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Design Studies of Indiana Bituminous Concrete Surface Mixtures

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For several years, the bituminous laboratory of the Joint Highway Research Project has been concerned with the testing of bituminous-aggregate mixtures and with the development of knowledge that would lead to an understanding of the properties of bituminous mixtures as satisfactory paving materials. At the Thirty-Eighth Annual Road School, a paper entitled, "Role of the Laboratory in the Design of Bituminous Mixes," was presented which included test data from the laboratory for the evaluation of a number of mixture variables including aggregate gradation, asphalt content, grade of asphalt cement, aggregate type, and testing speed (1, 2).

In this testing program two types of tests were used, the triaxial test and the Marshall test. The triaxial test is a rational one from which fundamental strength properties of a material may be obtained. This test has been found to be very useful as a research tool, but it is not well-adapted for use in the field either as a means of designing or controlling a bituminous mixture. For such use, the Marshall test has advantages of simplicity and convenience.

The apparatus used in the Marshall test is shown in Figure 1. The specimen is a cylinder 4-inches in diameter and 2½-inches high. A unique feature of the test is the method of loading the specimen. Unlike most compression tests, the Marshall specimen is loaded on the cylindrical surface rather than on the plane faces. The data normally obtained from a test of this type are the total load at failure (stability) and the total deformation of the specimen at failure expressed in hundredths of an inch (flow).

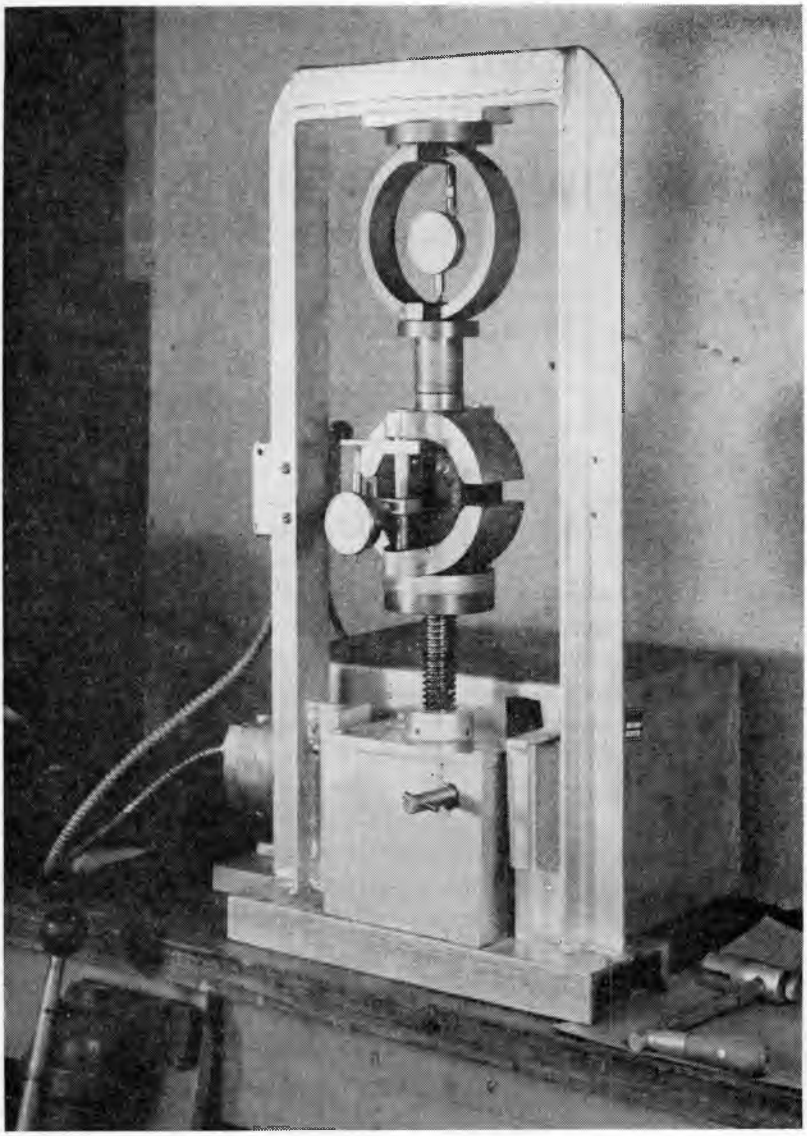

Fig. 1. Marshall test apparatus.

