**TESTING
OPEN-GRADED BITUMINOUS MIXTURES
IN THE HVEEM STABILOMETER**

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by
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Technical Paper

TESTING OPEN-GRADED BITUMINOUS MIXTURES
IN THE HVEEM STABILOMETER

TO: K. B. Woods, Director
Joint Highway Research Project

July 1, 1959

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

File: 2-17-17
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Attached is a technical paper entitled, "Testing Open-Graded Bituminous Mixtures in the Hveem Stabilometer," by R. A. Hannan and W. H. Goetz of our staff. This paper was presented at the 45th Annual Purdue Road School and is scheduled for publication in the Proceedings.

The paper is presented for the record and approval for publication.

Respectfully submitted,

H. L. Michael

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Technical Paper

TESTING OPEN-GRADED BITUMINOUS MIXTURES
IN THE HVEEM STABILOMETER

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TESTING OPEN-GRADED BITUMINOUS MIXTURES IN THE HVEEM STABILOMETER

The problem of designing stable bituminous paving mixtures has resulted in the development of a number of laboratory stability tests. One of the more prominent of these was originated by Francis N. Hveem and has been used by the California Division of Highways for several years.

In the past, most of the bituminous mixtures tested in the Hveem Stabilometer have been of the dense-graded type (22)*. Consequently, the significance of Stabilometer test results obtained from the testing of open-graded mixtures is subject to some question. Since the use of open-graded mixes has been quite widespread, especially in the State of Indiana, a laboratory investigation was conducted at Purdue University which attempted to determine the applicability of the Stabilometer to the testing of these mixtures. This paper reports a portion of the results obtained from that study.

OPERATION OF THE HVEEM STABILOMETER

The Hveem stabilometer is a form of the triaxial compression test cell in which a cylindrical test specimen is exposed to an axial load while the sides of the specimen are supported by a lateral confining pressure. It operates under the rather basic concept that the amount of deformation experienced by a loaded test specimen is an inverse measure of the specimen's stability. In other words, for a given vertical load, a weak specimen will deform more than will a strong one. Figure 1 shows a

*Numbers in parentheses refer to the list of references at the end of this paper.

FIG. 1 HVEEM STABILOMETER TEST WITH STRAIN MEASUREMENTS

photograph of the Hveem Stabilometer.

The schematic diagram of the Stabilometer in Figure 2 shows the cylindrical test specimen surrounded by a rubber diaphragm which in turn is confined by a combination of air and oil. When the specimen is axially loaded, it deforms outwards, causing a decrease in the volume of the confining fluids. Because of this volume reduction, a pressure is created in the fluids which is transmitted through the rubber diaphragm to the lateral surface of the specimen. This transmitted pressure serves two purposes. First, it simulates the lateral confinement that is present in a section of pavement, and in doing so, changes the test from one of unconfined compression to a form of triaxial compression. The second function of the lateral pressure is to provide a measure of the specimen's stability. This is possible since the magnitude of the pressure that is developed will depend upon how much the specimen deforms. Looking at Figure 2, it can be seen that the lower the strength of a specimen, the farther the specimen will deform laterally; hence the higher the lateral pressure will rise. Using this principle as an indication of strength, the measurement of deformation values becomes unnecessary and the stability can be expressed simply as a function of lateral pressure.

At this point, it would appear that the mechanics of the Stabilometer's operation are fairly straight-forward. Unfortunately, the inclusion of air in the Stabilometer system has an important influence on the magnitude of the transmitted pressure. This is due to the fact that air is highly compressible and, as a result, small increases in air content will permit greater specimen deformations without compensating increases in lateral pressure.

DIAGRAMATIC SKETCH OF THE HVEEM STABILOMETER

FIG. 2

After California (21)

Air can occur in two places in the Stabilometer system; in the chamber which contains the oil, and in voids on the surface of the specimen. Correcting for air in the confined chamber is relatively easy, because it can be controlled at a set quantity. In fact, the presence of some air in the cell is desirable, since a reduction in the volume of the fluid is needed to allow the specimen to deform when loaded. For the case of air on the surface of the specimen, the situation is quite different because this air will vary in quantity from specimen to specimen and cannot be easily controlled. In order to account for the presence of air, Hveem has added the displacement pump shown in Figure 2. This pump is merely a screw-type piston, which when turned inwards, reduces the volume of air in the system and causes a pressure increase which can be read on the pressure gage.

