NCAT Report 91-05

DESIGN OF LARGE STONE ASPHALT MIXES FOR LOW-VOLUME ROADS USING SIX-INCH DIAMETER MARSHALL SPECIMENS

By

P.S. Kandhal

National Center for Asphalt Technology
NCAT
AUBURN UNIVERSITY
277 Technology Parkway • Auburn, AL 36830

DESIGN OF LARGE STONE ASPHALT MIXES FOR LOW-VOLUME ROADS USING SIX-INCH DIAMETER MARSHALL SPECIMENS

By

Prithvi S. Kandhal
Assistant Director
National Center for Asphalt Technology
Auburn University, Alabama

NCAT Report 91-05

DISCLAIMER

The contents of this report reflect the views of the authors who are solely responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the National Center for Asphalt Technology of Auburn University. This report does not constitute a standard, specification, or regulation.

ABSTRACT

Premature rutting of road pavements constructed for hauling coal and logs is quite common. Although these roads carry low volumes of traffic they are subjected to very heavy and channelized wheel loads.

Unfortunately, conventional asphalt mixes containing aggregates less than one-inch 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 one-inch) will minimize or eliminate this problem. Large stone mixes are also very 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-inch diameter compaction mold intended for mixes containing aggregate up to l-inch maximum size only. This has inhibited the use of large stone mixes.

A standard method for preparing and testing 6-inch diameter specimens has been presented. Mixes containing aggregate up to 2-inch maximum nominal size can be tested. A typical mix design using 6-inch specimens for a coal-haul road in Kentucky is given. Construction data and experience gained from field projects in Kentucky is also included. It is believed that the proposed test method will be useful in determining the optimum asphalt content of large stone asphalt mixes which are recommended for use on low-volume roads subjected to very heavy and channelized wheel loads.

DESIGN OF LARGE STONE ASPHALT MIXES FOR LOW-VOLUME ROADS USING SIX-INCH DIAMETER MARSHALL SPECIMENS

Prithvi S. Kandhal

INTRODUCTION

Premature rutting of road pavements constructed for hauling coal and logs is quite common. The problem of these roads which provide the essential first link in the transportation chain that brings the products of mine and forest to market is unique. Although these roads carry low volumes of traffic they are subjected to very 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 pounds. Tire pressures are also higher than generally encountered ranging from 100 to 130 psi.

Unfortunately, conventional hot mix asphalt (HMA) mixes containing aggregates less than one-inch 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 one-inch) will minimize or eliminate this problem. Large stone mixes are also very 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-inch diameter compaction mold containing aggregate up to l-inch maximum size only. This has which is intended for mixtures also inhibited the use of HMA containing aggregate larger than one inch 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-inch diameter molds accommodating 1-1/2 -2 inch maximum aggregate size (*2*). However, most agencies are reluctant to buy new equipment because of cost and/or complexity. They tend to prefer and utilize the existing equipment and/or methodology (such as, Marshall test) with some modifications.

The term “large stone” is a relative one. For the purpose of this report large stone is defined as an aggregate with a maximum size of more than one inch which cannot be used in preparing standard 4-inch 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-inch diameter specimen mold for mixes containing aggregate up to l-inch maximum size. The compaction hammer weighs 10 pounds and a free fall of 18 inches is used. It became apparent that ASTM D 1559 could not be used for designing Pennsylvania ID-2 binder course mix and base course mix which specified maximum permissible sizes of 1-1/2 inches and 2 inches, respectively. Therefore, PennDOT completed a study in 1969 to develop the equipment and procedure for testing 6-inch diameter specimens (*3*).

A series of compaction tests were run using 4-inch and 6-inch diameter specimens of wearing and binder mixes. The nominal height of the 6-inch diameter specimen was increased to 3-3/4 inch to provide the same diameter/height ratio that is used for a 4-inch diameter x 2-1/2 inch high specimen. When the 6-inch 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-inch diameter specimens. The weight of the hammer, therefore, was increased from 10 lbs. to 22.5 lbs., and the hammer drop was maintained at 18-inches 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/cu inch of specimen instead of ft lb/sq inch of the specimen face. Therefore, to obtain the same amount of enerjg input per unit volume in a 6-inch by 3-3/4 inch specimen the number of blows had to be increased from 50 to 75. The comparative compaction data given in Table 1 substantiates this. Based on this data, it was specified that a 6-inch diameter, 3-3/4 inch high specimen should be compacted with a 22.5 lb. hammer, free fall of 18-inches 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).

