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LARGE STONE ASPHALT MIXES: DESIGN AND CONSTRUCTION

by

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ABSTRACT

Premature rutting of heavy duty asphalt pavements has been increasingly experienced in recent years primarily due to high pressure truck tires and increased wheel loads. Many asphalt technologists believe that the use of large size stone (maximum size of more than one inch) in the binder and base courses will minimize or eliminate the rutting of heavy duty pavements.

The equipment specified in the Marshall procedure (ASTM D 1559) used by 76 percent of the states in the United States consists of 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. The proposed method has the following significant differences from ASTM D 1559: (a) hammer weighs 22.5 pounds, (b) specimen size is 6-inch diameter and 3-3/4 inch height, (c) specimen weighs about 4,050 grams, and (d) the number of blows needed is 1-1/2 times the number of blows needed for a standard Marshall specimen to obtain equivalent compaction levels.

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. The

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average 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) were determined to be very close to the theoretically derived values of 2.25 and 1.50, respectively.

A typical mix design using 6-inch specimens is also given. Construction data and experience gained from six field projects in Kentucky and Pennsylvania 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.

LARGE STONE ASPHALT MIXES:
DESIGN AND CONSTRUCTION

INTRODUCTION

Premature rutting of heavy duty asphalt pavements has been increasingly experienced in recent years. This phenomenon is primarily resulting from high pressure truck tires and increased wheel loads. The design of Hot Mix Asphalt (HMA) which served reasonably well in the past needs to be re-examined to withstand the increased stresses. Various asphalt additives are being promoted to increase the stability of HMA pavements at high temperatures. However, most asphalt technologists believe that fundamental changes in the aggregate component of the HMA (such as, size, shape, texture and gradation) must be made first. 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 asphalt pavements.

The use of large stone mixes is not new. Warren Brothers Company had a patent issued in 1903 which specified a top size aggregate of three inches[1]. Most paving companies started to use small stone mixes to avoid infringement of the patent, and such use is still prevalent today.

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 diameter compaction mold which is intended for mixtures containing aggregate up to l-inch maximum size only. This has 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 refusal test and Minnesota DOT vibrating hammer which use 6-inch diameter molds accommodating 1-1/2 -2 inch maximum aggregate size[3]. 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. There are preliminary indications from the NCHRP'S AAMAS (Asphalt-Aggregate Mix Analysis System) research study that a laboratory gyratory compactor better simulates the aggregate particle orientation obtained in the field compared to an impact type compactor used in the Marshall procedure (4). However, it will be a few years before many agencies start to implement AAMAS study's recommendations and use gyratory compactors. In the meantime there is an urgent need to start designing large stone' hot mix asphalt using modified Marshall design procedures based on the current knowledge and experience. It is expected that these procedures will be continually modified as more experience is gained in the field.

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 1960's. 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 D1559 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, a study was undertaken by PennDOT in 1969 to develop the equipment and procedure for testing 6-inch diameter specimens (5) since it is generally recognized that the diameter of the mold should be at least four times the maximum nominal diameter of the coarsest aggregate in the mixture to be molded [Q].

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 energy 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 [z].

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, % air voids, % VMA and % VFA are also reasonably close. 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.

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 similar to the one tested in 1969 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 with 4-inch specimens when testing a large stone mix. This is evident from lower values of the coefficient of variation obtained on 6-inch specimens.

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 has prepared a draft for this proposed standard which is given in Appendix "A". The proposed standard follows ASTM D1559-82 [8] 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.

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).

The complete assembly of equipment for compacting 6-inch diameter specimens is shown in Figure 1.

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.

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

There are two known suppliers of 6-inch Marshall testing equipment:

1. Pine Instrument Company (Attention: Tim Knauff)
   101 Industrial Drive
   Grove City, PA 16127
   Phone (412) 628-6391

2. Rainhart Company (Attention: Larry Hart)
   P.O. Box 4533
   Austin, TX 78765
   Phone (512) 452-8848

The same mechanical compactor is used for compacting 4-inch and 6-inch diameter Marshall specimens. Therefore, if a mechanical compactor is already on hand, one needs to buy the following additional equipment (estimated cost $1,800):

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 (ensure that the spring is strong)
5. 6“ breaking head assembly
6. Specimen extractor for 6“ specimen
7. 6“ paper discs (box of 500)

Although not included in the proposed test method, the automatic recording equipment for stability and flow curve is recommended for reasonable interpretation of Marshall data. Flat topped curves are very common in large stone mixes. Frequently, a seating load also occurs prior to actual specimen loading. This can be readily observed and corrected when recording equipment is used. If not corrected excessive flow may be recorded. PennDOT requires the use of recording equipment for both 4-inch and 6-inch diameter Marshall specimens.

