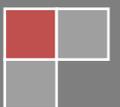


# WFLHD Sampling and Testing Methods



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**Standard Method of Test for**  
**Sieve Analysis of Fine and Coarse Aggregates**  
**WFLHD Designation: W 27-94**

**1. SCOPE**

1.1 This method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2 Some specifications for aggregates which reference this method contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3 The values stated in acceptable units (SI units and units specifically approve RI for use with SI units) are regarded as the standard. The values in parentheses as provided for information purposes only.

1.4 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 whoever uses this standard to consult established appropriate safety and health practices and determine the applicability of regulatory regulations prior to use.

**2. APPLICABLE DOCUMENTS**

**2.1 AASHTO Standards:**

M 92 Wire Cloth Sieves for Testing Purposes

RI Metric Practice

T 2 Sampling Aggregates

T 11 Amount of Material Finer than .075 mm Sieve in Aggregate

T 248 Reducing Field Samples of Aggregate to Testing Size

**2.2 ASTM Standards:**

C 670 Practice for Preparing Statements for Test Methods for Construction Materials.

**3. SUMMARY OF METHOD**

3.1 A weighed sample of dry aggregate is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

#### 4. SIGNIFICANCE AND USE

4.1 This method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable

specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

4.2 Accurate determination of material finer than the 75 $\mu$ m (No. 200) sieve cannot be achieved by use of this method alone. Test Method T 11 for material finer than 75 $\mu$ m sieve by washing should be employed.

#### 5. APPARATUS

5.1 Balance - The balance shall conform to the requirements of AASHTO M 231 for the class of general purpose balance required for the principal sample weight of the sample being tested.

5.2 Sieves - The sieves shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The sieves shall conform to M 92. Sieves with openings larger than 125 mm (5 in.) shall have a permissible variation in average opening of  $\pm$  2 percent and shall have a nominal wire diameter of 8.0 mm (5/16 in.) or larger.

Note 1 - It is recommended that sieves mounted in frames larger than standard 203 mm (8 in.) diameter frames be used for testing coarse aggregate.

5.3 Mechanical Sieve Shaker - A mechanical sieve shaker, if used, shall impart a vertical, or lateral and vertical, motion to the sieve, causing the particles thereon to bounce and turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 7.4 is met in a reasonable time period.

Note 2 - Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 min) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a smaller sample of coarse aggregate or fine aggregate.

5.4 Oven - An oven of appropriate size capable of maintaining a uniform temperature of 110  $\pm$  5 $^{\circ}$  C (230  $\pm$  9 $^{\circ}$  F).

**6. SAMPLING**

**6.1** Sample the aggregate in accordance with T 2. The weight of the field sample shall be the weight shown in T 2 or four times the weight required in 6.4 and 6.5 (except as modified in 6.6), whichever is greater.

**6.2** Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in T 248. The sample for test shall be approximately of the weight desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined weight shall not be permitted.

**Note 3** - Where sieve analysis, including determination of material finer than the 75µm sieve, is the only testing proposed, the size of the sample may be reduced in the field to avoid shipping excessive quantities of extra material to the laboratory.

**6.3 Fine Aggregate** - The test sample of the aggregate shall weigh, after drying, approximately the following amount:

- Aggregate with at least 95 percent passing a 2.36 mm (No. 8) sieve . . . . . 100 g
- Aggregate with at least 85 percent passing a 4.75 mm (No. 4) sieve and more than 5 percent retained on a 2.36 mm (No. 8) sieve . . . . . 500g

**6.4 Coarse Aggregate** - The weight of the test sample of coarse aggregate shall conform with the following:

Nominal Maximum Size Square Openings, mm (in.)	Minimum Weight of Test Sample, kg (lb.)
9.5 (3/8)	1 ( 2)
12.5 (1/2)	2 ( 4)
19.0 (3/4)	5 ( 11)
25.0 (1)	10 ( 22)
37.5 (1-1/2)	15 ( 33)
50 (2)	20 ( 44)
63 (2-1/2)	35 ( 77)
75 (3)	60 (130)
90 (3-1/2)	100 (220)
100 (4)	150 (330)
112 (4-1/2)	200 (440)
125 (5)	300 (660)
150 (6)	500 (1100)

**6.5 Coarse and Fine Aggregate Mixtures** - The weight of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate in Section 6.4.

**6.6** The size of sample required for aggregates with large nominal maximum size is such as to preclude testing except with the large mechanical sieve shakers. However, the intent of this method will be satisfied for samples of

aggregate larger than 50 mm nominal maximum size if a smaller weight of sample is used, provided that the criterion for acceptance or rejection of the material is based on the average of results of several samples, such that the sample size used times the number of samples averaged equals the minimum weight of sample shown in Section 6.4.

6.7 In the event that the amount of material finer than the 75 $\mu$ m (No. 200) sieve is to be determined by T 11, proceed as follows:

6.7.1 For aggregates with a nominal maximum size of 12.5 mm (1/2 in.) or less, use the same test sample for testing T 11 and this method. First test the sample in accordance with T 11 through the final drying operation, then dry sieve the sample as stipulated in 7.2 through 7.7 of this method.

6.7.2 For aggregates with a nominal maximum size greater than 12.5 mm (1/2 in.), a single test sample may be used as described in 6.7.1 or separate test samples may be used for T 11 and this method.

6.7.3 Where the specifications require determination of the total amount of material finer than 75 $\mu$ m (No. 200) sieve by washing and dry sieving, use the procedure described in 6.7.1.

## 7. PROCEDURE

7.1 Dry the sample to constant weight at a temperature of 110  $\pm$  5 $^{\circ}$  C (230  $\pm$  9 $^{\circ}$  F).

Note 4 - For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless (1) the nominal maximum size is smaller than about 12.5 mm (1/2 in.); (2) the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4) or (3) the coarse aggregate is highly absorptive (a lightweight aggregate for example). Also, samples may be dried at the higher temperature associated with the use of hot plates without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles and temperatures are not so great as to cause chemical breakdown of the aggregate.

7.2 Suitable sieve sizes shall be selected which furnish the information required by the specifications covering the material to be tested. The use of additional sieves may be desirable to provide other information such as fineness modulus, or to regulate the amount of material on a sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy or sieving described in Section 7.4.

7.3 Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than the 4.75 mm (No. 4), the weight retained on any sieve at the completion of the sieving operation shall not exceed 6 kg/m<sup>2</sup> (4 g/in.<sup>2</sup>) of sieving surface. For sieves with openings 4.75 mm

(No. 4) and larger, the weight in kg/m<sup>2</sup> of sieving surface shall not exceed the product of 2.5 x (sieve opening in mm). In no case shall the weight be so great as to cause permanent deformation of the sieve cloth. (See Table 2 on page T27-22W).

**Note 5** - The 6 kg/m<sup>2</sup> amounts to 195 g for the usual 203 mm (8 in.) diameter sieve. The amount of material retained on a sieve may be regulated by (1) the introduction of a sieve with larger openings immediately above the given sieve or (2) using the sample in a number of increments.

7.4 Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by weight of the total sample passes any sieve during 1 minute of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75 mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203 mm (8 in.) diameter sieves to verify the sufficiency of sieving.

7.5 In the case of coarse and fine aggregate mixtures, the portion of the sample finer than the 4.75 mm (No. 4) sieve may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

7.5.1 Alternatively, the portion finer than the 4.75 mm (No. 4) sieve may be reduced in size using a mechanical splitter according to T 248. If this procedure is followed, compute the weight of each size increment of the original sample as follows:

$$A = \frac{W_1}{W_2} X B$$

Where:

A = weight of size increment on total sample basis.