Since comparable mixtures were tested by these two test methods, there was an opportunity to evaluate the test properties measured in the Marshall test in terms of the fundamental properties obtained from the triaxial test. One of these properties, the angle of internal friction, largely determines the stability or supporting power which a bituminous mixture will be capable of mobilizing under many conditions of loading.

The most pertinent fact revealed by this comparison is shown in Figure 2, which is a plot of angle of internal friction (degrees)

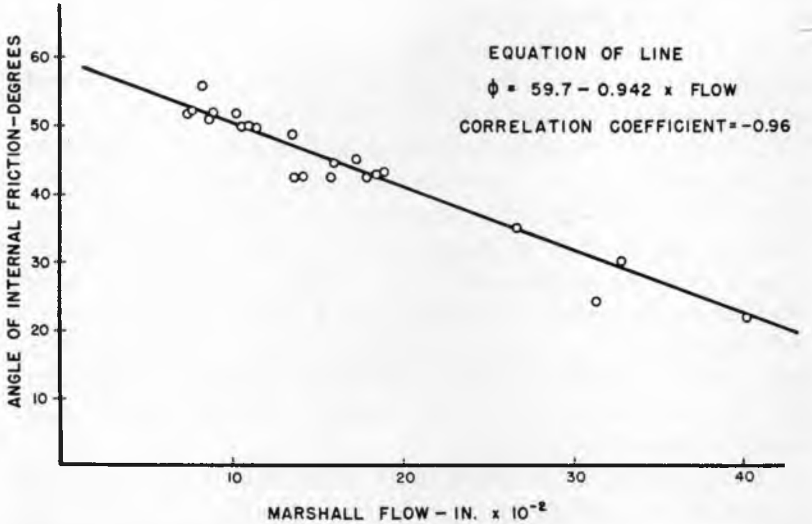

Fig. 2. Correlation of angle of internal friction with Marshall flow.

versus Marshall flow (3). Twenty-two cases are included in this plot and these in turn include all of the variables previously listed. A straight line has been fitted to the data and the coefficient of linear correlation was computed to be -0.96. Further comparisons of this nature have shown the same trend.

From these accumulated data it may be concluded that the Marshall test, while being an empirical test, nevertheless, is one which reflects the fundamental properties of a mixture. Further than this, since the Marshall test has been found to be one which does reflect these properties, the incorporation of the test as a part of some design procedure appears to be reasonable.

CORPS OF ENGINEERS DESIGN PROCEDURE

In any realistic design procedure, carried out under laboratory conditions, factors other than the stability of the mixture must be considered. These factors should include the method by which the specimen is formed and the density that is obtained. The total void content of the mixture and the percentage of aggregate voids filled with asphalt are known to affect the durability of the mixture in service and some limiting criteria should be set to control these characteristics. Finally, or perhaps primarily, it is necessary to correlate laboratory and field performance to establish the limiting criteria on which the design procedure is based. The U. S. Corps of Engineers has established a design procedure for asphaltic concrete in which the Marshall test is used to measure the stability of the mixture and durability factors are controlled by limiting the total void content and the percentage of aggregate voids filled with asphalt (4).

Five curves are needed to select the design asphalt content by the Corps of Engineers' design method (see Figures 4, 5, and 6). Marshall specimens are made at several asphalt contents which are selected so as to include the design asphalt content. The unit weight of each specimen is determined and mixture voids and aggregate voids filled are computed on the basis of the apparent specific gravity of the aggregate. The specimens are tested in the Marshall apparatus and values for stability and flow are found. Values for these five properties are plotted versus asphalt content and the design asphalt content is selected as follows:

The asphalt contents at the peak of the unit weight curve, at the peak of the stability curve, at 4 per cent total voids and at 80 per cent voids filled are picked from their respective graphs. The average of these four values is the preliminary estimate of the design asphalt content. This estimate is then checked by reference to the graphs. For surface mixtures designed to carry 100 p.s.i. tire pressures, the mixture must have a stability of 500 pounds or higher, a flow of 20 or less, a total void content of 3 to 5 per cent, and between 75 and 85 per cent voids filled. If the mixture at the estimated design asphalt content meets these requirements, this estimate becomes the final design. If the mixture does not meet one or more of the criteria, some adjustment is necessary (4).

