JOINT DISCUSSION

Mr. R. E. Bollen (presented in written form).—I wish to commend the authors of the three papers for their presentation of fundamental procedures and reasoning concerning measurement of stability in bituminous mixtures, and all members of the Triaxial Institute for their concentrated effort in their attempts to provide a method of test by which a rational method of design and a logical method of investigation can be established.

The triaxial test has been used in our laboratory for investigation and correlation to other stability tests, such as the compression test and the modified Hubbard-Field stability test, to a limited extent. We have experienced many of the same difficulties enumerated in the papers to some degree. The major reasons for its limited use has been our inability to apply the test to undisturbed specimens from the road and to the lack of a suitable method of compaction. In the past most of our aggregates have been the smooth, well-rounded particles found in our river sands and gravels, and we did not experience the degree of difficulty with the double-plunger method of compaction as described by the authors of the papers. When crushed aggregates were used, the difficulties of compaction increased and considerable doubt was raised as to the value of the test data.

Therefore I wish to emphasize the attention that the authors have devoted to the necessity for suitable methods of compaction in any method of stability test. Likewise I wish to emphasize the importance of providing a test specimen which is as near as possible to the condition of the bituminous pavement—that is, it should duplicate the degree of crushing or degradation produced by the approved method of rolling, the density or percentage of density desired in the pavement, and the position of the aggregate particles.

In Mr. Smith's description of the specimen preparation he states confined direct compression requires extreme pressures which result in puncturing the binder films between the particles. I should like to know the method of determination of the punctured films since it has been my understanding that the study of an interface located within a mass was limited to X-ray methods. I believe that the major difference produced by different methods of compaction is the orientation and crushing of the particles.

He recommends the confined direct method as an alternate method when the mix has more than 5 per cent voids. I should modify this to include a limitation as to the degree of crushing of the aggregate during compaction which is somewhat dependent on the angularity of the aggregate. In our laboratory we are still using the direct method of compaction.

Mr. Hveem's long and successful use of the Stabilometer should encourage other engineers to investigate the methods described by the three papers.
I would like to ask Mr. Hveem to what extent he could predict the failures shown in Table I of his paper without the use of the Stabilometer, and also if he has available the percentage of voids in the four specimens referred to in the table.

Mr. C. L. McKesson* (presented in written form).—This writer has been invited to present a brief discussion of the papers by Endersby, Hveem, and Smith. My discussion will refrain from consideration of purely scientific aspects of the tests presented here today but will be in the nature of a discussion of the application and the interpretation of the results obtained by the test methods.

All of these authors have presented their respective cases convincingly—they are entitled to the respect and gratitude of paving engineers everywhere for the splendid work which they have done in segregating and evaluating the factors which produce stability in bituminous pavements. Although the tests of Hveem and Smith differ in some details, both test methods are essentially related to triaxial shear, and, although a correlation between these two methods is not shown in the papers, there is no reason to believe that a pavement found to be stable by one method would be found unacceptable by the other. Likewise other forms of triaxial shear briefly mentioned by Endersby would probably lead to the same character of findings. Nothing said in this discussion is to be interpreted as a criticism of the very constructive work done by these authors.

The first phase of this discussion finds inspiration in Endersby's comment as to the desirability of bringing about "as complete correlation as possible with other tests, it being recognized that long-established tests will not be readily abandoned even though scientifically superior ones can be established." Every well-known or widely used method of stability determination which has an established service or performance background, even though purely empirical, should be related as closely as possible to the newer and probably more scientific tests presented here today. The committee for which Endersby is reporting has this task in hand, and other coordination studies are under way.

One of the oldest of these tests, the Hubbard-Field method, still has wide use. It appears from the papers of Hveem and Smith that this method tends to show maximum stability with an asphalt content over the safe limit, due to over-emphasis on cohesion resulting from the method of test rather than of frictional resistance. This commentator's experience fully confirms this finding. Is it not possible to correlate tests by the Hveem and Smith methods with the Hubbard-Field, for example, by fixing a minimum void content which should not be reduced by over-asphalt ing regardless of apparent (and temporary) increases in stability? Perhaps correlation might disclose similar minor variations in other widely used methods which would make them more useful to the highway profession.

It is noted with great satisfaction that Endersby, Hveem, and Smith all emphasize the critical importance of asphalt content and the dangers of reducing stability by over-asphalting. Hveem, for example, in his Fig. 8 shows maximum stability on two samples from one job with 5.3 and 6.2 per cent "liquid content" and two unstable samples with 6.7 and 8.2 per cent "liquid content." Actually asphalt content in the stable samples averaged 4.7 per cent and in the unstable samples averaged 5.5 per cent. Is this not an indictment of specifications which loosely specify asphalt content as, for example, from 5 per cent minimum to 8 per cent maximum?