W<sub>1</sub> = weight of fraction finer than a 4.75 mm (No. 4) sieve in total sample,

W<sub>2</sub> = weight of reduced portion of material finer than 4.75 mm (No. 4) sieve actually sieved, and

B = weight of size increment in reduced portion sieved.

7.6 Unless a mechanical sieve shaker is used, hand sieve particles larger than 75 mm (3 in.) by determining the smallest sieve opening through which each particle will pass. Start the test on the smallest sieve to be used. Rotate the particles, if necessary, in order to determine whether they will pass through a particular opening; however, do not force particles to pass through an opening.

7.7 Determine the weight of each size increment by weighing on a scale or balance conforming to the requirements specified in Section 5.1 to the nearest 0.1 percent of the total original dry sample weight. The total weight of the material after sieving should check closely with original weight of sample placed on the sieves. If the amounts differ by more than 0.3 percent based on the original dry sample weight, the results should not be used for acceptance purposes.

7.8 If the sample has previously been tested by T 11, add the weight finer than the 75 $\mu$ m (No. 200) sieve determined by that method to the weight passing the 75 $\mu$ m (No. 200) sieve by dry sieving of the same sample in this method.

## 8. CALCULATION

8.1 Calculate percentages passing, total percentages retained, or percentages in various size fractions to the nearest 0.1 percent on the basis of the total weight of the initial dry sample. If the same test sample was first tested by T 11, include the weight of material finer than the 75 $\mu$ m (No. 200) sieve by washing in the sieve analysis calculation; and use the total dry sample weight prior to washing in T 11 the basis for calculating all the percentages.

8.2 Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: 150 $\mu$ m (No.100), 300 $\mu$ m (No.50), 600 $\mu$ m (No. 30), 1.18 mm (No.16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm (3/8 in.), 19.0 mm (3/4 in.), 37.5 mm (1-1/2 in.), and larger, increasing the ratio of 2 to 1.

## 9. REPORT

9.1 Depending upon the form of the specifications for use of the material under test, the report shall include the following:

- 9.1.1 Total percentage of material passing each sieve, or
  - 9.1.2 Total percentage of material retained on each sieve, or
  - 9.1.3 Percentage of material retained between consecutive sieves.
- 9.2 Report percentages to the nearest 0.1 percent.
- 9.3 Report the fineness modulus, when required, to the nearest 0.01.

## 10. PRECISION

10.1 The estimates of precision of this method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program with testing conducted by this method. While there are differences in the minimum weight of the test sample required for other nominal maximum sizes of aggregate, no differences entered into the testing to affect the determination of these precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories. The values in the table are given for different ranges of percentage of aggregate passing one sieve and retained on the next finer sieve.

Table 1 Precision

	: % of Size Fraction : Between Consecutive : Sieves	: Coefficient of : Variation : (1S %), % <sup>B</sup>	: of : Standard : Deviation : (1S), % <sup>A</sup>	: Acceptable Range : of Test Results : (D2S %) <sup>B</sup> : % of Avg.: (D2S), % <sup>A</sup>
<b>Coarse Aggregates:<sup>C</sup></b>				
<b>Single-Operator Precision</b>	: 0 to 3	: 30 <sup>D</sup>	: . . . .	: 85 <sup>D</sup>
	: 3 to 10	:	: 1.4 <sup>D</sup>	: 4.0 <sup>D</sup>
	: 10 to 20	:	: 0.95	: 2.7
	: 20 to 50	:	: 1.38	: 3.9
<b>Multi-Laboratory Precision</b>	: 0 to 3	: 35 <sup>D</sup>	: . . . .	: 99 <sup>D</sup>
	: 3 to 10	:	: 1.06	: 3.0
	: 10 to 20	:	: 1.66	: 4.7
	: 20 to 30	:	: 2.01	: 5.7
	: 30 to 40	:	: 2.44	: 6.9
	: 40 to 50	:	: 3.18	: 9.0
<b>Fine Aggregates:</b>				
<b>Single-Operator Precision</b>	: 0 to 3	:	: 0.14	: 0.4
	: 3 to 10	:	: 0.43	: 1.2
	: 10 to 20	:	: 0.60	: 1.7
	: 20 to 30	:	: 0.64	: 1.8
	: 30 to 40	:	: 0.71	: 2.0
	: 40 to 50	:	: . . . .	: . . . .
<b>Multi-Laboratory Precision</b>	: 0 to 3	:	: 0.21	: 0.6
	: 3 to 10	:	: 0.57	: 1.6
	: 10 to 20	:	: 0.95	: 2.7
	: 20 to 30	:	: 1.24	: 3.5
	: 30 to 40	:	: 1.41	: 4.0
	: 40 to 50	:	: . . . .	: . . . .

<sup>A</sup> These numbers represent, respectively, the (1S) and (D2S) as described in ASTM C 670.  
<sup>B</sup> These numbers represent, respectively, the (1S %) and (D2S %) limits as described in ASTM C 670.  
<sup>C</sup> The precision estimates are based on coarse aggregates with nominal maximum size of 19.0 mm (3/4 in.).  
<sup>D</sup> These values are from precision indices first included in T 27. Other indices were developed in 1982 from more recent AASHTO Materials Reference Laboratory sample data, which did not provide sufficient information to revise the values as noted.

**Instructions for Sieve Analysis -  
AASHTO T 27, SUPPLEMENTAL INSTRUCTIONS**

**1. SCOPE**

These instructions cover the normally required sieve analysis and an abbreviated sieve analysis. Only the normal sieve analysis fulfills the testing requirements for statistical acceptance of aggregate. Both methods provide for drying and/or washing only a portion of the original field sample, and will provide test results with a minimum of testing time.

The abbreviated sieve analysis may be used for nonstatistical acceptance of aggregates. However, enough washed samples, normal sieve analysis, must be run to determine what effect fines clinging to other particles will have on the total sieve analysis. The type and degree of testing can be determined by the specifications, engineering needs, and judgment. Even when the 75  $\mu\text{m}$  (No. 200) sieve is not a specification; the 75  $\mu\text{m}$  (No. 200) minus material (clinging to coarse or fine aggregate) may influence proper acceptance or rejection of borderline aggregates.

**2. GENERAL**

The specifications require that samples be taken by the contractor in the presence of the engineer, and that the contractor provide and maintain sampling facilities. Contractor furnished FIELD SAMPLE sizes are set forth in T 2, TESTING SAMPLE sizes for sieve analysis in T 27, and for washing in T 11.

The following sample sizes (weight of dried aggregate) are taken from the above referenced Sections, represent the base aggregate gradings normally specified, and meet the requirements for sample size under T 2, T 11, and T 27 as approved for use in this Region.

Reference	Maximum Particle Size	
	50 mm (2")	25 mm (1")
Minimum FIELD SAMPLE size, AASHTO T 2 (Modified for gradation only)	41,000 g (90 lbs.)	23,000 g (50 lbs.)
Minimum TEST SAMPLE size, AASHTO T 27	20,000 g (44 Lbs.)	10,000 g (22 Lbs.)
Minimum size for washing coarse, AASHTO T 11	5,000 g (11 Lbs.)	3,600 g (8 Lbs.)
Minimum size for washing fine, AASHTO T 11	500 g (1.1 Lbs.)	500 g (1.1 Lbs.)

**Note a:** Samples of aggregate for bituminous mixtures shall be of a size meeting the above references when tested for gradation prior to the addition of bitumen. Sample size for gradation of extracted aggregate is approximately 2,500 grams as set forth in AASHTO T 164 of this Manual.

