

Design of Large-Stone Asphalt Mixes for Low-Volume Roads Using 6-in.-Diameter Marshall Specimens

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Premature rutting of road pavements constructed for hauling coal and logs is common. Although these roads carry low volumes of traffic, they are subjected to heavy and channelized wheel loads. Unfortunately, conventional asphalt mixes containing aggregates less than 1-in. maximum size in the base or binder course tend to develop premature rutting under these conditions. Many asphalt technologists believe that the use of large-size stone (maximum size of more than 1 in.) will minimize or eliminate this problem. Large-stone mixes are also economical for low-volume roads because of substantially reduced asphalt contents. However, most agencies use the Marshall design procedure (ASTM D1559), which uses a 4-in.-diameter compaction mold intended for mixes containing aggregate up to 1-in. maximum size only. This has inhibited the use of large-stone mixes. A standard method for preparing and testing 6-in.-diameter specimens has been presented. Mixes containing aggregate up to 2-in. maximum nominal size can be tested. A typical mix design using 6-in. specimens for a coal-haul road in Kentucky is given. Construction data and experience gained from field projects in Kentucky are also included. The proposed test method may be useful in determining the optimum asphalt content of large-stone asphalt mixes that are recommended for use on low-volume roads subjected to heavy and channelized wheel loads.

Premature rutting of road pavements constructed for hauling coal and logs is quite common. The problem of these roads that provide the essential first link in the transportation chain that brings the products of mines and forest to market is unique. Although these roads carry low volumes of traffic, they are subjected to heavy and channelized wheel loads. Coal-haul roads in Kentucky have been reported to carry trucks with gross loads ranging from 90,000 to 150,000 lb. Tire pressures are also higher than generally encountered, ranging from 100 to 130 pounds per square inch (psi).

Unfortunately, conventional hot-mix asphalt (HMA) mixes containing aggregates less than 1-in. maximum size tend to develop premature rutting under these conditions. Many asphalt technologists believe that the use of large-size stone (maximum size of more than 1 in.) will minimize or eliminate this problem. Large-stone mixes are also economical for low-volume roads because of substantially reduced asphalt contents. A thin asphalt surfacing needs to be provided over the large-stone asphalt mix to obtain smooth surface.

Marshall mix design procedures are used by 76 percent of the states in the United States according to a survey conducted in 1984 (1). The equipment specified in the Marshall procedure

(ASTM D1559) consists of a 4-in.-diameter compaction mold that is intended for mixtures containing aggregate up to 1-in. maximum size only. This has also inhibited the use of HMA containing aggregate larger than 1 in. because it cannot be tested by the standard Marshall mix design procedures. There are other test procedures such as gyratory compaction, TRRL (Transport and Road Research Laboratory, U.K.) refusal test, and Minnesota DOT vibrating hammer, which use 6-in.-diameter molds accommodating 1½- to 2-in. maximum aggregate size (2). However, most agencies are reluctant to buy new equipment because of cost and complexity. They tend to prefer and use the existing equipment and methodology (such as Marshall test) with some modifications.

The term "large-stone" is a relative one. For the purpose of this report, large-stone mix is defined as an aggregate with a maximum size of more than 1 in., which cannot be used in preparing standard 4-in.-diameter Marshall specimens.

BACKGROUND OF DEVELOPMENT

Pennsylvania Department of Transportation (PennDOT) implemented Marshall mix design procedures in the early 1960s. The Marshall method was generally based on ASTM D1559 (*Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*). ASTM D1559 specifies the use of 4-in.-diameter specimen mold for mixes containing aggregate up to 1-in. maximum size. The compaction hammer weighs 10 lb and a free fall of 18 in. is used. It became apparent that ASTM D1559 could not be used for designing Pennsylvania ID-2 binder course mix and base course mix, which specified maximum permissible sizes of 1½ and 2 in., respectively. Therefore, PennDOT completed a study in 1969 to develop the equipment and procedure for testing 6-in.-diameter specimens (3).

A series of compaction tests was run using 4- and 6-in.-diameter specimens of wearing and binder mixes. The nominal height of the 6-in.-diameter specimen was increased to 3¾ in. to provide the same ratio of diameter to height that is used for a 4-in.-diameter × 2½-in.-high specimen. When the 6-in. compactor was designed, it was assumed that the weight of the hammer should be increased in proportion to the face area of the Marshall specimen, and the height of hammer drop and the number of blows on the face of the specimen should remain the same as that used for the 4-in.-diameter specimens. The weight of the hammer, therefore, was increased from 10 to 22.5 lb, and the hammer drop was maintained at

18 in. with 50 blows on each face. However, the initial test data indicated that the energy input to the specimen during compaction should have been based on ft-lb/in.³ of specimen volume instead of ft-lb/in.² of the specimen face. Therefore, to obtain the same amount of energy input per unit volume in a 6- by 3¾-in. specimen, the number of blows had to be increased from 50 to 75. The comparative compaction data presented in Table 1 substantiates this result. On the basis of these data, it was specified that a 6-in.-diameter, 3¾-in.-high specimen should be compacted with a 22.5-lb hammer, free fall of 18 in., and 75 blows per face. The details of equipment, such as mold, hammer, and breaking head are given in Pennsylvania Test Method 705 developed by Kandhal and Wenger (4).