To control the amount of air inside the chamber, a calibration measurement is made with a metal cylinder which doesn't deform under the vertical loads applied in the Stabilometer test. The quantity of air is then adjusted through the needle valve (Figure 2) until two inward turns of the displacement pump will increase the lateral pressure from 5 to 100 psi.

Since air in the surface voids cannot be adjusted, Hveem introduces an approximate correction which he calls the "final displacement." At the end of each test, with the specimen still held in position in the Stabilometer, the number of turns of the pump required to raise the lateral pressure from 5 to 100 psi. is recorded. This value will account for the air in the surface voids as well as the air in the oil chamber, and the total number of turns required for the final displacement will increase as the volume of air in the system is increased. It should be noted that the

number of turns also can be expressed as a volume, since the area of the piston multiplied by the distance the piston travels is essentially the volume of air which has been compressed. For the sake of simplicity, however, the displacement measurement is generally left in the unit of "turns".

Briefly, then, a complete Stabilometer test will consist of the following operations:

1. The Stabilometer is calibrated with a dummy metal specimen to adjust the quantity of air inside the oil chamber.
2. The specimen is placed inside the Stabilometer, a vertical load is applied at a rate of 0.05 in. per min., and lateral pressure readings are taken at 1000 pound load increments up to a load of 6000 pounds.
3. At the end of the test, the vertical load is reduced to 1000 pounds and the final displacement measurement is made.

The results of a completed Stabilometer test are interpreted as a stability number computed from the following formula:

$$S = \frac{22.2}{\frac{P_h D_2}{P_v - P_h} + 0.222}$$

where: S = Hveem stability

P_v = Vertical pressure = 400 psi

P_h = Lateral pressure corresponding to P_v = 400 psi

D_2 = Final displacement on specimen = number of turns of displacement pump required to increase P_h from 5 to 100 psi at end of test

The above equation is strictly an empirical relationship based on field and laboratory correlation data, and does not lend itself to a

theoretical analysis. As seen from the formula, the Hveem stability number is computed from the Stabilometer gage pressure which corresponds to a vertical pressure of 400 psi. The final displacement factor has been added to correct for variations in lateral pressure due to surface air voids. It is apparent that for a given displacement value, any increase in lateral pressure will cause a decrease in the computed stability number. Also, the displacement number is used in the equation in a manner such that an increase in this value will tend to compensate for the decreased value of lateral pressure which occurs with the presence of excess air in the test system.

By substituting lateral pressure values of 0 and 400 psi into the equation, the stability number is seen to range from 0 to 100. This range was selected such that a liquid with no internal resistance, if tested in the Stabilometer, would have a stability value of 0, since a 400 psi vertical pressure would result in a 400 psi transmitted pressure. A stability value of 100 represents a perfectly rigid solid that would not deform under load; hence no lateral pressure would develop and a lateral pressure value of 0 substituted into the equation will give a stability number equal to 100. The range of values between 0 and 100 corresponds to the plastic mixtures with which we are concerned, and California experience shows that bituminous paving mixtures should have stability numbers of 35 or more to perform satisfactorily in the field under heavy traffic.

PURPOSE AND SCOPE OF THE INVESTIGATION

The research project conducted at Purdue was designed to investigate the feasibility of using the Liveem Stabilometer for the testing of open-graded bituminous mixtures. Two aspects of the test make it of questionable value when used for open mixtures. First, the limited amount of deformation permitted a Stabilometer specimen may be insufficient for open-graded specimens which develop additional strength as strain progresses. Secondly, the final displacement value is only an approximate correction for air voids on the surface of the test specimen. Since open-graded specimens generally have voids which are larger and more numerous than the voids present on dense-graded specimens, the validity of this displacement measurement is doubtful for the case of open-graded specimens.

Both of the above aspects were studied in the research program. However, this report presents only the results obtained from Stabilometer tests used in evaluating the displacement measurement. Those results not discussed here have been reported elsewhere (5).

MATERIALS

Three different bituminous mixtures were used in determining the validity of the displacement measurement when applied to open-graded specimens. For the purposes of this report, these mixes have been designated as mixtures A, B, and C. The aggregate gradation curve for each mix is shown in Figure 3.