Basically two types of samples are run in the field laboratory, samples for information and samples for acceptance. Both will normally require splitting before testing which is covered in T 248.

**INFORMATION** samples are normally taken at the crusher, contain only natural moisture, and are ready for splitting and testing.

**ACCEPTANCE** samples usually will contain optimum moisture for compaction and may require partial drying before splitting and testing. The sample may contain 6 to 7 percent moisture and should be carefully dried to around 4 percent or less. This partial drying should be controlled to prevent overdrying (or at least overdrying on part of the sample) which may cause fines to be "cooked" onto the coarse particles.

If heat in excess of 60°C (140°F) degrees F will be used for partial drying, a portion of the field sample should be quartered-out for S.E., L.L., and P.I. testing before partial drying is started. Excess moisture will not affect this quartering, and the portion can then be dried at low temperature to a moisture content around 4 percent or less before test specimens are prepared.

### 3. NORMAL SIEVE ANALYSIS

It is assumed at this point in these instructions that a 40 kg (90 lb.) plus sample of aggregate has been obtained, that it is at a suitable moisture content for sieving, and that temperatures in excess of 60°C (140°F) were not used to get the sample in this condition.

**Step #1.** The large square sieves furnished will not accommodate a 40 kg (90 lb.) sample, therefore, separate the total sample into at least two random portions. The nested sieves should contain all those listed in the specification plus whatever intermediate sizes may be necessary to eliminate the overloading of any sieve.

Shake the first portion through the nested sieves. Separate the sieves and place the material retained from each sieve in a separate container. Then shake the second portion through the nested sieves. Weigh the material retained on each specification sieve size, combining material from both sieving operations, and record the individual weights in Column 1 "WT. WET." The material from the pan, both sieving operations, should be set aside, and will be discussed in Step #3. The material retained on the 4.75 mm (No. 4) and larger sieves may be combined, and will be discussed in Step #2.

**Note b:** Coarse sieves [4.75 mm (No. 4) and larger] are overloaded when the particles are more than one deep, and fine sieves can handle about 4 grams per square inch or about 200 grams for an eight inch sieve.

**Note c:** Intermediate sieves are not necessarily reported by themselves, but combined with and reported as being retained on the next smaller specification sieve.

**Note d:** Shake the material in the nested sieves for a few minutes, stop the shaker and observe the fines clinging to the coarse particles. Shake again for a few minutes and then observe. Five to six minutes total shaking time should be sufficient to separate the particles such that clinging fines will not change the weight on any sieve by more than 1%. Normally, hand brushing of coarse particles will not be necessary. However, oversieving to remove clinging fines should be prevented. This is a matter of judgment.

**Step #2.** Recombine the coarse aggregate (CA) material developed in Step #1 and retained on the 4.75 mm (No. 4) sieve, and split-out two portions weighing approximately (but not less than) 5 kg (11 lbs.) Excess material may be set aside. Weigh one of the 5 kg (11-lb.) portions, record the weight as "Wt. Wet Aggre." in Column 2, and place it under the infrared oven for drying. The remaining 5 kg (11-lb.) portion will be discussed under Step #5.

**Note e:** Samples for "MOISTURE TEST" should be dried to constant weight at a temperature not exceeding 230°C (450°F).

**Step #3.** Take the fine aggregate (FA) material passing the 4.75 mm (No. 4) sieve developed in Step #1 and split-out two portions weighing approximately (but not less than) 500 grams. Weigh one of the 500 gram portions, record the weight as "Wt. Wet Aggr." in Column 3, and place it under the infrared oven for drying. The remaining portion will be discussed in Step #4.

**Note f:** If portions have not been set aside for S.E., L.L., and P.I. previously, they may now be taken since the total sample has not been exposed to temperatures in excess of 60°C (140°F).

**Step #4.** Take the remaining 500 gram portion of FA from Step #3, weigh, and record the weight as "Wt. Wet Aggr." in Column 4. Then proceed to wash the portion in accordance with AASHTO T 11. Washing in a coffee pot or similar vessel resting on nested sieves has been found a quick and efficient method for small samples. Do not be concerned about the P-75  $\mu\text{m}$  (P-200) minus material that is lost with the washing water. Combine the FA from the vessel and nested sieves and place them under the dryer.

**Step #5.** Take the 5 kg (11-lb.) portion of CA set aside in Step #2, weigh, and record the weight as "Wt. Wet Aggr." in Column 5. Then proceed to wash in accordance with AASHTO T 11. Combine the CA from the vessel and nested sieves and place it under the dryer.

**Step #6.** At this point there should be four samples or portions under the infrared dryer. As they dry, treat them as follows:

From Step #2 - weigh the CA and record as "Wt. Dry Aggr." in Column 2.

From Step #3 - weigh the FA and record as "Wt. Dry Aggr." in Column 3.

From Step #4 - weigh the FA and record as "Wt. Washed Dry Aggr." in Column 4. Then shake the material through nested fine sieves (specification and intermediate as outlined in Step #1). Record the individual weights of the "DRY NO. 4.75mm (No.4) MINUS" in Column 6.

From Step #5 - weigh the CA and record as "Wt. Washed Dry Aggr." in Column 5. Then shake the material through a large 4.75 mm (No. 4) sieve (because of the quantity that will be retained thereon) and then through nested fine sieves. Record the individual weights of "WASHED FROM COARSE" in Column 7.

At this point the physical testing is complete and the remainder of Form WDFD-247 can be completed by computations.

#### 4. COMPUTATIONS, NORMAL SIEVE ANALYSIS

Step #7. In the block "MOISTURE," the "Wt. of Water" equals the "Wt. Wet Aggr." less the "Wt. Dry Aggr.," and the "Percent of Moisture" (percent of the dry aggregate) equals the "Wt. of Water" divided by the "Wt. Dry Aggr."

Step #8. In the block P-75 $\mu$ m "(P-200) WASH," the "Wt. Dry Aggr." equals the "Wt. Wet Aggr." divided by the "Percent of Moisture" expressed as a decimal plus one (e.g. 740.0 divided by 1.057 = 700.09 or 700.1); and the "Wt. P-75 $\mu$ m (P-200)" equals the "Wt. Dry Aggr." less the "Wt. Washed Dry Aggr." At this point, the "Wt. P-75 $\mu$ m (P-200)" should also be entered in Columns 7 & 6 as the "Wt. P-75 $\mu$ m (P-200)." Now add the "Pan" and "Wt. P-75 $\mu$ m (P-200)" to find the "Total P-75 $\mu$ m (P-200)."

Step #9. Complete the coarse aggregate analysis as follows: The "Wt. Wet" values in Column 1 are converted to "Wt. Dry" by dividing them by 1.0 plus the "Percent of Moisture" expressed as a decimal (e.g.  $3.12 \div 1.031 = 3.026$  or 3.03).

The "%" retained in all blocks equals the "Wt. Dry" divided by the "Total Sample Wt."

Step #10. The "PERCENT PASSING" in all blocks is found by subtracting the "%" retained on the largest sieve from 100%. Subsequent values are found by subtracting each "%" retained from the previous "PERCENT PASSING."

Step #11. Under "DRY 4.75 mm (NO. 4) MINUS" the "PASSING," the 4.75 mm ("No. 4") sieve is the "RETAINED %" from above, and subsequent values are a percentage of this value (e.g.  $45.2 \times 65.7 = 29.7$ ).

