AN APPARATUS FOR MEASURING SLAB ACTION IN FLEXIBLE TYPE PAVEMENTS

By John Lowe

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SYNOPSIS

This paper is a report upon research on flexible type pavements conducted at the Soil Mechanics Laboratory of the Massachusetts Institute of Technology from October 1941 to June 1943 The research was sponsored by the U S Engineer Department and was supervised by Professor D W. Taylor A more detailed report in the form of a doctor's thesis is intended at a later date

The primary purpose of the research was the measurement and study of "slab-action" in materials of the type used in flexible type pavements The author believes that such measurements and studies are fundamental to a rational evaluation of the effectiveness of the various layers composing a flexible type pavement For the research an elaborate apparatus was designed and constructed for measuring slab-action and tests were performed on two materials The results so far prove the existence of appreciable slab-action in flexible type pavement materials, but are not sufficient at present for comparing various materials Such comparison work is contemplated in the near future

The paper is in four parts:

1 An analysis of the fundamental nature of slab-action.
2 A description of the apparatus for measuring it
3 The results of measurements of slab-action
4. The uses and significance of such measurements.

The main contribution of the research has been the development of an original slab testing apparatus and the demonstration by a few preliminary tests of the existence of appreciable slab-action in flexible type pavement materials.

1. FUNDAMENTAL NATURE OF SLAB-ACTION

The following analysis of the action of flexible type pavements under load is presented to show the fundamental nature of slab-action in this connection

Generally speaking the structural design of flexible type pavements is concerned with the proper relationship between four variables: the wheel load applied to a pavement,[1] the deflection pattern occurring at the surface of the pavement, the thickness and physical properties of the pavement and the thickness and properties of the subgrade supporting the pavement. In a satisfactory pavement these variables are related as follows When a wheel load is applied to the pavement, the pavement so distributes the load to the subgrade that the pattern of deflection which results at the surface of the pavement is less severe than the pattern of deflection allowable there. The allowable pattern of deflection is largely governed by the characteristics of the vehicles which are to operate on the pavement and/or by the deformation characteristics of the surfacing material of the pavement. Also the number of repetitions of load that the pavement will have to undergo will influence the allowable deflection; the more repetitions of load, generally speaking, the less severe the pattern allowable for any single application.

To describe the relationship between the four variables in more detail, the wheel applies load to the surface of the pavement; the pavement transmits and spreads the load, and the base of the pavement applies the load to the subgrade. Both the pavement and the subgrade compress because of the loading. Under usual conditions the compression in the subgrade is the major source of the total compression or surface deflection pattern. Because of the compression in the subgrade the pavement assumes a dishlike shape in the vicinity of the load. The immediate purpose of this research is to measure the effect of this dishing of the pavement on the distribution of

[1] In this paper the word pavement is used to denote the total of surfacing, base course and treated subgrade, frequently a pavement will be considered made of only one material

load to the subgrade, noting in particular any reduction in the severity of this distribution

The action which occurs upon dishing of a pavement to cause a change in distribution of load at the base of the pavement is termed "slab-action." To understand the action it is helpful to consider two extreme types of pavement. one with much slab-action, the other without any. Figure 1a shows a thin concrete pavement supported on a rigid subgrade, *i.e.* ledge rock or any material appreciably more rigid than the concrete itself. Figure 1b shows a pavement of loose bricks on the same rigid subgrade. For a particular wheel load the distribution of load to the rigid subgrade for both the concrete and loose brick pavement is practically the same as the distribution of the applied load. For comparison, these same two pavements are shown in Figures 1c and 1d on a yielding subgrade, for

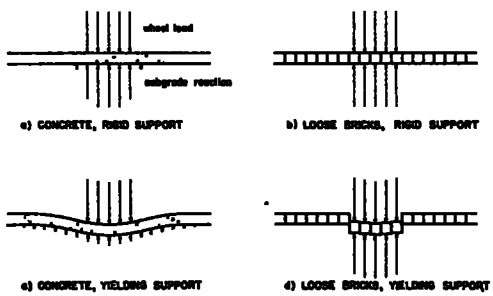

Figure 1. Comparisons of Action of Extreme Types of Pavement

instance a soft clay. Upon application of the wheel load and after yielding of the subgrade in the vicinity of the wheel load the distribution of load will be quite different for the two pavements. The concrete pavement will distribute the wheel load over a much larger area than it did for the rigid subgrade. The loose brick pavement on the other hand will not change its distribution of load from that of the previous case because any load transmitted to the surface of a brick is transmitted undiminished through the brick and to the subgrade beneath. The concrete pavement is said to have much slab-action and the loose brick pavement none. Flexible type pavements, like the concrete pavement, redistribute their loads to the subgrade upon yielding of the subgrade, but their load spreading ability is less. Usually, however, flexible pavements can take full advantage of an allowable pavement deflection pattern which for concrete pavements would not be possible without cracking.

