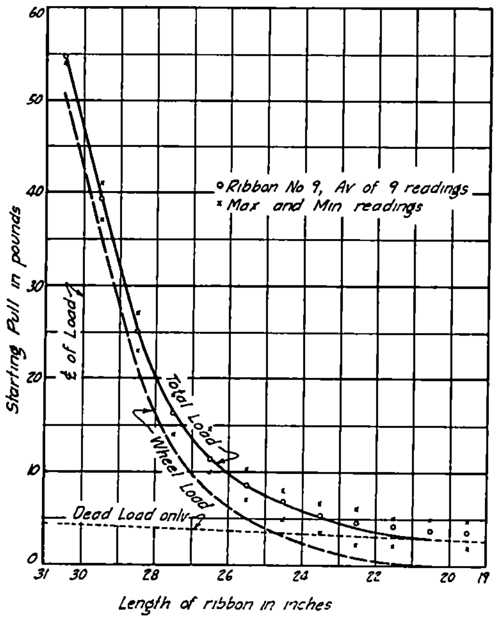

Figure 7. Data for 5-in. Base Course, Ribbon 9

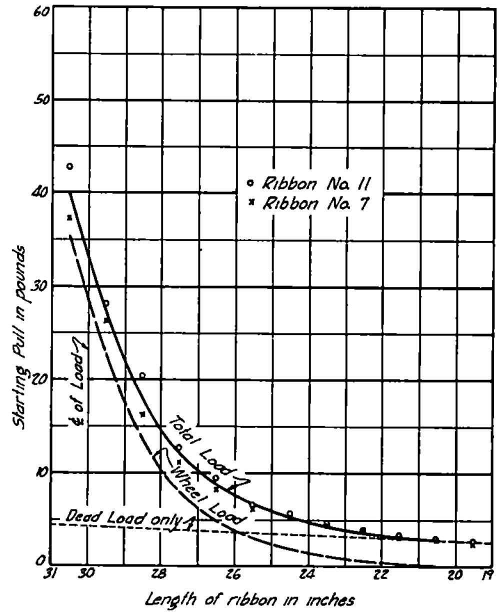

Figure 9. Data for 5-in Base Course, Ribbons 7 and 11

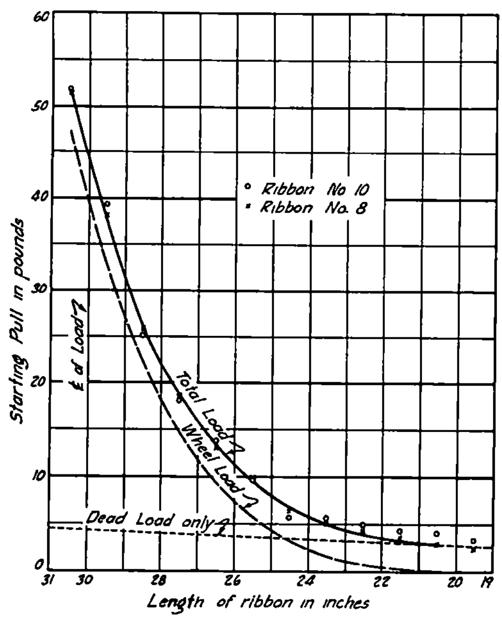

Figure 8. Data for 5-in. Base Course, Ribbons 8 and 10

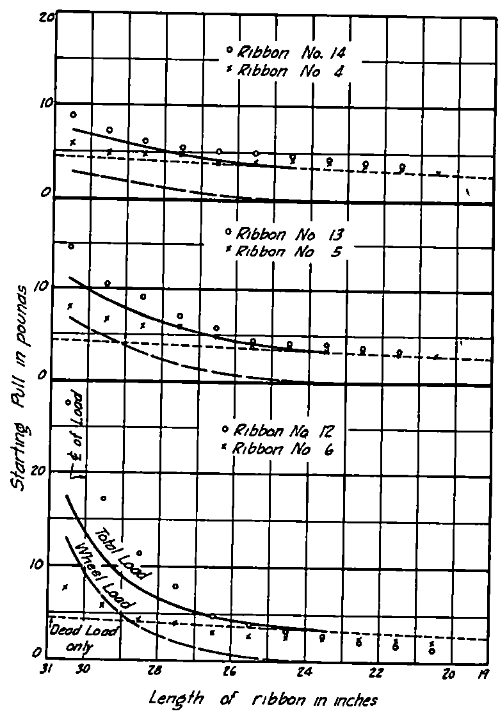

Figure 10 Data for 5-in. Base Course, Ribbons 5, 13, 6 and 12

was then calculated from areas measured by a planimeter, and this volume divided by the total applied load to obtain a value of K = 0 69 The ordinates to the pressure surface were converted to lb per sq in by dividing by this value of K applied occurred directly under the load and amounted to about 44 lb per sq. in

