DESIGN OF LARGE STONE ASPHALT MIXES TO MINIMIZE RUTTING

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ABSTRACT

Rutting of heavy duty asphalt pavements has been increasingly experienced in recent years primarily due to high tire pressures 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 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 along with limited field data is also given. It is believed that the proposed test method will be useful in determining the optimum asphalt content of large stone asphalt mixes.

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DESIGN OF **LARGE STONE** ASPHALT MIXES
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INTRODUCTION

Rutting of heavy duty **asphalt** pavements has been increasingly experienced in recent years. This phenomenon is primarily resulting from high tire pressures 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 the use of large size aggregate [1]. Unfortunately, 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**

(Transport and Road Research **Laboratory,** UK) 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, PennDOT completed a study 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 [8].

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 fail of M-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 [2].

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

dose 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 dose. 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 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 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 [2] 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). "

Relative sizes of mold and hammer assembly for compacting 4-inch and **6-inch** specimens **can be** seen in Figure 1.

Sins 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 allowed 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).

z 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)

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. his 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 134, respectively.

Pennsylvania Department of **transportation**   (p -

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 139 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** dose (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. All **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 dose 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 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

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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 [2].

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

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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 TRIALS AND 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 designed by this procedure. Some **preliminary** construction data is available from **Kentucky** DOH which will be **discussed** briefly. More data will **be** obtained from Kentucky DOH and other highway agencies and will be presented in the future.

Kentucky DOHS 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

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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   %.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 [2]. 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%).** However, it will have to be verified from periodical measurements of the pavement density.

SUMMARY, CONCLUSIOS 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 a-rid 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.S0, 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** has been described with limited 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 instruction and subsequently under traffic during the first 2-3 years. Additional field data will be obtained and reported in the future.

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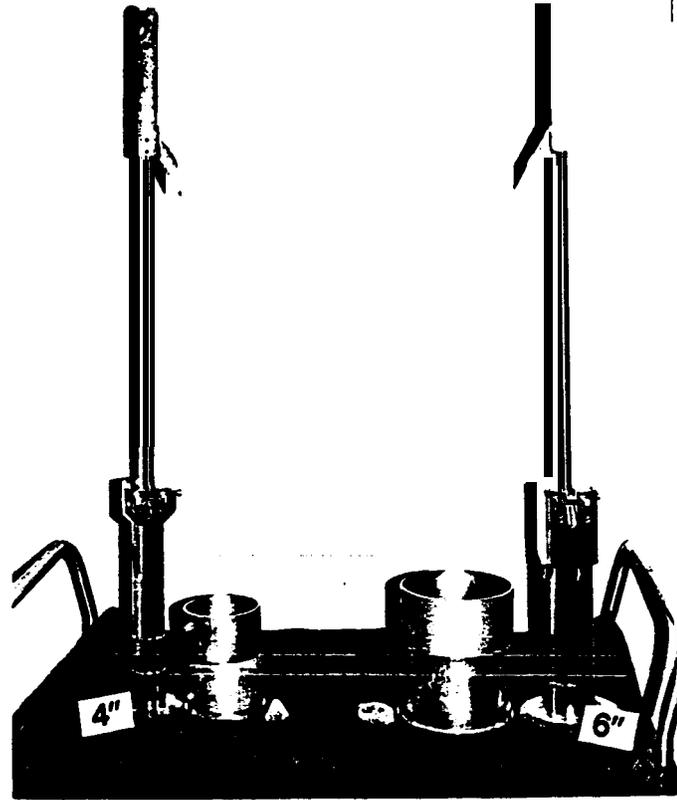
Figure 1. Mold and hammer assembly for 4" and 6"-diameter specimens (aggregate particles of 1" and 2" maximum size also shown)

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	2.60	3.76	2.50	3.75	3.76
Hammer Weight. lbs.	10	22.5	22.5	22.5	10	22.5	22.6
Hammer Drop, In.	18	18	18	18	18	18	18
No. of blows/Face	50	60	60	75	50	60	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   **Mix** type : IO- 2 Wearing Course.
           (1969 Data)
Aggregates : Limestone coarse aggregate and **limestone** fine aggregate.
Design Gradation (% Passing) :

2″	**1-1/2″**	**1″**	3/4″	1/2″	3/0″	#4	**#8**	#16	$30	**#50**	#loo	8200
			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	Remarks : Data on **Stability** and Flow of 6″		
% VFA	69.4	68.4	specimens Is not available.		

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TABLE 3 . COMPARATIVE TEST DATA (4″ VERSUS 6″-DIAMETER Specimens)

Source : Pennsylvania Dept. of Transportation   Mix type : ID- 2 Binder Course.
         (1969 Data)
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	1400	2.6
	1620	11.5	2.6
N	9.0	9*O	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)

	Stahl 1 ity 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 aand (40%).
Design Gradation (% Passing) :

2"	1-1/2-	1"	3/4″	1/2″	3/8″	94	#8	#16	#30	850	$100	#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	5 6 2 9
	(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
x VMA		14.0	13.6	Stability Ratio		2.08	
% VFA		76.0	78.3	Flow Ratio		1.34	

Remarks : AASHTO Gradations #57 (1 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   Mix type : ID- 2 Binder Course
         (1988 Data)   (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	#60	#loo	#200
100	100	90	-	65	59	47	35	20	12	7	5	4