4-INCH VERSUS 6-INCH DIAMETER 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, and the comparative data (4-inch versus 6-inch diameter specimens) was obtained. The discussion of data follows.

Kentucky Department of Highways (KY DOH)

KY DOH developed a large stone base course mix (Type K Base) containing a 2-inch maximum size aggregate for heavier coal haul roads. This mix is designed and controlled using 6-inch Marshall testing equipment. This mix was tried in the field during 1987 construction season. KY DOH obtained comparative test data (4" versus **6")** on their conventional Class I Base mix as shown in Table 6. The levels of compaction obtained in 4-inch and 6-inch molds using 75 and 112 blows, respectively are reasonably close. Stability and flow ratios are 2.08 and 1.34, respectively.

Pennsylvania Department of Transportation (PennDOT)

Comparative test data obtained in 1988 on two binder course mixes are given in Tables 7 and 8. The levels of compaction obtained in 4-inch and 6-inch molds using 50 and 75 blows, respectively are reasonably close. Surprisingly, the coefficient of variation (measure of repeatability) of the specimen bulk specific gravity of the 6-inch specimens was greater than 4-inch specimens. However, 6-inch specimens gave better repeatability on stability and flow compared to 4-inch specimens when large stone is used. Stability and flow ratios ranged from 1.95 to 2.17 and 1.39 to 1.58, respectively.

Table 9 gives the comparative test data obtained in early 1989 also on a binder mix. Six specimens each were compacted in 4-inch and 6-inch molds using 50 and 75 blows, respectively. The levels of compaction obtained in both molds was reasonably close. The test data indicates significantly better repeatability (lower coefficient of variation) of specimen specific gravity, stability and flow when 6-inch mold is used in lieu of 4-inch mold for large stone mixes. Stability and flow ratios were determined to be 1.68 and 1.40, respectively.

Jamestown Macadam, Inc.

Jamestown Macadam, Inc. of Jamestown, NY tested a binder course mix consisting of crushed gravel aggregate. The compaction levels achieved in 4-inch and 6-inch molds using 50 and 75 blows, respectively are very close (Table 10). Stability and flow ratios were determined to be 1.89 and 1.24, respectively.

American Asphalt Paving Company

American Asphalt Paving Company of Chase, PA tested four (4) binder course mixes. AU mixes had the same gradation, only the asphalt content and/or the proportion of manufactured sand were varied as shown in Tables 11, 12, 13, and 14. The compaction levels achieved in 4-inch and 6-inch molds using 75 and 112 blows, respectively are reasonably close except the mix in Table 14. Stability and flow ratios ranged from 1.98 to 2.58 and 1.27 to 1.68, respectively.

Analysis of All Comparative Data

The preceding discussion of comparative data (4-inch versus 6-inch specimens) obtained by various highway agencies and producers indicates that the compaction levels obtained in 4-inch and 6-inch molds (using the appropriate hammer and number of blows) are reasonably close. As expected, the repeatability of stability and flow test is significantly better when 6-inch diameter specimens are used for large stone mixes. Therefore, it is recommended that 6-inch diameter specimens be used for designing such mixes.

Table 15 summarizes the stability and flow ratio values obtained by various agencies and producers 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.

From a theoretical viewpoint, an external load applied to the circumference of a cylinder maybe 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.

It should be noted that Pennsylvania DOT requires the flow value to be measured at the point where the stability curve on the chart begins to level off, whereas other agencies measure the flow at the point where the stability starts to decrease. However, these differences in measuring methods will not significantly affect the flow ratios because the same method is employed both for 4-inch and 6-inch specimens by an agency.

TYPICAL MIX DESIGN USING 6-INCH SPECIMENS

Kentucky DOH has completed a substantial number of large stone mix designs 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). Tire pressures are also higher than generally encountered, ranging from 100 to 130 psi [9].

