

Flexible Pavement Research

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INTRODUCTION

It is the purpose of this paper to point out the problems associated with flexible pavements, to summarize the research that the Joint Highway Research Project has done in this field, and to outline present endeavors. In so doing, it must be recognized, first of all that flexible-pavement research, or the general problem of flexible-pavement design, consists of two parts.

One of these is the material design of competent layers of the flexible pavement, such as the subbase, base, or surface course. In addition to the strength characteristics of such layers, factors of durability also must be recognized in establishing their design. The second part of the problem is concerned with the thickness design of the component layers, wherein it is required that sufficient strength be built up to carry the imposed loads. In this connection the problem must be viewed as one in which the subgrade soil is required to carry the load, but that in order to do so it must be reinforced to the extent that stress applied to it will be so distributed as not to cause failure.

In conducting research on these problems, we have initiated both laboratory and field studies, and have recognized such factors as subgrade soil type, type and thickness of subbase, base, and surface courses, climatic conditions, amount and type of traffic, and position of the pavement with respect to the ground surface. Of these factors, the most difficult to evaluate by laboratory or field tests alone are climatic, traffic, and position with respect to the ground surface. However, laboratory or field tests, when used in conjunction with field performance surveys, can provide excellent design information. Performance surveys of existing pavements, in addition to aiding in evaluation of soil, climate, traffic, and position variables, also bring out important features of construction procedure and practical limitations.

With these considerations, a brief summary of the research that the Joint Highway Research Project has done and is doing on the general subject of flexible pavements is presented. It should be pointed out

that, up until the present time, these researches have not been directed specifically toward the development of a design procedure, either with regard to material components or thickness. Rather, it has been the aim to develop through research, including performance surveys of existing pavements, the basic information on which design procedures may be based. In discussing this research, it is convenient to start with studies of the subgrade soil and progress to those concerned with base materials, and finally to those involving the bituminous surface course.

SUBGRADE SOILS

In the design of flexible pavements, the first requisite is to adequately classify the subgrade soil so that its behavior under load in all seasons of the year may be predicted. How best to accomplish this objective is a matter on which little agreement is found as evidenced by the fact that some two dozen methods of flexible pavement design in use by various states and agencies have been listed (1). This list could probably be extended.

Most of these methods use some arbitrary and empirical test or method to rate the subgrade soil (2). Thus, one method in use classifies the subgrade soil by means of grain size and liquid and plastic limit tests. Another method evaluates subgrade strength by means of measuring the resistance offered to the penetration of a cylinder having an end area of three square inches, and expressing the result as a percentage of the resistance of a standard crushed stone.

Plate-loading tests are also used to determine strength of the subgrade soil. The results of these tests are applied to design strictly in an empirical fashion, often by means of design curves in which the subgrade rating is related to total thickness of pavement required by curves for different wheel loads. Intensity of traffic and moisture and frost conditions may also receive consideration empirically in these methods.

A fundamental test receiving increased use for flexible pavement design purposes is the triaxial compression test (3). Through the use of this test it is possible to evaluate various pavement materials and subgrade soils in a fundamental manner and to use the data to obtain a theoretical relationship between pavement thickness and the material test results. Even though the results of such tests must be applied in an empirical manner at the present time, the use of the test is favored by many because it is applicable to all components of the pavement from subgrade to surface course, and because its use advances the day when flexible-pavement design will be accomplished in a truly rational manner.

While we of the Joint Highway Research Project favor the use of the fundamental triaxial compression test for the strength evaluation of pavement materials including subgrade soils, for many years we have viewed the relationship between pavement design and subgrade soil as a regional problem of soil areas. This approach is preferred because it allows a direct evaluation of such intangible but real factors as climate and topography, and the relationship between the grade line and the soil profile. Further, it allows the accumulation of performance-survey data on a rational basis and provides a basic grouping on which to conduct either laboratory or field strength tests which otherwise would of necessity have to be performed on more or less random samples.

To illustrate, the state of Indiana can be divided into several regions relative to soil types and topographic and climatic features, each presenting design problems unique in themselves. Two of these areas, representing extremes, will serve to show that design is necessarily dependent on the area of the state being considered. Granular areas, represented by gravel and sand terraces, windblown-sand plains and granular outwash, contain materials of high bearing power, good drainage, and low susceptibility to frost. In contrast, the lacustrine areas are predominantly heavy clays where drainage is poor and the materials are highly susceptible to weakening by frost. These lacustrine areas frequently, however, contain old beach ridges of sandy material which if recognized can greatly simplify pavement design and construction in these adverse areas.

Research in the form of pavement performance surveys has brought out a well-defined correlation between soil area and flexible pavement performance (4,5,6). These surveys have repeatedly shown the effect of position of the grade line in the Wisconsin drift area where pavements located in shallow cuts that intersect the plastic "B" horizon, even though the cut is only a few inches in depth, are particularly susceptible to failure.

The importance of the depth of the weathered soil profile has been further brought out by the performance of pavements located on the deep, impervious clay horizon associated with Illinoian drift. However, this represents a different pavement design problem than the Wisconsin drift area because the grade line generally intersects this deep clay horizon only in cuts at valley walls rather than cutting plastic materials repeatedly as is generally the case with flexible pavements which have been constructed in the gently undulating Wisconsin drift of Indiana. Thus, the soil region or soil area concept of pavement design also provides the basis for the establishment of more uniform subgrade



FIGURE 1. Failure of a flexible pavement in a shallow cut which intersects the plastic "B" horizon.



FIGURE 2. Good performance of a flexible pavement located on granular soil.

conditions on which to place a flexible pavement, and therefore leads to more economical design. Figures 1 and 2 illustrate the relationship between soil type and pavement performance.