INDIANA SURFACE GRADING COMPARED TO CORPS OF ENGINEERS GRADING

During the past year the Corps of Engineers' design procedure has been applied to Indiana A H Type B bituminous concrete surface mixtures. An average aggregate grading within the specified allowable limits was used and Figure 3 shows this aggregate grading compared to the grading limits specified by the Corps of Engineers for a similar mixture (½-inch maximum aggregate size). The Corps of Engineers' grading limits are shown by the dashed lines and the average Indiana grading is shown by the solid line. It is

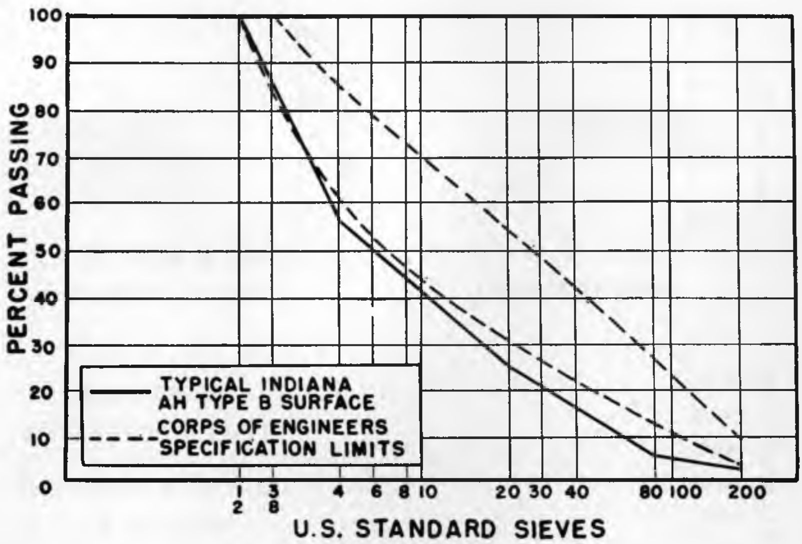

Fig. 3. Comparison of typical AH type B grading, Corps of Engineers specification limits.

evident that the typical Indiana mixture is not within the range for which correlation has been established by the Corps of Engineers. It is also evident from the curves that the mixtures specified by the Corps of Engineers are more densely graded than Indiana A H Type B mixtures. It is not the purpose here to compare the merits of the two types of mixtures, but only to point out that two types of mixtures are involved. Each type has its merits and shortcomings. It might be mentioned, however, that the Indiana grading, containing less fines, does tend to be less critical with small variations in asphalt content than is the case with the more densely-graded aggregate blends.

APPLICATION OF DESIGN USING ABSORPTIVE STONE

The Corps of Engineers' design method was first applied to the typical Indiana aggregate grading for a case in which an absorptive crushed limestone was used. The way in which stability, flow, and unit weight varied with asphalt content in the case of this aggregate is shown in Figure 4. These curves are typical of many other such curves found for various mixtures and are easily interpreted in applying the design method. In computing voids however, some difficulty was encountered.

It was mentioned earlier that two of the criteria for design by

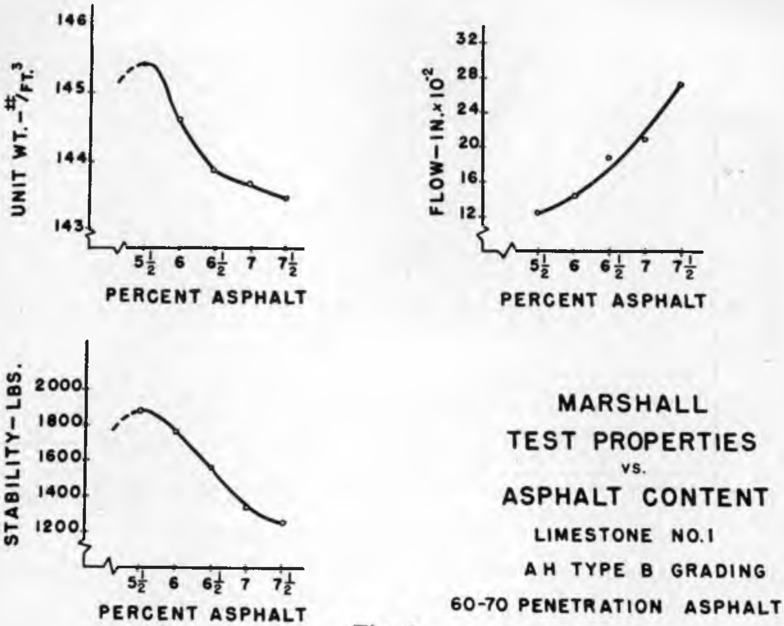

Fig. 4.