Preliminary test data obtained in 1969 during the developmental stage are given in Tables 2 and 3 for ID-2 wearing course (maximum aggregate size ½ in.) and ID-2 binder course (maximum aggregate size 1½ in.) mixtures, respectively. The data indicate that reasonably close compaction levels are achieved in 4- and 6-in.-diameter molds when the number of blows for 6-in. specimens is 1½ times that used for 4-in. specimens. Marshall void parameters such as percent air voids, percent VMA, and percent VFA are also reasonably close. The stability and flow values will increase when a larger 6-in. specimen is tested in lieu of a 4-in. specimen of the same mix. Table 3 indicates that a preliminary stability ratio (stability of 6-in. specimen/stability of 4-in. specimen) of 2.12, and a flow ratio (flow of 6-in. specimen/flow of 4-in. specimen) of 1.62 were obtained for the binder course mix. Additional comparative test data (4- versus 6-in.-diameter specimens) obtained by various agencies will be discussed later in this report.

The next step taken by PennDOT in 1970 was to evaluate the repeatability of the test results using 6-in. equipment. A binder course mix was used to compact nine 4-in.-diameter

specimens and ten 6-in.-diameter specimens. Statistical analysis of stability, flows, and air voids data presented in Tables 4 and 5 indicates better repeatability of 6-in. specimens compared to 4-in. specimens when testing a large-stone mix. This repeatability is evident from significantly lower values of the coefficient of variation obtained on 6-in. specimens. It is also expected because of the decreased ratio of aggregate maximum size to specimen diameter. The coefficients of variation of stability and flow were reduced by at least 50 percent.

ASTM Subcommittee D04.20 on Mechanical Tests of Bituminous Mixes appointed a task force in December 1988 to develop an ASTM standard test for preparing and testing 6-in.-diameter Marshall specimens. The chairman of this task force prepared a draft for this proposed standard that was published by Kandhal (5). The proposed standard follows ASTM D1559-82 (6), which is intended for 4-in.-diameter specimens, except with significant differences in the following areas:

1. Equipment for compacting and testing 6-in.-diameter specimens, such as molds and breaking head (Section 3);
2. Because the hammer weighs 22.5 lb, only a mechanically operated hammer is specified (Section 3.3);
3. About 4050 g of mix is required to prepare one 6-in. Marshall specimen, compared with about 1200 g for a 4-in. specimen;
4. The mix is placed in the mold in two approximately equal increments, and spading is specified after each increment (Section 4.5.1). Past experience has indicated that spading is necessary to avoid honeycombing on the outside surface of the specimen and to obtain the desired density. Mixing and compaction temperatures remain the same as for 4-in.-diameter specimens.
5. The number of blows needed for 6-in.-diameter and 3¾-in.-high specimen is 1½ times the number of blows needed

TABLE 1 COMPARATIVE DATA FOR 4- VERSUS 6-IN.-DIAMETER SPECIMENS, 1969 DATA

	WEARING MIX				BINDER MIX		
	4	6	6	6	4	6	6
Specimen Diameter, in.							
Specimen Height, in.	2.50	3.75	2.50	3.75	2.50	3.75	3.75
Hammer Weight, lbs.	10	22.5	22.5	22.5	10	22.5	22.5
Hammer Drop, in.	18	18	18	18	18	18	18
No. of Blows/Face	50	50	50	75	50	50	75
Energy Input :							
Ft. lb/sq. in. of Specimen Face	119.4	119.4	119.4	179.1	119.4	119.4	179.1
Ft. lb/cu. in. of Specimen	47.7	31.8	47.7	47.7	47.7	31.8	47.7
Percent Compaction of Theor. Max. Specific Gravity	94.2	92.9	93.9	94.0	97.5	96.4	97.4
Percent Void Content	5.8	7.1	6.1	6.0	2.5	3.6	2.6
Stability, lbs.	2049	5316	-	-	1622	3785	3440
Flow, Units	10.0	20.4	-	-	10.8	20.8	17.5

TABLE 2 COMPARATIVE TEST DATA FOR 4- VERSUS 6-in.-DIAMETER SPECIMENS (WEARING COURSE)

Source : Pennsylvania Dept. of Transportation (1969 Data)						Mix type : ID - 2 Wearing Course.						
Aggregates : Limestone coarse aggregate and limestone fine aggregate.												
Design Gradation (% Passing) :												
2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
-	-	-	-	100	95	63	43	28	18	12	8	4.5
				4"	6"					4"	6"	
				Specimen	Specimen					Specimen	Specimen	
No. of Blows				50	75	Stability, pounds				2049	-	
% Compaction				94.2	94.0	Flow, units				10.0	-	
% Air Voids				5.8	6.0	Remarks : Data on Stability and Flow of 6" specimens is not available.						
% VMA				18.8	18.9							
% VFA				69.4	68.4							

Remarks: Results are based on average of six 4"-dia. specimens and three 6"-dia. specimens.

for 4-in.-diameter and 2½-in.-high specimen to obtain equivalent compaction level (Note 4).