It can also be pointed out that, in many cases, division of the state into soil regions automatically takes into account other factors such as climate and traffic. For example, residual soils of the state are in the southern part where the climate is less severe and traffic is generally less. On the other hand, the large lacustrine areas of the state not only have adverse soils, but lie in regions where these adverse conditions are accentuated by more severe freezing and large amounts of heavy traffic.

Thus, the regional concept of soil areas can provide the very backbone for pavement design. This accounts for the years of effort we have expended in this direction. In so doing we have utilized both geologic and pedologic information wherein the research problem has been to evaluate soils differentiated by these means, in terms of their suitability for engineering usage (7). This background has provided the basis for the development of techniques to interpret soil conditions from aerial photographs (8,9). At the present time we are

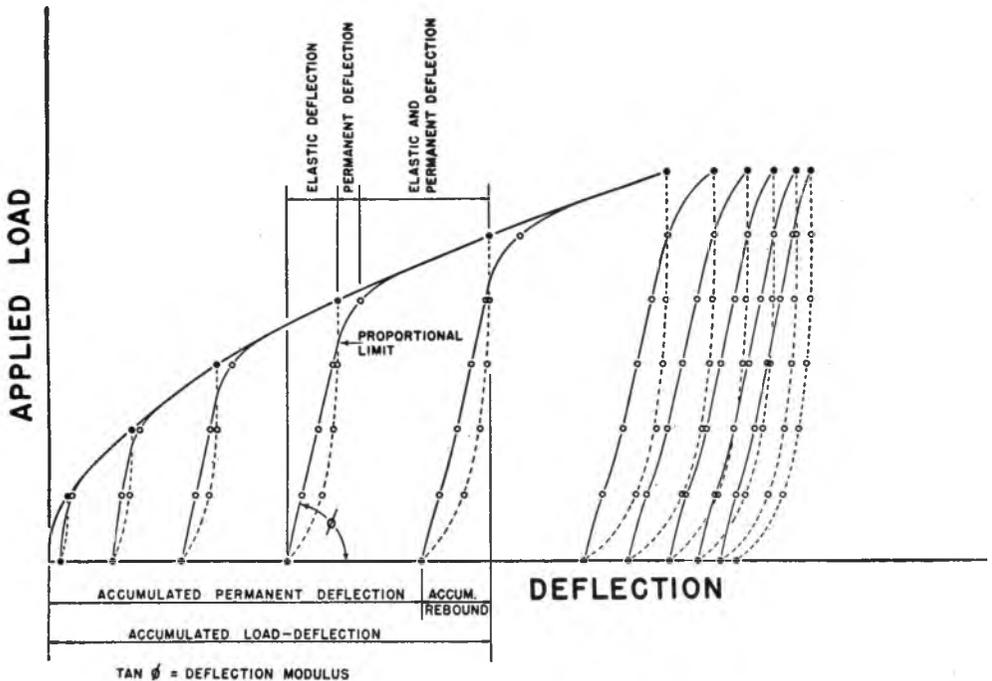


FIGURE 3. Typical cyclic Load-Deflection Curve.

using this means to produce county and regional soil maps of the state in which soils are differentiated according to their value as subgrade materials (10). Such maps provide the basic information necessary to pavement design, whether or not laboratory or field strength tests are used to augment this information.

Before discussing base and surface components of flexible pavements, it may be well to illustrate differential in the load-carrying ability of subgrade soils by means of some load-test data which were obtained with rigid plates and a cyclic-loading procedure (11). A typical load-deflection curve is shown in Figure 3 in which the pertinent parts of the curve are labeled. This curve was obtained by a procedure in which a number of loading cycles were employed each of which consisted of loading and unloading, or rebound, portions, and in which each succeeding cycle consisted of one more loading increment and decrement than the previous cycle (12).

Figure 4 shows cyclic-loading curves for three soils, designated as Brookston, Crosby and Warsaw. From pavement performance studies, it is known that as subgrades for flexible pavements these soils vary from poor to good. The Brookston soil is a plastic, organic, silty-clay and is a poor subgrade material, while the Warsaw soil is granular and shows good performance as a subgrade material. The Crosby soil is intermediate as a subgrade material between these two. These characteristics are reflected in the loading curves where it can be seen that the load-reflection curves for any cycle of loading are relatively flat for the Brookston soil, relatively steep for the Warsaw soil, and intermediate in slope for the Crosby soil. This means that a given applied load will produce the most deflection on the Brookston soil and the least on the Warsaw; or that it takes the most load to produce a given deflection on the Warsaw and the least to produce the same deflection on Brookston soil. It also can be seen from these curves that the Brookston soil is a much more elastic material than the Warsaw as indicated by the amount of deflection recovery after the removal of load. The Crosby is intermediate in this respect also. These data bring out a practical consideration of flexible pavement design in that they show the soil in greatest need of reinforcement to carry load to be the most difficult to reinforce because its "springy" nature makes the compaction of superimposed layers difficult.