Slab-action thus explains the difference in behavior between various pavements under load. As illustrated by the comparison between the concrete and loose brick pavements, a pavement with slab-action spreads out the wheel load applied to it upon yielding of the subgrade and the deflection pattern resulting from the new distribution of load is much less severe than that which would result if the pavement did not have slab-action. It is this change for the better in load distribution on the subgrade that is the important feature of good pavements For example, tests on 9-in. layers of sand and silt on a rigid support give the pressure distribution curves shown in

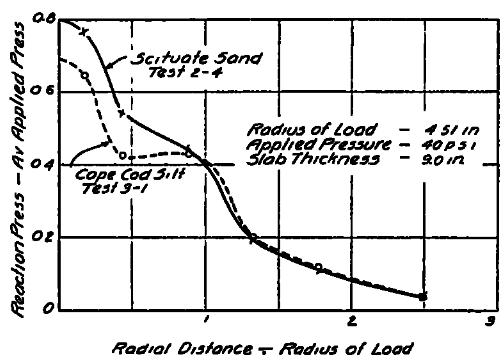

Figure 2. Pressure Distributions on Rigid Support

Figure 2 The two curves are practically the same for both materials and other flexible pavement course materials would probably give similar distributions for the same thickness and wheel loading Thus the difference in behavior between these materials is not at all apparent from their distributions of pressure on a rigid support Rather, curves of their distribution of pressure on a support which yields in a pattern typical of field conditions are essential for a comparison Measurement of such distributions on a properly yielding support would allow prediction of the difference in highway or runway behavior of such materials and allow the setting up of a rating system for them The procedure of so comparing and rating pavement materials is described in more detail in Section 4 on Uses and Significance of Slab-Action Measurements.

2. Description of Apparatus

The general features of the apparatus are shown in Figure 3, and are as follows. A slab of pavement material 4 ft. in diameter and 10 in. maximum thickness is loaded with a circular simulated wheel load at the center of its top surface and the pressure distribution over the base of the slab is measured as the base of the slab is made to deflect. There are two original and important features to the apparatus. One is that it affords measurement of the pressure distribution at the base of the slab not only for rigid support of the base, but also for yielding of the base according to any reasonable deflection pattern. The other is that the pressure is measured continuously over the entire base of the slab, not at isolated points as in many previous arrangements using pressure cells.

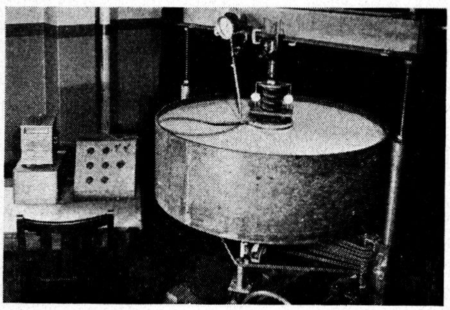

Figure 3. Slab-Action Apparatus

The support arrangement for the base of the slab is shown schematically in the perspective section view, Figure 4. The details of the apparatus will be described starting at the bottom. First are three 4-in. WF beams radiating from the center of the apparatus and at 120 deg. to each other. On top of the WF beams are 22 screw jacks, seven on each beam and one at the center. The jacks are similarly spaced on each beam. Supported on top of each set of three similarly located jacks is a 5-in. deep by $\frac{3}{8}$-in. thick steel ring; the center jack supports a ring by itself. There are thus eight concentric steel rings. The center ring has a mean radius of 0.75 in. and the successive outer ones have radii of 2, 4, 6, 8, 11.25, 15.9 and 24 in. The outermost ring is 11 in. deeper than the others and also forms the side of the apparatus. Spanning between the concentric steel rings are steel radial bars $\frac{1}{4}$ in. wide by $\frac{1}{2}$ in. deep. From each ring one series of bars span the distance to the next outer ring and another series the distance to the next inner ring; the innermost and outermost rings each have only one series of bars. The two series of bars at each ring are interspaced. All radial bars are supported on knife edges; one end of each bar is grooved to prevent sliding. On top of the radial bars are 95 concentric