	4 Specimen	6 Specimen		4 Specimen	6 Specimen
% Asphalt Content	4.6	4.6	Stability, pounds		
			Mean	2650	5169
No. Of Blows	50	75			
			Std. Dev.	319	530
Bulk Sp. Gr.					
Mean	2.541	2.549	Coeff. of Variation (%)	12.0	10.3
Std. Dev	0.009	0.013			
			Flow, units		
Coeff. of Variation (%)	0.35	0.51	Mean	21.0	29.1
			Std. Dev.	3.2	0.9
Max. Sp. Gr.	2.606	2.606			
			Coeff. of Variation (%)	15.2	3.1
% Air Voids	2.5	2.2			
% VMA	13.5	13.1	Stability Ratio		1.95
% VFA	81.4	83.4	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.   Mix type : ID-2 Binder.Course
          (1988 data)   (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	#loo	$200
100	100	90	73	63	54	44	30	17	10	7	6	4

	4" Specimen	6" Specimen			4" Specimen	6" Specimen
% Asphalt Content	4.3	4.3	Stability, pounds			
			Mean		2524	6477
No. Of Blows	50	76				
			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				
			Coeff. of Variation (%)		13.2	9.5
% Air Voids	3.5	3.8				
% 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.   Mix type : ID-2 Binder Course
        (1989 data)
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			4 Specimen	6 Specimen
% Asphalt Content	4.4	4.4	Stability, pounds (1)		2730	5350
			(2)		3640	5450
No. of Blows	50	75	(3)		2975	5500
			(4)		3430	5550
Bulk Sp. Gr. (1)	2.494	2.494	(5)		2870	4700
(2)	2.504	2.491	(6)		3185	5100
(3)	2.514	2.492	Mean		3138	5275
(4)	2.530	2.502	Std. Dev.		348	324
(5)	2.506	2.495	Coeff. of Var. (%)		11.1	6.1
(6).	2.611	2.483				
Mean	2.510	2.493	Flow, units (1)		13.3	25.0
Std. Dev.	0.012	0.006	(2)		19.3	21.6
Coeff. of Var. (%)	0.5	0.2	(3)		13.7	2 2 . 0
			(4)		16.3	24.0
Max. Sp. Gr.	2.613	2.613	(5)		15.0	22.3
			(6)		22.5	25.3
% Air Voids	3.9	4.6	Mean		16.7	23.4
			Std. Dev.		3.6	1.6
% VMA	13.4	14.0	Coeff. of Var. (%)		21.6	6.8
X VFA	70.8	67.3	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	#loo	#200
100	100	98	-	62	-	24	20	16	11	7	5	3

		4″ Specimen	6″ Specimen			4″ Specimen	6″ Specimen
% Asphalt Content		4*5	4.6	Stability, pounds (1)			2900
No. of Blows		50	76	(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″	94	#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
x 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	4.6	4.3	Stability Ratio	2.37	
% VMA	12.9	12.7	Flow Ratio	1.63	
% V F A	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 OATA (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	#loo	$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 : 10-'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″	94	$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	4.2	4.2	Stahl 1 ity, (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.S51	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″	3/0″	#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			
% VFA	63.3	68.9	Flow Ratio	1.27	

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. 00T (1988)	50	75	1.95	1.39
Penn. 00T (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) *	7 5	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 HARSHALL MIX DESIGN DATA (6"-DIAMETER SPECIMENS)

Source : Kentucky Dept. of Highways.   Mix Type : Class K Base
          (Lawrence Co. - Loulsa Bypass)
Aggregates : Limestone #467 (66%), 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	930	#50	#100	$200
100	99	86	75	58	50	29	21	15	10	8	s	3.6

	% 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 (1) (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	5 3 7 6
Mean	2.424	2.425	2.439	Mean		5448	5181	4973
Max. Sp. Gr.	2.546	2.530	2.515	Flow (1) (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.

DRAFT NO. 4
(July 26, 1989)

STANDARD TEST METHOD FOR
RESISTANCE TO PLASTIC FLOW OF BITUMINOUS MIXTURES USING
MARSHALL APPARATUS (6 INCH - DIAMETER SPECIMEN)

1.   Scope

1.1 This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. This method is for use with mixtures containing asphalt cement and aggregate up to 2 in. (50.8 mm) maximum nominal size.

1.2 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2   Significance and Use

21 This method is used in the laboratory mix design of bituminous mixtures. Specimens are prepared in accordance with the method and tested for maximum load and flow. Density and voids properties may also be determined on specimens prepared in accordance with the method. The testing section of this method can also be used to obtain maximum load and flow for bituminous paving specimens cored from pavements or prepared by other methods. These results may differ from values obtained on specimens prepared by this method.

3.

3.1 **Specimen Mold Assembly** - Mold cylinders nominal 6.5 in. (165.1 mm) outside diameter steel tubing with 6.000 ± 0.008 in. (152.4 ± 0.2 mm) inside diameter by 4.5 in. (114.3 mm) in **height,** base **plates,** and extension collars shall conform to the details shown in Fig. 1 (a). **All** shall be plated. Nine mold cylinders are recommended.

32 **Specimen Extractor, steel,** in the form of a disk with a diameter from 5.950 to 5.990 in. (151.1 to 1521 mm) and **0.5** in. (13 mm) thick for extracting the compacted specimen from the specimen mold with the use of the mold collar. A suitable bar is required to transfer the load **from** the ring dynamometer adapter to the extension collar while extracting the **specimen.**

3.3 **Mechanical Compactor and Comp**action Hammer.- Compactor with 1/3 hp **(250W)** minimum motor, chain **lift,** frame and automatic sliding weight release. The compaction hammer (Fig. 2) shall have a **flat,** circular tamping face 5.88 in. (149.4 mm) in diameter and a 22.50 ± 0.02 lb (10.21 ± 0.01 kg) sliding weight with a free **fall** of 18.0A **0.1 in.** (457.2& 2.5 mm). Two compaction hammers are recommended.