BASE MATERIALS

Thus, from classification of subgrade soils and strength tests to evaluate them, the amount of reinforcement which must be provided

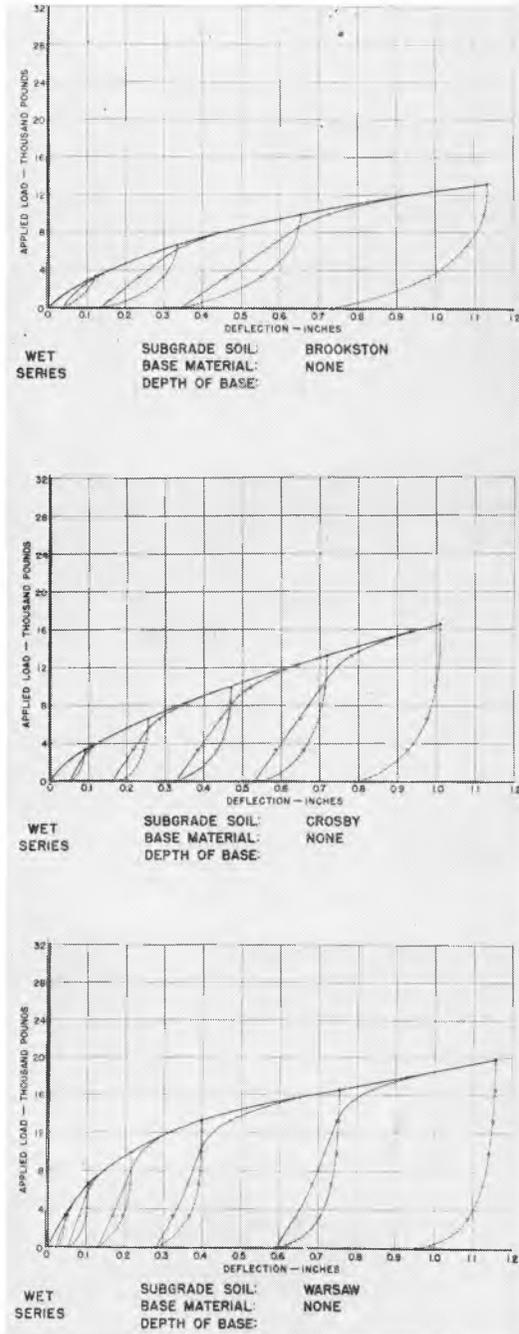


FIGURE 4. Loading Curves for three subgrade soils varying in engineering characteristics from poor to good.

in order that these materials will carry the traffic loads to which they will be subjected is evaluated. The next problem is to decide how this reinforcement will be provided. Since economical design is possible only if use is made of locally available materials, considerations of how best to provide the reinforcement immediately recall the area or regional concept of design that provided the basis for evaluation of the subgrade soil. In areas where gravels are abundant, we should not insist on using crushed stone and should not insist on a waterbound macadam base, for example. Also, if sand is the cheap locally available material, we should not insist, in all cases at least, on base types in which larger aggregate is required, but should direct our efforts toward pavement design using the local sand to best advantage. With these regional concepts in mind, the necessity for performing research on these reinforcing materials is clear.

In considering means to strengthen subgrade soils economically, one of the first possibilities that is recognized is that of changing the subgrade soil itself. This process usually is called soil stabilization. It goes beyond mere densification through compaction, a process recognized as universally desirable regardless of what reinforcing means are used. One of the first researches undertaken by the Joint Highway Research Project was in this field (13) and there has hardly been a time since then when a part of the total effort has not been expended along such lines, even to the present time. A great many stabilizing admixtures have been tried, always with the objective of determining their efficiency and limitations of use (14,15,16). The results of these studies have shown what benefit may be expected from a given admixture with a given soil, and provide the information necessary for the use of these materials in areas where it may be economical to do so. However, the results have also shown that those soils in greatest need of strengthening treatment are also the most difficult to treat economically by the use of admixtures, and therefore research on the best means of utilizing granular materials as reinforcing mediums continues to be of prime importance.

In the evaluation of granular materials we have conducted studies to determine the effect of such variables as compaction, grading, angularity of the aggregate, amount and type of soil fines, and amount of moisture (17). Bituminous bases have been included in these studies. The triaxial compression or shear test has been found very useful in the evaluation of these granular materials since many of them have no strength at all unless they are confined. While these studies in the past have been directed principally at evaluating the effect of variables such as those mentioned above, recently triaxial investigations of granu-

lar base materials have been inaugurated that point more specifically toward the evaluation of Indiana specification materials.

At the same time, pavement performance surveys have been started in which the aim is to evaluate various base types as reinforcing layers on different subgrade soils, particularly for heavy-traffic conditions. This field information will serve to correlate with the laboratory triaxial results, and is especially necessary for the evaluation of such types as waterbound macadam which do not lend themselves to laboratory evaluation in small-scale tests. In addition, it is hoped that some experimental test sections will be built into future flexible pavement construction to provide the direct correlation with laboratory results necessary to the development of flexible pavement design.

In considering the reinforcement of subgrade soils with granular materials, research has brought out some pertinent facts regarding the factors influencing the load carrying capacity of such combinations (11, 12). In Figure 5 are shown cyclic-loading curves for the same three subgrade soils as shown in Figure 4, this time with a reinforcing layer of six inches of crushed limestone. A comparison of these loading curves with those of Figure 4 shows that the three base-subgrade combinations have the same general deflection characteristics as the subgrade soils themselves, even though they are modified in magnitude by the base material. Figure 6 shows loading curves for 6, 12, and 18-inch gravel-bases on Warsaw soil. They show that increases in the depth of base are accompanied by corresponding increases in bearing value and by corresponding decreases in the amount of rebound for a given cycle of loading. This indicates that the base material had good stability characteristics and was capable of transmitting the plate loading to the subgrade without undergoing excessive compaction or deformation. This stable condition, with ability to distribute load to the subgrade in proportion to thickness, results from the fact that sufficient density was obtainable in this material when placed on the Warsaw soil.