6. Stability correlations ratios have been revised and are presented in Table 6. These ratios are based on percentage of increase or decrease in specimen volumes, similar to ASTM D1559.

Relative sizes of mold and hammer assembly for compacting 4- and 6-in. specimens are shown in Figure 1. The same mechanical compactor can be used for compacting both types

of specimens (Figure 2). Figures 3 through 6 show the details of the test equipment.

Because the hammer weighs 22.5 lb and the number of blows on each side is 75 or 112 depending on the anticipated traffic, some crushing of the aggregate at the surface has been observed. However, its effect on Marshall properties is believed to be minimal.

Vigorous spading in the mold is necessary to prevent voids near the large stones. The mix should not be allowed to cool below the intended compaction temperature.

TABLE 3 COMPARATIVE TEST DATA FOR 4- VERSUS 6-in.-DIAMETER SPECIMENS (BINDER COURSE)

Source : Pennsylvania Dept. of Transportation (1969 Data)						Mix type : ID - 2 Binder Course.						
Aggregates : Limestone coarse aggregate and limestone fine aggregate.												
Design Gradation (% Passing) :												
2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	95	-	58	-	34	25	20	15	10	7	3
				4"	6"					4"	6"	
				Specimen	Specimen					Specimen	Specimen	
No. of Blows				50	75	Stability, pounds				1622	3440	
% Compaction				97.5	97.4	Flow, units				10.8	17.5	
% Air Voids				2.5	2.6	Remarks : Results are based on average of 3 specimens each. Stability Ratio = Stability of 6" specimen / Stability of 4" specimen. Flow Ratio = Flow of 6" specimen / Flow of 4" specimen.						
% VMA				14.7	15.1							
% VFA				83.2	83.0							
				Stability Ratio				2.12				
				Flow Ratio				1.62				

Remarks : Results are based on average of 3 specimens each.
Stability Ratio = Stability of 6" specimen / Stability of 4" specimen.
Flow Ratio = Flow of 6" specimen / Flow of 4" specimen.

TABLE 4 REPEATABILITY OF MARSHALL TEST FOR 4-in.-DIAMETER SPECIMENS (BINDER COURSE MIX), 1970 DATA .

	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	22.0	3.2
	2090	13.5	2.8
	1975	19.0	2.3
	2200	14.0	2.6
	1620	11.5	2.6
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N	9.0	9.0	9.0
Mean	1793	14.4	2.9
Std Dev	300	4.2	0.4
Coeff of Var. (%)	16.7	29.2	13.8

TABLE 5 REPEATABILITY OF MARSHALL TEST FOR 6-in.-DIAMETER SPECIMENS (BINDER COURSE MIX), 1970 DATA

	Stability Pounds	Flow 0.01 Inch	Voids Percent
	4850	13.0	3.2
	4653	18.0	3.0
	4605	19.0	2.5
	5428	15.0	2.7
	5188	15.0	2.7
	4960	15.5	2.7
	5232	18.0	2.7
	5886	19.0	2.4
	-	-	2.8
	-	-	2.2
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N	8	8	10
Mean	5100	16.6	2.7
Std Dev	427	2.2	0.3
Coeff of Var. (%)	8.4	13.2	11.1

Note : Stability ratio and flow ratio (6" versus 4" diameter) in these repeatability experiments were determined to be 2.81 and 1.15, respectively.

TABLE 6 STABILITY CORRELATIONS RATIOS^A

Approximate Thickness of Specimen ^B		Volume of Specimen, cm ³	Correlation Ratio
in.	mm		
3-1/2	88.9	1608 to 1626	1.12
3-9/16	90.5	1637 to 1665	1.09
3-5/8	92.1	1666 to 1694	1.06
3-11/16	93.7	1695 to 1723	1.03
3-3/4	95.2	1724 to 1752	1.00
3-13/16	96.8	1753 to 1781	0.97
3-7/8	98.4	1782 to 1810	0.95
3-15/16	100.0	1811 to 1839	0.92
4	101.6	1840 to 1868	0.90

^A The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 3-3/4-in. (95.2 mm) thick specimen.

^B Volume - thickness relationship is based on a specimen diameter of 6 in. (152.4 mm).