Table 16 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 design criteria has been used by Kentucky DOH:

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

FIELD CONSTRUCTION DATA

The validity of any laboratory compaction method (such as, applying 112 blows to compact 6-inch Marshall specimens for heavy duty pavements) must be verified in the field. Usually it is not possible to achieve the laboratory density in the field at the time of construction. It is assumed in the Marshall mix design procedures that the laboratory density (if properly obtained) will be achieved in the field after 2-3 years' densification by traffic. Although it has been shown in the laboratory that 112 blows for 6-inch specimen and 75 blows for 4-inch specimen yield comparable densities, it is recommended to measure the actual densities achieved after 2-3 years' service. This would require collection of field compaction data just after construction and periodically thereafter for the projects utilizing large stone mixes. A discussion of preliminary construction data obtained from Kentucky DOH and PennDOT follows.

Ke tucky

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 for the compaction of the remainder Class K base is the average of these 10 measurements. The target density obtained from the control strip should be no greater than 97.0% nor less than 93.0% of the measured maximum specific gravity (Rice Specific gravity) as determined by AASHTO T209. The minimum acceptable density for the project is:

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

Four heavily trafficked sections were constructed during 1988 in Kentucky for field testing Type K Base. These projects comprised the Louisa Bypass in Lawrence County, the Mountain Parkway in Powell County, Route No. 3 in Johnson County, and the Pennyrile Parkway in Henderson County. Table 17 gives the mix design data and average field compaction data for the first three projects. It should be noted that the bottom lift has higher asphalt content than the top lift(s) and is typically designed for about 3 percent voids. This is done for full depth pavements or very thick asphalt layers (for example, Louisa Bypass had twelve inches of Type K Base placed in three lifts and one-inch thick surface course). The objective is to reduce water or vapor entry from the subgrade. The second and third top lifts are usually designed for about 4.5 percent voids.

Some lifts had more than one control strip which were used for determining target densities for accepting the corresponding field densities. AU projects generally exceeded the minimum specified density based on the control strip target density. Table 17 give the in-place voids just after construction for three projects. The data indicates that achieving the desired density (compaction) in the field does not appear to be a problem if the compaction process is optimized. The average void content of all three projects (both bottom and top lifts) was about 6.5 percent.

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. Limited crushing of coarse surface particles occurred. It should be noted that a double drum vibratory roller and a 25-ton pneumatic-tired roller (tire pressure up to 125 psi) were used for principal compaction on Louisa Bypass [9].

Careful attention to details was needed to assure uniform delivery and laydown of large stone mix without any significant segregation. The following factors [9] were considered important:

1. Uniform component aggregate gradations and good stockpiling practices.

2. Increased sampling and testing is desirable to assure good quality control. Usual extraction tests for control of gradation and asphalt content proved to be a problem due to difficulty in obtaining a representative sample for testing. Bin samples, recombined at the proper percentages, were more representative of gradation. Printout data was relied upon for asphalt content control.

3. Segregation in the surge bin was more difficult to control. This tendency to segregate extended to truck loading. However, segregation due to loading was overcome

by using a front, back, center loading scheme for single unit trucks. A five drop loading sequence (front, rear, center, for the first three drops with the last two drops between the front/center and the rear/center) was used for semi-trailer trucks.

4. Coarse particles accumulate in the receiving hopper wings. This effect was reduced by not clearing coarse material from the hopper until the end of each day’s paving. The accumulated coarse particles were wasted.

5. Mixture in the receiving hopper should be maintained at a minimum depth of 18 to 24 inches over the slat conveyor to prevent coarse particles collected in the wings from recentering the mix and producing concentrations of coarse particles.

6. Receiving hopper gates should be set to provide as nearly continuous operation of the slat conveyor as possible. Further, to supply mix to the screed at the required rate, continuous operation of the distribution augers is desirable.

7. Depth of mixture in front of the screed must be maintained at a constant level for the full screed width to assure a uniform spread. Auger extensions, as needed, supply material uniformly to the end plates. If extensions are not used, coarse particles tend to roll to the outer edge of the spread, creating a low density, porous area.

8. Paver speed is very important. The lowest rate of travel that will accommodate production should always be used. Slower rate of movement permits more uniform feeding of mixture under the screed and supplies more vibrating compaction by the screed. Both permit better positioning of coarse particles. Avoiding “stop and go” paving reduces segregation, improves the texture of the spread, and eliminates any tendency for screed

settlement.

