REQUIRED THICKNESS OF ASPHALT PAVEMENT IN RELATION TO SUBGRADE SUPPORT

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SYNOPSIS

Observation of the mechanism of failure of asphalt pavements resting upon soil masses by means of the tests described in the paper indicated that failure of the asphalt pavement under concentrated loading is directly dependent upon the deflection produced in the pavement section and not upon the maximum load supporting value of the soil upon which it rests

The critical deflection appeared to be between 0 5 and 0 6 in , irrespective of thickness of the pavement or diameter of the loaded area

With the available apparatus, the authors found that plastic or cohesive soils, subjected to concentrated loads over bearing areas not exceeding 58 sq in , conformed with the behavior of cohesive soils as observed by Housel in a series of field tests, where for any given deflection a straight line relation existed between the unit load and the perimeter-area ratio of different bearing areas

It was found that this same relation was developed when sections of pavement resting upon plastic soils were subjected to the same loading conditions

A circular bearing area of 130 sq in was tentatively selected as a basis of evaluating the load supporting characteristics of a soil with relation to an overlying asphalt pavement and the load supporting characteristics of the pavement with relation to the soil upon which it rests The method of evaluation is briefly as follows

1 The load supporting value of the soil with reference to the pavement is determined by running load deflection tests up to 0 5 in deflection using circular testing heads of 5 8, 13 0 and 58 sq in under a definitely established rate of unit load application Unit loads for this deflection are plotted against the $\frac{P}{A}$ value for each head A straight line relation between these values is determined and the line projected to a $\frac{P}{A}$ value of 0 31 The unit load at this point, representing an area of 130 sq in , is taken as the load supporting value of the soil

2 The load supporting value of different thicknesses of asphalt pavement placed upon the reconditioned soil is obtained by exactly the same method

3 The load supporting values so obtained were plotted against the different thickness of pavement tested to establish a curve showing the thickness required to carry any desired unit load.

This paper is a statement of procedure, observations and recorded test data in connection with an attempt to find a simple method of evaluating subgrade support with reference to thickness of pavement required to carry traffic loads satisfactorily. No new theories are advanced and no existing theories are questioned except insofar as the factual data presented may throw into question some conclusions previously drawn from theoretical considerations

Like most investigators the authors were limited by available equipment and other practical considerations to a scale of operation of considerably less magnitude than they would have preferred but one which developed more information than had been anticipated They felt that the mechanism of failure of asphalt pavements under concentrated loading when due to inadequate subgrade support, had not received sufficient attention and that useful information might be secured by detailed observation of loading tests conducted under carefully controlled conditions on sections of asphalt pavement of different thickness resting upon soil masses of low supporting value. So far, as a matter of convenience, the investigation has been limited to hot mix types of pavement such as sheet asphalt and asphaltic concrete and to plastic or cohesive soils which create the greatest problem from the standpoint of thickness design.

APPARATUS

The largest test specimen that could be readily accommodated by the testing machine, available for use, was limited to a top surface area about two feet square. The special apparatus used was therefore designed on this basis and was equipped with stress and strain measuring devices placed at locations where it was thought that useful information might be secured. It is shown in Figure 1. It consists essentially of a rigid metal box, 24 in. square and 12 in. deep, inside measurement. A Goldbeck type soil pressure cell is built into the bottom of this box with the weighing face directly in the center and flush with the inside bottom surface. A second soil pressure cell is built into one side of the box so that the center of its weighing face is equidistant from the adjacent sides and 3 in. below the top. The face of this cell is also flush with the inside surface of the box. This apparatus holds exactly 4 cu. ft. of compacted soil when level full.

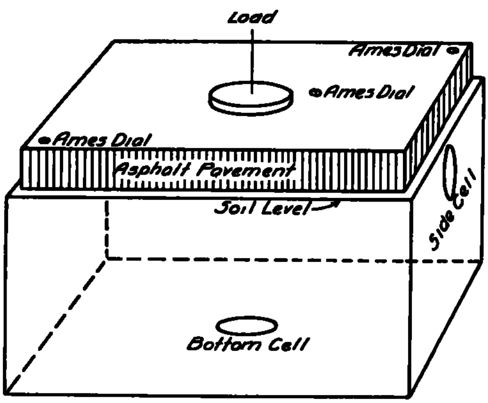

Figure 1. Soil Pressure Box

When filled with soil and centered on the base of the testing machine, under the testing head, pressure reactions developed in the soil, 12 in. below its original surface, and directly under any applied load are measured with considerable accuracy, the results being satisfactorily reproducible after the soil has been brought to a state of constant stability In like manner, lateral pressure developed at the fixed location of the side cell may be determined under any load applied at the center of the upper surface of the soil, provided the cell is within the range of measurable developed lateral pressure.

