NCAT Report No. 90-5

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Prithvi S. Kandhal, M.ASCE and E.R. Brown M.ASCE[1]

Abstract

Increased incidence of premature rutting of heavy duty asphalt pavements has been experienced in recent years. There is a general agreement among most asphalt paving technologists that the use of large size stone in the binder and base courses will minimize or eliminate the rutting of heavy duty-pavements. However, the wide acceptance of the Marshall and Hveem mix design procedures inhibits the use of large stone mixes because these methods use standard 4-inch (101.6 mm) diameter specimens and limit the maximum aggregate size to one inch (25.4 mm).

Modified Marshall equipment and Gyratory Testing Machine (GTM) are now available for compacting and testing 6-inch (152.4 mm) diameter specimens to accommodate aggregate up to 2-inch (50.8 mm) maximum size. However, some agencies continue to use 4-inch diameter specimens for mixes containing 1½-inch (38.1 mm) maximum size aggregate. This study compares the mix properties such as Marshall stability and flow, indirect tensile strength, and permanent deformation (from static creep test) obtained on 4-inch and 6-inch (101.6 and 152.4 mm) diameter specimens. Both Modified Marshall and GTM equipment were used to compact the specimens of these two sizes. The maximum aggregate size ranged from ½ to 1½-inches (12.5 to 38.1 mm).

The test data indicates increased coefficient of variation when testing 4-inch (101.6 mm) specimens of the mix containing aggregate larger than one inch (25.4 mm) compared to 6-inch (152.4 mm) specimens. The 6-inch (152.4 mm) diameter specimens also had lower variability in creep test compared to 4-inch (101.6 mm) specimens. Laboratory and rationally derived data indicating the ratios by which stability and flow values increased is also given in the paper. It has been recommended to use 6-inch (152.4 mm) diameter specimens for large stone asphalt mixes.

Introduction

Premature rutting of heavy duty hot mix asphalt (HMA) pavements has been a significant problem in recent years. High tire pressures and increased wheel loads are believed to be the primary causes of this phenomenon. Although the HMA has served reasonably well in the past there is a need to reexamine its design to withstand the increased stresses. Most asphalt technologists believe that fundamental changes in the aggregate component of the HMA (such as, size, shape, texture, and gradation)

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must be made. There is a general agreement that the use of large size stone in the binder and base courses will minimize or eliminate the rutting of heavy duty pavements. The term "large stone" is a relative one. For the purpose of this paper large stone is defined as an aggregate with a maximum size of more than one inch (25.4 mm).

Marshall mix design procedures are used by 76 percent of the states in the United States according to a **survey** conducted in 1984 [(2)]. The equipment **specified** in the Marshall procedure (ASTM **D1559)** consists of a 4-inch (101.6 mm) diameter compaction mold which is intended for mixtures containing aggregate up to l-inch (25.4 mm) maximum size only. This has also inhiiited the use of HMA containing aggregate larger than one inch (25.4 mm) because it cannot be tested by the standard Marshall mix design procedures. Hveem mix design procedures (ASTM **D1560)** used by 20 percent of the states in the United States also **uses** 4-inch (101.6 mm) diameter specimens thus restricting the maximum aggregate size to l-inch (25.4 mm). There is a need to use larger diameter (such as 6-inch) specimens for testing large stone asphalt mixes.

Results of two test series which involved the comparative evaluation of 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens in testing large stone asphalt mixes, are reported in this paper.

TEST SERIES I

Materials

A dense **graded** binder course asphalt mix meeting the Pennsylvania Department of **Transportation (PennDOT)'s** specifications for **ID-2** Binder **Course** Mix was used. The maximum aggregate size was 1%-inches (38. 1 mm). AC-20 asphalt cement was used in the **mix.**

Testing **Equipment and Procedures**

Nine 4-inch (101.6 mm) diameter specimens were compacted using a standard Marshall mold in accordance with ASTM **D1559.** Compaction was achieved with" a mechanical hammer by applying 50 blows on each face of the specimen.