In contrast, the loading curves in Figure 7 for 6, 12, and 18-inch clay-gravel bases on Crosby soil show decreases in bearing value for thicker base sections, indicating that this base material was not stable under the loading conditions. From a study of load-test data of several base-subgrade combinations, it was found that the type of base material, the base density and the plate diameter-base depth ratio have a controlling influence upon the stability of base materials under load. This influence of the ratio of size of loaded area to depth of base is illustrated by the curves of Figure 8. Here the deflection of the base is expressed as a percentage of the total deflection of the loading plate.

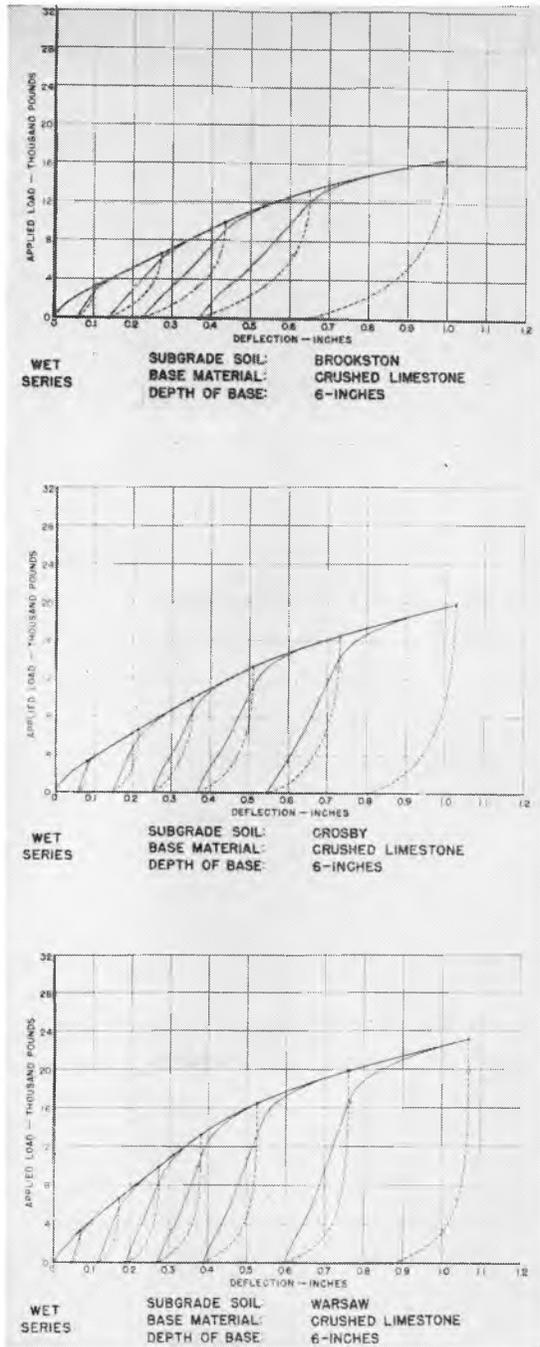


FIGURE 5. Loading curves for soils reinforced with 6-in. of crushed limestone. The subgrade soils are the same as those of Figure 4.

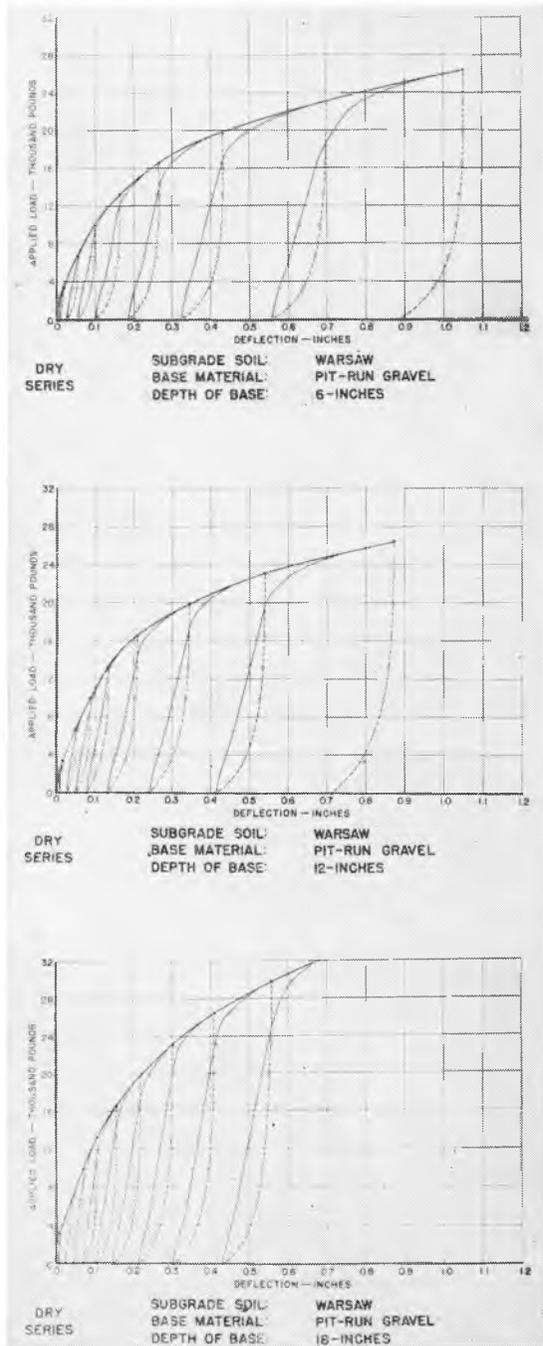


FIGURE 6. Loading curves for 6, 12, and 18-in. Gravel bases on Warsaw Subgrade soil.