3.4 **Compaction Pedestal** - The compaction pedestal shall consist of an 8 by 8 by 18-in. (2032 by 2032 by 4572-mm) wooden post capped with a 12 by 12 by l-in. (304.8 by 304.8 by 25.4-mm) steel plate. The wooden post shall be **oak,** pine, or other wood having an average dry weight of 42 to 48 **lb/ft3** (0.67 to 0.77 **g/cm3).** The wooden post shall be secured by four angle brackets to a solid concrete slab. The steel cap shall be firmly fastened to the post. The pedestal assembly shall be installed so that the' post is plumb and the cap is level.

3.5 **Specimen Mold Holder**, mounted on the compaction pedestal so as to center the compaction mold over the center of the post. Fig. 1 (b) or equivalent arrangement. It shall hold the compaction **mold,** collar, and base plate securely in position during compaction of *the* specimen.

3.6 **Breaking Head** - The breaking head **(Fig.** 3) shall consist of upper and lower cylindrical segments or test heads having an inside radius of curvature of 3 in. **(76.2** mm) accurately machined. - The lower segment shall-be mounted on ·**a** base having two perpendicular **guide** rods or posts extending upward. Guide sleeves in the upper segments shall be in such a position as to direct the two segments together without appreciable binding or loose motion on the guide rods. When a 6.000 in. (152.4 mm) diameter by 4 in. (100 mm) thick metal block is placed between the two **segments,** the inside diameters and the gaps between the segments shall conform to Fig. 3. All steel components shall be plated.

3.7 **Loading Jack** - The loading jack **(Fig.** 4) shall consist of a screw jack mounted in a test **frame** and shall produce a uniform vertical movement of 2 *in.* (50.8 **mm)/min.** An electric motor may be attached to the jacking mechanism.

NOTE 1- Instead of the loading **jack,** a mechanical or hydraulic testing machine maybe used provided the rate of movement can be maintained at 2 in. (50.8 **mm)/min** while the load is applied.

3.8 **Ring Dynamometer Assembly** - One ring dynamometer (Fig. 4) of 10,000-lb. (4536-kg) capacity and sensitivity of 10 lb (4.536 kg) up to 1000 lb (453.6 kg) and 25 lb (11.340 kg) between 1000 and 10,000 lb (453.6 and 4536 kg) shall be equipped with a micrometer dial. The micrometer dial shall be graduated on 0.0001 in (0.0025 mm). Upper and lower ring dynamometer attachments are required for fastening the ring dynamometer to the testing

frame and transmitting the load to the breaking head.

NOTE 2- Instead of the ring dynamometer assembly, any suitable load-measuring device may be used provided the capacity and sensitivity meet the above requirements.

3.9 **Flowmeter** - The **flowmeter** shall consist of a guide sleeve and a gage. The activating - pin of the gage shall slide inside the guide sleeve with a slight amount of frictional resistance. The guide sleeve shall slide freely over the guide rod of the breaking head. The flowmeter gage shall be adjusted to zero when placed in position on the breaking head when each individual test specimen is inserted between the breaking head segments. Graduations of the flowmeter gage shall be in 0.01-in (0.25-mm) divisions.

NOTE 3- Instead of the flowmeter, a micrometer dial or stress-strain recorder graduated in 0.001 in (0.025-mm) may be used to measure flow.

3.10 Ovens or Hot Plates - Ovens or hot plates shall be provided for heating aggregates, bituminous material, specimen molds, compaction hammers, and other equipment to the required mixing and molding temperatures. It is recommended that the heating units be thermostatically controlled so as to maintain the required temperature within 5 degrees Fahrenheit (2.8 degrees Celsius). Suitable shields, baffle plates or sand baths shall be used on the surfaces of the hot plates to minimize localized overheating.

3.11 **Mixing Apparatus** - Mechanical mixing is recommended. Any type of mechanical mixer may be used provided it can be maintained at the required mixing temperature and will provide a well-coated, homogeneous mixture of the required amount in the allowable time, and further provided that essentially all of the batch can be recovered. A metal pan or bowl of sufficient capacity (such as, standard 13 qt. size approximately 6-1/4 inch deep) and hand mixing may also be used.

4

3.12 Water Bath - The water bath shall be at least 9 in. (228.6 mm) deep and shall be thermostatically controlled so as to maintain the bath at 140 ± 1.8 degrees Fahrenheit (60 ± 1.0 degrees Celsius) or 100 ± 1.8 degrees Fahrenheit (37.8 ± 1 degree Celsius). The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 2 in (50.8 mm) above the bottom of the bath.

3.13 Miscellaneous Equipment:

> 3.13.1 Containers for heating aggregates, flat-bottom metal pans or other suitable containers.
>
> 3.13.2 Containers for heating bituminous material, either gill-type tins, beakers, pouring pots, or saucepans maybe used.
>
> 3.133 Mixing Tool either a steel trowel (garden type) or spatula, for spading and hand mixing.
>
> 3.13.4 Thermometers for determining temperatures of aggregates, bitumen, and bituminous mixtures. Armored-glass or dial-type thermometers with metal stems are recommended. A range from 50 to 400 degrees Fahrenheit (9.9 to 204 degrees Celsius), with sensitivity of 5 degrees Fahrenheit (2.8 degrees Celsius) is required.
>
> 3.13.5 Thermometers for water and air baths with a range from 68 to 158 degrees Fahrenheit (20 to 70 degrees Celsius) sensitive to 0.4 degrees Fahrenheit (0.2 degrees Celsius).
>
> 3.13.6 Balance 10-kg capacity, sensitive to 1.0g.
>
> 3.13.7 Gloves for handling hot equipment.
>
> 3.13.8 Rubber Gloves for removing specimens from water bath.
> 3.13.9 Marking Cravens for identifying specimens.
>
> 3.13.10 Scoop, flat bottom, for batching aggregates.
>
> 3.13.11 Spoon, large, for placing the mixture in the specimen molds.