Step #12. Under "WASHED FROM COARSE," the "PASSING" is equal to 1.0 less the "RETAINED %" from above expressed as a decimal (e.g. 1.0 less .452 = .548  $\times$  9.2 = 5.04 or 5.0), and so forth.

Step #13. The "TOTAL % PASSING" for the coarse fraction was found in Step #10. For the fine fraction, it is the sum of the "PASSING" columns.

**5. ABRIDGED SIEVE ANALYSIS**

Step #1A. Shake the sample through nested sieves as in Step #1, and record the results in Column 1.

Step #2A. Recombine the CA as in Step #2, split-out one 5 kg (11-lb.)  $\pm$  portion, weigh it, record the weight in Column 2, and place it in the infrared oven to dry.

Step #3A. Take the FA from Step #1A and split-out one 500-gram  $\pm$  portion, weigh it, record the weight in Column 3, and place it under the dryer.

Step #4A. When the CA dries, weigh the portion and record as "Wt. Dry Aggr." in Column 2.

Step #5A. When the FA dries, weigh and record the weight as "Orig. Dry Wt." in Column 6. Next, shake the sample through fine nested sieves and record the results in Column 6. This completes the physical testing.

**6. COMPUTATIONS, ABRIDGED SIEVE ANALYSIS**

Make computations as set forth in Steps #7, #9, #10, and #11.



**\*\*NORMAL SIEVE ANALYSIS\*\***

**WORKSHEET FOR SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE  
AASHTO T 11 AND AASHTO T 27**

Project \_\_\_\_\_ Source \_\_\_\_\_ Sample No. \_\_\_\_\_

Sample of \_\_\_\_\_ Quantity represented \_\_\_\_\_ Lot No. \_\_\_\_\_

Sampled by \_\_\_\_\_ Date \_\_\_\_\_ Tested by \_\_\_\_\_ Date \_\_\_\_\_

MOISTURE DETERMINATION			PERCENT PASSING NO. 200 SIEVE (P-200) WASH		
Moisture content	Coarse (2)	Fine (3)	P-200 content	Coarse (5)	Fine (4)
Weight of wet aggregate	14.18	680.7	Weight of wet aggregate	13.40	740.0
Weight of dry aggregate	13.75	644.0	Weight of dry aggregate	13.00	700.1
Weight of water	0.43	36.7	Weight of washed dry aggregate	12.88	635.1
Moisture (%)	3.1	5.7	Weight of P-200	0.12	65.0

REMARKS:	Coarse Aggregate Sieve size	(1) Retained			Total Passing (%)	Spec's
		Wt Wet	Wt Dry	%		
	inch					
	2 inch	0	0	0	100	
	1 1/2 inch	3.12	3.03	3.3	96.7	
	1 inch	8.98	8.71	9.4	87.3	
	1/2 inch	19.31	18.73	20.2	67.1	
	inch					
	No. 4	20.89	20.26	21.9		
	No. 4 minus	44.20	41.82	45.2		
	Total sample Wt	96.50	92.55			

Fine Aggregate Sieve size	WASHED FROM COARSE				DRY NO. 4 MINUS				Total Passing (%)	Spec's
	(7) Retained		Percent Passing	Adjusted (%) Passing	(6) Retained		Percent Passing	Adjusted (%) Passing		
	Wt. Dry	%				Wt Dry			%	
No. 4	11.80	90.8	9.2	5.0	0	0	100	45.2	50.2	
No. 10	0.34	2.6	6.6	3.6	240.4	34.3	65.7	29.7	33.3	
No. 40	0.50	3.8	2.8	1.5	214.6	30.7	35.0	15.8	17.3	
No. 100	0.06	0.5	2.3	1.2	85.5	12.2	22.8	10.3	11.5	
No. 200	0.10	0.8	1.5	0.8	89.5	12.8	10.0	4.5	5.3	
Pan	0.08				4.3					
Wt. P-200	0.12				65.0					
Total P-200	0.20	1.5			69.3	10.0				
Orig. Dry Wt.	13.00				699.3					

Form FHWA 1021 (Rev 3-94)



**WORKSHEET FOR SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE  
AASHTO T 11 AND AASHTO T 27**

Project \_\_\_\_\_ Source \_\_\_\_\_ Sample No. \_\_\_\_\_

Sample of \_\_\_\_\_ Quantity represented \_\_\_\_\_ Lot No. \_\_\_\_\_

Sampled by \_\_\_\_\_ Date \_\_\_\_\_ Tested by \_\_\_\_\_ Date \_\_\_\_\_

MOISTURE DETERMINATION			PERCENT PASSING NO. 200 SIEVE (P-200) WASH		
Moisture content	Coarse (2)	Fine (3)	P-200 content	Coarse	Fine
Weight of wet aggregate	14.18	680.7	Weight of wet aggregate		
Weight of dry aggregate	13.75	644.0	Weight of dry aggregate		
Weight of water	0.43	36.7	Weight of washed dry aggregate		
Moisture (%)	3.1	5.7	Weight of P-200		

REMARKS:	Coarse Aggregate Sieve size	(1) Retained			Total Passing (%)	Spec's
		Wt Wet	Wt Dry	%		
	inch					
	2 inch	0	0	0		
	1 1/2 inch	3.12	3.03	3.3		
	1 inch	8.88	8.61	9.3		
	1/2 inch	18.80	18.23	19.7		
	inch					
	No. 4	17.08	16.57	17.9		
	No. 4 minus	48.62	46.00	49.8		
	Total sample Wt	96.50	92.44			

Fine Aggregate Sieve size	WASHED FROM COARSE				(6) DRY NO. 4 MINUS				Total Passing (%)	Spec's
	Retained		Percent Passing	Adjusted (%) Passing	Retained		Percent Passing	Adjusted (%) Passing		
	Wt. Dry	%				Wt Dry			%	
No. 4				0	0	100			49.8	
No. 10				218.3	33.9	66.1			32.9	
No. 40				206.1	32.0	34.1			17.0	
No. 100				76.0	11.8	22.3			11.1	
No. 200				94.7	14.7	7.6			3.8	
Pan				48.9	7.6					
Wt. P-200										
Total P-200										
Orig. Dry Wt.				644.0						

# SIEVE ANALYSIS OF COARSE & FINE AGGREGATE

## Instructions

TOTAL SIZE OF SAMPLE TO BE TESTED:

Split or quarter out the size of sample to test using the following table.

Maximum size of Rock	Weight of sample to test
9.5 mm (3/8")	1 kg
12.5 mm (1/2")	2 kg
19.0 mm (3/4")	5 kg
25.0 mm (1")	10 kg
*37.5 mm (1 1/2")	15 kg
50 mm (2")	20 kg
63 mm (2 1/2")	35 kg
75 mm (3")	60 kg
90 mm (3 1/2")	100 kg

For this example we will use \*37.5 mm (1-1/2) minus size rock. This means you will need a 15 kg (33) pound sample to test.

Step (1) Get total weight of the sample, record this on sieve form.

Step (2) Check the project specifications for the sieve sizes to use, record these on sieve form under Step (2) - NOTE see Step (26).

Sieve the total sample over a set of screens, using the ones shown in Step (2) on the form (you will be using screens and a shaker like we used in the barn).

Step (3) Weigh each of the sizes you sieved and record them on the sieve form, Step (3). This should check the total weight shown on the form under Step (1).

Next combine all of the 4.75 mm (No. 4) plus material and split out two samples (approximately 5,000 grams) of this material.

Step (4) Mark one of these samples moisture content weight and record it as wt. of wet aggregate next to Step (4) on the form. Weigh this sample in grams.