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Hveem in his graphs shows stability in relation to "total liquid content (asphalt plus water)". It is here urged that water or moisture contents encountered in the field greatly influence the stability of a pavement, particularly pavements with low-void content and that "total liquid content" as defined by Hveem should be considered rather than mere bituminous content whenever such action is possible or can be anticipated.

This leads to the expression of this commentator's opinion that every sample tested for stability should be tested when it is in the most unfavorable condition likely to be encountered in service on the particular project under consideration. This applies to moisture content, temperature, compaction, and the like. This does not necessarily mean that materials should be tested under the most unfavorable conditions which might exist anywhere.

It is noted that Smith tests under "static loadings," a condition which he says reduces to zero the shearing displacement resistance resulting from the presence of either hard or soft asphalts.

Bituminous pavements are built primarily for moving traffic with only a small fraction subjected to static loadings. Bituminous materials under normal temperatures do increase shear resistance and it might be questioned whether static loading is not an overly severe condition which might tend to appear to nullify the benefits obtained by the use of bituminous binder. Hveem tests at 140 F. with field moisture present in field samples. This appears to be a reasonably severe condition.

Smith believes that static loading eliminates necessity for curing samples in which cutback asphalt has been used as a binder. Certainly static loading which reduces the value of shear resistance of bituminous binder to zero is questionable. With emulsified asphalt as a binder, tests with static loading and no curing would not be an indication of pavement performance because the asphalt does not form into a film until after reasonable dehydration or curing.

This discussion will close with a word of caution. In testing bituminous pavements, simple compression tests with a constant rate of loading or a constant rate of strain, extrusion tests, punching shear tests and other tests, have furnished useful data for experienced engineers when these tests have been carefully related to performance. The newer tests will probably be even more useful when they are fully related to performance in each field in which they are to be used. The Hveem test has been studied in relation to field performance in bituminous pavement for highways for nearly 20 yr. The Smith method has been studied with reference to field performance in asphalt concrete surfacing over a period of years. The use of either of these methods in these fields appears to be fully justified.

It is indicated by both of these fine technicians that they expect to extend the usefulness of their tests into fields of pavement thickness and subgrade design. Subgrade and over-all thickness design involves many factors not encountered in the design of pavement mixtures—as, for example, moisture and temperature conditions, nonuniformity of subsoils and other local factors due to general climatic and drainage conditions. Both are cautious investigators and it can well be assumed that when they advocate their methods for uses other than the design of pavement mix, they will provide adequate information which will enable the experienced engineer to adapt their design to his particular local conditions.

Serious disasters have resulted in the use of test methods for purposes for
which they were not intended or recommended. Future disasters might be prevented through a proper correlation of these different stability test methods.

MR. L. F. ERICKSON—Referring to Mr. Hveem’s paper, has anyone had experience with preparation of specimens by the Texas Method? that is, a rotating compression ram and straight compression working both of them together?

MESSRS. R. J. HANK and L. E. MCCARTY (presented in written form).—While this is primarily intended as a discussion of Mr. Hveem’s paper, it is necessary to make brief reference to the other papers prepared by members of the Triaxial Institute for purposes of comparison.

Because of the existing state of widespread confusion concerning interpretation of data from various triaxial tests performed in different laboratories, it appears that the program of standardization of equipment and test procedure undertaken by the recently organized Triaxial Institute is of primary importance. It is believed that practically all of the current differences of opinion on such points as the physical significance and values of “cohesion intercept,” “angle of internal friction,” and cause and meaning of curvature in the Mohr rupture envelope, as well as many other diverse conclusions often derived from triaxial test data, are directly due to variations in some or all of the following factors:

1. Type of equipment used.
2. Test procedure, including mixing, molding and processing of the specimen.
3. Specimen dimensions and specimen height-aggregate diameter ratio.
4. Test conditions, such as temperature, rate of deformation, etc.
5. Physical properties of components in the mixture and changes in physical properties accompanying compaction of the specimen during the test.

All three of the tests advocated in the papers may, and probably do, yield equivalent final results when the data from each test is properly, and differently, interpreted and employed in the designs; but the secondary results and graphical constructions are not comparable because of differences in equipment, specimen dimensions, test procedures, etc.

As indicated by Mr. Endersby and Mr. Smith, the common test to be adopted, which might be a single one of the proposed tests or a composite of all three, must meet certain criteria, such as (a) ability to test all types of road materials, (b) elimination of variables which are difficult to measure accurately, (c) convenience of operation with a minimum of time and expense, and (d) yielding of results which are consistent and reproducible and are easily interpreted in terms of practical concepts, and which possess high correlation with field performance.