Mixture A was composed of 5% asphalt cement blended with uncrushed gravel and natural sand. Mixture B consisted of 5% asphalt cement, crushed limestone, and natural sand. For mixture C, which contained 5% asphalt cement, crushed limestone was used for both fine

FIG. 3

aggregate and coarse aggregate. Asphalt cement of 60-70 penetration grade was used in all mixtures.

PROCEDURE

If the final displacement value is a true correction for air in the system of a Stabilometer test, Hveem stability numbers computed from data taken on duplicate test specimens should remain constant as the amount of air in the Stabilometer test system is varied. In this study, the validity of the final displacement measurement was checked over a wide range of air contents for duplicate specimens made from mixture A, B, and C.

For mixture A, test specimens were compacted by the double-plunger method and air in the test system was controlled in two ways. Under the first technique, the Stabilometer was initially calibrated at 2.00 turns of the displacement pump and the amount of air in the system was varied by treating the lateral surfaces of test specimens in one of three different ways (Figure 4). One group of specimens had its surface air voids filled by coating the surfaces with a mixture of plaster of Paris, portland cement and water. For another group, the surfaces were drilled with shallow holes to increase the size and number of voids. A third set of specimens was tested without changing the surface characteristics of the specimens.

The above procedures for varying displacement measurements were of limited use because of the possibility that differences existed between the actual strength values of drilled, unaltered, and coated specimens. As a result, this method of controlling air in the test system was replaced by a second procedure in which the surfaces of all specimens were coated and the amount of air in the system was adjusted in the

COATED
SURFACE

UNALTERED
SURFACE

DRILLED
SURFACE

FIG. 4 TYPICAL TEST SPECIMENS

Stabilometer oil chamber rather than on the surface of the specimen. The second method was far more acceptable than the first in that it permitted a wider range of displacement values (initial displacement values were varied from 1.00 to 5.00 turns), provided better control over final displacement values, and eliminated the variable of true strength which was present under the original method. For this reason, only a few specimens from mixture A were tested with surfaces unaltered or drilled. All specimens from mixtures B and C were coated and tested at initial Stabilometer displacement values ranging between 1.00 to 5.00 turns.

It should be pointed out that the double-plunger method of compaction was used for specimens of mixtures A and B. Specimens of mixture C were compacted with the mechanical kneading compactor (Figure 5) specified by the California Division of Highways (21). The mixtures were not subjected to a fifteen hour curing period that is included in the California procedure and all tests were conducted at room temperature.

HVEEM STABILITY VERSUS STABILOMETER DISPLACEMENT

Figures 6, 7, 8, and 9 are graphs of the final displacement measurements plotted against the computed Hveem stability numbers for the specimens tested in this study. If the final displacement number was a valid correction for air present in the system of a Stabilometer test, each of the curves shown would be a straight, horizontal line.

Figure 6 shows the relationship between the final displacement number and the Hveem Stability value for coated, drilled, and unaltered specimens of mixture A tested at an initial displacement value of 2.00 turns. The "best-fit" straight line plotted for these data shows a decrease in computed stability values with increased displacement

FIG. 5 MECHANICAL KNEADING COMPACTOR

FIG. 7 HVEEM STABILITY vs FINAL DISPLACEMENT

Final Displacement, turns

FIG. 8 HVEEM STABILITY vs FINAL DISPLACEMENT

FIG. 9 HVEEM STABILITY vs FINAL DISPLACEMENT

measurements. Since the lowest stability numbers were obtained from drilled specimens, however, there was some uncertainty as to whether the negative slope of the straight line was caused by actual differences in strength of the coated, unaltered and drilled specimens or by variations in the displacement measurements.

In Figure 7, the plot of Hveem stability versus the final displacement number is shown for coated specimens of mixture A which were tested at initial displacement values of 1.00, 2.00, 3.00, 4.00, and 5.00. In this case, the relationship appears to be non-linear and increased values of displacement results in reduced stability values. Also, the reproducibility of test results was better for coated specimens tested at high air contents than for tests conducted on coated specimens at low air contents or on specimens with large surface air voids.

As seen in Figure 8, test results obtained from mixture B were very erratic. Those wide variations in strength were presumably due to segregation of the large, angular pieces of crushed limestone used in this mix. The relationship between final displacement and Hveem stability for specimens of mixture B shows a slight decrease in stability values as displacement measurements were increased.