Step (5) Mark the other coarse sample P-75  $\mu$ m (P-200) content. Weigh and record it as wt. of wet aggregate next to Step (5) on the form. Weigh this sample in grams.

Next take all of the 4.75 mm (No. 4) minus and split out two 500 to 600 gram samples.

Step (6) Mark one of these samples moisture content, weigh and record it as wt. of wet aggregate under Step (6), weigh this sample in grams.

Step (7) Mark the other fine sample P-75  $\mu\text{m}$  (P-200) content, weigh and record it as wt. wet aggregate under Step (7) on the form. Weigh this sample in grams.

Next place the samples from Step (4) and Step (6) under the dryer. These are your moisture samples. Next wash the coarse material next to Step (5). This is done by placing a sieve in the range of 2.36 mm (No. 8) to 1.18 mm (No. 16) sieve over the 75  $\mu\text{m}$  (No. 200) sieve, then pouring the coarse material over the nested sieves and wash till clean. Then remove all of the clean material from the nested sieves and put it in a pan and place it under the dryer to dry.

Next wash the fine material recorded under Step (7). This is done by pouring the sample over the 75  $\mu\text{m}$  (No. 200) sieve and washing till clean. Then remove all clean material from the 75  $\mu\text{m}$  (No. 200) sieve and put it in a pan and place it under the dryer to dry.

When samples recorded next to Step (4) and Step (5) and under Step (6) and Step (7) are dry, do the following.

Step (8) Weigh up the sample of coarse material recorded next to Step (4) and record this weight under Step (8).

Step (9) Subtract Step (8) from Step (4) and record the results under Step (9).

Step (10) Divide Step (8) into Step (9) and record results under Step (10).

$$\frac{70.1 \times 100}{3649.3} = 1.92$$

Step (11) Weigh up the sample of fine material recorded under Step (6) and record this weight under Step (11).

Step (12) Subtract Step (11) from Step (6) and record results under Step (12).

Step (13) Divide Step (11) into Step (12) and record results under Step (13).

$$\frac{15.0}{510.0} \times 100 = 2.94$$

Step (14) Add moisture content under Step (10) plus 100.0 (1.92 + 100.0 = 101.92) then divide the results by 100.

$$\frac{101.92}{100} = 1.0192$$

Next divide the results into the value next to Step (5).

$$\frac{3764.8}{1.0192} = 3693.9$$

Record this result next to Step (14).

Step (15) Weigh up the material recorded next to Step (5) and record this weight next to Step (15).

Step (16) Subtract Step (15) from Step (14) and record results next to Step (16).

$$\begin{array}{r} 3693.9 \\ -3662.0 \\ \hline 31.9 \end{array}$$

Step (17) Add moisture content under Step (13) plus 100.0 (2.94 + 100 = 102.94) then divide the result by 100.

$$\frac{102.94}{100} = 1.0294$$

Next divide the result into the value next to Step (7).

$$\frac{530.5}{1.0294} = 515.3$$

Record this result under Step (17).

Step (18) Weigh up the material recorded under Step (17) and record this weight under Step (18).

Step (19) Subtract Step (18) from Step (17) and record results under Step (19).

$$\begin{array}{r} 515.3 \\ -489.1 \\ \hline 26.2 \end{array}$$

Step (20) Add moisture content under Step (10) plus 100.0 (1.92 + 100.0 = 101.92). Then divide the result by 100.

$$\frac{101.92}{100} = 1.0192$$

Next divide this result into each of the weights under Step (3) down through the 4.75 mm (No. 4) size. Example:

$$\frac{2.55}{1.0192} = 2.50 \quad \frac{3.45}{1.0192} = 3.39 \quad \frac{2.00}{1.0192} = 1.96 \quad \frac{4.00}{1.0192} = 3.92$$

$$\frac{4.50}{1.0192} = 4.42$$

Step (21) Add moisture content under Step (13) plus 100.0 (2.94 + 100.0 = 102.94). Then divide the result by 100.

$$\frac{102.94}{100} = 1.0294$$

Next divide this result into the wet wt. next to the 4.75 mm (No. 4) minus size.

$$\frac{16.50}{1.0294} = 16.03$$

Record this under Step (21).

Step (22) Add all weights under Step (20) plus Step (21) and record total under Step (22).

Step (23) Take result under Step (22) and Divide this by 100

$$\frac{32.22}{100} = .3222$$

Example

$$\frac{2.50}{.3222} = 7.8, \quad \frac{3.39}{.3222} = 10.5, \quad \frac{1.96}{.3222} = 6.1$$

$$\frac{3.92}{.3222} = 12.2, \quad \frac{4.42}{.3222} = 13.7, \quad \frac{16.03}{.3222} = 49.8$$

Step (24) Add all results under Step (23) and record total under Step (24), Step (24) result should equal between 99.9 to 100.1.

Step (25) Subtract each of the results under Step (23) starting with 100.0 and record these results under Step (25).

Example

$$\begin{array}{r} 100.0 \\ - 7.8 \\ \hline 92.2 \end{array} \quad \begin{array}{r} 92.2 \\ - 10.5 \\ \hline 81.7 \end{array} \quad \begin{array}{r} 81.7 \\ - 6.1 \\ \hline 75.6 \end{array} \quad \begin{array}{r} 75.6 \\ - 12.2 \\ \hline 63.4 \end{array} \quad \begin{array}{r} 63.4 \\ - 13.7 \\ \hline 49.7 * \end{array}$$

\* This value should check with the last result under Step (23).

Step (26) Again check the specifications for the sieve sizes to use and record them under Step (26).

Step (27) Take the sample weighed up next to Step (15) and hand sieve it over a 4.75 mm (No. 4) sieve, then record the weight of the material retained on the 4.75 mm (No. 4) sieve next to the 4.75 mm (No. 4) sieve. All of the rest of the sample that went through the 4.75 mm (No. 4) sieve shall be placed on a stack of sieves that are recorded under Step (26) starting with the 2.00 mm (No. 10) size through the pan, this stack of sieves plus the 4.75 mm (No. 4) minus material is then placed on a sieve shaker and sieve for approximately 5 minutes.

Next weigh the material retained on each sieve and the pan under Step (27).

Step (28) Bring the result next to Step (16) and record it next to Step (28).

Step (29) Add pan weight plus result next to Step (28) record next to Step (29)

$$2.0 + 31.9 = 33.9$$

Then mark out weights recorded next to pan also result next to Step (28).

Step (30) Add the following results under Step (27).

4.75 mm	(No. 4)	=	3591.0
2.00 mm	(No. 10)	=	40.0
425 $\mu$ m	(No. 40)	=	10.0
150 $\mu$ m	(No. 100)	=	10.0
75 $\mu$ m	(No. 200)	=	9.0
Total P-75 $\mu$ m (P-200)	Step (29)	=	<u>33.9</u>
Total		=	3693.9

Record this weight under Step (30). NOTE: The total of Step (30) should check Step (14).

Step (31) Take result under Step (30) and divide this by 100.

$$\frac{3693.9}{100} = 36.939$$

Then use this result and divide it into each of the results under Step (26) down through the 75  $\mu$ m (No. 200), also divide into result next to Step (29).

Record all results opposite their sieve sizes under Step (31).