In this apparatus, pressure reactions by increasing load increments, transmitted through circular steel bearing plates, were determined both when the pressure was applied directly to the soil and also to the surface of asphalt pavements with an area of 22 in. by 22 in. placed directly upon the soil surface. Load was applied in increments of 10 lb. per sq. in. with a three minute period of load maintenance between increments. Each increment was developed by gradual increase of load throughout a 1½ min. interval. At each increment of load, strain reactions were measured directly under the bearing plate by means of a compressometer attached to an autographic stress-strain recorder, and at three points on the surface by means of dial gauges rigidly attached to the soil pressure box. One of the gauges was located exactly 2 in. away fron the edge of each bearing plate selected for use. A disk of thin rubber sheeting was interposed between the bearing plate and specimen to be tested and each center deflection reading was corrected for compression of the rubber disk at that particular load.

No attempt will here be made to describe in detail all of the many niceties of procedure required to obtain closely reproducible tests and reliable comparative results. These were gradually evolved as the investigation proceeded. It is sufficient to say that results presented in this paper were obtained under the most carefully standardized procedure so far developed.

MECHANISM OF FAILURE OF ASPHALT PAVEMENTS UNDER CONCENTRATED LOADING DUE TO INADEQUATE SUBGRADE SUPPORT

When preformed sections of asphaltic pavements were laid directly upon a compacted soil mass and gradually loaded to point of failure in the apparatus described, the following typical behavior was invariably observed.

1. Deformation under the testing head took the form of a flat bottomed circular cup shaped depression which increased in depth until ultimate failure of the pavement in punching shear was developed.
2. The section eventually punched out was a truncated cone which was almost cylindrical as the diameter of the base was only slightly greater than that of the loaded area.
3. Initial failure was first evidenced by the development of an irregular circular crack or cracks which appeared at the interface of pavement and soil before any evidence of failure occurred in the surface of the pavement and which approximated the diameter of the section finally punched out.
4. This cracking was evidently due to failure in tension produced by bending of the pavement. Underlying plastic soils frequently showed a reproduction of these cracks in their upper surface caused by the drag of the pavement.
5. All thicknesses of pavement withstood without visible failure, a deflection of 0.5 in. directly below the testing head irrespective of area of head but developed cracking, or punching shear at a deflection of between 0.5 and 0.6 in.
6. Failure of the pavement under deflection occurred when placed on soils which showed no appreciable change in slope of their load deflection curves at this deflection and which were far from being stressed to their own maximum load supporting capacity for the same loaded area.

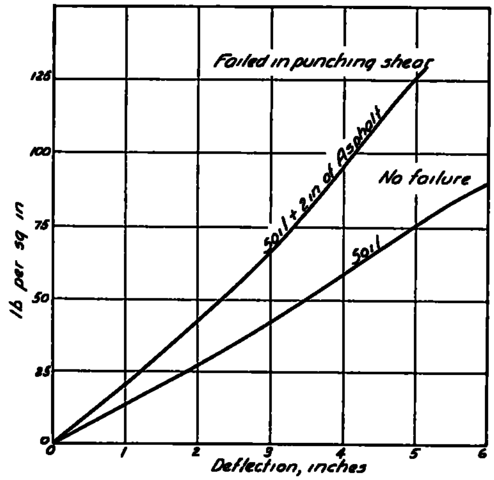

Figure 2

Stated in another way the last mentioned observation leads to a most important conclusion, namely:

Failure of an asphalt pavement under concentrated loading is directly dependent upon the deflection produced in the pavement section and not upon the maximum load supporting value of the soil upon which it rests. A typical example is illustrated in Figure 2.

Resistance to some critical deflection then becomes the proper basis of evaluating the supporting capacity of the subgrade for the pavement rather than its mere ability to support load. From observations so far made it would seem that 0.5 in. might be safely taken as the critical deflection.

At first thought it may seem strange

that the same critical deflection exists for loaded areas of different diameter and irrespective of thickness of pavement. Throughout the tests deflection measurements were taken on the pavement surface two inches distant from the testing head. It was found that a practically constant relation existed between the deflection at this point and deflection directly under the testing head, irrespective of diameter of head and thickness of pavement This is illustrated by typical results shown in Figure 3 where deflection at these two locations are plotted against each other.