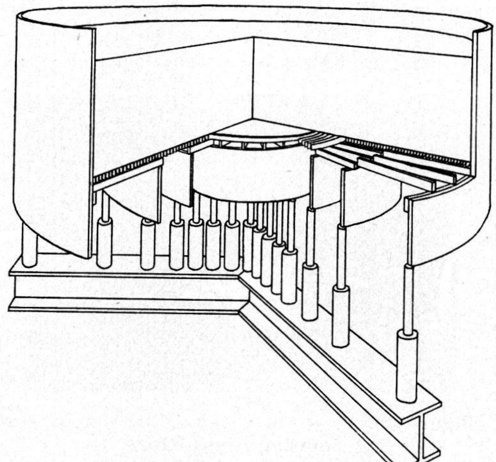

Figure 4. Perspective Section View—Slab-Action Apparatus

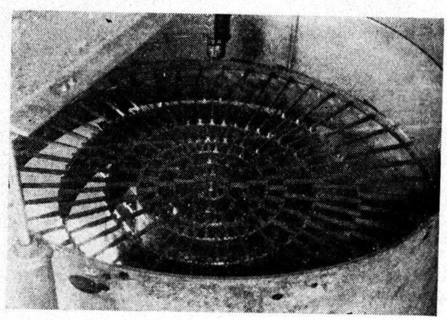

Figure 5. View of Slab-Action Apparatus Showing Radial Bars and Steel Rings

brass rings, $\frac{1}{8}$ in. wide by $\frac{3}{8}$ in. deep with $\frac{1}{8}$ in. spaces between them. On top of the brass rings is a sheet of canvas and above this a sheet of rubberized cloth. The material to be tested is placed on the rubberized cloth. Figures 5, 6 and 7 show successive views of the apparatus.

The load carried by each jack is measured by electrical strain gages and from such measurements the pressure distribution at the base of the slab is computed. Each jack ram contains a short thin wall section on which is mounted a special S-R[2] type electrical resistance wire strain meter. For the loads which come to the jacks when a 9-in. thick slab is subjected to a 40-lb. per sq. in., 9-in. diameter wheel load under rigid support conditions, the strain meter section deflects a maximum of 0.0004 in., and the maximum relative motion between the central four sets of jacks is about 0.0002 in. Thus because of the small deflection required to operate the electrical strain

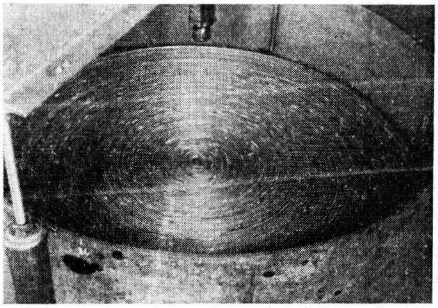

Figure 6. View of Slab-Action Apparatus Showing Brass Rings

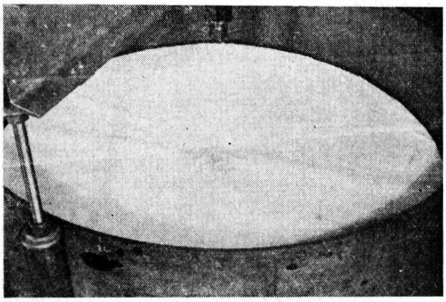

Figure 7. View of Slab-Action Apparatus Showing Rubber Sheet on which Pavement Material is Placed.

meters the support may be said to be essentially rigid. By adding up the load coming to each of the three jacks supporting any steel ring the total load coming to that ring can be found. From the loads at each ring a smooth curve of pressure distribution may be computed. Briefly, the relationship between ring loads and pressure values which has been used in this research is set up as follows: The pressures existing over the eight rings are taken as eight unknowns. Each set of three adjacent unknown pressures are used to set up a parabolic type equation between pressure and radial distance. By averaging the two parabolic equations thus set up for each span a pressure curve for each span is made available in terms of the four adjoining unknown ring pressures. The equation for the load coming to each jack is found by properly integrating the load contributed by each span adjacent to a ring. Thus the load to each ring is expressed in terms of the unknown pressures at the ring itself and at the two rings on each side of it. Since there are eight rings, eight such equations are available. By solving these equations simultaneously the pressure at any ring is found in terms of eight coefficients. The pressure at any ring can be determined by multiplying each of the eight ring loads by the proper coefficient and adding the products algebraically.