the Corps of Engineers' method are limiting values for total void content of the mixture and percentage of aggregate voids filled with asphalt. Further, it was stated that these values of voids are to be computed using the *apparent* specific gravity of the aggregate. It is recognized that when computing voids on this basis it is assumed that all of the voids that were water-permeable under the conditions of the apparent specific gravity determination are permeable to hot asphalt cement to the same degree. This may or may not be true in all cases. However, all of the correlation work performed by the Corps of Engineers, from which evolved the various design criteria, was based on certain standard procedures one of which was a voids calculation based on the standard A.S.T.M. apparent specific gravity of the aggregate (ASTM Designations C 127-42 and C 128-42). When attempting to apply an empirical design procedure, test methods should be the same as those used in establishing the design procedure. However, in the case under consideration this was not possible.

The variation of total voids and voids filled with asphalt content is shown in Figure 5. The horizontal broken lines indicate the void contents at which, according to the design procedure, the asphalt contents should be picked in making the preliminary estimate of the design asphalt content. These figures are 4 per cent total voids and 80 per cent voids filled. The solid horizontal lines delineate the ranges

VOIDS CURVES

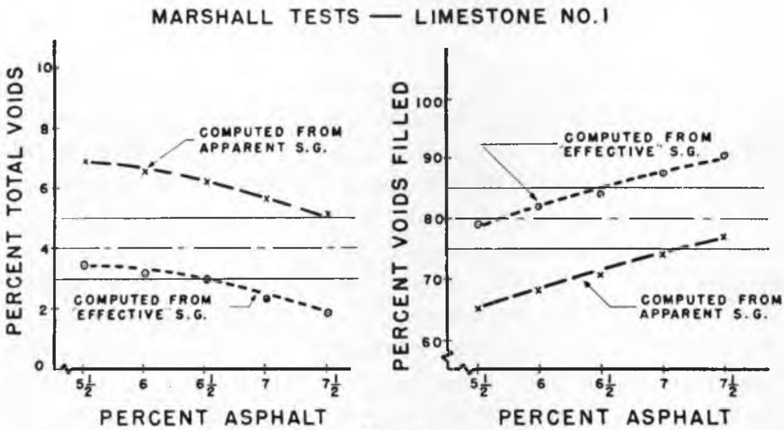

Fig. 5.

which are considered satisfactory in the final design (3-5 per cent total voids and 75-85 per cent voids filled). Note the positions of the voids curves, computed from the apparent specific gravity of the aggregate, in relation to these boundaries. These are the curves shown by the dashed lines with the points denoted by crosses. The total voids curve reaches a value of about 5.2 per cent at 7½ per cent asphalt. If the curve were extrapolated, 4 per cent voids would be reached at 8 or 8½ per cent asphalt.

In any case, the minimum design asphalt content necessary to satisfy the total void requirement on this basis is about 7½ per cent. Approximately the same is true of per cent voids filled. It can be seen from the curves on the right that the minimum requirement is not met until the asphalt content is approximately 7¼ per cent. Reference to Figure 4, however, shows that this mixture reaches the maximum allowable flow of 20 at an asphalt content of approximately 6¾ per cent. It is apparent, then, that no satisfactory asphalt content can be found for this particular aggregate blend which will meet all of the requirements as they have been defined when voids computations are based on apparent specific gravity of the aggregate.

Proceeding on the assumption that, in the case of an absorptive aggregate, voids calculated on the basis of apparent specific gravity may sometimes give an erroneous result, a specific gravity value for the aggregate was determined which attempted to take into account the actual absorption of asphalt into the aggregate pores. This specific gravity value was termed "effective" specific gravity.