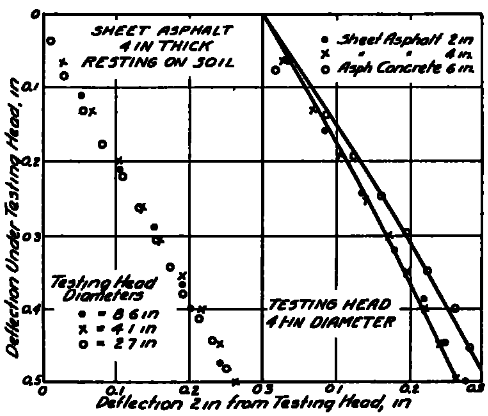

Figure 3

The left hand diagram in Figure 3 shows plotted points for a 4-in sheet asphalt pavement under loading applied by testing heads of three different diameters. In the right hand diagram the lower curve represents the deflection of sheet asphalt pavements 2 and 4 in. thick, loaded with a 4.1-in. diameter testing head and the upper curve a 6-in. asphaltic concrete under the same loaded area. It is seen that even difference in type of asphalt pavement does not greatly affect these relations.

The relation of the two deflections at 0.5 in. center deflection for sheet asphalt is shown in diagram in Figure 4 and illustrates the fact that the angle of deflection from the flat loaded area is not dependent upon either the diameter of head or thickness of pavement. At a given center deflection the tensile stress

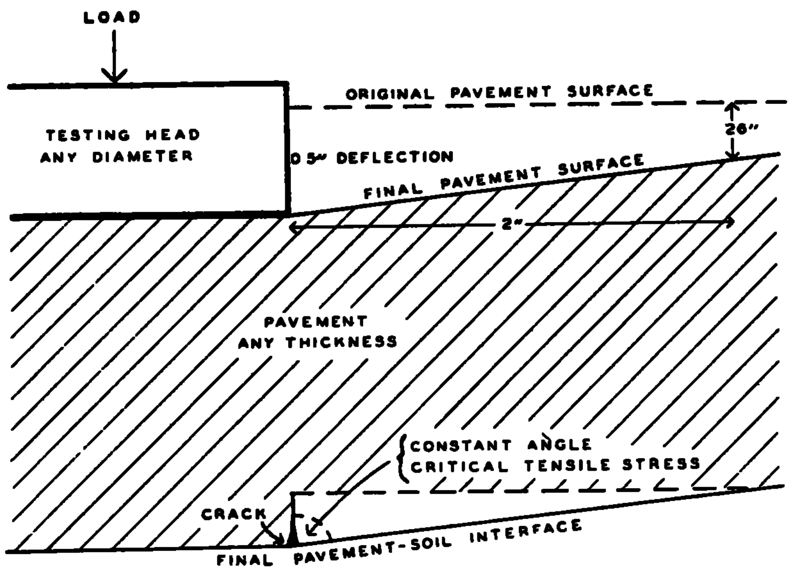

Figure 4. Critical Deflection

in the bottom fibers of the pavement must be approximately the same irrespective of diameter of head and thickness of pavement and failure in tension therefore should be expected to occur at approximately the same critical deflection irrespective of diameter of loaded area and thickness of pavement The relative deflections illustrated in Figure 3 indicate a critical angle of about 81 deg. for the sheet asphalt and 83 deg. for the asphaltic concrete, the two being probably the same within the limit of experimental error.

EVALUATION OF LOAD SUPPORTING CAPACITY OF SOIL AND PAVEMENT WITH RELATION TO EACH OTHER

If 0.5-in. deflection under concentrated loading causes failure of an asphalt pavement resting upon a soil mass, its load supporting value with reference to any given soil would be the unit load applied to a given selected area which produces a deflection of 0.5 in , when the pavement is resting upon that soil. In like manner the load supporting value of the soil with reference to the pavement may be taken as the unit load applied to the same area which produces a deflection of 0.5 in.

The nature and distribution of stresses within the pavement and within the soil, as well as the mechanism of stress distribution to the soil from the pavement under concentrated loading, may then be eliminated from consideration insofar as the present problem is concerned. Whether deflection of the soil is due to any or all of such factors as reduction of voids by additional compaction, elastic deformation, plastic deformation or shear, becomes of secondary importance although evaluation of these properties may sometimes be of interest from the standpoint of safety factor.

The selection of a representative bearing area as a basis of evaluation of pavement and soil with reference to traffic loads merits some consideration as the unit load required to produce a given soil deflection varies greatly with the area over which it is distributed. The contact area of heavy truck tires designed to carry a 12,000 lb. wheel load is approximately 130 sq. in. and suggests itself as at least representing the most severe loading condition to which a highway is subjected. Besides having the greatest contact area the unit load of 92 3 lb. per sq. in. is greater than for any other tire As practically all trucks carrying wheel loads of this magnitude are now equipped wih dual tires the actual loading of the pavement surface is really much less severe. However, 130 sq in. area and 92.3 lb. per sq. in. has been taken as a tentative basis of evaluation in the present investigation.

