Effect of Specimen Size on Marshall Test Results of Cold-Mixed, Asphalt-Stabilized Bases

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Because base-course aggregate gradations frequently have aggregate top sizes greater than 1 in., the use of the standard Marshall procedure in characterizing black-base mixtures has been questioned. A laboratory investigation was performed to evaluate the effect of increasing specimen size on the Marshall test results of emulsified-asphalt mixtures with an aggregate top size of 1.5 in. Two specimen sizes—4- and 6-in. diameters—were fabricated and tested with Marshall equipment at 72°F. The effects of other factors such as aggregate type, aggregate gradation, and emulsion content were investigated. The modified Marshall stability and flow values increased because of increasing specimen size. Large specimens displayed a slow rate of curing that resulted in larger values of bulk specific gravity, retained moisture, and total liquid and a smaller percentage of air voids than the standard-sized specimens. The cold-mixed, asphalt-stabilized bases can be adequately characterized in the standard Marshall size specimens if the Marshall test results are correlated with field performance.

The Marshall design procedure (ASTM D1559) is applicable only to hot-mix asphalt paving mixtures with aggregate top sizes no greater than 1 in. Because base-course aggregate gradations frequently have top sizes greater than 1 in., the adequacy of the standard Marshall specimens has been questioned. In such cases, the designer must rely on previous experience. A number of studies have analyzed the Marshall test results by using larger-sized specimens that allow the use of aggregates with larger top sizes. Maupin (1), for example, used 6-in.-diameter specimens to examine a modified version of the Marshall design procedure applicable for black-base mixes containing aggregate larger than 1 in. Most of the previous studies that examined large specimens used hot-mixed asphalt mixtures. The effect of increasing the specimen size on the properties of cold-mixed, asphalt-treated bases, however, is not fully understood.

The findings of a laboratory investigation that evaluated the effect of increased specimen size on the Marshall parameters as well as other properties of stabilized bases with large aggregate top sizes are reported in this paper. A cold-mix emulsified-asphalt mixture with an aggregate top size of 1.5 in. was used in the experimental program. In addition to the specimen size, the influence on the mixture properties of other factors such as aggregate type, aggregate gradation, and emulsion content was determined.

MATERIALS

Aggregate Types and Gradations

Two aggregate types commonly found in bituminous stabilized base courses were used. The first type was a mixture of sand and gravel consisting approximately of 50 percent calcareous and 50 percent siliceous pieces. The sand and gravel blend had apparent and bulk specific gravities of 2.71 and 2.64, respectively. About 60 percent of the gravel particles retained on the No. 4 sieve had crushed faces. The second type was totally crushed limestone with apparent and bulk specific gravities of 2.74 and 2.70, respectively. Two aggregate gradations, with a maximum size of 1.5 in., were used in the study (see Figure 1). The first had a medium gradation that followed the midspecification of the Indiana State Highway Commission 53B gradation band. The second was a coarse gradation that was selected at the quarter point--i.e., midway between the midpoint and the lower limit of the specification band.

Asphalt

A high-float emulsified asphalt [HFMS-2s (ASTM D977)] was used. The physical properties of the emulsion were as follows:

Property	Value
Saybolt Furol viscosity at 77°F (sec)	$\geq$50
Residue by distillation (%)	$\geq$70.0
Penetration of residue after distillation (77°F, 5 sec, 100 g)	$\geq$200
Specific gravity of residue after distillation at 77°F	0.999

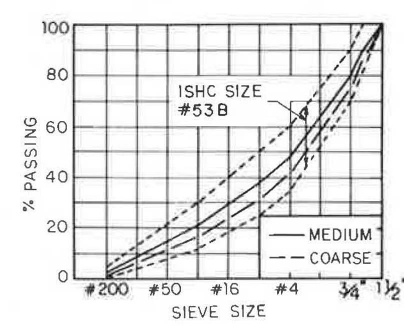
SPECIMEN PREPARATION AND TESTING

Recently, several techniques have been developed to prepare the emulsified-asphalt mixture in the laboratory (2-6). However, there is no widely accepted standard method. In this investigation, the mixture was prepared as suggested in previous studies (5,6).

One initial moisture addition of 3 percent (by dry weight of aggregate) was used. Three emulsified-asphalt contents were evaluated to provide residue contents of 2.5, 3.25, and 4 percent of the aggregate dry weight, which is within the recommended range used in the field. Specimens with 4- and 6-in. diameters were used. To maintain the proportionality of the standard Marshall specimen size, the small and large heights of the specimens were set at 2.5 and 3.75 in. Therefore, the height to diameter ratio is maintained at approximately 0.625 for both specimen sizes.