By a similar process, the distributions of pressure on the subgrade under the 10-in and 15-in. base courses were measured In these cases, however, it

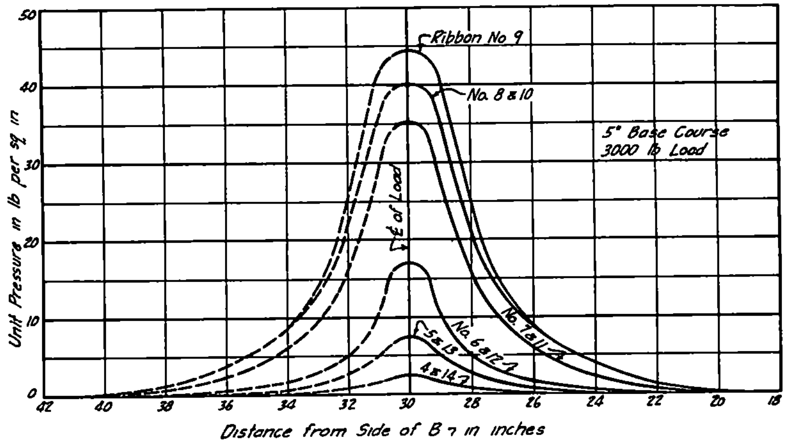

Figure 11. Pressure Distribution Curves

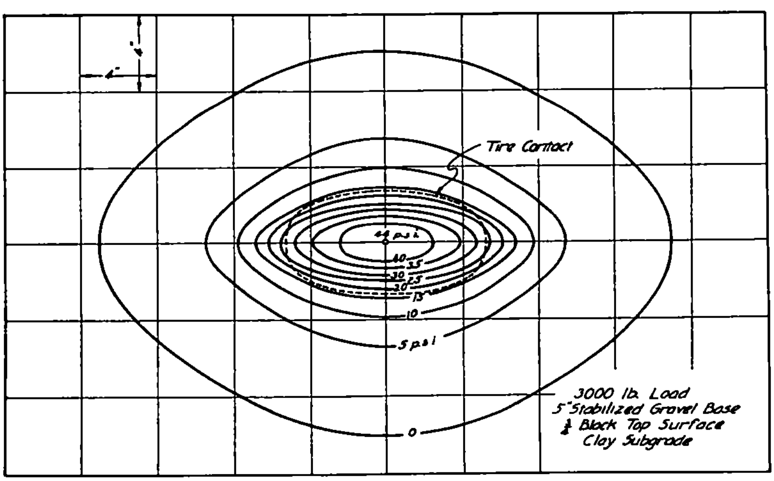

Figure 12. Distribution of Pressure on Subgrade

and the pressure distribution curves for the various ribbons as shown in Figure 11 and the iso-pressure diagram of Figure 12 was obtained The maximum pressure on the subgrade under the 5-in base course with a 3000 lb load statically was not possible to determine the proportionality factor in the manner described for the 5-in. base course It appeared that the lateral distribution of pressure was sufficiently great that the restraining planks interfered with the free transmission of pressure to the subgrade and it was impossible to obtain a satisfactory integration of the unit pulls from which to obtain values of the proportionality factor K However, it is not believed that the side walls interfered with the pressures directly under the load and using K = 0 69 as determined for the 5-in base course, the maximum unit pressure directly under the load was 18 5 lb per sq. in for the 10-in base course and 13.0 lb. per sq in for the 15-in base course.