Figure 9 is a graph of the Hveem stability numbers versus the final displacement values secured from specimens of mixture C. This curve, unlike those for mixtures A and B, does not show a steady decline in stability values when displacement measurements are increased. Instead, the curve was concave downward and gave maximum values of stability between displacements of 2.00 and 3.00 turns. Stability values were very high for this mix due to its dense grading and because specimens were compacted in the kneading compactor. Also, when tests were conducted at initial

displacement values of three or more turns, results were more reproducible than those obtained at initial displacement values of one or two turns.

STABILOMETER DISPLACEMENT VERSUS RECIPROCAL OF TRANSMITTED PRESSURE

The preceding discussion was concerned with the relationship between Hveem stability values and final displacement measurements obtained from the mixtures tested. A second, and perhaps a more basic approach to the problem of checking the validity of the displacement value, is to present the results of this study in terms of the final displacement measurement and the value of lateral pressure transmitted by the specimen under a 400 psi vertical stress.

Examination of the Hveem stability equation shows that for a given stability number, a hyperbolic relationship exists between the variables of lateral pressure and final displacement. Therefore, a graph of final displacement versus lateral pressure will result in a family of hyperbolas for a range of stability values. For the sake of convenience, the relationship between final displacement and the reciprocal of lateral pressure is plotted here. This relationship, when plotted from hypothetical values substituted into the Hveem equation, is represented by a family of straight lines. It follows, then, that the graphs of final displacement versus the reciprocal of lateral pressure for each of mixtures A, B, and C should plot as straight lines if the Hveem equation is applicable to these mixtures. Moreover, these lines should have slopes which conform to the family of curves which represent theoretical values computed from the Hveem formula.

In Figures 10, 11, and 12, the relationships between final displacement and the reciprocal of lateral pressure are shown for coated

FIG. 10 RECIPROCAL OF LATERAL PRESSURE vs FINAL DISPLACEMENT

FIG. II RECIPROCAL OF LATERAL PRESSURE vs FINAL DISPLACEMENT

FIG. 12 RECIPROCAL OF LATERAL PRESSURE vs FINAL DISPLACEMENT

specimens of mixtures A, B, and C, respectively. The curves for mixtures A and B appear to be straight lines, but that for mixture C follows a non-linear trend.

Figure 13 compares the curves obtained for mixtures A, B, and C with the theoretical curves computed from Hveem's stability equation. Although straight lines were obtained from data for mixes A and B, the slopes of these lines do not fit into the pattern of slopes representing the theoretical family of curves. The curve for mixture C conforms to the theoretical data reasonably well between displacement values of 1.00 and 3.00 turns. At high air contents, however, the curve deviates downward. This dropping-off trend is probably due to the very low lateral pressure values (9 and 11 psi) transmitted by the specimen at high values of displacement. The sensitivity of the Stabilometer pressure gauge at these low pressures is subject to question.

SUMMARY OF RESULTS AND CONCLUSIONS

For the specimens tested in this study, the final displacement measurements, when substituted into the Hveem stability equation, did not totally compensate for the variations in lateral pressure values caused by the presence of air in the test system. As displacement values were increased beyond 2.00 turns, computed stability numbers became smaller.

The reproducibility of test results was improved when the lateral surfaces of specimens were coated and when tests were conducted at high values of initial displacement (3.00 to 5.00 turns).

When testing open-graded bituminous mixtures in the Hveem Stabilometer, the following modifications in test procedure are suggested:

FIG. 13 RECIPROCAL OF LATERAL PRESSURE vs FINAL DISPLACEMENT

1. Specimens capable of developing final displacement measurements of 3.00 turns or more should have their surface voids filled prior to testing. Although a mixture of plaster of Paris, portland cement, and water was used to coat the specimens discussed in this paper, a non-cementing mixture such as limestone mineral filler and water is probably more desirable.

2. When the lateral surfaces of test specimens are coated, the Stabilometer should be calibrated at an initial displacement value of 3.00 turns instead of the standard number of 2.00 turns. This increased displacement number will provide more reproducible results and will permit more specimen deformation than what would occur for coated specimens tested at 2.00 turns initial displacement. The process of coating test specimens reduces the quantity of air in the test system and, as a result, cuts down on the amount of specimen deformation. The additional deformation obtained by increasing the initial displacement value to 3.00 turns will help to offset the reduced strain caused by coating test specimens.

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