Marshall size specimens were compacted at a room temperature of 72°F by using the standard 10-lb hammer. The 6-in.-diameter specimens, however, were compacted at the same temperature by using a hammer with a weight of 25 lb and a diameter of 6 in. A total of 65 blows with the 25-lb hammer was applied on each side of the large specimens, which provided initial specific gravities close to those of the Marshall size specimens that were compacted with 50 blows of the 10-lb. hammer on each side. A completely randomized factorial design with two replicates for each treatment combination was used to test the effect of various factors on the mixture

Figure 1. Aggregate gradations used in the study.



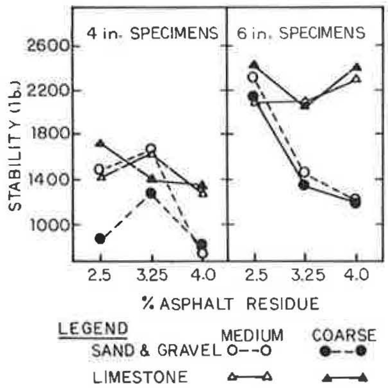


Figure 2. Effect of specimen size, aggregate type, aggregate gradation, and asphalt content on modified Marshall stability.

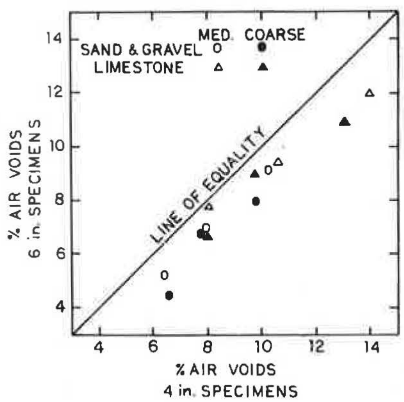


Figure 3. Air voids of 4- and 6-in-diameter specimens.

properties. Specimens were cured out of the mold for 3 days at room temperature to represent an intermediate curing condition in the field (5).

Specimens were tested by using Marshall equipment with breaking-head sizes that matched the specimen sizes. Because the mixture was relatively tender after 3 days of air curing, the Marshall test was conducted at a room temperature of 72°F (4). An autographic Marshall machine was used that provided a continuous recording of load versus deformation throughout the test. The Marshall stability and Marshall flow values were determined according to the standard ASTM procedure except for test temperature. Two other parameters were also obtained: Marshall stiffness and Marshall index (4,5). Marshall stiffness is defined as the ratio between Marshall stability and flow, and Marshall index is the slope of the linear portion of the load versus deformation trace. After the test was completed, specimens were broken apart and dried and then the oven-dried weights were obtained. Bulk specific gravity, air voids, voids in the mineral aggregate (VMA), moisture content, and total liquid content at time of testing were evaluated. Statistical analysis was performed on the data with a level of significance of 5 percent to determine the effect of specimen size and other factors on the emulsion mixture properties as well as the Marshall test results.

ANALYSIS OF RESULTS

Marshall Stability and Flow at 72°F

The increase in the specimen size improved the Marshall stability to a large extent (see Figure 2). The modified Marshall stability ranged between 720 and 1,650 lb for the standard-sized specimens and between 1,200 and 2,420 lb for the large-sized specimens. The average value of stability for the large specimens was approximately 50 percent higher than that for the small specimens. No correlation for Marshall stability and flow values at 72°F was found between 4- and 6-in.-diameter specimens. Limestone mixtures resulted in a larger average stability than sand and gravel mixtures. In addition, emulsified-asphalt content had some effect on Marshall stability. However, this effect did not show a consistent trend in all cases, as shown in Figure 2.

Large specimens provided larger flow values than small specimens. An average flow value of 13 was obtained for large specimens compared with 9 for the small specimens. Other factors did not show a marked effect on the flow values.

Specific Gravity, Air Voids, and VMA

After 3 days of curing at room temperature, the large specimens demonstrated slightly higher specific gravities than those of the small specimens, as indicated below:

Specimen Diameter (in.)	Residue Content (%)	Bulk Specific Gravity: Sand and Gravel Mixture	Bulk Specific Gravity: Limestone Mixture
4	2.50	2.31	2.25
	3.25	2.33	2.29
	4.00	2.34	2.31
6	2.50	2.33	2.28
	3.25	2.35	2.29
	4.00	2.36	2.32

Because of the slower curing rate, large specimens maintained higher moisture than did the small specimens, which in turn increased the bulk specific gravity. Under field conditions, curing of emulsified-asphalt mixtures may require several months, even as much as 2 years (7). On the other hand, because the asphalt residue contents were less than the amount needed to fill all the voids, the increase in the emulsified-asphalt content resulted in a continuous increase in the bulk specific gravities of the specimens. Furthermore, the sand and gravel mixtures provided larger bulk specific gravities than the limestone mixtures, as the table above indicates. The aggregate gradation, however, did not show a significant effect on the bulk specific gravity of the specimens.