Ten 6-inch (152.4 mm) diameter specimens were compacted using the modified Marshall test procedures reported in detail by **Kandhal** elsewhere [(3)]. The modified method follows ASTM **D1559** which is intended for 4-inch (101.6 mm) diameter specimens except the following significant differences:

1. Specimen size is 6-inch (152.4 mm) diameter by 3%-inch (95.2 mm) height.
2. Size of the mold and breaking head **modified** to accommodate the increased specimen size given in Item 1.
3. Hammer weight increased from 10 to 22.5 pounds (4.53 to 10.21 kg).
4. Because the hammer is too heavy only a mechanically operated hammer specified.
5. About 4,050 grams of mix is required to prepare one 6-inch (152.4 mm)

Marshall specimen compared to about 1,200 grams for a 4-inch (1OL6 mm) specimen.

6. The mix is placed in the mold in two approximately equal increments, spading is specified after each increment. Past experience has indicated that this is necessary to avoid honey-robing on the outside surface of the specimen and to obtain the desired density.
7. The number of blows needed for 6-inch (152.4 mm) diameter and **3¾-inches (95.2 mm) high** specimen is **1½** times the number of blows needed for 4-inch (101.6 mm) diameter and **2½-inches** (63.5 mm) specimen to obtain equivalent compaction level.

Mold and hammer assembly for compacting 6-inch (152.4 mm) specimens can be seen in Figure 1.

All specimens were tested for Marshall stability and flow after conducting voids analysis.

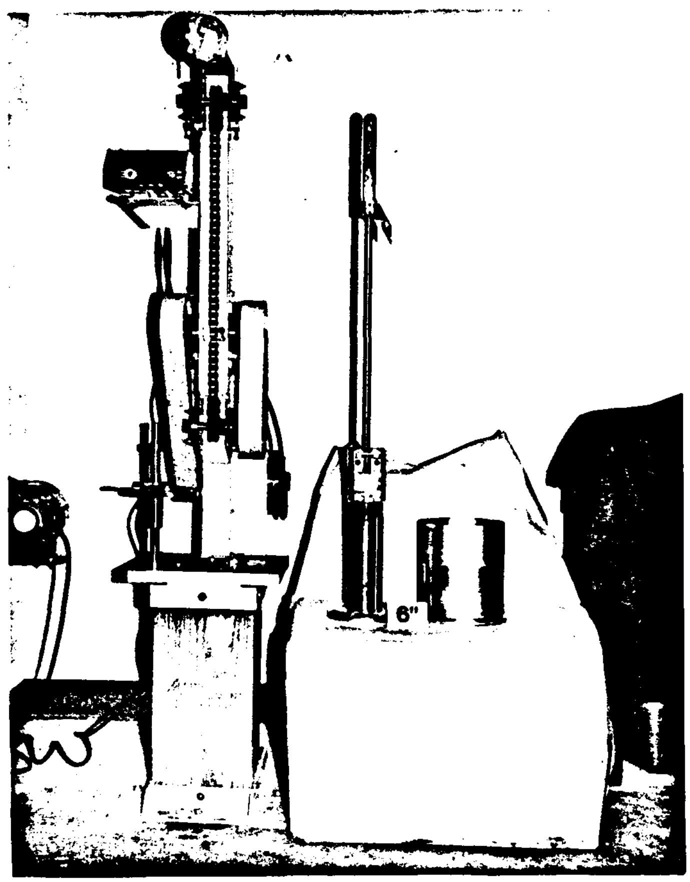

Figure 1. Mold and hammer assembly for compacting 6-inch diameter specimens.