The concept of effective specific gravity may be understood most simply by imagining a standard A.S.T.M. apparent specific gravity test being made, but substituting hot asphalt cement for water. In the usual case, the asphalt will not permeate the aggregate pores to as great an extent as will water. This has the effect of *increasing* the volume of aggregate that is impervious to the permeating liquid under the conditions of the test and, hence, of reducing the specific gravity value from that found in an apparent specific gravity determination using water. Effective specific gravity should have some value less than apparent but greater than bulk specific gravity.

The method used to measure the effective specific gravity of an aggregate may take one of several forms. The hypothetical method outlined in the previous discussion has several practical limitations. A system which utilizes a voidless, compacted specimen of the bituminous-aggregate mixture has been reported (5). For the present work, a standard Marshall specimen was formed at an asphalt content of 6 per cent. The voids in this specimen were saturated with water using a vacuum technique and the actual void content of the specimen was computed. Knowing the actual void content and the composition of the specimen, the effective specific gravity of the aggregate, as it existed in the mixture, could be computed.

The voids computed using the effective specific gravity are shown in Figure 5 by the dotted lines with the points denoted by circles. On this basis a design is possible which will meet the criteria of the Corps of Engineers. It can be seen from the curves computed from effective specific gravity that an asphalt content of as much as 6½ per cent may be used without having a total void content of less than 3 per cent or a percentage of aggregate voids filled of greater than 85 per cent.

TABLE I
Determination of Design Asphalt Content
Limestone No. 1

Test Property	*Asphalt Content at Selected Point on Design Curve*		*Test Value at Asphalt Content of 5.5%*
	Point on Curve	*% Asphalt*	
Unit Weight	Peak	5.5	----
Stability	Peak	5.5	1890#
Flow	----	----	12.0
% Voids	4	5.2	3.6
% Voids Filled	80	5.7	79.0

Design Asphalt Content (Average) 5.5%

In Table I are shown the asphalt contents picked from the peak of the unit weight curve, peak of the stability curve (Figure 4), and from the voids curves (Figure 5), following the standard Corps of Engineers' procedure except that the voids were computed by using effective rather than apparent specific gravity. The average of these asphalt contents is 5.5 per cent. Checking this asphalt content back against stability, flow, and voids requirements, it is found to be satisfactory and according to the Corps of Engineers' design procedure modified to include effective specific gravity, this asphalt content of 5.5 per cent would be the one selected for use.

APPLICATION OF DESIGN USING NON-ABSORPTIVE STONE

Since the design asphalt content found in the previous application is at least one per cent lower than that thought to be satisfactory on the basis of field performance of many comparable mixtures, it remains open to question as to whether the established criteria did not fit the case because of the fundamentally different type of mixture or because an absorptive aggregate was used. Consequently, a second series of similar tests was performed using a more normal, non-absorptive crushed limestone. The design curves for this series are shown in Figure 6. For this case, application of the design criteria for voids based on apparent specific gravity of the aggregate was possible and the test values found and the resulting design asphalt content are shown in Table II.

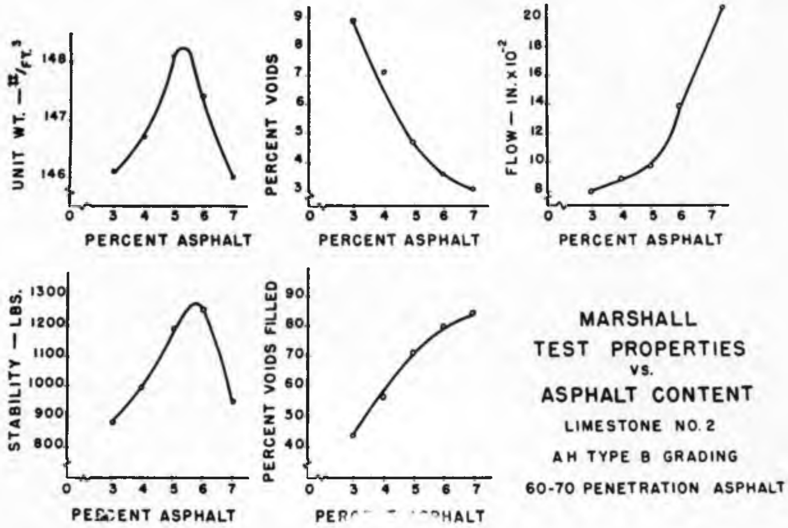

Fig. 6.