4.   Test Specimens

4 . 1 Number of Specimens - Prepare at least three specimens for each combination of aggregates and bitumen content.

4.2   **Preparation of Aggregates - Dry** aggregates to constant weight at 221 to 230 degrees Fahrenheit (105 to 110 degrees Celsius) and separate the aggregates to dry sieving into the **desired** size **fractions.**[1] The following size fractions are recommended:

1-1/2 to 1 **in.** (38.1 to 25.4 mm)

1 to 3/4 in. (25.4 to 19.0 mm)

3/4 to 3/8 in. (19.0 to 9.5 mm)

3/8 in. to No. 4 **(9.5** mm **to** 4.75 mm).

No. 4 to No. 8 (4.75 mm to 236 mm)

Passing No. 8 (236 mm)

'Detailed requirements for these sieves are given **in** ASTM Specification E 11, for Wire-Cloth Sieves for Testing Purposes see **Annual** Book of ASTM Standards, Vol. 14.02.

4 3   Determination of Mixing and Compacting Temperatures:

43.1 The temperatures to which the asphalt cement and asphalt cut-back must be heated to produce a viscosity of 170 $\pm$ 20 **cSt** shall be the mixing temperature.

43.2 The temperature to which asphalt cement must be heated to produce a viscosity of 280 $\pm$ 30 **cSt** shall be the compacting temperature.

4.4   Preparation of Mixtures:

4.4.1 Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 3.75 $\pm$ 0.10 in (95.2 $\pm$ 2.54 mm) in height (about 4050 g). Place the pans on the hot plate or in the oven and heat to a temperature not exceeding the mixing temperature established in 43 by more than approximately 50°F **(28°C).** Charge the mixing bowl with the heated aggregate and dry mix thoroughly. Form a crater in the **dry** blended

6

aggregate and weigh the preheated required amount of bituminous material into the mixture. Care must be exercised to prevent loss of the mix during mixing and subsequent **handling.** At this **point,** the temperature of the aggregate and bituminous material shall be within the limits of the mixing temperature established in 43. Mix "the aggregate and bituminous **material rapidly until** thoroughly **coated.**

45   **Compaction of Specimens:**

4.5.1 Thoroughly clean the specimen mold assembly and the face of the compaction hammer and heat them either in boiling water or on the hot plate to a temperature between 200 and **300°F** (933 and **148.9°C).** Place a piece of filter paper or paper toweling cut to size **in** the bottom of the mold before the mixture is introduced. Place approximately one half of the batch in the **mold,** spade the mixture vigorously

with a heated spatula or trowel 15 times around the perimeter and 10 times over the interior. Place the second half of the batch in the mold and repeat the foregoing procedure. Remove the collar and smooth the surface of the mix with a trowel to a slightly rounded shape. Place a piece of filter paper or paper toweling cut to size on top of the mix. Temperatures of the mixtures immediately prior to compaction shall be within the limits of the compacting temperature established in 43.

4.5.2 Replace the collar, place the mold assembly on the compaction pedestal in the mold holder, and unless **otherwise specified,** apply 75 blows with the compaction hammer with a free fall of 18 in (457.2 mm). Remove the base plate and collar, and reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen.

NOTE 4. It has been determined that 75 and 112 compaction blows applied to a 6-inch (38.1 mm) diameter specimen using the apparatus and procedure in this standard give densities equivalent to 50 and 75 compaction blows, respectively,

applied to a 4-inch (101.6 mm) diameter specimen using ASTM D 1559.

4.5.3 After compaction, remove the base plate and place the sample extractor on that end of the specimen. Place the assembly with the extension collar up in the testing **machine,** apply pressure to the collar by means of the load transfer bar, and force the specimen into the extension collar. Lift the collar from the specimen. · Carefully transfer the specimen to a **smooth,** flat surface and allow it to stand Overnight at rmm temperature **Weigh, measure,** and test the specimen.

NOTE 5. In **general,** specimens shall be cooled. as specified in 4.53. When more rapid cooling 'is **desired,** table fans **may be used. Mixtures that lack sufficient** cohesion to **result** in the required cylindrical shape on removal from the mold immediately after compaction may be cooled in the mold in air until sufficient cohesion has developed to result in the proper cylindrical shape.

5 . **Procedure**

5.1   Bring the specimens to the specified temperature by immersing **in** the water bath 30 to 40 min. or placing in the oven for 2 hr. Maintain the bath or oven temperature at 140 **± 1.8°F** (60& **1.0°C).** Thoroughly clean **the** guide rods and the inside surfaces of the test heads prior to making the **test,** and lubricate the guide rods so that the upper test head slides freely over them. The testing-head temperature shall be maintained between 70 to 100"F (21.1 to **37.8°C)** using a water bath when required. Remove the specimen from the water **bath, oven,** or air bath, and place in the lower segment of the breaking head. Place the upper segment of the breaking head on the specimen, and place the complete assembly in position on the testing machine. Place the **flowmeter,** where used, in position over one of the guide rods and adjust the **flowmeter** to zero while holding the sleeve **firmly** against the upper segment of the **breaking·head.** Hold the **flowmeter** sleeve **firmly** against the upper segment of the breaking head while the test load is being applied.