Table 1. Comparative Data (4" Versus 6"-Diameter Specimens) - 1969 Data

	Wearing Mix				Binder Mix		
Specimen Diameter, in.	4	6	6	6	4	6	6
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	4316	---	---	1622	3785	3440
Flow, Units	10.0	20.4	---	---	10.8	20.8	17.5

Preliminary test data obtained in 1969 during the developmental stage is given in Tables 2 and 3 for ID-2 wearing course (maximum aggregate size 1/2 inch) and ID-2 binder course (maximum aggregate size 1-1/2 inches) mixtures, respectively. The data indicates that reasonably close compaction levels are achieved in 4-inch and 6-inch diameter molds when the number of blows for 6-inch specimen is 1-1/2 times that used for 4-inch specimen. Marshall void parameters such as, percent air voids, percent VMA and percent VFA are also reasonably close. It was obvious that the stability and flow values will increase when a larger 6-inch specimen is tested in lieu of a 4-inch specimen of the same mix. Table 3 shows that a preliminary stability ratio (stability of 6-inch specimen/stability of 4-inch specimen) of 2.12, and a flow ratio (flow of 6-inch specimen/ flow of 4-inch specimen) of 1.62 was obtained for the binder course mix. Additional comparative test data (4-inch versus 6-inch diameter specimens) obtained by various agencies will be presented and discussed later in this report.

Table 2 . Comparative Test Data (4" Versus 6"-Diameter Specimens)

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" Specimen	6" Specimen		4" Specimen	6" Specimen
No. of Blows	50	75	Stability, pounds	2049	--
% Compaction	94.2	94.0			
% Air Voids	5.8	6.0	Flow, units	10.0	--
% VMA	18.8	18.9			
% VFA	69.4	68.4			

Remarks: Data on stability and flow of 6" specimens is not available.

Table 3 . Comparative Test Data (4" Versus 6"-Diameter Specimens)

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" Specimen	6" Specimen		4" Specimen	6" 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	Stability Ratio	2.12	
% VMA	14.7	15.1	Flow Ratio	1.62	
% VFA	83.2	83.0			

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.

The next step taken by PennDOT in 1970 was to evaluate the repeatability of the test results using 6-inch equipment. A binder course mix was used to compact nine 4-inch diameter specimens and ten 6-inch diameter specimens. Statistical analysis of stability, flow and air voids data given in Tables 4 and 5 indicates better repeatability of 6-inch specimens compared to 4-inch specimens when testing a large stone mix. This is evident from significantly lower values of the coefficient of variation obtained on 6-inch specimens. This is also expected because of the decreased aggregate maximum size/specimen diameter ratio. The coefficients of variation of stability and flow was reduced by at least 50 percent.

Table 4. Repeatibility of Marshall Test (4" 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
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. Repeatibility of Marshall Test (6" 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
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.

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-inch diameter Marshall specimens. The author who is chairman of this task force prepared a draft for this proposed standard which is given in Reference 5. The proposed standard follows ASTM D1559-82 (6) which is intended for 4-inch diameter specimens except the following significant differences:

1. Equipment for compacting and testing 6-inch diameter specimens such as, molds and breaking head (Section 3).
2. Since the hammer weighs 22.5 pounds, only a mechanically operated hammer is specified (Section 3.3).
3. About 4,050 grams of mix is required to prepare one 6-inch Marshall specimen compared to about 1,200 grams for a 4-inch specimen.
4. The mix is placed in the mold in two approximately equal increments, spading is specified after each increment (Section 4.5. 1). Past experience has indicated that this is necessary to avoid honey-combing on the outside surface of the specimen and to obtain the desired density. Mixing and compaction temperatures remain the same as 4-inch diameter specimens.
5. The number of blows needed for 6-inch diameter and 3-3/4 inches high specimen is 1-1/2 times the number of blows needed for 4-inch diameter and 2-1/2 inches high specimen to obtain equivalent compaction level (Note 4).
6. Stability correlations ratios have been revised and are given in Table 6. These ratios are based on percentage increase/decrease in specimen volumes similar to ASTM D1559.