Pennsylvania

Tables 18 through 20 give mix composition and compaction data obtained on three projects using large stone mixes for the binder course. Mix composition was determined by running extraction tests on mix samples obtained at random behind the paver. Compaction data is based on 6-inch diameter roadway cores taken just after construction. No significant problems in obtaining a uniform mix and achieving specified compaction levels (92 percent minimum of maximum specific gravity) are indicated by the field data. The average void content of all three projects was about 6.5 percent.

SUMMARY. CONCLUSIONS AND RECOMMENDATIONS

1. Since large stone mixes will be increasingly used to minimize rutting potential of HMA pavements there is a need to standardize a Marshall design procedure which can test 6-inch diameter specimens. 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. Background and preliminary data obtained during the development of Marshall design procedures for preparing and testing 6-inch diameter specimen has been discussed.

3. A draft standard method has been prepared and is included in Appendix "A". The testing equipment is available commercially from two suppliers.

4. 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.

5. 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.

6. 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.

7. 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.

8. A typical mix design using 6-inch specimens is given.

9. The use of large stone mix in field trials in Kentucky and Pennsylvania has been described along with field construction data.

10. There is a need to correlate the compaction levels achieved in 6-inch mold with the field densities obtained at the time of construction and subsequently under traffic during the first 2-3 years.

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Mr. Thomas Kerestes, American Asphalt Paving Company
Mr. Thomas Olson, Jamestown Macadam, Inc.

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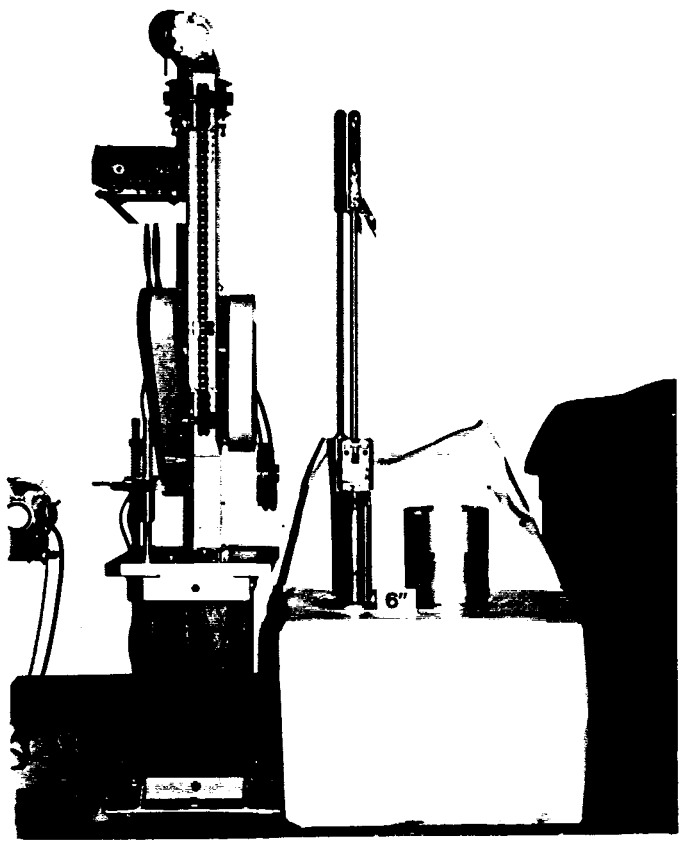

Figure 1. Compaction assembly for 6-inch Marshall specimens

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	5316	-	-	1622	3785	3440
Flow, Units	10.0	20.4	-	-	10.8	20.8	17.5

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	#loo	#200
				100	95	63	43	28	18	12	8	4.5

	4" Specimen	6" Specimen
No. of Blows	50	75
% Compaction	94.2	94.0
% Air Voids	5.8	6.0
% VMA	18.8	18.9
% VFA	69.4	68.4

	4" Specimen	6"* Specimen
Stability, pounds	2049	
Flow, units	10.0	

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			
% VMA	14.7	15.1	Stability Ratio	2.12	
% VFA	83.2	83.0	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 (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.