Example:

$$4.75 \text{ mm (No. 4): } \frac{3591.0}{36.939} = 97.2 \quad 2.00 \text{ mm (No. 10): } \frac{40.0}{36.939} = 1.1$$

$$425 \mu\text{m (No. 40): } \frac{10.0}{36.939} = 0.3 \quad 150 \mu\text{m (No. 100): } \frac{10.0}{36.939} = 0.3$$

$$75 \mu\text{m (No. 200): } \frac{9.0}{36.939} = 0.2 \quad (\text{Total } 75 \mu\text{m (P-200) Step(29)}):$$

$$\frac{33.9}{36.939} = 0.9$$

Step (32) Add all results under Step (31), they should equal between 99.9 to 100.1.

Step (33) Subtract each of the results under Step (31) starting with 100.0 and record these results under Step (33).

Example:

$$\begin{array}{r}
 100.0 \\
 - \underline{97.2} \\
 2.8
 \end{array}
 \quad
 \begin{array}{r}
 2.8 \\
 - \underline{1.1} \\
 1.7
 \end{array}
 \quad
 \begin{array}{r}
 1.7 \\
 - \underline{0.3} \\
 1.4
 \end{array}
 \quad
 \begin{array}{r}
 1.4 \\
 - \underline{0.3} \\
 1.1
 \end{array}
 \quad
 \begin{array}{r}
 1.1 \\
 - \underline{0.2} \\
 0.9
 \end{array}$$

Step (34) Take the last value under Step (25) and subtract it from 100.0.

$$\begin{array}{r}
 100.0 \\
 - \underline{49.7} \\
 50.3
 \end{array}$$

Then divide 100 into this result divide  $\frac{50.3}{100.0} = .503$

Take this result times each of the results under Step (33).

Example:

$$\begin{array}{l}
 2.8 \times .503 = 1.4 \\
 1.7 \times .503 = 0.9 \\
 1.4 \times .503 = 0.7 \\
 1.1 \times .503 = 0.6 \\
 0.9 \times .503 = 0.5
 \end{array}$$

Step (35) Take the sample weighed up under Step (18) and place it on a stack of sieves recorded under Step (26), starting with the 2.00 mm (No. 10) size through the pan. Sieve these for approximately 5 minutes.

Next weigh the material retained on each sieve and the pan and record these weights under Step (35) opposite the size they represent.

Step (36) Bring the result under Step (19) and record it under Step (36).

Step (37) Add pan weight plus result under Step (36) record this under Step (37).

$$4.1 + 26.2 = 30.3$$

Then mark out weights recorded next to pan also result under Step (36).

Step (38) Add the following results under Step (35).

2.00 mm	(No. 10)	= 150.0
425 μm	(No. 40)	= 200.0
150 μm	(No. 100)	= 100.0
75 μm	(No. 200)	= 35.0
Total P- 75 μm (P-200) Step (37)		= <u>30.3</u>
		Total = 525.3

---

Step (39) Take result under Step (38) and divide this by 100,  $515.3 = \frac{5.153}{100}$

Then use this result and divide it into each of the results under Step (35) down through the 75  $\mu\text{m}$  (No. 200) also divide into result under Step (38).

Record all results opposite their sieve sizes under Step (39).

Example: 2.00 mm (No. 10):  $\frac{150.0}{5.153} = 29.1$       4.25 mm (No.40):  $\frac{200.0}{5.153} = 38.8$

150  $\mu\text{m}$  (No. 100):  $\frac{100.0}{5.153} = 19.4$       75  $\mu\text{m}$  (No. 200):  $\frac{35.0}{5.153} = 6.8$

Total 75  $\mu\text{m}$  (P-200) Step (37):  $\frac{30.3}{5.153} = 5.9$

Step (40) Add all results under Step (39) they should equal between 99.0 to 100.1.

Step (41) Subtract each of the results under Step (39). Starting with 100.0 and record these results under Step (41).

Example:  $100.0 - 70.9 = 29.1$        $70.9 - 32.1 = 38.8$        $32.1 - 12.7 = 19.4$        $12.7 - 5.9 = 7.8$

Step (42) Take the last value under Step (25) and divide 100 into this result

$\frac{49.7}{100.0} = .497$

Take this result times each of the results under Step (41).

Example:  $100.0 \times .497 = 49.7$   
 $70.9 \times .497 = 35.2$   
 $32.1 \times .497 = 16.0$   
 $12.7 \times .497 = 6.3$   
 $5.9 \times .497 = 2.9$

Step (43) Add the results under Step (34) and Step (42), record results under Step (43).

Example: Sieve Size

4.75 mm (No. 4)       $1.4 + 49.7 = 51.1$   
2.00 mm (No. 10)       $0.9 + 35.2 = 36.1$   
425  $\mu\text{m}$  (No. 40)       $0.7 + 16.0 = 16.7$   
150  $\mu\text{m}$  (No. 100)       $0.6 + 6.3 = 6.9$   
75  $\mu\text{m}$  (No. 200)       $0.5 + 2.9 = 3.4$

Step (44) Cross out last result under Step (25) this result is changed as shown in the first value under Step (43).

Note: The last result under Step (25) is not crossed out on this example, but it should be when running the gradation test for control results.

Table 2  
MAXIMUM LOADING FOR TYPICAL SIEVES

Sieve Size (mm)	Sieve Size	Maximum Wt. in (kg/m <sup>2</sup> )	Maximum Wt. in (g/in <sup>2</sup> )	Round Sieve 203 mm (8 in) Max wt. (g)	Round Sieve 305 mm (12 in) Max wt. (g)	Square Sieve 356 mm (14 in) Max wt. (g)
75.0	3"	188	121	6,079	13,678	23,704
63.0	2 1/2 "	158	102	5,106	11,489	19,911
50.0	2"	125	81	4,053	9,119	15,803
37.5	1 1/2"	94	60	3,040	6,839	11,852
31.5	1 1/4"	79	51	2,553	5,745	9,956
25.0	1"	63	40	2,026	4,559	7,901
19.0	3/4"	48	31	1,540	3,465	6,005
12.5	1/2"	31	20	1,013	2,280	3,951
9.5	3/8"	24	15	770	1,733	3,002
6.3	1/4"	16	10	511	1,149	1,991
4.75	#4	12	8	385	866	1,501
2.36	#8	6	4	195	438	759
2.00	#10	6	4	195	438	759
1.70	#12	6	4	195	438	759
1.18	#16	6	4	195	438	759
0.600	#30	6	4	195	438	759
0.425	#40	6	4	195	438	759
0.300	#50	6	4	195	438	759
0.180	#80	6	4	195	438	759
0.150	#100	6	4	195	438	759
0.075	#200	6	4	195	438	759

Note: The above data is based on the 1993 AASHTO Methods of Sampling and Testing, T-27 and T-30 requirements for sieve loading. This requirement states that the maximum load for sieves with openings of 4.75 mm (#4) and larger shall not exceed the product of 2.5 x (the sieve opening in millimeters), and 6kg/square meter for sieves with openings smaller than the 4.75 mm (#4).



**WORKSHEET FOR SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE  
AASHTO T 11 AND AASHTO T 27**

Project EXAMPLE Source \_\_\_\_\_ Sample No. \_\_\_\_\_

Sample of 1 1/2" MINUS Quantity represented \_\_\_\_\_ Lot No. \_\_\_\_\_

Sampled by \_\_\_\_\_ Date \_\_\_\_\_ Tested by \_\_\_\_\_ Date \_\_\_\_\_

MOISTURE DETERMINATION			PERCENT PASSING NO. 200 SIEVE (P-200) WASH		
Moisture content	Coarse	Fine	P-200 content	Coarse	Fine
Weight of wet aggregate	3719.4 (4)	525.0 (6)	Weight of wet aggregate	3764.8 (5)	530.5 (7)
Weight of dry aggregate	3649.3 (8)	510.0 (11)	Weight of dry aggregate	3693.9 (14)	515.3 (17)
Weight of water	70.1 (9)	15.0 (12)	Weight of washed dry aggregate	3662.0 (15)	489.1 (18)
Moisture (%)	1.92 (10)	2.94 (13)	Weight of P-200	31.9 (16)	26.2 (19)

REMARKS:  
  
○ = STEP NO.  
  