Test Data

Tables 1 and 2 give the Marshall test data obtained on nine 4-inch (101.6 mm) diameter specimens and ten 6-inch (152.4 mm) diameter specimens, respectively, using the same large stone asphalt mix. Statistical analysis of stability, flow, and air voids data given in these tables indicates better repeatability of 6-inch (152.4 mm) specimens compared to 4-inch (101.6 mm) specimens when testing a large stone mix. This is evident from lower values of the coefficient of variation obtained on 6-inch (152.4 mm) specimens. The coefficient of variation for stability and flow was reduced by at least 50 percent when the specimen size was increased from 4-inch (101.6 mm) to 6-inch (152.4 mm). This significant improvement in repeatability warrants the use of 6-inch (152.4 mm) specimens for testing large stone asphalt mix by the Marshall method.

Stability and Flow Ratios

As expected, both Marshall stability and flow values were higher when 6-inch (152.4 mm) specimens were tested in comparison to 4-inch (101.6 mm) specimens made from the same mix. It was necessary to find the ratios by which these values increased so that the minimum stability values and the range of flow for 6-inch (152.4 mm) specimens could be derived from the values specified for 4-inch (101.6 mm) specimens in the specifications.

Personal contacts were made with various agencies and producers who had both 4-inch (101.6 mm) and 6-inches (152.4 mm) Marshall testing equipment. They were requested to compact both 4-inch (101.6 mm) and 6-inch (152.4 mm) specimens using their mixes to measure Marshall test properties, and to furnish test results. Table 3 summarizes the stability ratio (stability of 6-inch specimen/stability of 4-inch specimen) and flow ratio (flow of 6-inch specimen/flow of 4-inch specimen) data obtained by these agencies and producers on large stone base or binder mixes (maximum aggregate size 1½-2 inches or 38.1 to 50.8 mm). The average of 11 stability ratios is 2.18, and the average of 11 flow ratios is 1.44. These values are very close to theoretically derived values as follows.

From a theoretical viewpoint, an external load applied to the circumference of a cylinder may be considered as acting directly on the diametrical cross section of the cylinder. This permits calculation of the stress in pounds per square inch. The standard 6-inch (152.4 mm) specimen is 3¾-inches (95.2 mm) high, which gives a diametrical cross section of 22.5 square inches (145 sq cm). The standard 4-inch (101.6 mm) specimen is 2%-inches (63.5 mm) high and it has a diametrical cross section of 10.0 square inches (64.5 sq cm). Therefore, on the basis of unit stress, the total load on a 6-inch (152.4 mm) specimen should be 2.25 times the load applied to a 4-inch (101.6 mm) specimen of the same mix. This means the stability ratio should be 2.25.

Flow units measured by the testing machine are the values for the total movement of the breaking head to the point of maximum stability. When flow is considered on a unit basis (inches per inch of diameter), the flow value for a 6-inch (152.4 mm) specimen will be 1.5 times that of a 4-inch (101.6 mm) diameter specimen. This means the flow ratio should be 1.5.

Table 1. **Repeatibility** of **Marshall** Test - **4-inch** (101.6 mm) **Diameter Specimens of Binder Course Mix**

	Stability (Pounds)'	**Flow (0.01 Inch)**	Voids (Percent)
	1290	9.0	3.2
	1750	**13.5**	3.4
	1635	17.0	2.8
	2035	10.0	3.0
	1540	220	3.2
	2090	135	2.8
	1975	19.0	23
	2200	14.0	26
	1620	11.5	2.6
N ,	9.0	9.0	9.0
Mean	1793	14.4	29
Std **Dev**	300	4.2	0.4
Coeff of var. (%)	16.7	292	13.8

Table 2. Repeatibility of Marshall Test - 6-inch (152.4 mm) Diameter Specimens of Binder Course Mix

	Stability (Pounds)	**Flow (0.01 Inch)**	Voids (Percent)
	4850	13.0	32
	4653	18.0	3 . 0
	4605	19.0	25
	5428	15.0	27
	5188	15.0	2.7
	4960	15.5	2.7
	5232	18.0	2.7
	5886	19.0	2.4
			2.8
	-		2.2
N	8	8	10
Mean	5100	16.6	2.7
Std **Dev**	427	22	0.3
Coeff of var. (%)	8.4	132	11.1