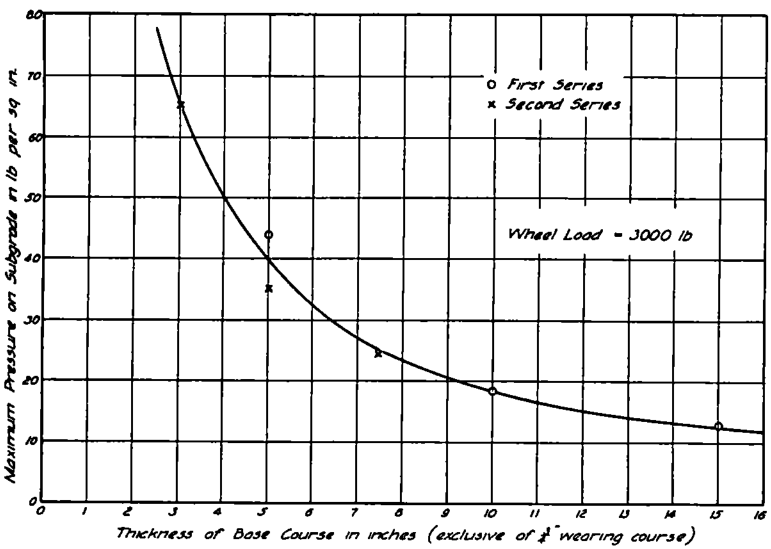

Figure 13 Relation between Base Course Thickness and Maximum Subgrade Pressure

These values are not considered to be conclusive, but are given for the purpose of illustrating the nature of the data which were obtained by the use of friction ribbons in the study of this problem

The distributions of pressure on the subgrade beneath flexible pavements 3 in , 7½ in , and 5 in thick, respectively, have also been measured All characteristics of the subgrade, base course, wearing surface, and the applied load in these latter trials were the same as in the first reported experiments, the only variable being the thickness of the various base courses. The maximum pressure on the subgrade in these trials was 65, 24 and 35 lb per sq in , respectively, for an applied load of 3000 lb The relationship between base course thickness and maximum subgrade pressure as indicated by all of these exploratory experiments is shown in Figure 13

After the second series of experiments was completed, the ribbons were calibrated independently to determine the value of K, the ratio between starting pull and vertical pressure on the ribbons Vertical pressure was applied to the ribbons by means of about 3½ ft of sand in a bottomless bin having friction reducing sides The bin was about 4½ ft square inside and the sand load was applied over practically the whole area of the subgrade The total weight of the sand was assumed to be uniformly distributed over the area of the bin The average value of K obtained in these calibration operations was 0 65 as compared with 0 69 obtained by the integration method in the case of the first 5-in base course

DISCUSSION ON DISTRIBUTION OF LOADS THROUGH FLEXIBLE PAVEMENTS

MR L W TELLER, *Bureau of Public Roads:* Laboratory tests such as described have one weakness regardless of the method of pressure measurement It is not possible to consolidate materials in the laboratory in the same way that they are consolidated in the road structure and these data indicate, by the concentration of pressure in the area of the wheel load, that the consolidation obtained by this method was not very great In the discussion of this paper in the Design Department meeting, Mr Spangler stated that he recognized this fact and that he expected to attempt to apply the same method on actual road surface sections placed and compacted by the methods ordinarily used in construction If he is able to secure similar data by this method under such conditions he will have made a real contribution in a field that sadly needs data at the present moment

MR B E GRAY, *The Asphalt Institute:* As I interpret the report, an effort is being made to determine the manner in which loads are distributed through a flexible pavement of given depth In order to eliminate the possible effect of subgrade movement, would not a standard type base be desirable for establishing the first range of values, such as for example a steel plate, rather than an earth subgrade? Having determined the absolute values of load distribution, further studies then would indicate the effect of variable subgrade conditions on a given pavement, if any.