5.2 Apply the load to the specimen by means of the constant rate of movement of the load jack or testing-machine head of 2 in. **(50.8mm)/min.** until the maximum load is reached and the load decreases as indicated by the dial. Record the **maximum** load noted on the testing machine or converted from the maximum micrometer dial reading. Release the **flowmeter** sleeve or note the micrometer dial **reading,** where **used,** the instant the maximum load begins to decrease. Note and record the indicated flow value or equivalent units in hundredths of an inch (twenty-tie hundredths of a millimeter) if a micrometer dial is used to measure the flow. The elapsed time for the test from removal of the test "specimen from the water bath to the maximum load determination shall not exceed 30 s.

NOTE 6. For mre **specimens,** correct the load when thickness is other than 3.75 in. (95.2 mm) by using the proper multiplying factor from Table 1. This table has been developed after Table 1 of ASTM **D1559** basing the correlation ratio on the percent change **in** specimen volume from standard specimen volume.

6. Report

6.1 The report shall include the following information:

6.1.1 **Type** of sample tested (laboratory sample or pavement core specimen).

NOTE 7. For core **specimens,** the height of each test specimen in inches (or millimeters) shall be reported.

6.1.2 Average maximum load **in** pounds-force (or newtons) of a least three specimens, corrected when required.

6.13 Average flow **value,** in hundredths of an inch, twenty-five hundredths of a . millimeter, of three **specimens,** and

6.1.4 Test temperature.

7. **Precision and Bias**

7.1 The precision and bias of this test method are being determined.

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TABLE 1. 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	%.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.

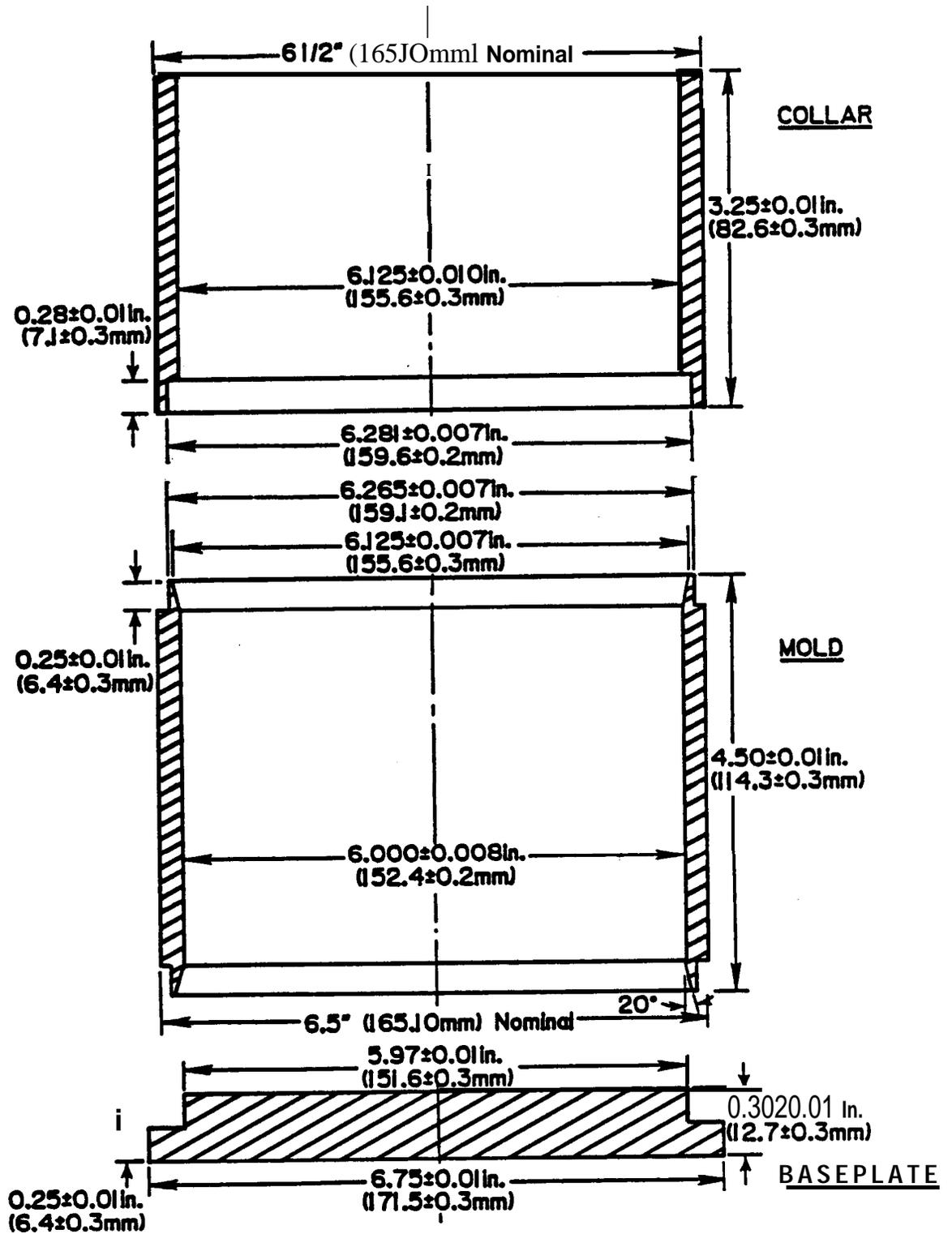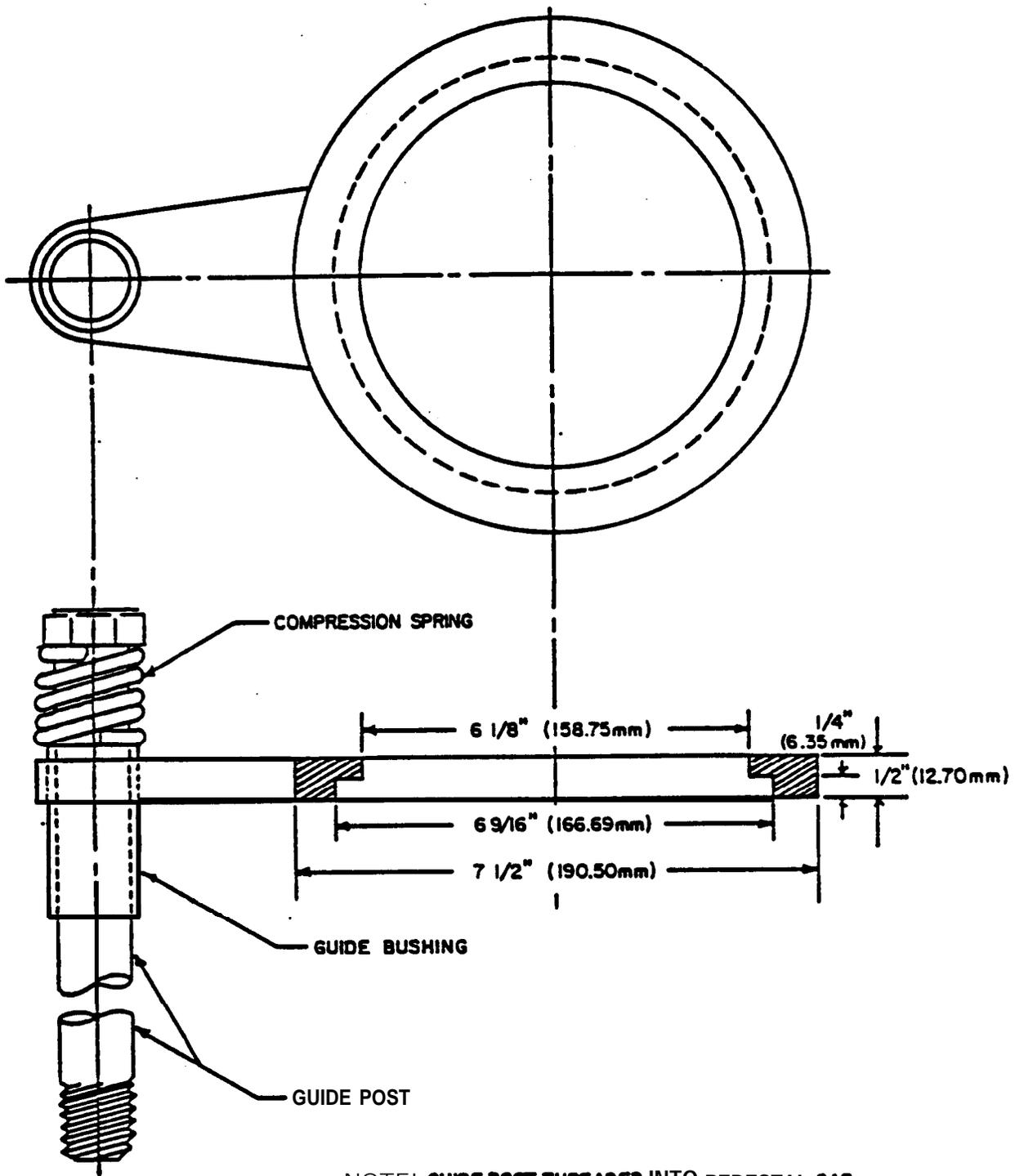[B] Volume - thickness relationship is based on a specimen diameter of 6 in. (152.4 mm).