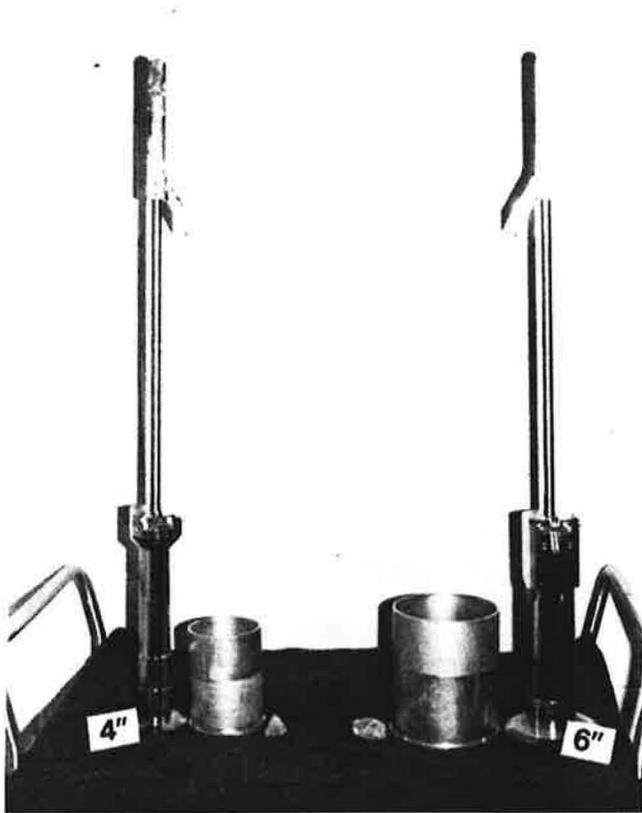


FIGURE 1 Mold and hammer assembly for 4- and 6-in.-diameter specimens. Aggregate particles of 1- and 2-in. maximum size are also shown.

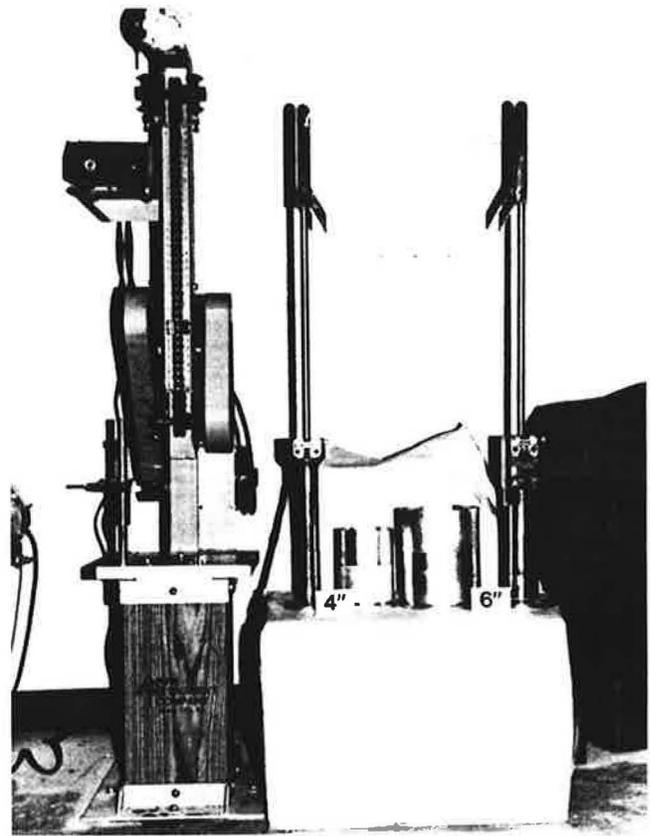


FIGURE 2 Compaction equipment for 4- and 6-in.-diameter specimens.

At the present time, there are two known suppliers of 6-in. Marshall testing equipment in the U.S.:

1. Pine Instrument Company
101 Industrial Drive
Grove City, PA 16127
2. Rainhart Company
P.O. Box 4533
Austin, TX 78765

If a mechanical compactor is already on hand, the following additional equipment (estimated cost \$1,800) must be purchased:

1. 6-in. complete mold assembly consisting of compaction mold, base plate, and collar (three are recommended);
2. 6-in. additional compaction molds (six are recommended);
3. 6-in. compaction hammer (two are recommended);
4. 6-in. mold holder (ensure that the spring is strong);
5. 6-in. breaking head assembly;
6. Specimen extractor for 6-in. specimen; and
7. 6-in. paper discs (box of 500).

4- VERSUS 6-in.-DIAMETER SPECIMENS

After the preliminary developmental work done by PennDOT during 1969 and 1970, there was minimal use of 6-in. Marshall

equipment until 1987. Interest in this equipment was revived because various agencies and producers wanted to test large-stone mixes for minimizing or eliminating rutting of HMA pavements as discussed earlier. These agencies (including PennDOT) and producers who procured the 6-in. Marshall testing equipment ran a limited number of tests to verify the degree of compaction obtained in 6-in. mold compared to 4-in. mold. Also, a need was felt to verify the stability ratio (stability of 6-in. specimen/stability of 4-in. specimen) and the flow ratio (flow of 6-in. specimen/flow of 4-in. specimen) obtained in PennDOT's preliminary work. These tests were necessary so that minimum stability values, and the range of flow for 6-in. specimens could be derived from the values specified for 4-in. specimens. Personal contacts were made with various agencies and producers to obtain comparative test data.