TABLE II
Determination of Design Asphalt Content
Limestone No. 2

Test Property	*Asphalt Content at Selected Point on Design Curve*		*Test Value at Asphalt Content of 5.6%*
	Point on Curve	*% Asphalt*	
Unit weight	Peak	5.4	----
Stability	Peak	5.6	1300#
Flow	----	----	11.8
% Voids	4	5.6	3.8
% Voids Filled	80	6.0	77.0

Design Asphalt Content (Average) 5.6%

It can be seen in Table II that the preliminary estimate of 5.6 per cent meets the criteria established by the Corps of Engineers and under their method, 5.6 per cent asphalt would be the design asphalt content for this case.

Compare this design asphalt content to that previously noted for the other aggregate. Both are approximately 5½ per cent, a figure which, from experience, is perhaps one per cent too low. From these considerations, the conclusion may be drawn that the design method used by the Corps of Engineers is not applicable to Indiana A H Type B bituminous concrete surface mixtures because of fundamental differences in the types of mixtures involved. However, what of the criteria set up as stability and durability requirements for the mixture, that is, minimum stability of 500 pounds, maximum flow of 20, 3-5 per cent total voids and 75-85 per cent voids filled? Since the research done has shown that the Marshall test reflects the fundamental properties of a mixture that are of interest in design, it may be that the case bears further consideration.

The difficulty may lie in one of three directions. It may be that the design *criteria* used by the Corps of Engineers need modification for application to Indiana mixtures. Secondly, there exists the possibility that the specimen produced by the Marshall method of compaction is not representative of the mixture on the road, a condition which must be met to some degree if a laboratory test is to be useful. Lastly, it may be that the *criteria* themselves need little or no revision but that the design *procedure* needs to be changed for application to Indiana conditions. That is, perhaps the change should be made in the way the design asphalt content is chosen from the test data.

The first possibility may be investigated by picking from the respective test curves, the test values at an asphalt content about 1 per cent higher than the design asphalt content. For example, choose 6.5 per cent.

TABLE III
Test Values at 6.5% Asphalt
Limestone Nos. 1 and 2

Test Property	*Test Values at 6.5% Asphalt* *Limestone No. 1*	*Limestone No. 2*	*Criteria To Be Met*
Stability	1570#	1140#	500#+
Flow	17.6	16.7	20—
% Voids	3.0	3.3	3–5
% Voids Filled	84.5	82.5	75–85

The test values at 6.5 per cent asphalt for Limestone No. 1, the absorptive aggregate, and for Limestone No. 2, the non-absorptive aggregate, are shown in Table III. Also shown are the limits for the various criteria that are specified by the Corps of Engineers. A comparison between the test values at 6.5 per cent asphalt and the specified limits shows that these criteria are met by mixtures made from each aggregate at this asphalt content. The established criteria, then, are met at an asphalt content known to be realistic.

VARIABLE SPECIMEN COMPACTION

To explore the effect of variable specimen compaction and degradation of the aggregate, specimens were made with Limestone No. 2 using a compactive effort equal to one-half that normally employed in the standard Marshall test. These specimens were tested by the Marshall method and a design asphalt content was computed for this series by the methods previously outlined.

The data pertinent to this selection are shown in Table IV. In general, it may be seen that the lesser compactive effort caused a shift to higher asphalt contents. The design asphalt content is 6.6 per cent, which experience has shown to be satisfactory. However, limited density data that are available indicate that the specimen density produced by this lower compactive effort is not realistic for field conditions and this modification is probably not satisfactory even though a more realistic design asphalt content is obtained.

TABLE IV
Determination of Design Asphalt Content
Limestone No. 2—Compaction ½ Normal

Test Property	*Asphalt Content at Selected Point on Design Curve*		*Test Value at Asphalt Content of 6.6%*
	Point on Curve	*% Asphalt*	
Unit Weight	Peak	6.0	----
Stability	Peak	7.0	1050#
Flow	----	----	17.3
% Voids	4	6.5	3.9
% Voids Filled	80	7.0	79.5

Design Asphalt Content (Average) 6.6%

Sufficient data have not yet been accumulated to say whether either compactive effort is realistic with respect to degradation of the aggregate.