Table 3. Summary of Stability and Flow Ratios for, Large Stone Mixes

Agency (Year data obtained)	No. of Blows		Ratio	
	4"	6"	Stability	Flow
Penn. DOT (1969)	50	75	2.12	1.62
Penn. DOT (1970)	50	75	2.81	1.15
Penn. DOT (1988)	50	75	1.95	1.39
Penn. DOT (1988)	50	75	2.17	1.58
Penn. DOT (1989)	50	75	1.68	1.40
Jamestown Macadam (1989)	50	75	1.89	1.24
Kentucky DOH (1988) *	75	112	2.08	1.34
American Asphalt Paving (1989) *	75	112	2.37	1.63
American Asphalt Paving (1989) *	7 5	112	2.58	1.52
American Asphalt Paving (1989) *	75	112	1.98	1.68
American Asphalt Paving (1989) *	75	112	2.40	1.27
		No of Mixes (N) ‘	11	11
		Mean	**2.18**	**L44**
		Std. Dev.	0.33	0.18

*Note: The average stability and flow ratio for these five mixes compacted with 75/112 blows are 2.28 and 1.49, respectively.

It is recommended that the minimum Marshall stability requirement for 6-inch (152.4 mm) diameter specimens should be 2.25 times the requirement for 4-inch (101.6 mm) diameter specimens. For example, if 1000 pounds (4,448 N) minimum stability is currently being speci.tied using ASTM D1559 (4-inch specimen), then 2,250 pounds (10,008 N) minimum stability should be specified for large stone mixes using the 6-inch (152.4 mm) Marshall testing equipment.

TEST SERIES II

This test series was a part of a research project which evaluated the effects of maximum aggregate size on rutting potential of HMA pavements as reported by Brown and Bassett(1).

Materials

Crushed limestone aggregate was used to prepare five different mixtures that contained maximum aggregate sizes of 3/8-inch (9.5 mm), %-inch (12.5 mm), 3A-inch (19.0 mm), l-inch (25.4 mm), and 1½-inch (38.1 mm). An AC-20 asphalt cement was used. The asphalt content for all mixes was selected to provide an air voids content of 4 percent under a compactive effort in the Gyratory Testing Machine (GTM) equivalent of 75 blows of a Marshall hammer. Mix gradations and optimum asphalt contents are given in Table 4.

Testing Equipment and Procedures

Four-inch (101.6 mm) diameter specimens of all five mixes were compacted in GTM using 30 revolutions at a pressure of 200 psi (1,379 kPa) and 1° gyratory angle. Six-inch (152.4 mm) diameter specimens of all five mixes were also compacted in GTM using 30 revolutions, 200 psi (1,379 kPa) and 1° gyratory angle. A comparison of the densities obtained in the 4-inch (101.6 mm) and 6-inch (152.4 mm) samples showed almost equal densities.

Indirect tensile test in accordance with ASTM D4123-82 was conducted on both 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens of all five mixes. This test was conducted at 77°F (25°C) using a standard loading rate of 2-inches per minute (50.8 mm/min).

Unconfined static creep tests were also conducted on all specimens. A load of approximately 50 psi (345 kPa) was applied at room temperature for one hour followed by unloading for one hour.

Test Data

Detailed test data obtained from the indirect tensile test and the creep test is given in Reference 1. The data is shown graphically in Figures 2 and 3.