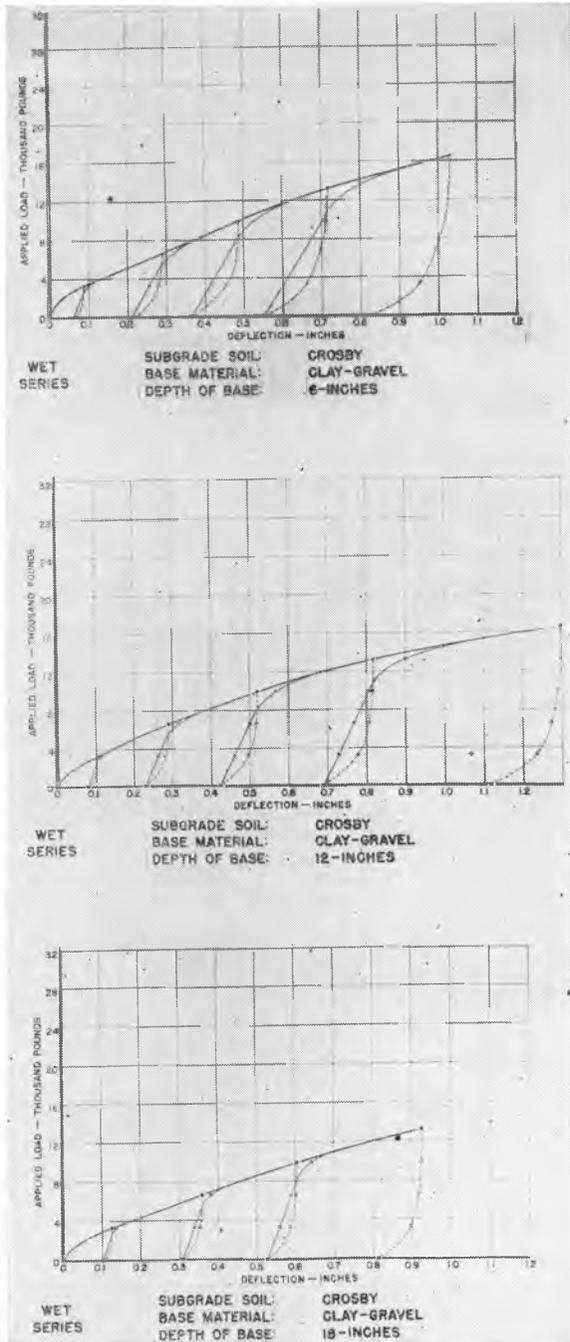


FIGURE 7. Loading curves for 6, 12, and 18-inch. Clay-gravel bases on Crosby Subgrade soil.

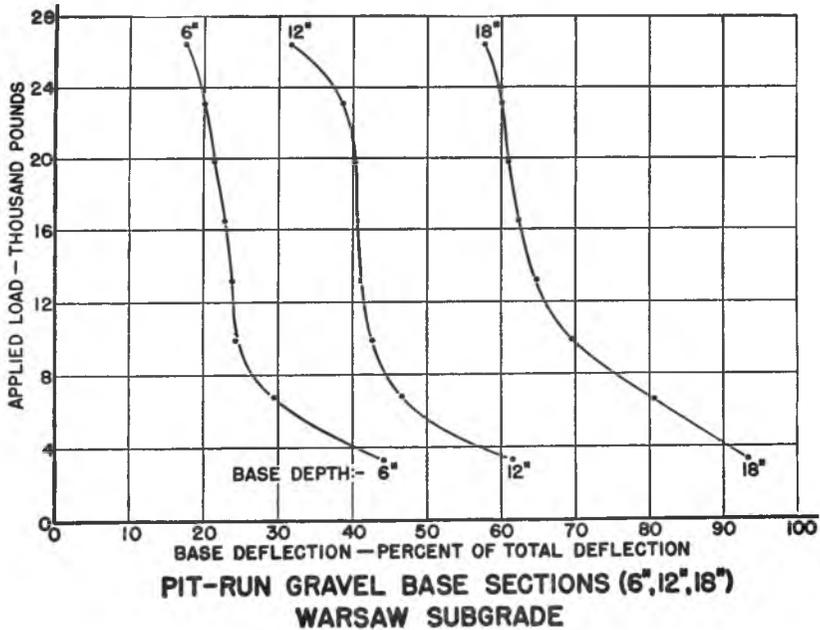


FIGURE 8. Base-stability curves for 6, 12, and 18-in. gravel bases.

The curves represent tests of 6, 12, and 18-inch gravel base on Warsaw soil. They indicate that, as the loading progresses, the percentage of the total plate deflection occurring in the gravel bases decreased. Thus, as the applied loads are increased the deflections are forced into the subgrade soil. In addition, the loading curves of Figure 8 indicate that, for a given plate diameter, applied load, and plate deflection, a greater percentage of the total deflection occurs in the thicker bases.

These plate-loading data have been presented to demonstrate certain factors of importance to the reinforcement of subgrade soils with granular-base materials. It is not to be implied that we advocate design on the basis of such tests, but they are valuable for an understanding of the basic problems involved. One of these problems is illustrated in Figure 9 where rutting of the pavement in the wheel tracks is pronounced. Failure of this kind is typical for flexible pavements constructed with thick granular bases and subjected to heavy traffic loads. Research is needed to develop economical construction procedures which will produce adequate density and stability in granular bases during construction to prevent this further consolidation under traffic, especially for thick bases on poor soils.