MODIFIED DESIGN PROCEDURE

In view of these considerations, suppose that a design procedure is contemplated in which the established criteria are kept relatively unchanged and in which the standard compactive effort is used. It may be recalled that two of the points chosen for design by the Corps of Engineers' method are the peak of the unit weight curve and the peak of the stability curve. It has been found that these factors carry a weight in the design which may cause the selection of too low an asphalt content for Indiana mixtures. It is suggested that perhaps the design asphalt content might be selected not by recourse to maximum stability and density but by choosing the asphalt contents which produce some minimum allowable stability and maximum allowable flow. This concept, together with voids requirements, may constitute a more satisfactory procedure for A H Type B mixtures.

To illustrate, Table V has been prepared in which a design asphalt content has been calculated for Limestone No. 2 using these concepts. The asphalt contents giving a flow of 20, a stability of 1000 pounds (taken at the high asphalt side of peak stability), 4 per cent total voids, and 80 per cent voids filled have been averaged to give a preliminary estimate of the design asphalt content. These four values, as shown in Table V, have an average of 6.4 per cent.

TABLE V
Determination of Design Asphalt Content Limestone No. 2—
Modified Design Method

Test Property	*Asphalt Content at Selected Point on Design Curve*		*Test Value at Asphalt Content of 6.4%*
	Point on Curve	*% Asphalt*	
Stability	1000#	6.9	1160#
Flow	20	6.9	16.0
% Voids	4	5.6	3.4
% Voids Filled	80	6.0	82.0

Design Asphalt Content (Average) 6.4%

The test values at 6.4 per cent asphalt, shown in the right-hand column of Table V, satisfy the criteria before mentioned.

SUMMARY

In this presentation no attempt has been made to give a specific design procedure for Indiana A H Type B bituminous concrete mixtures. An attempt has been made only to show evidence to the fact that if the necessary correlating data are obtained, it is likely that a satisfactory design procedure may be established having the Marshall test as its basis. Further, it is shown to be possible that the Corps of Engineers' design procedure, including the specific gravity value used for voids calculations, would need modification for the particular conditions under consideration.

Even though the Marshall test is empirical, there are points of simplicity and possibilities of correlation with performance that favor this test as a basis for a design method. It would be a fallacy, however, simply to assume that a specific design method based on the Marshall or any other empirical design test would be applicable to conditions other than those for which correlation had been established.

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APPENDIX

TABLE VI

Corps of Engineers and A H Type B Gradings

Sieve Size	*% Passing*	
	*Corps of Engineers' Grading Limits**	*A H Type B Grading*
½"	100	100
⅜"	84–100	89
# 4	60– 85	52
# 10	43– 70	41
# 40	23– 42	17
# 80	13– 26	4
#200	4– 9	3

* Information from reference 4

TABLE VII

Marshall Test Data

Limestone No. 1

% Asphalt	*Unit Wt. Mixture #/ft³*	*Marshall Stability #*	*Marshall Flow 1/100"*	*% Total Voids*		*% Voids Filled*	
				Apparent Sp. Gr.	*Effective Sp. Gr.*	*Apparent Sp. Gr.*	*Effective Sp. Gr.*
5½	145.4	1890	12.3	6.8	3.4	65.3	78.9
6	144.6	1775	14.6	6.5	3.1	68.3	81.9
6½	143.9	1570	18.7	6.2	2.9	70.9	83.8
7	143.7	1355	21.0	5.6	2.3	74.2	87.5
7½	143.5	1270	27.3	5.1	1.8	77.2	90.5

Limestone No. 2—Standard Marshall

% Asphalt	*Unit Wt. Mixture #/ft³*	*Marshall Stability #*	*Marshall Flow 1/100"*	*% Total Voids*	*% Voids Filled*
3	146.1	880	8.0	8.9	44.0
4	146.7	1000	8.8	7.1	57.0
5	148.1	1195	9.7	4.7	71.5
6	147.4	1255	13.8	3.6	80.0
7	146.0	945	20.7	3.1	84.0

Limestone No. 2—Compaction ½ Standard

% Asphalt	*Unit Wt. Mixture #/ft³*	*Marshall Stability #*	*Marshall Flow 1/100"*	*% Total Voids*	*% Voids Filled*
4	146.6	665	8.0	7.1	57.0
5	146.8	800	10.5	5.5	68.2
6	146.7	930	13.7	4.1	77.5
7	144.8	1060	20.0	3.9	80.6