The yielding of the support in any desired pattern, allowing the choice of the pattern believed most closely to simulate actual field conditions, is one of the outstanding contributions of this apparatus. It is effected by operating all the jacks at once. The three screw jacks supporting each steel ring have sprockets which are connected together by a continuous chain. The chains from the seven sets of three and from the single central jack are connected to a master drive. By varying the size of the sprockets on the master drive, the relative amounts that the various sets of jacks move in a given time can be nicely controlled and any reasonable pattern of deflection imposed at the base of the slab. Actually the pattern of deflection is not a curved surface but is made up of a series of eight intersecting cones, the cones being exceedingly flat, i.e. having apex angles slightly less than 180 deg.

The apparatus for measuring slab-action thus affords determinations of the relationship between the vertical pressure distribution curve and vertical displacement pattern at the base of a slab of flexible type pavement material when the slab is subjected to a wheel load at the center of its surface. The apparatus

[2] For general description see article: "Characteristics and Aircraft Applications of Wire Resistance Strain Gages," by A. V. de Forest, *Instruments*, April 1942, v. 15, p. 112 et seq. A complete up-to-date bibliography may be obtained from Baldwin Southwark Division of Baldwin Locomotive Works, Philadelphia.

does not afford measurement of the relationship between tangential or shear stresses and tangential displacements at the base of the slab. Such tangential stress displacement relationships are necessary in addition to the vertical pressure-displacement relationships for a complete picture of the stress-displacement conditions at the base of a slab, but so far as is now known do not play a major part in the action. The apparatus does make available, however, a wealth of heretofore unobtainable information which even if not exactly similar to is at least a close approximation of the stress deflection relationships at the base of a pavement slab.

3. MEASUREMENT OF SLAB-ACTION

In this section are presented the results of measurements of slab action in a 9-in. thick slab of Scituate Sand at about 0.65 relative density. These results show that appreciable slab-action exists in this sand when at this density. Also they show that the changes in pressure distribution caused by slab-action dissipate very little with time.

The results of test No. 2–4 on the Scituate Sand are shown in Figure 8. This figure contains three plots of pressure vs. radial distance and a plot of the deflection pattern used in the test In the pressure distribution plots the ratio of reaction pressure to average applied pressure is plotted as ordinates and the ratio of the radial distance from the center line of the load to the radius of loaded area as abscissae Such ordinates and abscissae are dimensionless and allow best facility for comparison of tests at different applied pressures and different radii of loaded area. The deflection pattern plot shows the relative deflection at the various ring supports but to a greatly exaggerated scale The load for this test was applied using a rigid steel plate of 4 51-in. radius. Other tests performed later made use of a better loading arrangement which closely simulates a flexible tire load. This unit is shown in Figure 3 The average applied pressure was 40 p s i With no yielding of the support the pressure distribution was as given by the full (x mark) curve of the figure. A dip appears in this curve at a distance approximately one-half the radius of the load out from the center line of the load Practically all tests showed this dip and it seems to be characteristic of the no yield pressure curve When the support was made to yield according to the deflection pattern to an average deflection of 0.005 in. directly underneath the loaded area, the pressure distribution became that shown by the dashed (circular mark) curve. When the yielding was increased until the average deflection was 0.015 in., the reaction pressure distribution became that shown by the dotted (plus mark) curve. It is possible that the dashed curve pressure distribution approximates that which might develop on a silt subgrade, the dotted pressure distribution, that which might develop on a clay subgrade. The test definitely shows that an appreciable change in pressure distribution occurs at the base of a pavement when the support for the pavement yields an amount typical of satis-

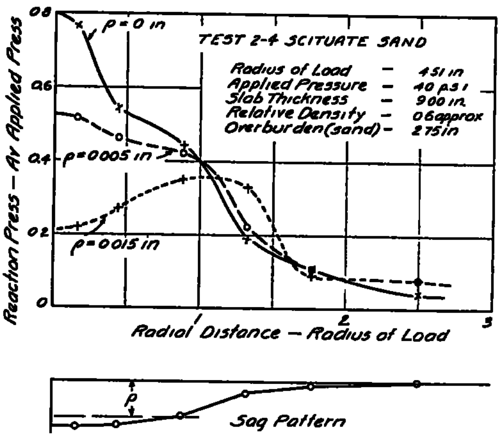

Figure 8. Pressure Distribution Curves for Rigid and Yielding Base Support, Scituate Sand.