Tahk 4. Mix **Gradations** and optimum Asphalt **Content**

Sieve	3/8 Inch	1/2 Inch	3/4 Inch	1 Inch	1-1/2 Inch
1 1/2”					100
1“				100	83
3/4”			100	87	73
1/2”		100	83	73	61
3/8’	100	87	72	63	54
#4	72	62	52	46	39
#8	51	44	37	33	29
#16	36	31	26	23	21
#30	26	21	1 9	17	15
#50	18	14	12	12	11
# 100	12	9	8	8	8
#200	8.2	5.8	5.2	5.5	6.1
Optimum Asphalt Content	4.s	5.0	43	3.8	3.4

Note: 1 inch . 2S.4 mm

Table 4. Mix **Gradations and Optimum Asphalt Content**

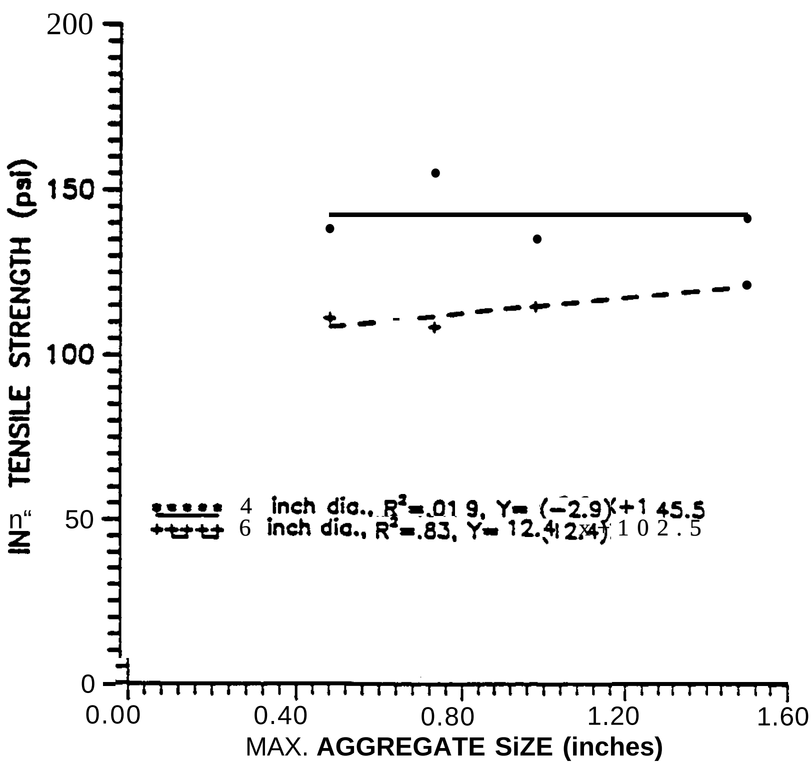

Figure 2. Indirect **Tensile Test**

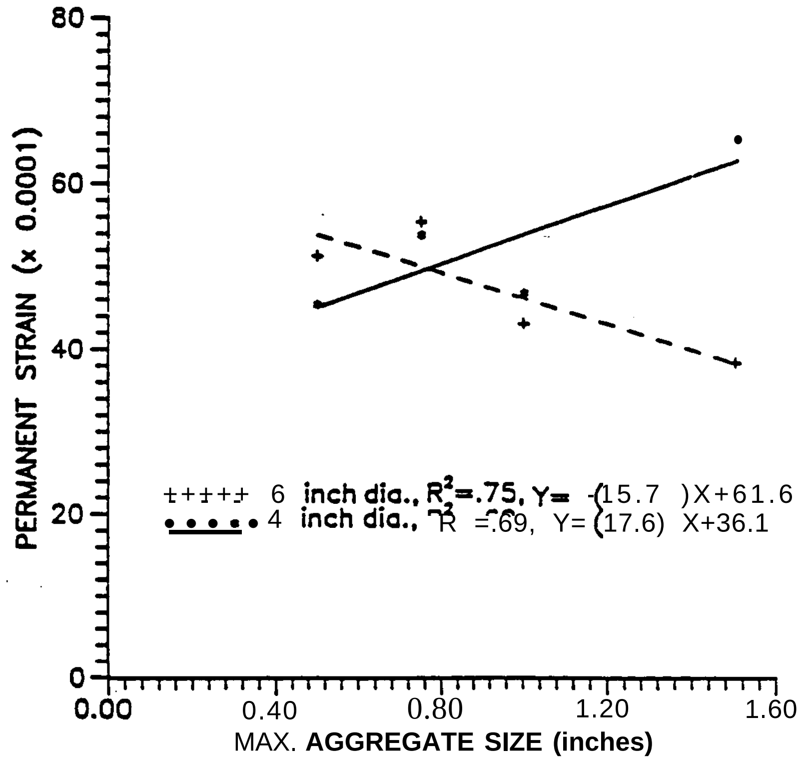

Figure 3. **Average Permanent** Strain **for 4-Inch** and **6-Inch** Diameter Creep **Test.**

Figure 2 indicates that there was very little change in indirect tensile strength as the maximum aggregate size changed. Even though the 6-inch (152.4 mm) specimens had a high R^2 value of 0.83, the increase in strength was only approximately 10% as maximum aggregate size increased from ½ to **1½-inches** (12.5 to 38.1 mm). Little change in tensile strength with changes in aggregate gradation was expected since tensile strength is more affected by stiffness of the asphalt cement than by aggregate properties.

Figure 2 also shows that the tensile strengths for the 6-inch (152.4 mm) diameter specimens were always lower than the 4-inch (101.6 mm) diameter specimens. One of the differences between the two tests for the specific diameters was in strain rate. Since the loading rate (2-inches or 50.8 mm per minute) was the same for both sets of specimens, the strain rate for the 6-inch (152.4 mm) diameter specimens was 50% lower than that for the 4-inch (101.6 mm) diameter specimens. A lower loading rate should produce a lower tensile strength in the 6-inch (152.4 mm) diameter specimens and this was the case for every mix evaluated.

The 6-inch (152.4 mm) diameter specimen also showed higher tensile strength for higher maximum aggregate size while the 4-inch (191.6 mm) diameter specimens showed an opposite trend. Because of the higher R^2 value (0.83) for the 6-inch (152.4 mm) diameter specimens, it appears that the data for 6-inch (152.4 mm) specimens is more precise and hence a better measure of tensile strength. R^2 value for the 4-inch (101.6 mm) diameter specimens was only 0.019.