INITIAL SAMPLE  
WT. = 33 LBS. (1)  
  
SHOULD CHECK

Coarse Aggregate Sieve size	Retained			Total Passing (%)	Spec's
	Wt Wet	Wt Dry	%		
(2) inch	(25)	(20)	(23)	(25)	
1 1/2 inch	0	0	0	100.0	
1 inch	2.55	2.50	7.8	92.2	
3/4 inch	3.45	3.39	10.5	81.7	
1/2 inch	2.00	1.96	6.1	75.6	
3/8 inch	4.00	3.92	12.2	63.4	
No. 4	4.50	4.42	13.7	49.7	
No. 4 minus	16.50	16.03	49.7	CHECK	
Total sample Wt	33.00	32.22	100.0		

Fine Aggregate Sieve size	WASHED FROM COARSE				DRY NO. 4 MINUS				Total Passing (%)	Spec's
	Retained		Percent Passing (33)	Adjusted (%) Passing (41)	Retained		Percent Passing (41)	Adjusted (%) Passing (42)		
	Wt. Dry (27)	% (31)			Wt Dry (25)	% (29)				
(26) No. 4	3591.0	97.2	2.8	1.4	0	0	100.0	49.7	51.1 (44)	
No.	40.0	1.1	1.7	0.9	150.0	29.1	70.9	35.2	36.1	
No.	10.0	0.3	1.4	0.7	200.0	38.8	32.1	16.0	16.7	
No.	10.0	0.3	1.1	0.6	100.0	19.4	12.7	6.3	6.9	
No.	9.0	0.2	0.9	0.5	35.0	6.8	5.9	2.9	3.4	
Pan	2.0				4.1					
Wt. P-200 (28)	31.9				26.2 (36)					
Total P-200 (29)	33.9	0.9			30.3 (32)	5.9				
Orig. Dry Wt (30)	3693.9	100.0			515.3 (38)	100.0 (40)				

Form FHWA 1621 (Rev. 3-84)

(32)

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## Standard Method of Test for

# Bulk Specific Gravity ( $G_{mb}$ ) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens

WFL Designation: W 166-19

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## 1. SCOPE

- 1.1. This method of test covers the determination of bulk specific gravity ( $G_{mb}$ ) of specimens of compacted hot mix asphalt (HMA).
  - 1.2. This method should not be used with samples that contain open or interconnecting voids or absorb more than 6.0 percent of water by volume, as determined by this procedure. If the sample contains open or interconnecting voids or absorbs more than 6.0 percent of water by volume, then T 275 or T 331 should be used.
  - 1.3. The bulk specific gravity ( $G_{mb}$ ) of the compacted asphalt mixtures may be used in calculating the unit mass of the mixture.
- 

## 2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
    - M 231, Weighing Devices Used in the Testing of Materials
    - T 275, Bulk Specific Gravity ( $G_{mb}$ ) of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
    - T 331, Bulk Specific Gravity ( $G_{mb}$ ) and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method
  - 2.2. *ASTM Standards:*
    - C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
    - D7227/D7227M, Standard Practice for Rapid Drying of Compacted Asphalt Specimens Using Vacuum Drying Apparatus
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## 3. TEST SPECIMENS

- 3.1. Test specimens may be either laboratory-compacted HMA or sampled from HMA pavements.
  - 3.2. *Size of Specimens*—It is recommended that: (1) the diameter of cylindrically compacted or cored specimens, or the length of the sides of sawed specimens, be at least equal to four times the maximum size of the aggregate; and (2) the thickness of specimens be at least one and one-half times the maximum size of the aggregate.
-

- 3.3. Specimens shall be taken from pavements with a core drill, diamond or carborundum saw, or by other suitable means.
- 3.4. Care shall be taken to avoid distortion, bending, or cracking of specimens during and after the removal from the pavement or mold. Specimens shall be stored in a safe, cool place.
- 3.5. Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.
- 3.6. If desired, specimens may be separated from other pavement layers by sawing or other suitable means. Care should be exercised to ensure sawing does not damage the specimens.

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## METHOD A

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### 4. APPARATUS

- 4.1. *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231. The weighing device shall be equipped with a suitable suspension apparatus and holder to permit weighing the specimen while suspended from the center of the scale pan of the weighing device.
- 4.2. *Suspension Apparatus*—The wire suspending the container shall be the smallest practical size to minimize any possible effects of a variable immersed length. The suspension apparatus shall be constructed to enable the container to be immersed to a depth sufficient to cover it and the test sample during weighing. Care should be exercised to ensure no trapped air bubbles exist under the specimen.
- 4.3. *Water Bath*—For immersing the specimen in water while suspended under the weighing device, equipped with an overflow outlet for maintaining a constant water level.

---

### 5. PROCEDURE

- 5.1. Dry the specimen to a constant mass (Note 1) at a temperature of  $52 \pm 3^\circ\text{C}$  ( $125 \pm 5^\circ\text{F}$ ). Samples saturated with water shall initially be dried overnight and then weighed at 2-h drying intervals. Recently compacted laboratory samples, which have not been exposed to moisture, do not require drying. As an alternative to oven drying to constant mass, drying the sample according to ASTM D7227/D7227M may be used. When using ASTM D7227/D7227M to achieve constant mass (Note 1), perform the drying procedure at least twice, with a mass determination after each drying cycle.  
**Note 1**—Constant mass shall be defined as the mass at which further drying at  $52 \pm 3^\circ\text{C}$  ( $125 \pm 5^\circ\text{F}$ ) does not alter the mass by more than 0.05 percent when weighed at 2-h drying intervals when using oven drying, or by more than 0.05 percent when weighed after at least two drying cycles of the vacuum-drying apparatus required in ASTM D7227/D7227M.
- 5.2. Cool the specimen to room temperature at  $25 \pm 5^\circ\text{C}$  ( $77 \pm 9^\circ\text{F}$ ), and record the dry mass as *A* (Note 2). Immerse each specimen in the water bath at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 1.8^\circ\text{F}$ ) for  $4 \pm 1$  min, and record the immersed mass as *C*. Remove the specimen from the water bath; damp-dry the specimen by blotting it with a damp (Note 3) towel, and determine the surface-dry mass as *B*. The elapsed time from when the specimen is removed from the water bath until it is placed on the balance shall not exceed 5 seconds. Any water that seeps from the specimen during the weighing operation is considered part of the saturated specimen. Each specimen shall be immersed and weighed individually.

**Note 2**– The sequence of testing operations may not be changed.

**Note 3**– Damp is considered to be when no water can be wrung from the towel.

---

## 6. CALCULATION

6.1. Calculate the bulk specific gravity of the specimen as follows:

$$\text{bulk specific gravity} = \frac{A}{B - C}$$

where:

$A$  = mass of the specimen in air, g;

$B$  = mass of the surface-dry specimen in air, g; and

$C$  = mass of the specimen in water, g.

6.2. Calculate the percent of water absorbed by the specimen (on a volume basis) as follows:

$$\text{percent of water absorbed by volume} = \frac{B - A}{B - C} \times 100$$

6.3. If the percent of water absorbed by the specimen as calculated in Section 5.2 exceeds 6.0 percent, use AASHTO T 275 or T 331 to determine the bulk specific gravity.