Table 7 presents the stability and flow ratio values obtained by two agencies and two producers (Jamestown Macadam, New York, and American Asphalt Paving Co., Pennsylvania) on large-stone base or binder mixes (maximum aggregate size 1½ to 2 in.). The average of 11 stability ratios is 2.18, and the average of 11 flow ratios is 1.44. These values are close to theoretically derived values.

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-in. specimen is 3¾ in. high, which gives a

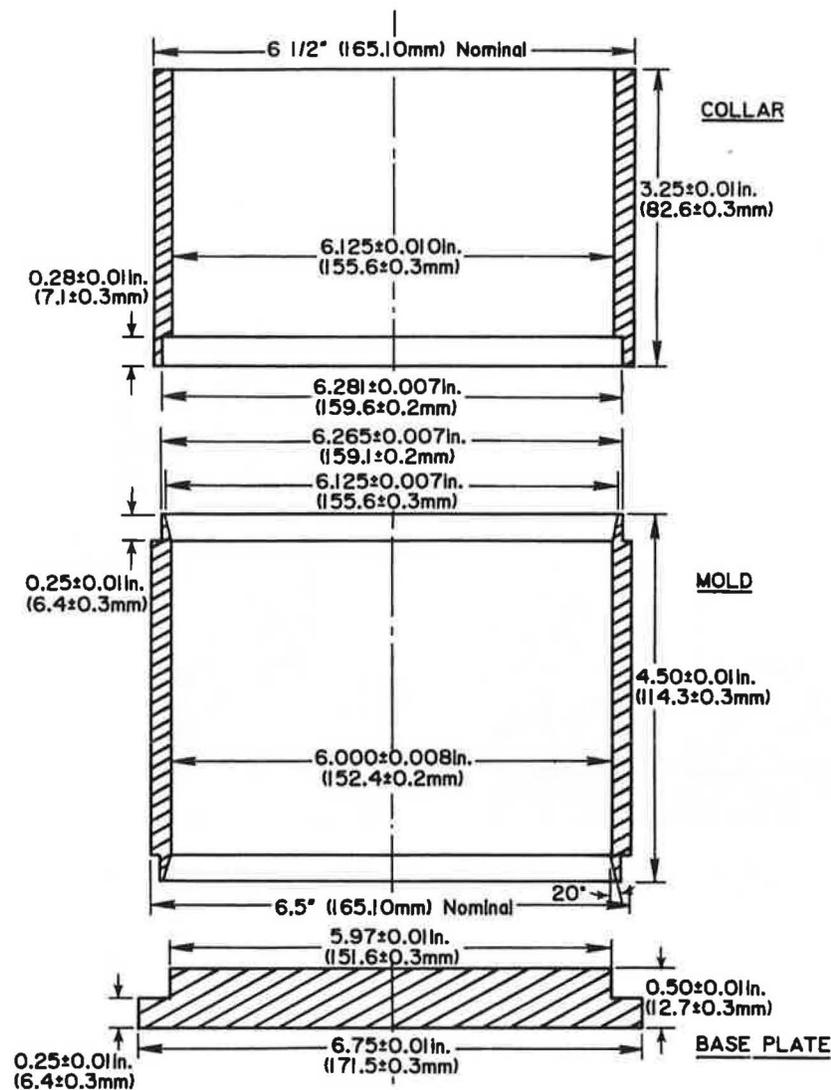


FIGURE 3 Compaction mold.

diametrical cross section of 22.5 in.². The standard 4-in. specimen is 2½ in. high and it has a diametrical cross section of 10.0 in.². Therefore, on the basis of unit stress, the total load on a 6-in. specimen should be 2.25 times the load applied to a 4-in. 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 heads 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-in. specimen will be 1.5 times that of a 4-in. diameter specimen. This means the flow ratio should be 1.5.

Surprisingly, the average stability and flow ratio of specimens compacted with 75 and 112 blows (4- and 6-in. molds, respectively) are 2.28 and 1.49, which are close to the theoretically derived values of 2.25 and 1.50, respectively.