factorily functioning pavements in the field. It may be noted that the changes in pressure distribution as pointed out previously are always such as to cause a spreading out of the load and a less severe loading condition on the support

In order that slab-action may be of value in reducing the severity of a wheel loading on a subgrade it is essential that the spreading out of the load resulting from the dishing exist as long as the deflection pattern is maintained, in other words, it is important that the more favorable pressure distribution existing after the deflection does not creep back to the no yield distribution because of the lapse of time or the existence of vibrations. Some information is available on the effect of time on the pressure distribution after dishing; no results are available, however, on the effect of vibrations The pressure curves of Figure 8 are computed from reaction measurements taken about 30 min after yielding of the support. In Figure 9 two pressure distributions have been plotted for the 0 015-in. average yield case. The lower curve is the same as the one on Figure 8, 30 min after yielding; the upper curve is a plot of the pressure computed from measurements taken 1 day after yielding. The difference between the two curves is small and it is therefore concluded that for this soil the slab-action is not greatly dependent upon time.

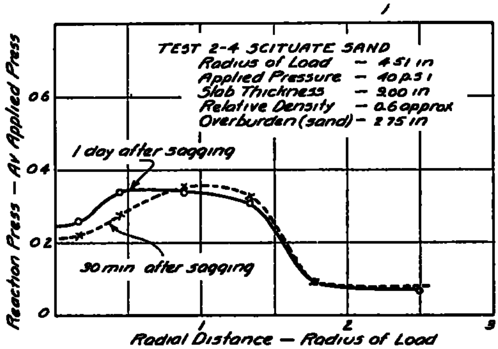

Figure 9. Effect of Duration of Load on Sagged Pressure Distribution Curve

4. USES AND SIGNIFICANCE OF SLAB-ACTION MEASUREMENTS

Measurements of slab-action in flexible type pavement materials have significance for both immediate and future testing and research on flexible type pavements. They have immediate importance for comparing and rating various pavement materials according to their load spreading ability, and future importance for developing understanding of the relationship between the stress-strain properties of flexible type pavement materials and the load deflection properties of pavements composed of such materials.

Measurements of the change in pressure distribution at the base of a pavement upon dishing can be used to compare the load spreading ability of various materials or of the same material under various conditions The procedure for making such comparisons is as follows. First choose a subsidence pattern which is reasonable for both the pavement and the subgrade on which the pavement is to be placed. Then for each material determine by means of the slab-action apparatus the pressure distribution on its base after application of the chosen deflection pattern The materials can then be compared by inspection of their pressure distributions after deflection and rated according to the severity of the distribution. Of course the deflection pattern would be slightly different for each pavement if it were actually placed on the subgrade and subjected to the wheel load This would not invalidate the test, however, because the materials would probably be found to rate in the same order for almost any reasonable deflection pattern. The important thing is that a material with more slab-action than another will be better than the other for spreading load whenever comparable yieldings of their supports occur. The fact that the deflection pattern to which a pavement will be subjected in the field is not known exactly in no way invalidates the foregoing rating procedure

Several very worth-while studies could be conducted following out the testing procedure thus outlined. For instance, the effect of the degree of compaction or of admixtures upon the ability of a given soil to spread load could be studied Also pavements of various combinations of materials could be investigated. For example, the action of a pavement composed entirely of a good material could be compared with that of one of equal thickness, but with only the upper half composed of the good material. Such laboratory studies of the relative field merits of various pavements are possible only because the slab-action apparatus affords measurement of the fundamental aspects of load spreading ability, namely, the changes of pressure distribution at the base of a pavement with deflection of the base.

The use of the slab-action apparatus for comparing and rating pavement materials requires much time and energy and therefore it is reasonable to expect that considerable effort will be expended in the future to develop a rational procedure for predicting the behavior of pavement materials from simpler laboratory tests At present flexible type pavements are being designed by methods based on more or less empirical correlations between pavement behavior and laboratory tests. Any rational correlation should tie together pavement behavior and the fundamental stress-strain properties of pavement materials. The cylindrical compression (triaxial compression) test satisfactorily measures the stress-strain properties of pavement materials, but so far no one has been able to combine such stres -strain measurements with equations of equilibrium to solve for the distribution of stress at the base of a pavement The particular solution desired is the distribution of stress at the base of a pavement when the pavement is subjected to a surface wheel load and deflection of its base. If such a solution were available the slab-action or load spreading ability of a pavement could be predicted by computation from cylindrical compression test data

Until a solution is available, such information can only be obtained from apparatus of the same general type as the slab-action apparatus where essentially full-scale pavement models are tested. In addition to furnishing information on the stress-deflection characteristics of pavements, valuable in itself for rating pavements, the slab-action apparatus also will greatly assist in solving the analytical problem. It will do this by furnishing solutions to the problem for any reasonable setup, such solutions then acting as guides for the analytical solution If the rigorous solution is too difficult, and it might well be, the data from the slab-action apparatus will be useful for developing approximate rational correlations between the fundamental cylindrical compression data and pavement behavior.