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).

Relative sizes of mold and hammer assembly for compacting 4-inch and 6-inch specimens can be seen 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.

Since the hammer weighs 22.5 pounds 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, it is believed that its effect on Marshall properties is minimal.

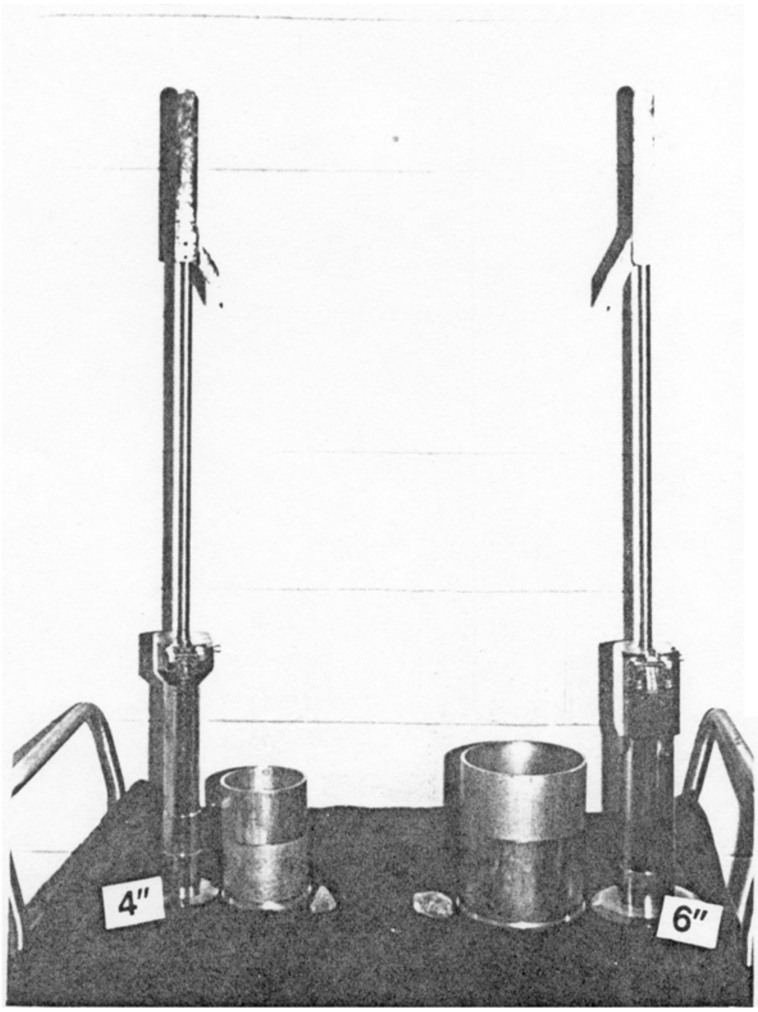

Figure 1. Mold and Hammer Assembly for 4" and 6"-Diameter Specimens (Aggregate Particles of 1" and 2" Maximum Size Also Shown)

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.

At the present time there are two known suppliers of 6-inch Marshall testing equipments in the U.S.A.:

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, one needs to buy the following additional equipment (estimated cost $1,800):