In view of these criteria and others mentioned in the papers referred to, it appears that the triaxial test, in any of its several forms, is preferable to other types in common use, such as the Hubbard-Field and Marshall tests; and either type of apparatus proposed in the papers by Mr. Hveem and Mr. Smith might be used, at least with slight alterations, to accomplish the same ends.

The chart used by Mr. Smith furnishes a convenient means for evaluating road mixes, but it seems that a chart constructed by plotting directly the angle of inclination and intercept in the axial stress—radial stress diagram would be better, since the rather tedious calculation of cohesion and angle of internal
friction, with their loose meanings and questionable values, would thereby be avoided. Incidentally, similar charts may be constructed for evaluation of materials tested in the Hveem Stabilometer test.

Based on our 10 yr. experience with the Hveem Stabilometer, both in routine testing and investigational research, we believe it possesses all the requisite qualities for testing road materials for design purposes, especially for the comparatively thin layers of bituminous mixes employed in pavement surfaces for which purpose it has been mostly used in this laboratory. Although the small height-diameter ratio of the test specimen prevents direct application of the results to the design of thicker layers, it is possible to make a correct evaluation in these cases by applying a simple correction to the original results. Also, while the stabilometer, when used in the normal manner, that is, for the empirical determination of the stability or rigidity of the material, does not produce data that permits satisfactory separation of the physical properties of "cohesion" and "internal friction," which properties are probably never completely separable in a compression test on granular-plastic materials and are not required in the design, it is nevertheless possible, by proper interpretation of the data, to arrive at values of these properties believed to be about as accurate as those obtained by other tests. With slight adaptation of test procedure, the stabilometer may also be used for the static type of closed system test employed by V. A. Smith and L. W. Nijboer, or the reverse type used by V. A. Endersby in which the radial stress is adjusted and the developed axial stress is measured.

The Hveem Stabilometer is compact, sturdy, and easily operated, and, when correctly used, it yields reproducible results which are susceptible to physical interpretation in terms of shear strength of the material and, in addition to meeting these necessary requirements for an adequate test, it has been found that the Hveem stability index derived from the test data shows a high degree of correlation with field performance.

Mr. V. R. Smith (author's closure, presented in written form).—I should like to answer Mr. Bollen's query regarding the source of information upon which we drew the conclusion that double plunger compaction results in the puncturing of the asphalt films between aggregate particles. To the best of our knowledge Mr. Bollen is correct in stating that the only direct method for studying conditions at solid-interfaces is by X-ray methods. However, in the study of our data comparing direct confined compression with mechanical kneading compaction it was noted that the quantity $\phi$ did not change significantly at relatively high asphalt contents when direct confined compression was used, while $\phi$ changed markedly under kneading compaction conditions. Inasmuch as the degradation of mineral aggregate which occurred in the former series of tests was virtually identical, the retention of $\phi$ at higher asphalt contents cannot in these instances be attributed to degradation effects. Rather, the identity of results suggests that the aggregate particles are in the same fundamental type of contact in the over-asphalted samples as was characteristic of the properly asphalted samples. The test results presented in Table II show this effect when summarized as follows:

<table>
<thead>
<tr>
<th>Method of Compaction</th>
<th>Asphalt, per cent</th>
<th>$\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kneading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>46.4</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>44.2</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>38.3</td>
<td></td>
</tr>
<tr>
<td>Direct compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>6.4</td>
<td>39.0</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>33.0</td>
<td></td>
</tr>
</tbody>
</table>
The data given above suggest, however, that the term "punctured" connotes a more severe action than actually occurs. Perhaps it would be more in accordance with the test results to term this effect a "thinning" of the binder films. However, as this effect is marked and has been noted repeatedly in experimental work, it has been called to the attention of this group as being of some importance in stability studies.

Mr. McKesson is entirely correct in stating that pavement performance cannot be predicted accurately from test results obtained on specimens prepared from uncured mixes. Our intent was not to imply that static load triaxial testing eliminates the need to cure a mix, but rather that it minimizes the differences in test results on specimens from similar mixes varying only slightly in degree of curing (cutter stock evaporation). Slight differences in amount of curing result in marked changes in stability when loading is conducted at a relatively high rate of strain. Such large differences do not show up in field behavior nor in the static load triaxial test. We also concur with Mr. McKesson that it is essential to cure emulsified asphalt mixes before testing if a true measure of their field performance characteristics is to be obtained.