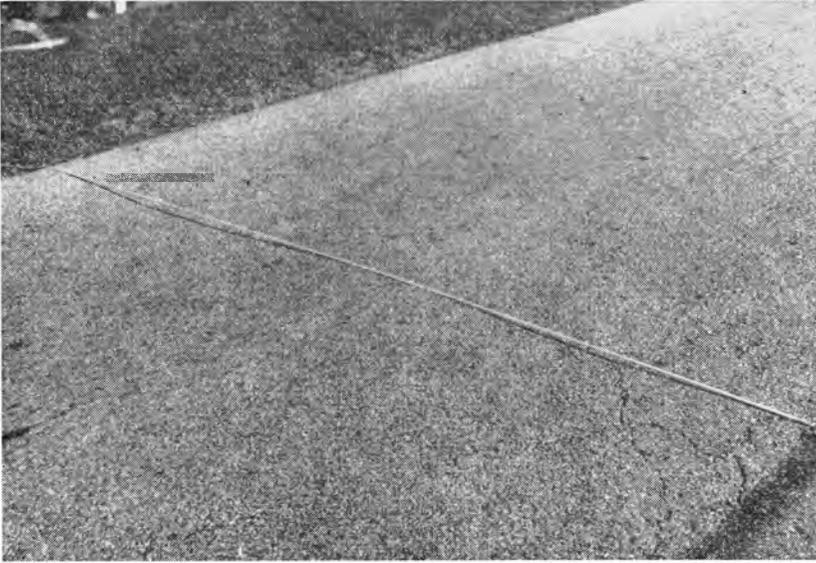


FIGURE 9. Rutting failure in the wheel tracks on a flexible pavement.

BITUMINOUS SURFACES

Now that subgrade soils and base materials have been considered as elements in the design of flexible pavements, consideration of the design of surfacing materials is in order. In so doing, the first consideration is one of materials, particularly the aggregates. This consideration again emphasizes the importance of a regional or area concept of design for reasons that have been discussed in connection with materials for base courses. The design of surface courses includes considerations other than strength and in this respect differs from other components of the flexible pavement. Many bituminous surfaces are not considered to be a structural part of the pavement, but serve only to provide a dustless wearing surface capable of withstanding the abrasive action of traffic and to provide a "roof" for the pavement. Thus, bituminous surface courses are designed as much for their resistance to weathering action, resistance to skidding, etc., as for structural strength, though sufficient strength is recognized as being necessary.

Research studies on bituminous surface courses by the Joint Highway Research Project have been many and varied. They include studies on the adhesion of bituminous films to aggregates (18), studies aimed at the use of local materials (19, 20), surface-treatment studies in

both the laboratory and field (21, 22, 23) and studies of laboratory test methods. These test methods have been investigated in an attempt to

TYPICAL STRESS-STRAIN CURVES GRAVEL - GRADING C - 5% MEDIUM ASPHALT

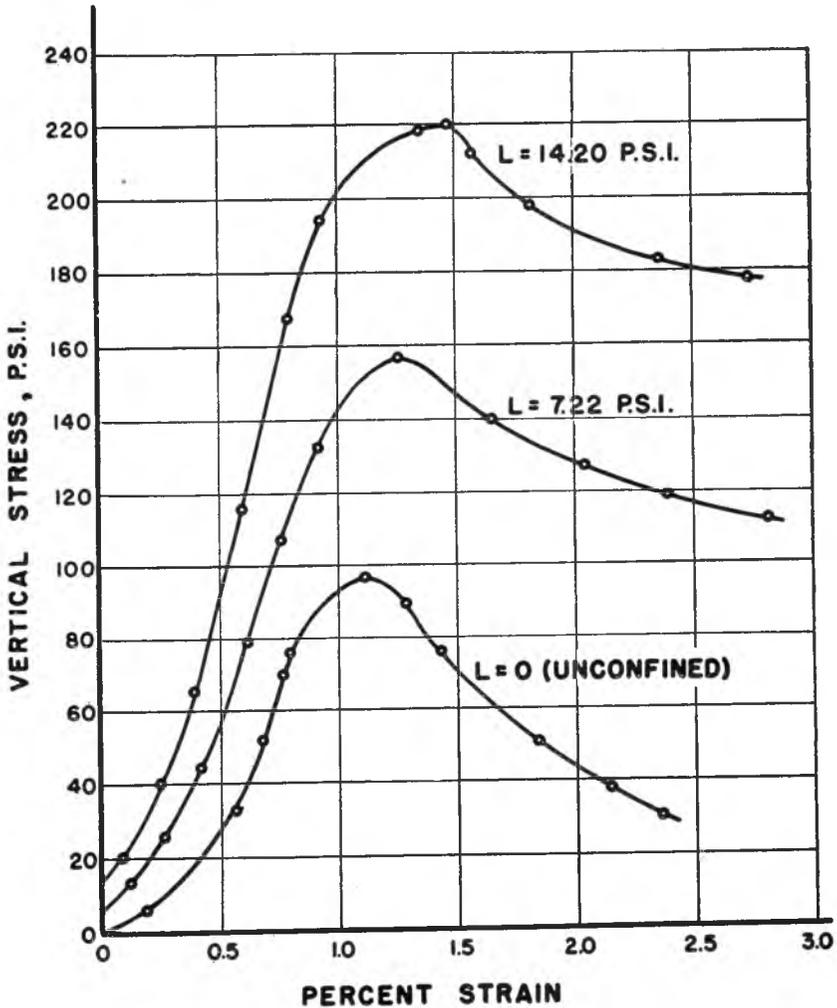


FIGURE 10. Typical stress-strain curves for unconfined and triaxial tests on bituminous mixtures.

arrive at the most satisfactory method for the design of a bituminous-aggregate mixture. At the same time we have been interested in determining the effect of such variables as type and grading of aggregate, type and consistency of bituminous material, amount of bituminous material, density, and testing speed. Among the tests that have been used can be listed unconfined compression, squeeze and impact tests (24), laboratory tests under moving wheel loads (25), Marshall, and triaxial tests (26). Of these, the emphasis has now been placed on the triaxial test because it allows evaluation of the influence on the total result of the separate ingredients of the bituminous mixture, and because it thus provides the basis for the design of bituminous courses from a variety of local materials. The following is presented to illustrate the type of data and the evaluation of variables which this test provides (27).