The air voids values in the compacted specimens showed trends highly correlated with, and almost the reverse of, those for bulk specific gravity. A smaller percentage of air voids was observed for large specimens than for small specimens, as shown in Figure 3. In addition to the effect of specimen size, the increase of the asphalt residue content from 2.5 to 3.25 to 4 percent decreased the average air voids from 10.9 to 8.5 to 6.6 percent. Moreover, limestone mixtures provided large percentages of air voids: an average of 9.9 percent compared with 7.4 percent for sand and gravel mixtures. Unlike air voids, VMA was not highly affected by specimen size. On the other hand, the limestone mixes resulted in an average VMA value of 10.2 percent compared with 7.4 percent obtained for sand and gravel mixes. The emulsion content, however, did not significantly change the amount of VMA.

Retained Moisture and Total Liquid

The influence of specimen size on the amount of moisture retained in the specimen was apparent, especially with limestone mixtures. After 3 days of curing, the average amount of moisture retained by large specimens was about 50 percent higher than that retained by small specimens. The average moisture content after curing was 1.5 percent for all large specimens versus 1.0 percent for all small specimens.

Limestone specimens retained a higher amount of moisture than sand and gravel specimens. In addition, increasing the asphalt residue in the mix increased the amount of retained moisture. Emulsified asphalt fills the voids among aggregate particles and consequently reduces the curing rate. It also increases the amount of initial moisture in the mix because of the moisture contained in the emulsion itself. Finally, the aggregate gradation did not have an apparent influence on the amount of retained moisture.

The total liquid in the emulsified-asphalt mixture, which is the sum of the asphalt residue and the retained moisture, was highly affected by the size of the specimen. Large specimens retained 12 percent more total liquid than small specimens. Furthermore, the total liquid content was affected by other factors in a pattern similar to that of the retained moisture content.

Marshall Stiffness and Index

The specimen size did not change the Marshall stiffness in a consistent manner. Average stiffness values of 145 and 150 lb/0.01 in. were obtained for the small and large specimens, respectively. Large Marshall stiffness values were obtained for the limestone mixtures and coarse-graded mixtures in comparison with the sand and gravel mixtures and medium graded mixtures. Moreover, the emulsion content showed some effect on the stiffness value. In addition to the Marshall stiffness, there were some changes in the Marshall index with a change in the specimen size, but there was no consistent trend. Limestone mixtures had larger index values than sand and gravel mixtures. The effect of specimen size and residue content on average Marshall stiffness and index values is given below:

Specimen Diameter (in.)	Residue Content (%)	Stiffness	Index
4	2.50	155	380
	3.25	165	370
	4.00	115	240
6	2.50	200	370
	3.25	115	300
	4.00	130	300

CONCLUSIONS

Based on the results of the study, it was found that the 6-in.-diameter specimens resulted in an average value of Marshall stability at 72°F approximately 50 percent higher than that of the standard 4-in.-diameter specimens and that the Marshall flow at the same temperature was 30 percent higher for the large specimens. In addition, specimen size affected the Marshall stiffness and index values to some extent. Because of the slow curing rate, the average retained moisture of the large specimens after 3 days of air curing was 50 percent higher than that of the standard-sized specimens at the same curing condition and the total liquid content of large specimens was 12 percent higher than that of small specimens. The large specimens resulted in slightly larger values of bulk specific gravity and smaller values of air voids than the standard-sized specimens. VMA, however, was not greatly affected by specimen size. In addition, limestone mixtures resulted in large Marshall stability and small Marshall flow values at 72°F as well as low values of bulk specific gravity in comparison with sand and gravel mixtures. The effect of asphalt emulsion content on the Marshall test results showed no consistent trend.

No correlation was found between 4- and 6-in.-diameter specimens for Marshall stability and flow values at 72°F. It is believed that cold-mixed, asphalt-stabilized bases with aggregate top sizes greater than 1 in. can be adequately characterized in the standard 4-in.-diameter Marshall specimens if the Marshall test results are correlated with field performance.

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