LABORATORY EVALUATION OF THE SOIL

A circular area of 130 sq. in. has a diameter of about 12 9 in It would be highly desirable to obtain all test data with a testing head of this diameter and attempts were made to use this head. It was found however, that the size of specimens that could be used with the available equipment was not sufficiently large for this purpose and the desired information was therefore secured by other means.

Some years ago Housel[1] found when testing soil deposits in the field that if areas of different magnitude were subjected to uniform loading the unit loads for any given deflection, plotted against the perimeter area ratios of the loaded areas, showed a straight line relation. Thus, the straight line developed between two or more areas could be projected to show the unit load required to produce the same deflection for other areas

[1] "A Practical Method for the Selection of Foundations Based on Fundamentals Research in Soil Mechanics," by W S Housel, University of Michigan, Engineering Research Bulletin No. 13, October, 1929

With the testing equipment available it was found that this straight line relation held true when the area of the testing heads did not exceed 58 sq. in., which incidentally is that of the tire contact area of a truck designed to carry a 4,000-lb. wheel load. The diameter of a circle of this area is 8.6 in. and its $\frac{P}{A}$ is 0.46. A circular area of 130 sq. in. has a $\frac{P}{A}$ of 0.31. By selecting testing heads with $\frac{P}{A}$ values of 1.47, 0.99 and 0.46, it was found that unit loads for any given deflection developed a straight

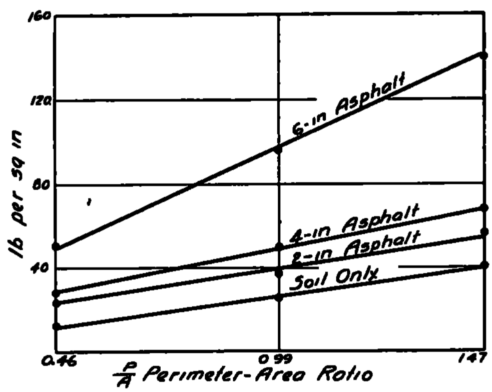

Figure 5. Soil S1—12.1, 0.3-in. Deflection

line which need be projected only a relatively short distance to indicate the unit load required to produce the same deflection under a 130 sq. in. loading area.

LABORATORY EVALUATION OF THE PAVEMENT

When pavement sections 22 in. square and varying in thickness from ½ to 6 in. were placed upon a soil mass within the soil testing box and subjected to loading tests with the same testing heads adopted for soil tests alone, it was found that the load deflection curves were similar in character to load deflection curves for soil as illustrated in Figure 2. In every instance, however, as the center load was gradually increased it was found that the corners and edges of the test specimen curled upward and left the soil base. Such behavior was of course abnormal, as under actual service conditions the mass of adjacent pavement would prevent curling in the vicinity of the loaded area. It was then found that by clamping a metal restraining band from a flange on the soil pressure box around the upper edge of the test specimen without creating pressure against the soil, upward curling could be practically prevented and the trend of test

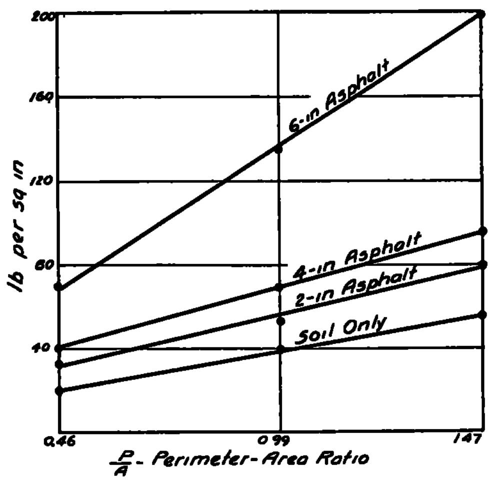

Figure 6. Soil S1—12.1, 0.4-in. Deflection

results coincided even more closely with those obtained in testing soil only.

In fact a straight line relation could be found for any given deflection between unit load and perimeter-area ratio of testing head.

Figures 5, 6 and 7 illustrate typical results obtained for deflections of 0.3 in., 0.4 in. and 0.5 in. when testing a given soil alone and with superimposed sections of asphalt pavement of 2, 4 and 6 in. thickness. Dotted extensions of the lines for the critical deflection of 0.5 in. have been carried to a $\frac{P}{A}$ of 0.31 to show the unit loads required on an area of 130 sq. in. to produce a deflection of 0.5 in.