Figure 2. Compaction Equipment for 4" and 6"-Diameter Specimens

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

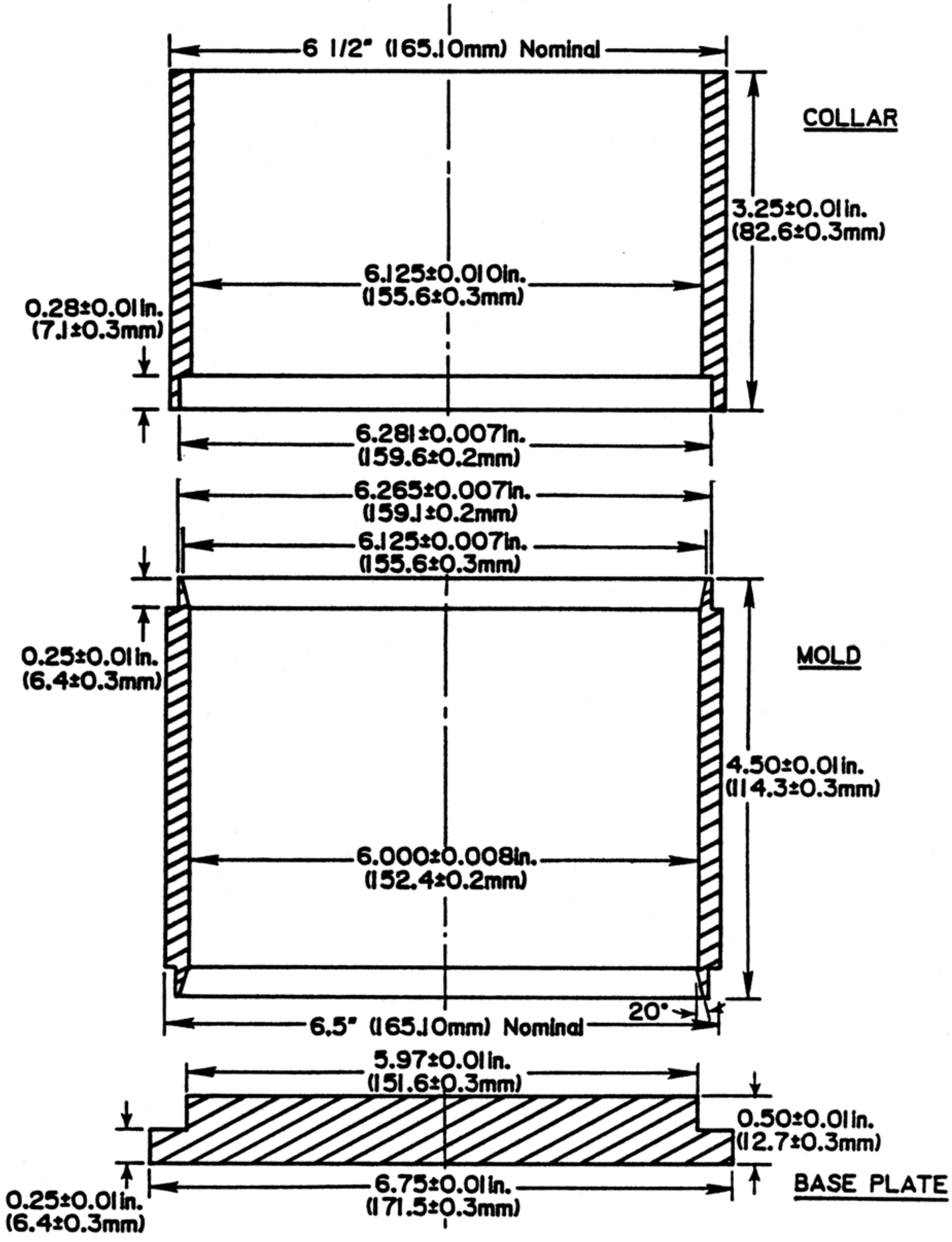

Figure 3. Compaction Mold

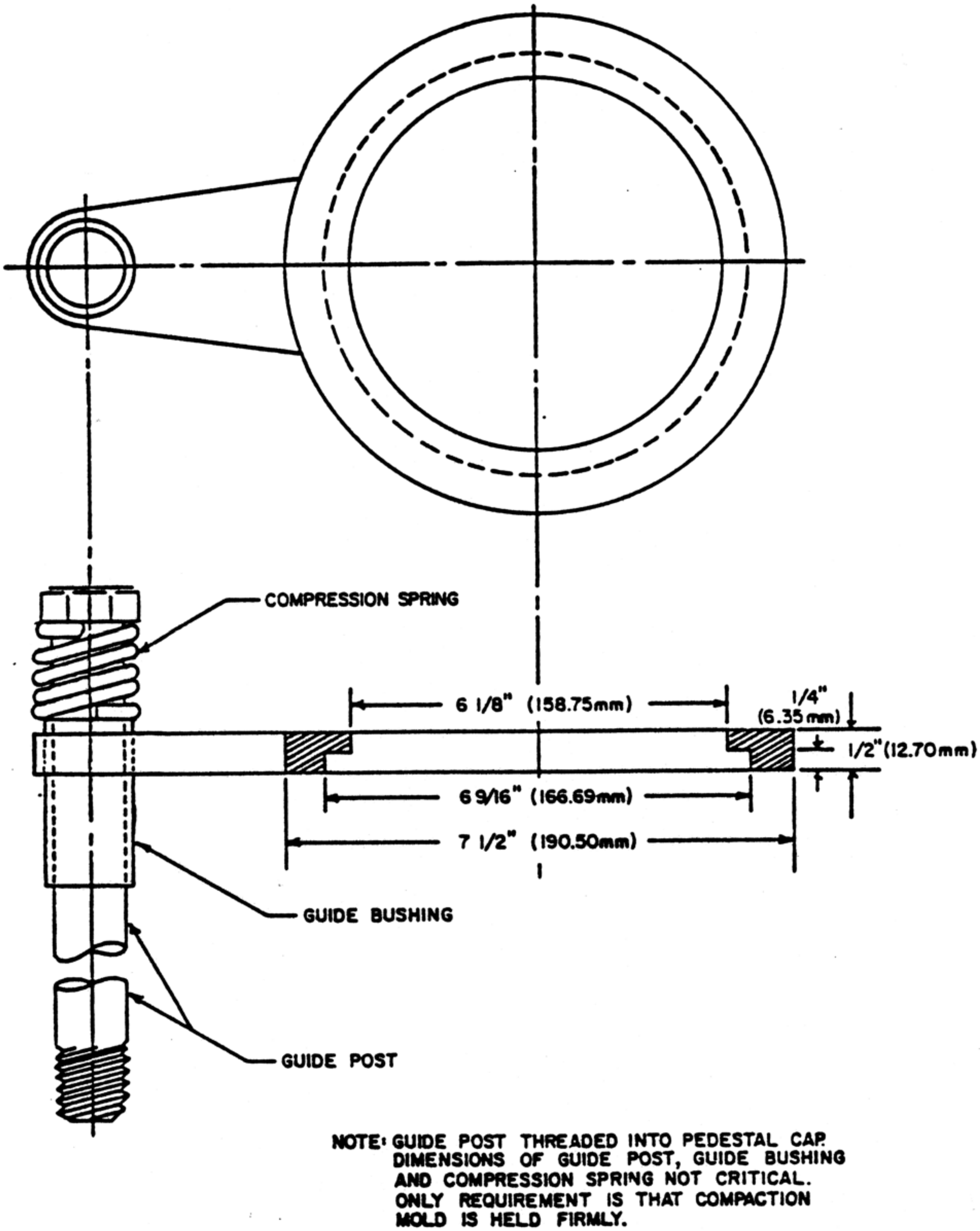

Figure 4. Specimen Mold Holder

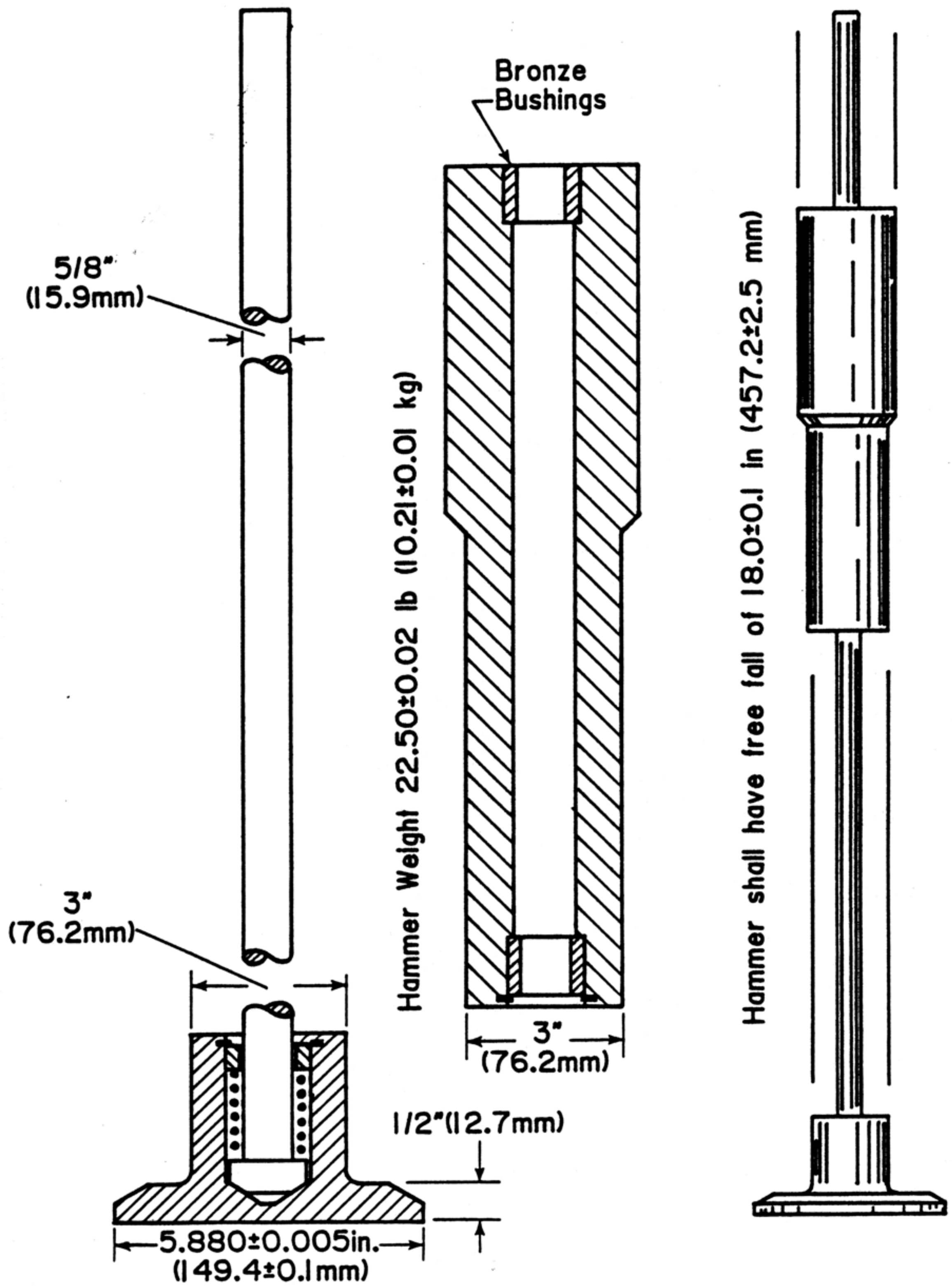

Figure 5. Compaction Hammer

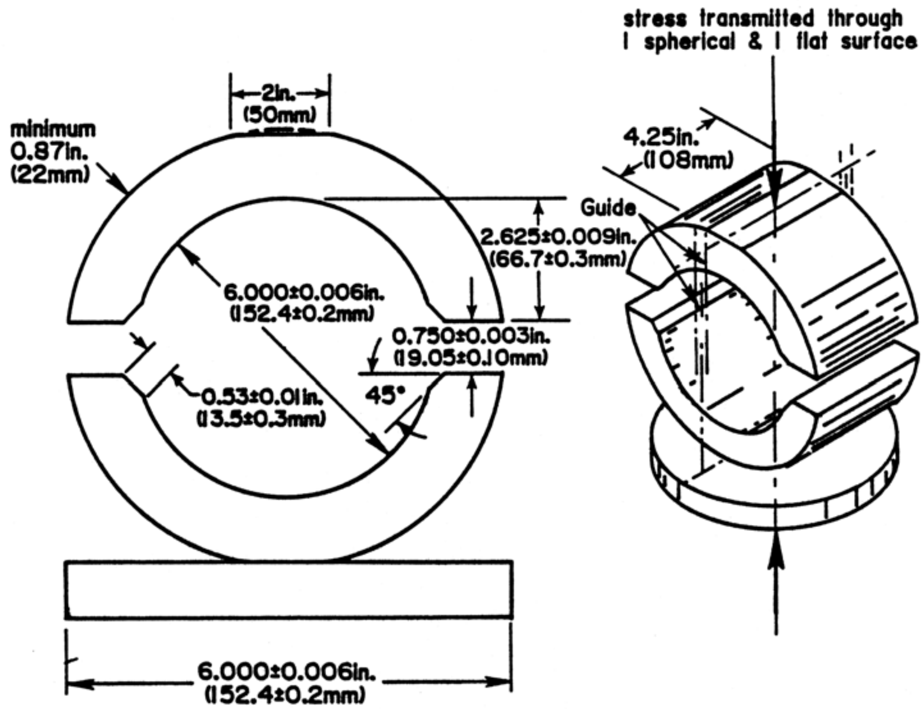

Figure 6. Breaking Head

4-INCH VERSUS 6-INCH DL4METER SPECIMENS

After the preliminary developmental work done by PennDOT during 1969 and 1970 there was minimal use of 6-inch 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-inch Marshall testing equipment ran a limited number of tests to verify the degree of compaction obtained in 6-inch mold compared to 4-inch mold. Also, a need was felt to verify the stability ratio (stability of 6-inch specimen/stability of 4-inch specimen) and the flow ratio (flow of 6-inch specimen/flow of 4-inch specimen) obtained in PennDOT’s