In conclusion, it may be stated that an original and valuable apparatus has been developed for rational study of the action of flexible type pavements. The apparatus is original in that it affords control of the vertical deflection of the base of a pavement slab and continuous measurement of the pressure over the base for any deflection pattern It is valuable in that it makes available for the first time measurement of the load-deflection relationships in a slab of material which are fundamental to predicting the effectiveness of that material for flexible type pavements. Specifically, the apparatus should furnish valuable information for comparing various materials. What is more important, it may also supply data essential to the developing of more advanced theories of pavement action

The writer wishes to express his appreciation to the following persons and organizations for their contributions to this research· to Professor D W. Taylor for advice, encouragement, innumerable and invaluable discussions on every aspect of the research and critical review of this paper, to the U S. Engineer Corps for sponsoring the research, in particular to Mr. T. A Middlebrooks, Office of the Chief of Engineers, and Mr. William Shannon, Office, Boston District, and to Professor Arthur C. Ruge for help in adapting and setting up the electrical resistance wire strain gages

DISCUSSION ON APPARATUS FOR MEASURING SLAB ACTION

Prof. Gregory P. Tschebotarioff, *Princeton University:* Slab action or arching or dome action must be present in different types of pavements, and it is important to ascertain that action if we are to make more economical designs in the future. I believe that the apparatus described may provide qualitative information on the subject. However, I would like to sound a word of caution about the quantitative data it might give, because I doubt that model similarity will exist between different thicknesses of base courses and also because sag patterns cannot be chosen arbitrarily

The sag pattern of a base course is a function of the pressure distribution both through the base course and the subgrade beneath it and, since the pressure distribution varies for different soils, these sag patterns will be different for different soils. There is very little numerical information on the subject at present Possibly the type of electric settlement recording gauges used in the field by Mr. O. J. Porter, of the California Division of Highways, may provide some information later But the question of model similarity will arise even if a reasonable sag pattern is chosen.

We have given some thought in the past at Princeton to the use of a similar apparatus, similar in some respects but not in all, to the one which has now been built at Massachusetts Institute of Technology. Perhaps I had better discuss some figures illustrating the work done by Dr. Oscar Faber in London on the general ideas of which work we had planned to design our apparatus. These figures are taken from a paper published in the "Structural Engineer" in London in March, 1933.

Dr. Faber was principally interested in ascertaining the distribution of pressure reactions against a footing resting on different types of soils (See Fig. 1). The lower test plate rested on the soil and consisted of a series of concentric rings of equal area, each connected by three rods to an upper rigid plate. Readings were taken with strain gauges on these rods before and after loading. From the strains in the rods were determined the pressures against each corresponding ring.

model similarity would not be present and that it would be important to build a very large testing tank in order to get numerically correct results.

To explain this point, perhaps it would be preferable to show results of Dr. Oscar Faber's tests. Figure 2 presents a series of curves giving the distribution of pressure reactions against the test plate on the surface of a sand layer without any surcharge. A greater concentration of soil reactions at the center takes place due to yielding of the sand on the periphery. Each point of the curve represents the value of the mean pressure on one of the rings.