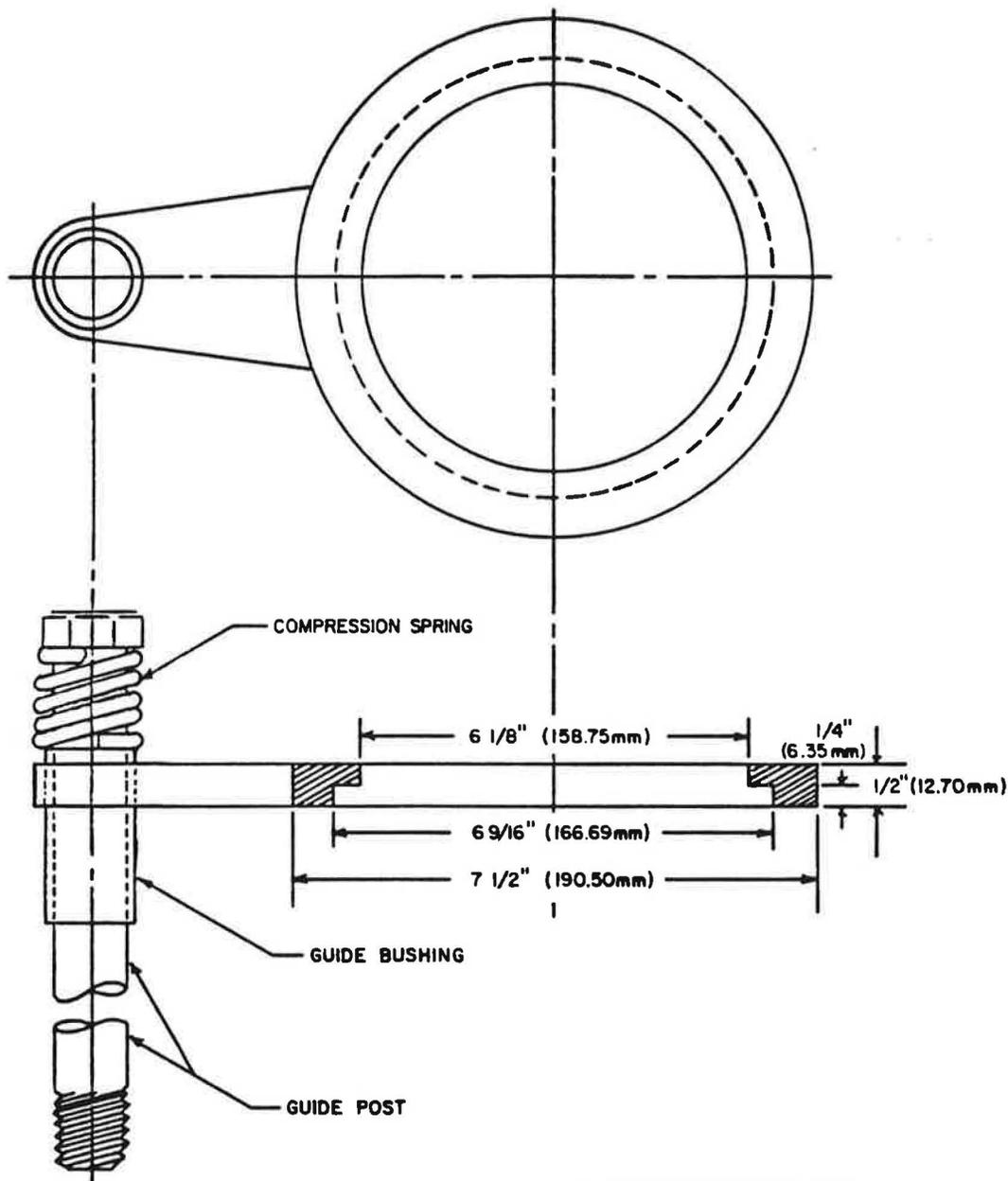
It is recommended that the minimum Marshall stability requirement for 6-in.-diameter specimens should be 2.25 times the requirement for 4-in.-diameter specimens. For example,

if 1,000-lb minimum stability is currently being specified using ASTM D1559 (4-in. specimen), then 2,250-lb minimum stability should be specified for large-stone mixes using the 6-in. Marshall testing equipment.

Similarly, the range of flow values for 6-in. specimens should be adjusted to 1½ times the values required for 4-in. specimens. For example, if the specified range for 4-in. specimens is 8 to 18, it should be adjusted to 12 to 27 for 6-in. specimens.

TYPICAL MIX DESIGN USING 6-in. SPECIMENS

Kentucky DOH has completed a substantial number of large-stone mix designs for coal-haul roads using the 6-in. Marshall testing equipment. The contractor is required to buy the testing equipment for the project so that proper quality control is maintained. Kentucky DOH Class K base mix has been used on coal-haul roads carrying heavy trucks (gross loads varying from 90,000 to 150,000 lb or more), as mentioned



NOTE: GUIDE POST THREADED INTO PEDESTAL CAP. DIMENSIONS OF GUIDE POST, GUIDE BUSHING AND COMPRESSION SPRING NOT CRITICAL. ONLY REQUIREMENT IS THAT COMPACTION MOLD IS HELD FIRMLY.

FIGURE 4 Specimen mold holder.

earlier. Tire pressures are also higher than generally encountered, ranging from 100 to 130 psi (7).

Table 8 presents the typical Marshall mix design data for one project along with the gradation used for Class K base. The mix contains limestone aggregates and a maximum aggregate size of 2 in. with a substantial amount of material retained on the 1-in. sieve. This results in substantial amount of 1- to ¾-in. material in the mix. The mix design was developed using a 6-in. mold and 112 blows on each side. Asphalt content was varied from 3.2 to 4.0 percent in 0.4 percent increments.