preliminary work. This was necessary so that minimum stability values, and the range of flow for 6-inch specimens could be derived from the values specified for 4-inch specimens. Personal contacts were made with various agencies and producers to obtain comparative test data.

Table 7 summarizes the stability and flow ratio values obtained by two agencies and two producers (Jamestown Macadam, N.Y. and American Asphalt Paving Co., Pennsylvania) on large stone base or binder mixes (maximum aggregate size 1-1/2 -2 inches). 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.

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.

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 specimen is 3-3/4 inches high, which gives a diametrical cross section of 22.5 square inches. The standard 4-inch specimen is 2-1/2 inches high and it has a diametrical cross section of 10.0 square inches. Therefore, on the basis of unit stress, the total load on a 6-inch specimen should be 2.25 times the load applied to a 4-inch 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-inch specimen will be 1.5 times that of a 4-inch 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-inch and 6-inch mold, respectively) are 2.28 and 1.49 which are very close to the theoretically derived values of 2.25 and 1.50, respectively.

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

Similarly, the range of flow values for 6-inch specimens should be adjusted to 1-1/2 times the values required for 4-inch specimens. For example, if the specified range for 4-inch is 8-18, it should be adjusted to 12-27 for 6-inch specimens.

TYPICAL MIX DESIGN USING 6-INCH SPECIMENS

Kentucky DOH has completed a substantial number of large stone mix designs for coal haul roads using the 6-inch Marshall testing equipment. They require the contractor 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 very heavy trucks (gross loads varying from 90,000 to 150,000 pounds or more) as mentioned earlier. Tire pressures are also higher than generally encountered ranging from 100 to 130 psi (7).

Table 8 gives 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 inches with a substantial amount of material retained on l-inch sieve. This results in substantial amount of l-inch - 3/4 inch material in the mix. The mix design was developed using 6-inch 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 (1-1/2 inch to No. 4) or #4 (1-1/2 inch to 3/4 inch) is used for coarse aggregate to incorporate + l-inch material in the mix. The following preliminary design criteria has been used by Kentucky DOH based on laboratory and field evaluation of such mixes:

Stability	3000 lbs. minimum
Flow	28 maximum
Air Voids	4.5 ± 1.0 percent
VMA	11.5 percent minimum

Table 8. Typical Marshall Mix Design Data (6"-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%).