Figure 8 shows the unit loads for the 130-sq. in. area plotted against thickness of pavement with an extension of the curve to a load of 92.3 lb. per sq. in. to indicate the probable thickness required for that unit load.

It is seen that upon this basis of evaluation the soil would be rated as a 20-lb. soil. It is also evident that the proposed method is equally adaptable to any other

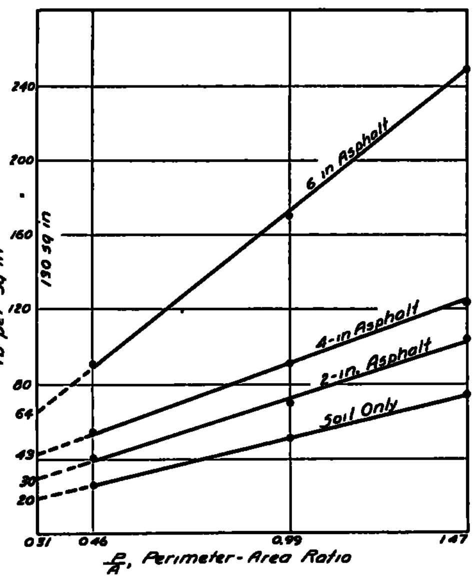

Figure 7. Soil S1—12.1, 0.5-in. Deflection

basis of rating, including other areas and other deflections if for any reason they are desired. For instance, the method may be adapted to the tire contact area of heavy airplanes so as to indicate the thickness required for airport runway construction.

OTHER STRESS STRAIN RELATIONS

As the described method has produced test results which conform with Housel's field tests on cohesive soils, it may be assumed that the equipment permits the soil to function normally when subjected to concentrated loading producing deflections up to at least 0.5 in. While very pretty regular curves were produced by plotting soil pressure readings at bottom and side of the soil pressure box against each other and against center loads and deflections, the authors have been unable to derive any information from them bearing directly upon the problem under investigation. In general, for any given unit load applied through the testing head both bottom and side pressures increased rather directly within the diameter of the head. Whether relative pressure distributions were typical of what might be expected in larger soil masses is not known. It

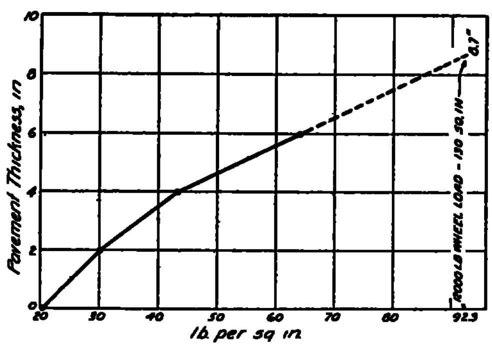

Figure 8. Soil S1—12.1, 0.5-in. Deflection

is believed however that this is not a material consideration in connection with the method which has been described if this method is considered primarily as a means for accumulating data to be applied to load supporting ratings of soils in the field, by determining the load required over an area of 130 sq. in. to produce a deflection of 0.5 in.

RECAPITULATION

1. The load supporting value of the soil with reference to the pavement is determined by running load deflection tests up to 0.5-in. deflection using circular testing heads of 5.8, 13.0 and 58 sq. in. under a definitely established rate of unit load application. Unit

loads for this deflection are plotted against the $\frac{P}{A}$ value (perimeter-area ratio) for each head. A straight line relation between these values is determined and the line projected to a $\frac{P}{A}$ value of 0.31. The unit load at this point, representing an area of 130 sq in., is taken as the load supporting value of the soil.

2. The load supporting value of different thicknesses of asphalt pavement placed upon the reconditioned soil is obtained by exactly the same method.

3. The load supporting values so obtained are plotted against the different thicknesses of pavement tested to establish a curve showing the thickness required to carry any desired unit load.

If this method is suitable for determining the load supporting value of asphalt pavements with relation to the load supporting value of a subgrade upon which it is laid, it should be equally useful in determining the thickness of any stabilized soil layer required to support satisfactorily an asphalt pavement of any given thickness.

The method is suggested only as a means of accumulating thickness design data which can be readily applied to a field determination of the unit load required over a given tire contact area to produce a given deflection or settlement. The laboratory data relative to thickness of pavement can then be directly applied to the field rating of the soil. In this paper data has been given only for a 20 pound soil rating but if the method proves acceptable as a basis of design, similar and more complete data will be developed for a wide range of load supporting soil ratings. No theoretical assumptions are involved in the method and no mathematical formulas are needed.