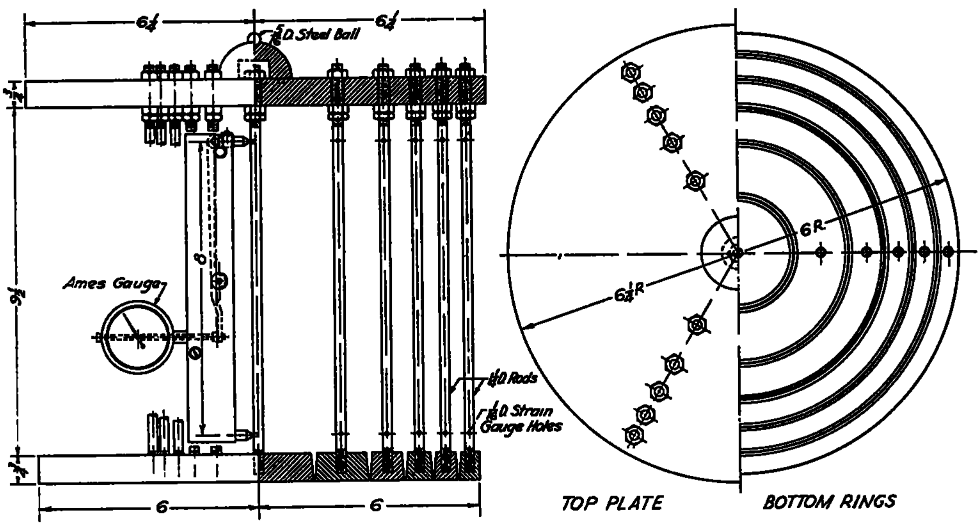

Figure 1. Dr. Faber's Device for Determining Soil Reactions Against Rigid Plates. From: The Structural Engineer, London, March, 1933

I must emphasize that they had no provision for creating any deflection, as is the case in the apparatus described by Mr. Lowe

About five years ago we thought of building at Princeton a testing box with a similar ring base, but using more modern methods of measurement than the ones used by Dr. Faber. The presence of the subgrade was to be simulated by layers of rubber of suitable compressibility to be placed over the ring base. The sag pattern would then be a function of the pressure distributory properties of the base course. However, one of the several reasons which deterred us from carrying this out at the time was the fact that we felt that

Figure 3 presents a similar result of a test on sand with 1.46 ton per sq. ft surcharge around the plate. The pressure reactions are equalized to a certain extent, but not entirely. The surcharge is much larger than it ever would have been under a pavement.

Figure 4 represents the distribution of reactions on a clay soil (London blue clay). A reversed pattern of reactions with greater concentration at the edges was observed as this was to be expected on an elastic material in accordance with the laws of the theory of elasticity. I believe this is the first time any tests measuring the pressure distribution on clay soils have been performed. On the basis of the theory of elasticity it is reasonable to assume that the pressure distribution below the soil surface will follow the same general lines, therefore, we will have a difference in the distribution of pressure at different depths. The sag patterns also vary with depth. A similar reasoning holds for two-layered systems. Therefore a sag pattern measured in

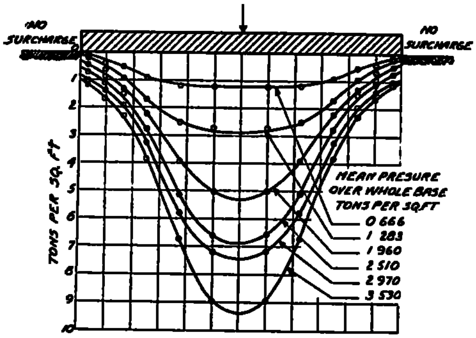

Figure 2. Dr. Faber's Tests on Sand—No Surcharge. Distribution of Soil Reactions Against a Rigid Test Plate. From: The Structural Engineer, London, March, 1933.

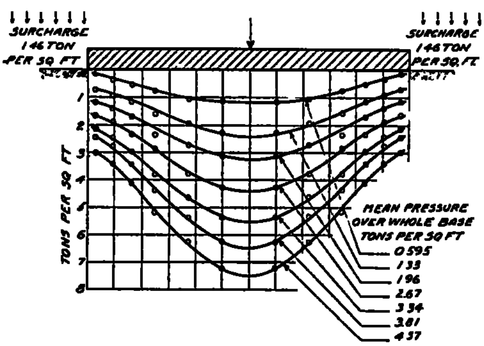

Figure 3. Dr. Faber's Tests on Sand with Surcharge. Distribution of Soil Reactions Against Rigid Test Plate. From: The Structural Engineer, London, March, 1933.

the field for a full-scale base cannot be directly applied to a model base.