As outlined in Mr Benkelman's paper on flexible pavements in 1937,[1] a number of formulae have been suggested for calculating required thickness of pavement for variable subgrade conditions It has been my contention that if a flexible type pavement was constructed having appropriate shear resistance, a load applied to its surface then would be distributed to the base or subgrade within the frustrum of a cone having sides at an angle of approximately 45° with the base, and this distribution would be in the same manner regardless of subgrade Thus knowing the bearing power of the foundation the thickness of pavement required could be readily determined

There has been some tendency to confuse the behavior of untreated soils, having resistance values depending upon varying moisture content, with bituminous pavements designed for a definite minimum shear resistance and unaffected by moisture Thus to have the results obtained by the method outlined by Prof Spangler of definite value, it would appear desirable to have the surfaces (under test) further described in respect to their stability (shear) values There are several laboratory machines available for such a test, the best known in the East being the Hubbard-Field type Such measures of stability values would immediately determine whether or not the laboratory pavement had been consolidated to a condition similar to the ultimate field condition The bearing values would then show the differences brought about as a result of varying pavement characteristics

The report indicates that tests so far have been confined to gravel mixtures stabilized chemically, and that bituminous mixtures have not as yet been tried. Nevertheless the same considerations apply, as it would seem that very considerable difference in bearing values would result as a gravel-chloride mixture hardened

As to the method itself, it would appear to be a sound procedure, provided the

[1] Proceedings, Highway Research Board, Vol 17, p 144

results can be duplicated for a given condition within a small margin of error. There is a very real need for some laboratory method of a simple type

MR FRED BURGGRAF, *The Calcium Chloride Association* Were these stabilized bases permitted to dry out or season?

MR SPANGLER The bases used in these experiments were not permitted to season They were submitted to no traffic This particular work was for the purpose of developing a method of measurement Later we hope to adapt the method more nearly to service conditions.

MR BURGGRAF I should like to discuss briefly the results of some recent tests, which reveal the relationship of the seasoning action of roads of this type and their structural stability These tests were made under construction conditions

In this investigation both the density and structural stability of a graded stabilized road mix at different intervals starting when the material was deposited on the grade from the spreader-box were determined The results are shown graphically in Figure 1 This figure shows that 85 per cent of the resultant density was obtained during the compaction period by a multiple wheel roller and the remaining 15 per cent of the density was due to the shrinkage compaction or the seasoning of the road On the other hand the roller compaction only accounted for 10 per cent of the structural stability and the remaining 90 per cent of the stability was obtained during the shrinkage, compaction or seasoning period This added stability, due to seasoning, undoubtedly would greatly increase the area of load distribution on the subgrade

I should also like to suggest if Mr Spangler continues this work that he use some method for determining the structural stability of both the subgrade and the stabilized base and correlate these results with his pressure intensity or distribution information Such a correlation may lead to a rather simple stability test for design and construction purposes In my work during the past two years on developing some practical apparatus for making field tests on the structural stability of subgrades and stabilized roads, I have found it necessary to obtain the following information. (1) load and deformation data, (2) moisture content at time of test and, (3) density at time of test These tests should be supplemented by the gradation and regular soil constant tests

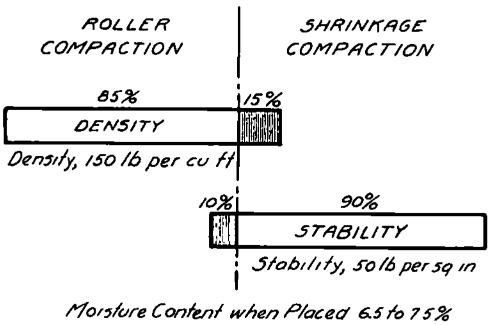

Figure 1. Average Relative Effects of Roller and Shrinkage Compaction on the Density and Structural Stability of Calcium Chloride Stabilized Roads.

MR SPANGLER In the paper are some figures regarding the density of the surfaces and base courses which were used in these experiments The optimum moisture content of the base course material was 9 12 per cent which gave a maximum dry density of 130 96 lb per cu ft The moisture content of the base course as used was approximately 5 to 5½ per cent and it showed a dry density in place of 126 or 127 pounds per cubic ft

MR J A BUCHANAN, *Bureau of Public Roads*· Were the results checked by determining the total load as represented by an integration of the load intensities and their corresponding areas of application? That is, the solid volumes represented by the intensity distribution drawings should equal the applied loads

MR SPANGLER After completion of all of these trials, we attempted to calibrate the ribbons independently to determine the proportionality factor by loading the whole area of this 5 by 5 box with a column of sand about 5½ ft high The total load was assumed to be uniformly distributed and by that method we got an independent calibration of the coefficient of friction of the ribbons which was 0 65 as against 0 69 which we obtained by the integration method In other words, the measured pressure on the subgrade equalled about 94 per cent of the applied load on the pavement surface