Either AASHTO Gradation #467 (1½ in. to No. 4) or Gradation #4 (1½ to ¾ in.) is used for coarse aggregate to incorporate +1-in. material in the mix. The following preliminary design criteria have been used by Kentucky DOH on the basis of laboratory and field evaluation of such mixes:

Stability	3,000 lb, minimum
Flow	28, maximum
Air Voids	4.5 ± 1.0 percent
VMA	11.5 percent, minimum

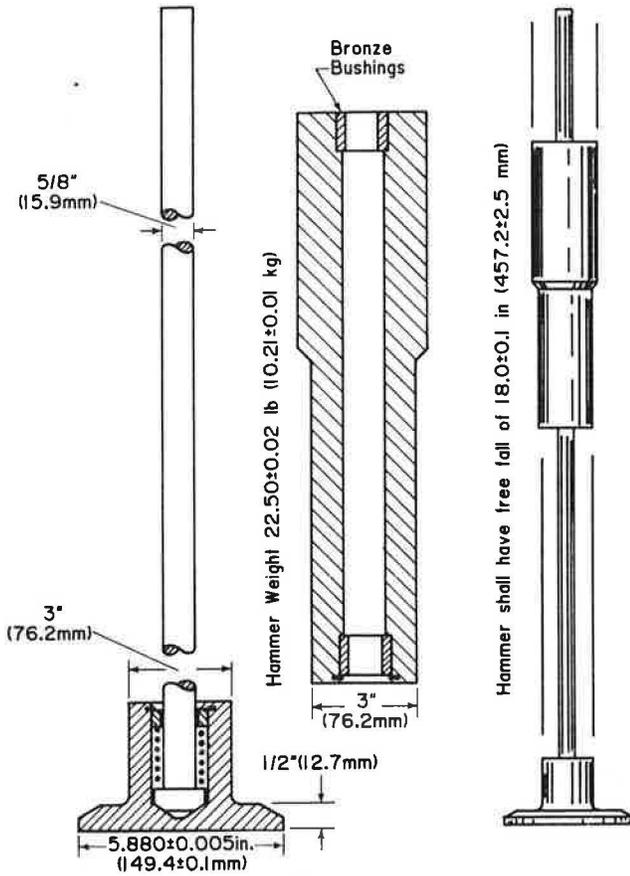


FIGURE 5 Compaction hammer.

FIELD TRIALS AND DATA

Kentucky DOH's experimental specifications require construction of a control strip (at least 500 ft long and 12 ft wide) at the beginning of construction of Class K base. Construction of the control strip is accomplished using the same compaction equipment and procedures to be used in the remainder of the Class K base course. After initial breakdown rolling and two complete coverages of the pneumatic-tired intermediate roller, three density measurements are made at randomly selected sites. Measurements are repeated at the same sites after each two subsequent complete coverages by the pneumatic-tired roller until no further increase in density is obtained. After the completion of the control strip, 10 field density measurements are performed at random locations. The target density to be used for the compaction of the remainder Class K base is the average of these 10 measurements. However, the target density obtained from the control strip should be no greater than 97.0 percent nor less than 93.0 percent of the measured maximum specific gravity (Rice specific gravity) as determined by AASHTO T209. The minimum acceptable densities for the remainder project are as follows:

Single test:	96.0 percent of the target density.
Moving average of last 10 tests:	98.0 percent of the target density.

Density measurements performed on Louisa bypass indicate that the compaction was consistently within the required range. Average void content of the in-place pavement was slightly less than 6 percent (7). Limited crushing of coarse surface particles occurred. Because of the coarse surface texture,

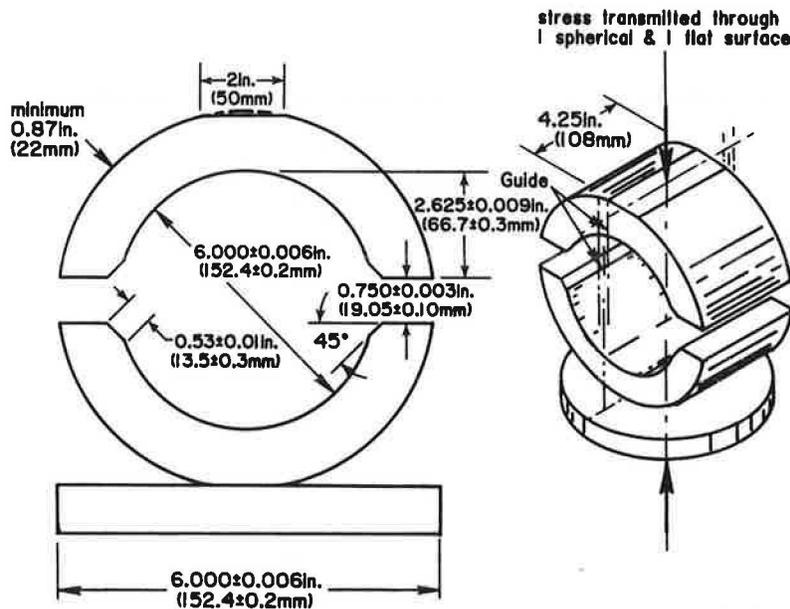


FIGURE 6 Breaking head.

TABLE 7 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) *	75	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	1.44
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.