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6 1/2" (165JOmml **Nominal**

<u>COLLAR</u>

3.25±0.0l in.
(82.6±0.3mm)

6.l25±0.0l0in.
(l55.6±0.3mm)

0.28±0.0l in.
(7.l±0.3mm)

6.28l±0.007ln.
(l59.6±0.2mm)

6.265±0.007ln.
(l59.l±0.2mm)

6.l25±0.007ln.
(l55.6±0.3mm)

<u>MOLD</u>

0.25±0.0l in.
(6.4±0.3mm)

4.50±0.0l in.
(ll4.3±0.3mm)

6.000±0.008ln.
(l52.4±0.2mm)

20°

6.5" (165JOmm) **Nominal**

5.97±0.0l in.
(l5l.6±0.3mm)

i

0.3020.01 In.
(l2.7±0.3mm)

6.75±0.0l in.
(l7l.5±0.3mm)

<u>BASEPLATE</u>

0.25±0.0l in.
(6.4±0.3mm)

FIG. l(a). Compaction Mold

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COMPRESSION SPRING

6 1/8" (158.75mm)

1/4"
(6.35 mm)

1/2" (12.70mm)

6 9/16" (166.69mm)

7 1/2" (190.50mm)

GUIDE BUSHING

GUIDE POST

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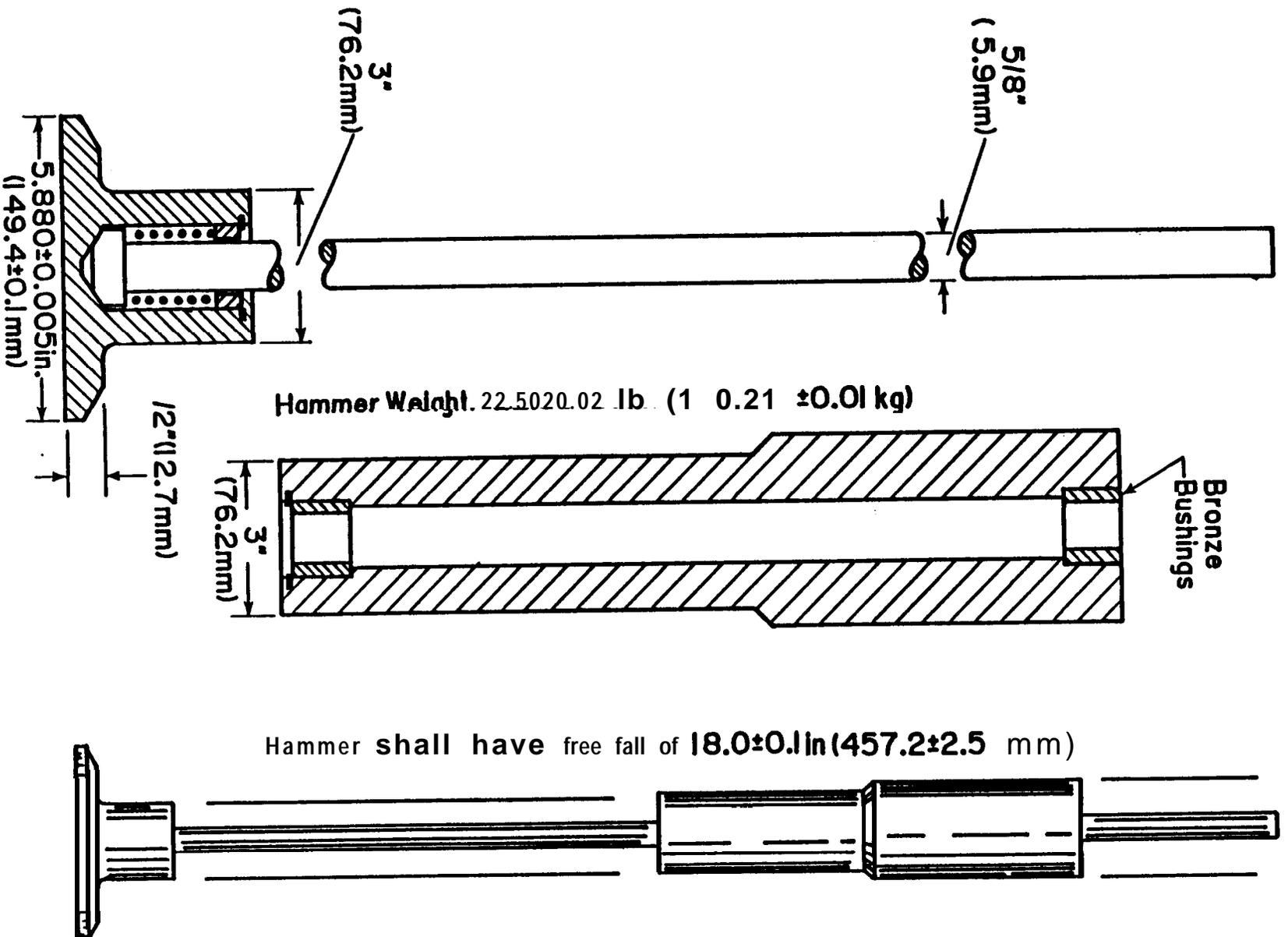MOLD IS HELO FIRMLY.

FIG. I(b). Specimen Mold Holder

Hammer Weight. 22.50±0.02 lb (10.21 ±0.01 kg)

Hammer shall have free fall of 18.0±0.1 in (457.2±2.5 mm)

FIG. 2. Compaction Hammer.

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stress transmitted through spherical & flat surface

minimum 0.87in. (22mm)

2in. (50mm)

6.000±0.006in. (152.4±0.2mm)

0.53±0.01in. (13.5±0.3mm)

45°

2.625±0.009in. (66.7±0.3mm)