Figure 10 shows typical stress-strain curves for a gravel aggregate with five percent asphalt tested in an unconfined condition and at confining pressures of 7.2 and 14.2 psi. When this data is plotted in the form of a Mohr diagram, the result is as shown in Figure 11. The angle, ϕ , which the tangent to the Mohr stress circles makes with the horizontal is the angle of internal friction of the aggregate, and the intercept of this line on the vertical axis gives a value for

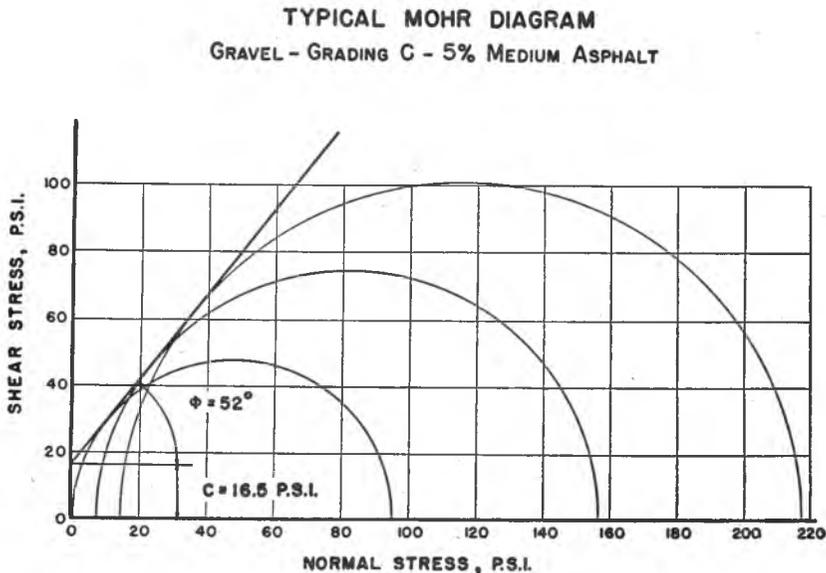


FIGURE 11. Typical Mohr Diagram for a bituminous-aggregate mixture.

TEST PROPERTIES vs. ASPHALT CONTENT

GRAVEL - GRADING A - MEDIUM ASPHALT

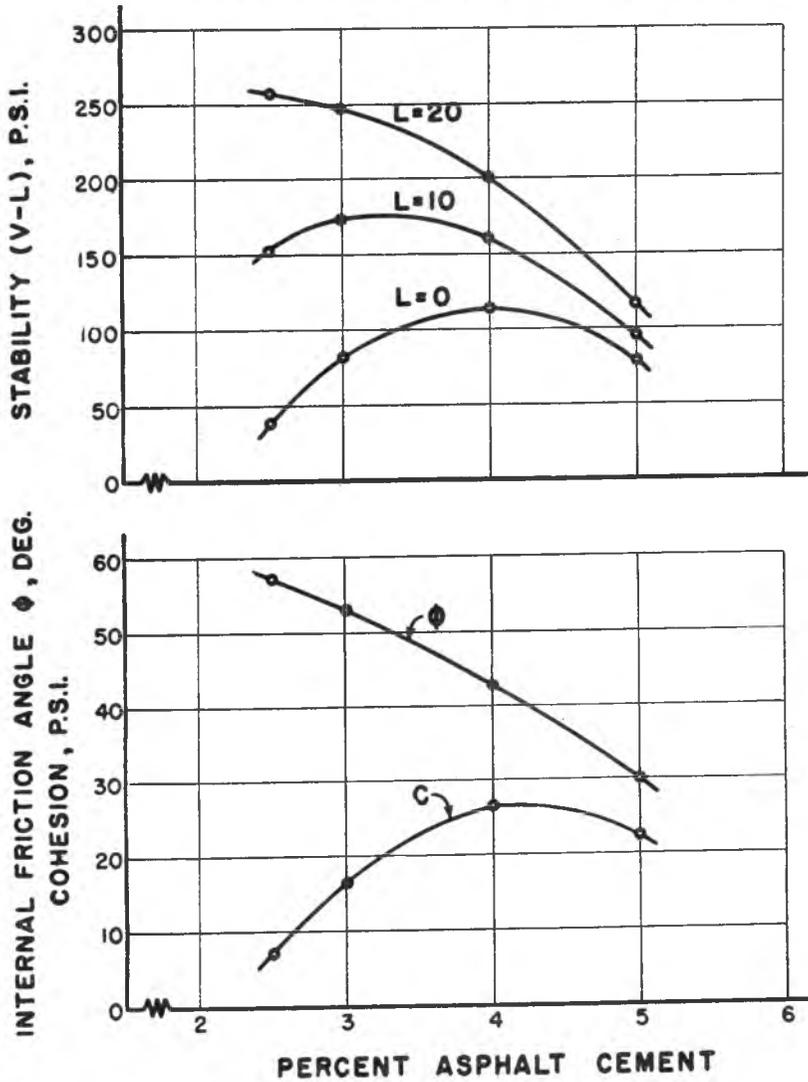


FIGURE 12. Effect of asphalt content on angle of internal friction, cohesion, and stability.

the cohesion, C , of the asphalt. In this case $\phi = 52^\circ$ and $C = 16.5$ psi. Angle of internal friction and cohesion values depend upon the variables of the mix and will change as the mix is changed. The Mohr diagram can also be used to calculate a stability value for the material at any lateral or confining pressure.