The creep test data plotted in Figure 3 indicates that the 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens give opposing results. Permanent strain (Figure 3) was calculated by dividing the deformation at 120 minutes by the original height of the test specimen.

The 4-inch (101.6 mm) diameter samples show a decrease in strength with an increase in aggregate size. However, the 6-inch (152.4 mm) diameter samples show that strength increases with increased aggregate size as expected. Results for the 4-inch (101.6 mm) diameter specimens are likely unduly influenced by the 1½-inch (38.1 mm) maximum aggregate size mix.

Based on the results from the 6-inch (152.4 mm) diameter specimens, permanent strain decreased with increased aggregate size. Hence increasing the aggregate size should result in an asphalt mixture that is more resistant to permanent deformation. It should be noted in Figure 3 that R^2 value for 6-inch (152.4 mm) specimens is higher than the R* value for 4-inch (101.6 mm) specimens.

CONCLUSIONS

Since large stone mixes will be increasingly used to minimize rutting potential of hot mix asphalt (HMA) pavements it is no longer possible to use the standard MarshalI and Hveem test procedures which use 4-inch (101.6 mm) diameter specimens and restrict the maximum aggregate size to one inch (25.4 mm). It is recommended to use 6-inch (152.4 mm) diameter specimens which can be compacted either by the Modified Marshall method or by the Gyratory Testing Machine (GTM) described in the paper. Comparative evaluation of 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens in this study has indicated that the test results for large stone asphalt mixes obtained with 6-inch (152.4 mm) specimens had better repeatability, and were more meaningful compared to 4-inch (101.6 mm) specimens.

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LIST OF KEY WORDS

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Indirect Tensile Test

Creep Test

Maximum Aggregate Size

Repeatability