0.750±0.003in. (19.05±0.10mm)
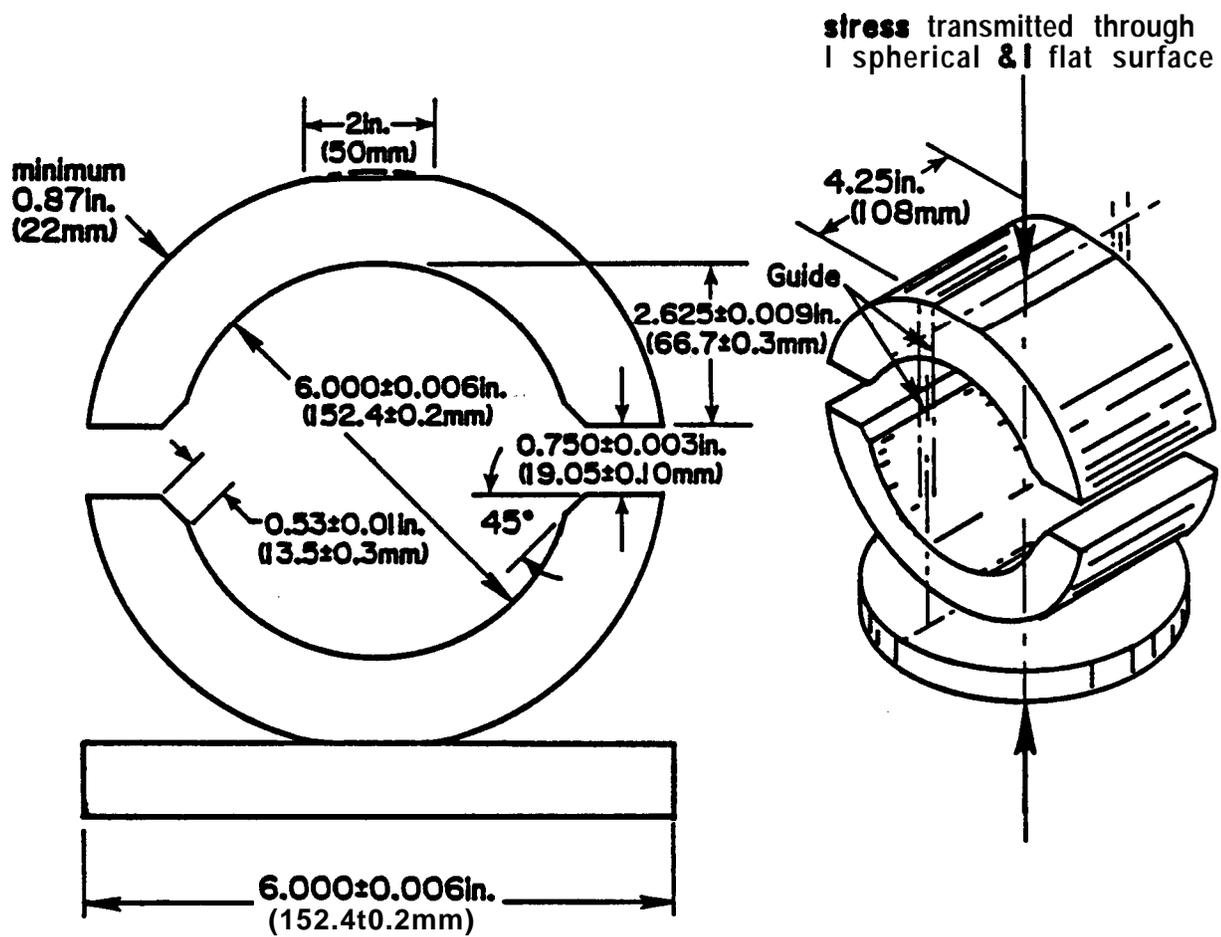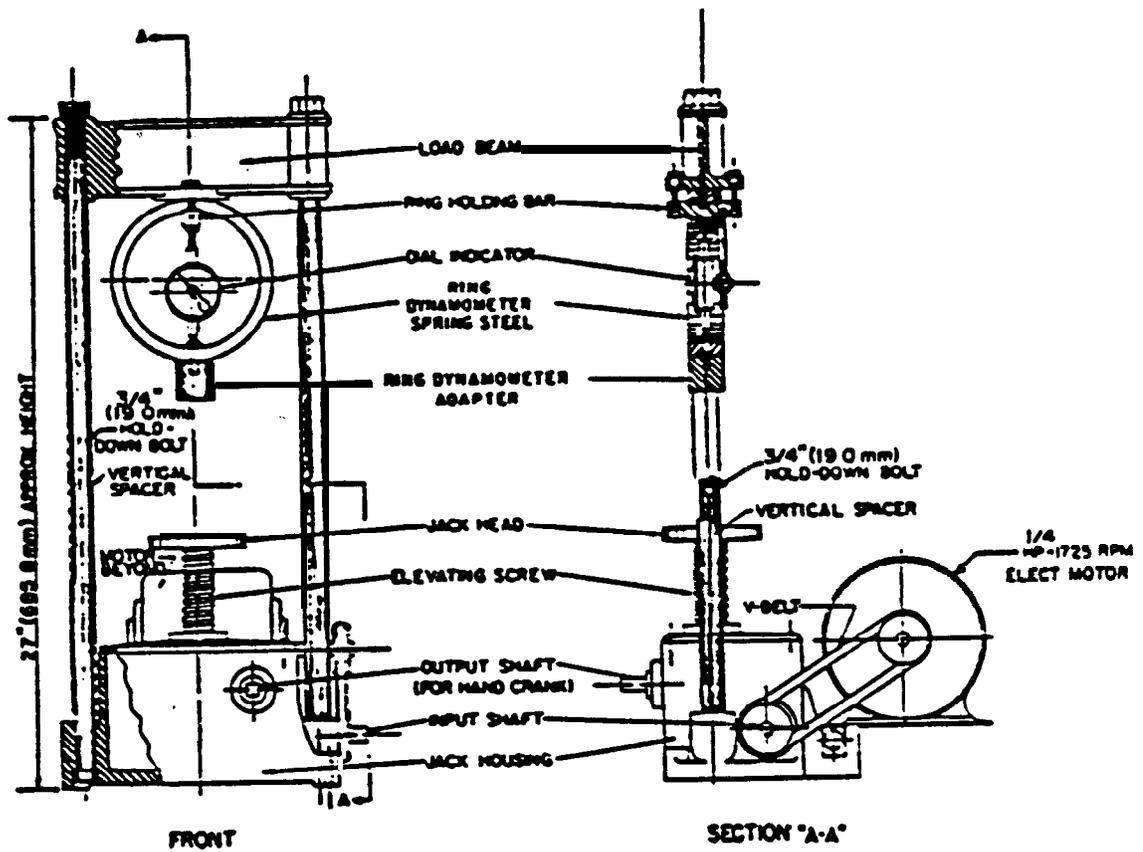
4.25in. (108mm)

Guide

6.000±0.006in. (152.4t0.2mm)

FIG. 3. Breaking Head

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FIG 4 **Compression** Testing Machine