In Figure 12 is shown the effect of changes in asphalt content on angle of internal friction, cohesion, and stability of mixtures made with a gravel. The angle of internal friction decreased as the asphalt content was increased. The value for cohesion increased with each addition of asphalt until a maximum value was reached at about 4 percent, and then decreased with further increase in asphalt content. The curves for stability versus asphalt content show that maximum stability for this aggregate occurred at about 4 percent asphalt for the unconfined condition, at about $3\frac{1}{2}$ percent for a confining pressure of 10 psi. and at about $2\frac{1}{2}$ percent for a confining pressure of 20 psi.

The effect of asphalt penetration, as measured by the triaxial test, is shown in Figure 13. From the upper set of curves in the lower graph it can be seen that the values for angle of internal frictions were virtually unaffected at any grading by changes in penetration of the asphalt, the values increasing very slightly as the penetration was increased. On the other hand, the values for cohesion were markedly affected by changes in grade of the asphalt cement. For the three gradings and asphalt contents used, the cohesion values decreased from values of the order of magnitude of 50 to 60 psi. down to values of 15 to 20 psi. as the penetration was increased from 54 to 266. These changes are reflected in the stability values shown in the upper graph. The curves show that stability decreased with an increase in penetration of the asphalt, but not as rapidly as cohesion itself was decreased.

SUMMARY

The data presented in this discussion have been extracted from studies much more comprehensive in scope than is indicated by the information presented. It has been the object to illustrate the information that we have obtained in the field of flexible pavements, and not to give a complete summary of the many related investigations that have been conducted. Flexible pavement design is a complicated problem requiring an understanding of many basic factors of materials and load transmission for its solution. Research conducted over the life of the Joint Highway Research Project has provided essential information on many phases of the problem. The area or regional

concept of design, both from the standpoint of subgrade soils and construction materials, appears fundamental to the solution of design problems and the use of rational test methods such as the triaxial compression test is essential to the development of rational design procedures.

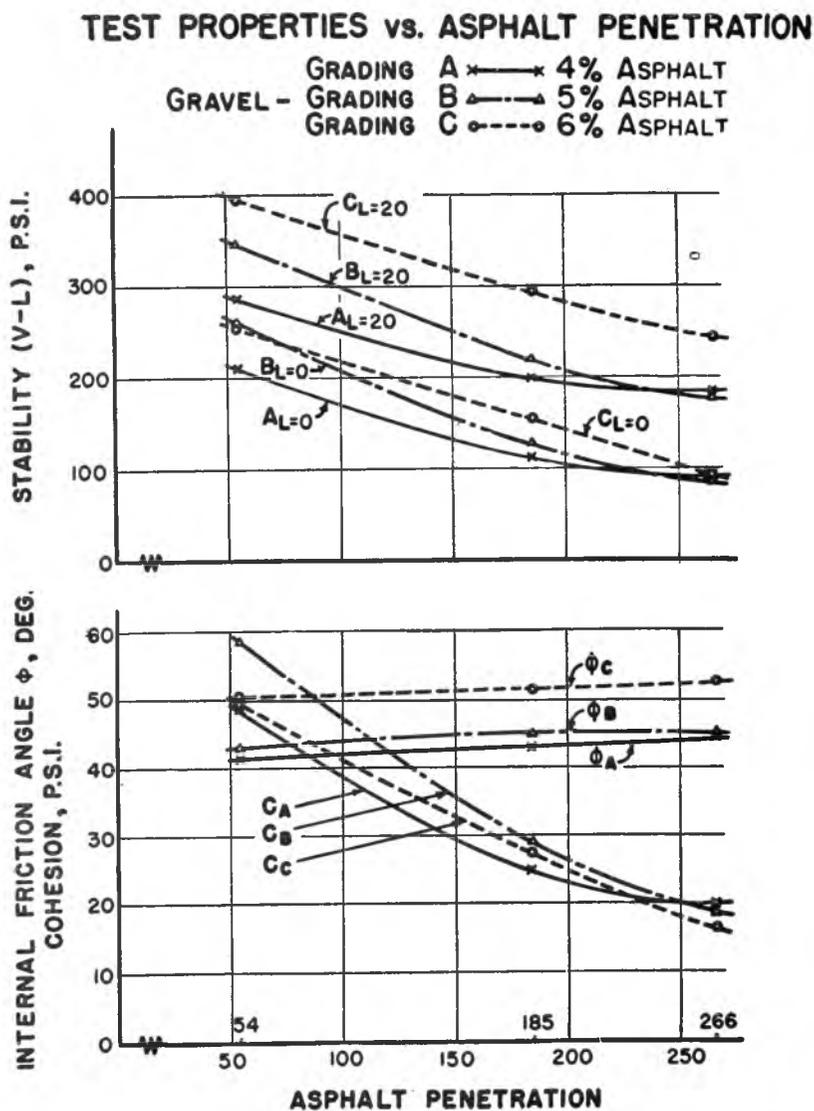


FIGURE 13. Effect of asphalt penetration on angle of internal friction, cohesion, and stability.

Pavement performance surveys have and will continue to provide the necessary correlation between the laboratory and the field, to be further established by the construction of controlled test sections in selected locations.

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