No. of Blows: 112   Asphalt: AC-20

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, pounds	(1)	5037	4980	4915
	(2)	2.428	2.430	2.440		(2)	5663	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	(1)	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.

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 2 complete coverages of the pneumatic-tired intermediate roller, 3 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 density for the remainder project is:

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. Due to the coarse surface texture, nuclear densities were consistently lower than core densities taken at the same spot. The average nuclear density was about one pound per cubic foot less than core density, indicating that calibration is necessary for determination of actual values. It should be noted that a double drum vibratory roller and a 25-ton pneumatic-tired roller (tire pressure up to 125 psi) was used for principal compaction.

It is expected that the traffic will 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 (l") asphalt concrete surfacing over Class K base to obtain a smooth and impermeable surface. Some technologists believe that 1/2" thick hot sand-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 is given in Reference 5. The test data indicates 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", respectively, on Kentucky projects. Pennsylvania used 1 1/2" maximum aggregate size and 2" lift thickness for the large stone binder course mixes (5) All projects are reportedly performing satisfactorily having been in service up to two years.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. Premature rutting of low-volume roads used for hauling coal and logs is quite 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 very heavy and channelized traffic. For the purpose of this report "large stone" is defined as an aggregate with a maximum size of more than l-inch which cannot be used in preparing standard 4-inch diameter Marshall specimens.
2. A modified Marshall method for testing .6-inch 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 indicates better repeatability of 6-inch specimens compared to 4-inch 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-inch specimens.
   (a) Hammer weighs 22.5 pounds. Only a mechanically operated hammer is specified.
   (b) The specimen size is 6-inch diameter and 3-3/4 inch height.
   (c) The specimen usually weighs about 4050 grams.
   (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-inch diameter and 3-3/4 inch high specimens is 1-1/2 times the number of blows needed for 4-inch diameter and 2-1/2 inch high specimen to obtain equivalent compaction levels.
   (f) A new table for stability correlations ratio needs to be used.
5. Comparative test data (4-inch versus 6-inch diameter specimens) obtained from various highway agencies and producers indicates that the compaction levels are reasonably close.
6. Data obtained on 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) by various agencies was obtained and analyzed. The average stability and flow ratios were determined to be very 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-inch diameter specimens should be 2.25 times the requirement for 4-inch diameter specimens. Similarly, the range of flow values for 6-inch specimens should be adjusted to 1-1/2 times the values required for 4-inch specimen.
7. A typical mix design using 6-inch 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.

ACKNOWLEDGMENTS

Cooperation of the following persons in supplying the relevant data and information is gratefully acknowledged:

Mr. Larry Epley, Kentucky Department of Highways
Mr. David Allen, Transportation Center, University of Kentucky
Mr. Dean Maurer, Pennsylvania Department of Transportation
Mr. Ellis G. Williams, Consulting Engineer
Mr. Thomas Kerestes, American Asphalt Paving Company
Mr. Thomas Olson, Jamestown Macadam, Inc.

REFERENCES

1. Kandhal, P.S., "Marshall Mix Design Methods: Current Practices," Proceedings, Association of Asphalt Paving Technologists, Vol. 54, 1985.
2. Acott, Mike, "The Design of Hot Mix Asphalt for Heavy Duty Pavements," National Asphalt Pavement Association, QIS 111/86, October 1987.
3. "Comparison of 4 and 6-Inch Diameter Molded Specimens," Pennsylvania Department of Transportation, Bureau of Materials, Testing and Research, Status Report, February 21, 1969.
4. "Marshall Criteria for Compacted Bituminous Specimens," Pennsylvania Test Method 705, Pennsylvania Department of Transportation, Field Test Manual, March 1983.
5. Kandhal, P.S., "Large Stone Asphalt Mixes: Design and Construction," Paper presented at the Annual Meeting of the Association of Asphalt Paving Technologists held in Albuquerque, NM (February 1990).
6. "Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus," ASTM D1559-82, American Society for Testing and Materials, Vol. 04.03, 1988.
7. Williams, Ellis G., "Design and Construction of Large Stone HMA Bases in Kentucky," Hot Mix Asphalt Technology, Winter 1988.