Figure 5 gives the results of tests performed at Zurich in Switzerland, and compares the distribution actually measured in sand by batteries of pressure cells at a depth of 18 in., as compared to the theoretical distribution based on the laws of the theory of elasticity. There is a considerable difference between the two results, with sand giving a much greater concentration, e g , having a lesser distributing action

If one wants to use an apparatus of the type described by Mr. Lowe and if one employs an identical sag pattern for the purpose of getting quantitative data it should therefore be remembered that in the case of a material which has poor distributing properties one may obtain misleading values, as compared to a cohesive material, because the actual sag pattern

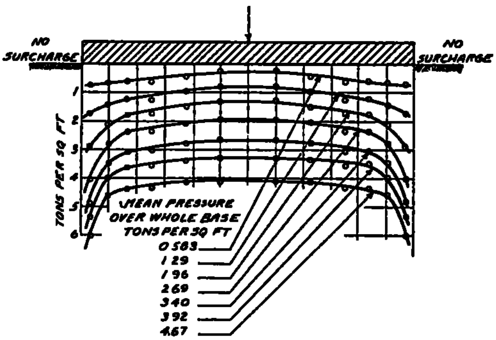

Figure 4. Dr. Faber's Tests on Clay with No Surcharge. Distribution of Soil Reactions Against a Rigid Test Plate. From: The Structural Engineer, London, March, 1933.

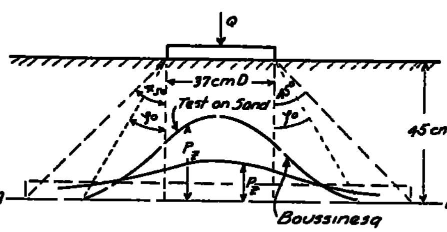

Figure 5. Swiss Tests Showing Lesser Spread of Pressures in Sand, as Compared to an Elastic Medium.

is more pronounced in the case of a sand than of a clay soil.

Summing up, although this study is a step in the right direction, it will be preferable later to have apparatus of a larger size. The question of sag patterns should be treated differently.

I believe that the present M.I.T. apparatus, without any question of model similarity arising, could be used for the studies of possible differences of stress distribution under static loads and under dynamic loads. We are carrying out at Princeton research on the effect of vibrations for the Civil Aeronautics Authority. I believe that for comparative evaluation of vibration effects, the M.I T. apparatus as designed, is entirely adequate. I would like to wish good luck to Mr. Lowe in the continuation of his work and will be interested to hear further about it.

THE THEORY OF STRESSES AND DISPLACEMENTS IN LAYERED SYSTEMS AND APPLICATIONS TO THE DESIGN OF AIRPORT RUNWAYS

By Donald M Burmister

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SYNOPSIS

In foundation and particularly in airport design and construction, the engineer is dealing basically with layered soil deposits. The theory of stresses and displacements in a two-layer system was developed in accordance with the methods of the mathematical theory of elasticity and is presented in order to reveal some of the fundamental relations existing between the physical factors, which control the load-settlement relations, and in order to provide a practical method of analysis for the design of airport runways. The theory reveals the controlling influence of two important ratios on the load-settlement characteristics of the "two-layer system," namely: (1) the ratio r/h_1 of the radius bearing area to the thickness of the reinforcing or pavement layer; and (2) the ratio E_2/E_1 of the modulus of the subgrade to that of the pavement. For practical design purposes, the theoretical results have been evaluated numerically and expressed in Basic Influence Curves, giving values of the settlement coefficient F_w in terms of these basic ratios The settlement coefficient is applied as a simple multiplying or correction factor to the familiar Boussinesq Equation for surface settlement at the center of a circular flexible bearing area. The practical design problem for airport runways involves the selection of suitable and economical types of pavement construction and the determination by means of the influence curves for the "two-layer system" of the thickness required to give adequate support to airplane wheel loads and reasonable length of service.

THE TWO-LAYER SYSTEM THEORY—ASSUMPTIONS AND CONDITIONS

The "two-layer system" theory is presented first of all in order to provide a basis for a better understanding of the nature of the real phenomena, and to reveal some of the fundamental relations existing between the physical factors which control the load-settlement relations Second, it is intended to provide a practical method of analysis for the design of airport runways

Boussinesq solved the problem of stresses and displacements in a uniform deposit for concentrated load applied at the surface. The scientific approach in the present problem involved the rigorous development of a theory of stresses and displacements in the more general case of a "two-layer system" by the methods of the mathematical theory of elasticity, which is believed to be correct. The general solution of the "two-layer" problem required that the necessary assumptions of the theory of elasticity be made, and that certain essential boundary and continuity conditions be satisfied, but did not require any radical simplifying assumptions beforehand as to the nature of the distribution of stresses on the subgrade or of their relation to displacements.

It must be realized that all theories deal with ideal materials and ideal conditions, which are only imperfectly satisfied in natural soil deposits. Judgment as to realm of