TABLE 8 TYPICAL MARSHALL MIX DESIGN DATA FOR 6-in.-DIAMETER SPECIMENS

Source : Kentucky Dept. of Highways. (Lawrence Co. - Louisa Bypass)						Mix Type : Class K Base							
Aggregates : Limestone #467 (55%), limestone #8 (20%), limestone sand (25%).						Asphalt : AC - 20							
No. of Blows : 112													
Design Gradation (% Passing) :													
2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	
100	99	86	75	58	50	29	21	15	10	8	5	3.5	

	% Asphalt Content				% Asphalt Content			
	3.2	3.6	4.0		3.2	3.6	4.0	
Bulk Sp. Gr. (1)	2.424	2.410	2.440	Stability (lbs)	5037	4980	4915	
(2)	2.428	2.430	2.440		(2)	5683	5326	4627
(3)	2.419	2.434	2.437		(3)	5625	5236	5376
Mean	2.424	2.425	2.439	Mean	5448	5181	4973	
Max. Sp. Gr.	2.546	2.530	2.515	Flow (units)	17.5	14.5	14.0	
% Air Voids	4.8	4.2	3.0		(2)	19.0	19.5	17.0
% VMA	11.4	11.7	11.6		(3)	17.0	14.5	15.0
% VFA	57.8	64.5	73.8		Mean	17.8	16.2	15.3

Remarks : AASHTO Gradations #467 (1-1/2" to #4) and #8 (3/8" to #8) were used.
Stability values adjusted for specimen thickness.

nuclear densities were consistently lower than core densities taken at the same spot. The average nuclear density was about 1 lb/ft³ less than core density, indicating that calibration is necessary for determination of actual values. A double-drum vibratory roller and a 25-ton pneumatic-tired roller (tire pressure up to 125 psi) were used for principal compaction.

The traffic is expected to densify the pavement to reduce air void content from about 6 percent as constructed to the design air void content (4.5 ± 1.0 percent).

Kentucky DOH provides a thin (1 in.) AC surfacing over Class K base to obtain a smooth and impermeable surface. Some technologists believe that 1/2-in.-thick hot sand and asphalt mix can also suffice. In any case, thicker surfacings should be avoided.

Field compaction data from projects in Kentucky and projects in Pennsylvania where large-stone mixes were used were provided by Kendhal (5). The test data indicate no significant problem in achieving compaction levels of >92 percent of the maximum mix specific gravity. Maximum aggregate size and lift thickness were 2 and 4 in., respectively, on Kentucky projects. Pennsylvania used 1 1/2-in. maximum aggregate size and 2-in. lift thickness for the large-stone binder course mixes (5). All projects are reportedly performing satisfactorily, having been in service up to 2 years.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

1. Premature rutting of low-volume roads used for hauling coal and logs is common. Use of large-stone asphalt mixes has been proposed to minimize the rutting potential of hot-mix asphalt used on these roads, which are subjected to heavy and channelized traffic. For the purpose of this report, "large stone" is defined as an aggregate with a maximum size of more than 1 in., which cannot be used in preparing standard 4-in.-diameter Marshall specimens.

2. A modified Marshall method for testing 6-in.-diameter specimens to accommodate large stones has been developed. The testing equipment is available commercially from two suppliers.

3. Statistical analysis of stability, flow, and air voids data indicate better repeatability of 6-in. specimens compared to 4-in. specimens when testing a large stone mix. The coefficient of variation for stability and flow values was reduced by at least 50 percent when the specimen size was increased.

4. The proposed method has the following significant differences from ASTM D1559-82 intended for testing 4-in. specimens:

- (a) Hammer weighs 22.5 lb. Only a mechanically operated hammer is specified.
- (b) Specimen size is of 6-in. diameter and 3 3/4-in. height.
- (c) Specimen usually weighs about 4050 g.
- (d) The mix is placed in the mold in two approximately equal increments, spading is specified after each increment.
- (e) The number of blows needed for 6-in.-diameter and 3 3/4-in.-high specimens is 1 1/2 times the number of blows

needed for 4-in.-diameter and 2 1/2-in.-high specimen to obtain equivalent compaction levels.

(f) A new table for stability correlations ratio needs to be used.

5. Comparative test data (4- versus 6-in.-diameter specimens) obtained from various highway agencies and producers indicate that the compaction levels are reasonably close.

6. Data obtained on stability ratio (stability of 6-in. specimen/stability of 4-in. specimen) and flow ratio (flow of 6-in. specimen/flow of 4-in. specimen) by various agencies was obtained and analyzed. The average stability and flow ratios were determined to be close to the theoretically derived values of 2.25 and 1.50, respectively. Therefore, it has been recommended that the minimum stability requirement for 6-in.-diameter specimens should be 2.25 times the requirement for 4-in.-diameter specimens. Similarly, the range of flow values for 6-in. specimens should be adjusted to 1 1/2 times the values required for 4-in. specimens.

7. A typical mix design using 6-in. specimens for a coal-haul road is given.

8. The use of large-stone mix on coal haul roads in Kentucky has been described with limited data. It has been recommended to use a thin hot-mix asphalt surfacing over the large-stone asphalt mix to provide a smooth and impermeable surface.

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