TABLE 6 . COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : Kentucky Dept. of Highways (Johnson County). Mix type : Class I Base.
Aggregates : Limestone #57 (50%), limestone #8 (10%) and limestone sand (40%).
Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#loo	#200
100	100	-	91	-	64	44	34	24	18	14	7	3.5

		4" Specimen	6" Specimen			4" Specimen	6" Specimen
% Asphalt Content		4.1	4.1	Stability, pounds	(1)	2898	
No. of Blows		75	112		(2)	2998	6430
Bulk Sp. Gr.	(1)	2.439	2.441		(3)	2798	5629
	(2)	2.428	2.450		Mean	2898	6030
	(3)	2.430	2.437	Flow, units	(1)	13.0	
	Mean	2.432	2.443		(2)	14.0	18.0
Max. Sp. Gr.		2.517	2.517		(3)	14.0	18.5
% Air Voids		3.4	3.0		Mean	13.7	18.3
% VMA		14.0	13.6	Stability Ratio		2.08	
% VFA		76.0	78.3	Flow Ratio		1.34	

Remarks : AASHTO Gradations #57 (l" to #4) and #8 (3/8" to #8) used.
Stability values adjusted for specimen thickness.

TABLE 7. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : Pennsylvania Dept. of Transportation (1988 Data)

Mix type : ID - 2 Binder Course (Interstate Amiesite)

Aggregates : Dolomite coarse aggregates #467 (48%), #8 (9%) and Dolomite fine aggregate (43%).

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	90	-	65	59	47	35	20	12	7	5	4

	4" Specimen	6" Specimen
% Asphalt Content	4.6	4.6
No. of Blows	50	75
Bulk Sp. Gr. Mean	2.541	2.549
Std. Dev	0.009	0.013
Coeff. of Variation (%)	0.35	0.51
Max. Sp. Gr.	2.606	2.606
% Air Voids	2.5	2.2
% VMA	13.5	13.1
% VFA	81.4	83.4

	4" Specimen	6" Specimen
Stability, pounds Mean	2650	5169
Std. Dev.	319	530
Coeff. of Variation (%)	12.0	10.3
Flow, units Mean	21.0	29.1
Std. Dev.	3.2	0.9
Coeff. of Variation (%)	15.2	3.1
Stability Ratio	1.95	
Flow Ratio	1.39	

Remarks : Five (5) samples each of 4" and 6" diameter specimens were analyzed.

TABLE 8. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : Pennsylvania Dept. of Transportation. (1988 data)

Mix type : ID-2 Binder Course (Eastern Industries)

Aggregates : Limestone coarse aggregate # 467 (60%) and limestone fine aggregate (40%)

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	90	73	63	54	44	30	17	10	7	5	4

	4" Specimen	6" Specimen		4" Specimen	6" Specimen
% Asphalt Content	4.3	4.3	Stability, pounds		
			Mean	2524	5477
No. of Blows	50	75			
			Std. Dev.	530	363
Bulk Sp. Gr.					
Mean	2.461	2.455	Coeff. of Variation (%)	21.0	6.6
Std. Dev.	0.009	0.031			
			Flow, units		
Coeff. of Variation (%)	0.37	1.27	Mean	16.7	26.4
			Std. Dev.	2.2	2.5
Max. Sp. Gr.	2.551	2.551			
% Air Voids	3.5	3.8	Coeff. of Variation (%)	13.2	9.5
% VMA	13.9	14.1	Stability Ratio	2.17	
% VFA	74.5	73.6	Flow Ratio	1.58	

Remarks : Seven (7) samples each of 4" and 6" diameter specimens were analyzed.

TABLE 9. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : Pennsylvania Dept. of Transportation. (1989 data)   Mix type : ID-2 Binder Course

Aggregates : Dolomite coarse and Dolomite fine aggregate.

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#loo	#200
100	100	92	-	62	-	40	30	19	13	9	7	4.3

		4" Specimen	6" Specimen
% Asphalt Content		4.4	4.4
No. of Blows		50	75
Bulk Sp. Gr.	(1)	2.494	2.494
	(2)	2.504	2.491
	(3)	2.514	2.492
	(4)	2.530	2.502
	(5)	2.506	2.495
	(6)	2.511	2.483
	Mean	2.510	2.493
	Std. Dev.	0.012	0.006
	Coeff. of Var. (%)	0.5	0.2
Max. Sp. Gr.		2.613	2.613
% Air Voids		3.9	4.6
% VMA		13.4	14.0
% VFA		70.8	67.3

		4" Specimen	6" Specimen
Stability, pounds	(1)	2730	5350
	(2)	3640	5450
	(3)	2975	5500
	(4)	3430	5550
	(5)	2870	4700
	(6)	3185	5100
	Mean	3138	5275
	Std. Dev.	348	324
	Coeff. of Var. (%)	11.1	6.1
Flow, units	(1)	13.3	25.0
	(2)	19.3	21.6
	(3)	13.7	22.0
	(4)	16.3	24.0
	(5)	15.0	22.3
	(6)	22.5	25.3
	Mean	16.7	23.4
	Std. Dev.	3.6	1.6
	Coeff. of Var. (%)	21.6	6.8
Stability Ratio		1.68	
Flow Ratio		1.40	

TABLE 10. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : Jamestown Macadam, Inc., Jamestown, N.Y. Mix type : ID-2 Binder Course
Aggregates : Crushed gravel coarse aggregate (76%), gravel fine aggregate (12%) and concrete sand (12%).
Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	98	-	62	-	24	20	16	11	7	5	3

		4" Specimen	6" Specimen			4" Specimen	6" Specimen
% Asphalt Content		4.5	4.5	Stability, pounds	(1)		2900
No. of Blows		50	75		(2)		3200
Bulk Sp. Gr.	(1)	2.357	2.369		(3)		3400
	(2)	2.350	2.340		Mean	1675	3167
	(3)	2.346	2.355	Flow, units	(1)		18.0
	Mean	2.351	2.355		(2)		20.0
Max. Sp. Gr.		2.430	2.439		(3)		18.5
% Air Voids		3.3	3.4		Mean	15.2	18.8
% VMA		13.5	12.9	Stability Ratio		1.89	
% VFA		76.0	73.3	Flow Ratio		1.24	

Remarks : Max. Sp. Gr. values of the mixes used in 4" and 6" specimens are different because the specimens were compacted in different years.

TABLE 11. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : American Asphalt Paving Co., Chase. PA. Mix type : ID-2 Binder Course (Special) Design #2

Aggregates : Siltstone coarse aggregate (64%), manufactured sand (27%) and natural sand (9%).

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	$4	#8	#16	#30	#50	#loo	#200
100	100	90	-	61	-	40	30	18	15	12	7	4.5

	Specimen	Specimen		Specimen	Specimen
% Asphalt Content	4.0	4.0	Stability, pounds	2723	6450
No. of Blows	75	112			
Bulk Sp. Gr.	2.450	2.457	Flow, units	9.8	16.0
Max. Sp. Gr.	2.565	2.565			
% Air Voids	4.5	4.3	Stability Ratio	2.37	
% VMA	12.9	12.7	Flow Ratio	1.63	
% VFA	65.1	66.6			

Remark : 4" data is average of 3 specimens whereas 6" data is average of 2 specimens only.

TABLE 12. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : American Asphalt Paving Co., Chase. PA.   Mix type : ID-2 Binder Course (Special) Design #5

Aggregates : Siltstone coarse aggregate (64%), manufactured sand (27%) and natural sand (9%).

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	90	-	61	-	40	30	18	15	12	7	4.5

	4" Specimen	6" Specimen		4" Specimen	6" Specimen
% Asphalt Content	3.8	3.8	Stability, pounds	2416	6225
No. of Blows	75	112			
Bulk Sp. Gr.	2.444	2.446	Flow, units	10.0	15.2
Max. Sp. Gr.	2.573	2.573			
% Air Voids	5.0	5.0	Stability Ratio	2.58	
% VMA	13.0	12.9	Flow Ratio	1.52	
% VFA	60.3	61.5			

Remark : 4" data is average of 3 specimens whereas 6" data is average of 2 specimens only.

TABLE 13. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : American Asphalt Paving Co., Chase. PA. Mix type : ID-2 Binder Course (Special) Design #3

Aggregates : Siltstone coarse aggregate (64%), and manufactured sand (36%)

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	90	-	61	-	40	30	18	15	12	7	4.5

	Specimen	Specimen		Specimen	Specimen
% Asphalt Content	4.2	4.2	Stability, (pounds)	2961	5850
No. of Blows	75	112			
Bulk Sp. Gr.	2.435	2.448	Flow, (units)	11.3	19.0
Max. Sp. Gr.	2.551	2.551			
% Air Voids	4.5	4.1	Stability Ratio	1.98	
% VMA	13.5	13.1	Flow Ratio	1.68	
% VFA	66.6	69.2			

Remark : 4" data is average of 3 specimens whereas 6" data is average of 2 specimens only.

TABLE 14. COMPARATIVE TEST DATA (4" VERSUS 6"-DIAMETER SPECIMENS)

Source : American Asphalt Paving Co., Chase. PA. Mix type : ID-2 Binder Course (Special) Design #6

Aggregates : Siltstone coarse aggregate (64%), and manufactured sand (36%)

Design Gradation (% Passing) :

2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
100	100	90	-	61	-	40	30	18	15	12	7	4.5

	4" Specimen	6" Specimen		4" Specimen	6" Specimen
% Asphalt Content	4.0	4.0	Stability, pounds	2791	6700
No. Of Blows	75	112			
Bulk Sp. Gr.	2.432	2.559	Flow, units	14.0	17.8
Max. Sp. Gr.	2.559	2.559			
% Air Voids	5.0	3.9	Stability Ratio	2.40	
% VMA	13.5	12.6	Flow Ratio	1.27	
% VFA	63.3	68.9			

Remark : 4" data is average of 3 specimens whereas 6" data is average of 2 specimens only.

TABLE 15. 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 16 . 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 (lbs) (1)	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) (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.

TABLE 17 - FIELD COMPACTION DATA SUMMARY (KENTUCKY PROJECTS)

Project	Lift	Asphalt Content, percent	Design			Field Compaction			
			Lab Density	Max. Density	Percent Voids	Control * Strip No.	Avg. Field Density	% of Max. Density	% Voids
Lawrence County (Louisa Bypass)	Bottom	4.0	152.2	156.9	3.0	(1)	149.9	95.5	4.5
						(2)	149.2	95.1	4.9
						(3)	147.2	93.8	6.2
	Top	3.6	151.3	157.9	4.2	(1)	148.9	94.3	5.7
						(2)	149.2	94.5	5.5
Powell County (Mountain Pkwy)	Bottom	4.0	152.5	157.1	2.9		148.4	94.5	5.5
	Top	3.5	150.9	158.2	4.6	(1)	148.9	94.1	5.9
						(2)	144.5	91.3	8.7
						(3)	145.2	91,8	8.2
Johnson County (Route No.3)	Bottom	4.1	151.8	157*1	3*4	-	148,4	94.5	5.5
	Top	3.7	152.1	158.9	4.3	(1)	146.4	92.1	7,9
						(2)	143.7	90.4	9.6

* Some lifts had more than one control strip which were used for determining target densities for accepting the corresponding field densities.

Note: All density values are reported in pounds per cubic foot.

TABLE 18 - FIELD DATA (PENNSYLVANIA DOT PROJECT NO.1)

Test	JMF	Averages for Lot Numbers *							
		1	2	3	4	5	6	7	8
Gradation: % Passing									
2"	100	100	100	100	100	100	100	100	100
1-1/2"	95	100	100	100	100	100	98	100	100
1"	90	98	94	92	95	95	90	92	92
1/2"	64	76	73	68	73	72	68	68	61
#4	37	39	37	36	39	36	35	34	33
#8	25	28	27	27	28	28	26	26	25
#16	20	23	21	21	22	22	20	20	20
#30	18	19	17	18	18	18	17	17	16
#50	12	12	10	10	11	11	12	11	10
#loo	7	8	6	7	7	7	7	7	6
#200	4.0	5.2	4.3	500	4*5	4.3	4.5	4.8	4.2
Asphalt Content, %	4.5	4.6	4,5	4.6	4.7	4.6	4*5	4.4	4.4
Density, pcf		147.9	147.8	147.7	148.1	146.3	146.1	144.9	147.0
Std. Dev.		1.71	1.64	1.74	1.79	1.86	1.93	2.38	2.50
Max. Sp.Gr., pcf	156.0	157.1	157.1	157.1	157.1	157.1	157*1	157.1	157.1
% of Max. Sp.Gr.	92+	94	94	94	94	93	93	92	94

* Each lot consists of 4 sublets. Mix composition is based on extraction tests run on loose mix samples taken behind the paver. Density results were obtained on roadway cores .