---

## METHOD C (RAPID TEST)

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### 7. PROCEDURE

7.1. This procedure can be used for testing specimens that are not required to be saved and that contain a substantial amount of moisture. Specimens obtained by coring or sawing can be tested the same day by this method.

7.2. The testing procedure shall be the same as given in Section 4 except for the sequence of operations. The dry mass  $A$  of the specimen is determined last as follows:

7.2.1. Place the specimen in a large, flat-bottom drying pan of known mass. Place the pan and specimen in an oven at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ). Leave the specimen in the oven until it can be easily separated to the point where the particles of the fine aggregate-asphalt portion are not larger than 6.3 mm ( $\frac{1}{4}$  in.). Place the separated specimen in an oven at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ), and dry to a constant mass (Note 1).

7.2.2. Cool the pan and specimen to room temperature at  $25 \pm 5^\circ\text{C}$  ( $77 \pm 9^\circ\text{F}$ ). Determine the mass of the pan and specimen, subtract the mass of the pan, and record the dry mass,  $A$ .

---

### 8. CALCULATIONS

8.1. Calculate the bulk specific gravity as given in Section 5.1.

---

**9. REPORT**

9.1. *The report shall include the following:*

9.1.1. The method used (A or C).

9.1.2. Bulk specific gravity reported to the nearest thousandth.

9.1.3. Absorption reported to the nearest hundredth.

---

## Standard Method of Test for

# Sampling Bituminous Paving Mixtures

WFL Designation: W 168-19

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## 1. SCOPE

- 1.1. This method covers the procedures for obtaining representative samples of asphalt mixtures to determine compliance with requirements of the specifications under which the asphalt mixture is furnished. The method includes sampling from the roadway before compaction.
- 

## 2. SIGNIFICANCE AND USE

- 2.1. This practice is intended to provide standard requirements and procedures for asphalt mixture sampling. The detailed requirements as to materials, interpretation of results, and precision and bias are described in specific test methods.
- 

## 3. APPARATUS

- 3.1. *Sampling containers*— Such as cardboard boxes, metal buckets, stainless steel bowls, or other containers as approved
- 3.2. *Shovels or scoops, or other equipment* —To obtain asphalt mixture
- 3.3. *Sampling plate*— Thick metal plate, minimum 8 gauge, sized to accommodate sample requirements, with a wire long enough to reach from the center of the paver to the outside of the farthest auger extension attached to one corner. Each corner of the plate should have ¼ in. diameter holes.
- 3.4. *Cookie cutter sampling device*— Formed steel angle with two 100 mm by 150 mm by 9 mm (4 in. by 6 in. by 3/8 in.) handles, sized to accommodate sample requirements; minimum 50 mm (2 in.) smaller than the sampling plate when used together.
- Example:* Sampling plate 380 mm (15 in.) square and a cookie cutter sampling device 330 mm (13 in.) square.
- 3.4.1. *Release agent* —A non-stick product that prevents the asphalt material from sticking to the apparatus.
- 

## 4. SAMPLING

- 4.1. *Sampling from Roadway before Compaction*
- Sampling is performed behind the paver and in front of the breakdown roller. Sample size depends on the test method(s) to be performed. Obtain sufficient quantity of material to perform all testing.
-

- 4.1.1. *Plate Method*—Obtaining samples of asphalt mixture being placed on grade or base material using a plate and the “cookie cutter” sampling device
- 4.1.1.1. Smooth out a location in front of the paver at least 0.5 m (2 ft.) inside the edge of the mat.
- 4.1.1.2. Lay the plate down diagonally with the direction of travel, keeping it flat and tight to the base with the lead corner facing the paver. (Note 1)
- Note 1**—Secure the plate in place by driving a nail through the hole in the lead corner of the plate to prevent movement when the paver passes over the plate.
- 4.1.1.3. Pull the wire, attached to the outside corner of the plate, taut past the edge of the mat and secure.
- 4.1.1.4. Let the paving operation pass over the plate and wire.
- 4.1.1.5. Pull the wire up through the fresh asphalt mixture to locate the corner of the plate. Align the “cookie cutter” sampling device over the plate. Press down through the asphalt mixture to the plate.
- 4.1.1.6. Using a small square tipped shovel or scoop, or both, carefully remove all the asphalt mixture from inside the cutter and place in a sample container. (Note 2). Take care to prevent contamination of asphalt mixture by dust or other foreign matter, and avoid segregation of aggregate and asphalt binder.
- Note 2**— When split sampling is required, the sample may be split in the field if desired. To perform a field split, before removing any of the asphalt mixture from the sheet, separate the mixture into four quarters of approximately equal size. Remove opposite corners from the sheet using a scoop or shovel to form a field sample whose quantity equals or exceeds the minimum required to perform all testing. Repeat for the remaining two corners to create the split sample. Each sample shall be reduced to the required size in accordance with AASHTO R 47.
- 4.1.1.7. Remove the cutter and the plate from the roadway. The hole in the mat made from the sampling must be filled with loose asphalt mixture prior to compaction.

---

## Standard Method of Test for

# Accelerated Weathering of Aggregate by use of Dimethyl Sulfoxide

WFL Designation: W DMSO-19

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## 1. SCOPE

- 1.1. This method covers the determination of aggregate resistance to disintegration when immersed in a solution of dimethyl sulfoxide (DMSO). This test method furnishes information helpful in judging the durability of aggregates subject to weathering action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions.
- 

## 2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- M 92, Wire-Cloth Sieves for Testing Purposes
  - M 231, Weighing Devices Used in the Testing of Materials
- 

## 3. APPARATUS

- 3.1. The apparatus shall consist of the following:
- 3.1.1. *Sieves* — With square openings of the following sizes conforming to AASHTO M 92, for sieving the samples in accordance with Sections 4 and 5:
- |         |              |
|---------|--------------|
| 4.75 mm | (No. 4)      |
| 8.0 mm  | (5/16 inch)  |
| 9.5 mm  | (3/8 inch)   |
| 12.5 mm | (1/2 inch)   |
| 16.0 mm | (5/8 inch)   |
| 19.0 mm | (3/4 inch)   |
| 25.0 mm | (1 inch)     |
| 31.5 mm | (1-1/4 inch) |
| 37.5 mm | (1-1/2 inch) |
| 50 mm   | (2 inch)     |
| 63 mm   | (2-1/2 inch) |
- 3.1.2. *Containers for Samples* — Containers for immersing the samples of aggregate in the solution, in accordance with the procedures described in this method, shall be prepared of materials not attacked by the solution used (Note 1).
- Note 1**— Baskets of suitable wire mesh or sieves with suitable openings are satisfactory containers for the samples. Pans or other containers without perforations may be used.
- 3.1.3. *Thermometer* — A thermometer covering the recommended temperature range for solutions during test and readable to 0.1°C (0.2°F).
-

- 3.1.4. *Temperature Regulation* — Suitable means for regulating the temperature of the samples during immersion in the dimethyl sulfoxide solution shall be provided.
- 3.1.5. *Balance* — The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of AASHTO M 231.
- 3.1.6. *Drying Oven* — The oven shall be capable of being heated continuously at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ).

---

## 4. SPECIAL SOLUTION REQUIRED

- 4.1. Prepare the solution for immersion of test samples in dimethyl sulfoxide in accordance with Section 4.1.1.
- 4.1.1. *Dimethyl Sulfoxide* — Dimethyl sulfoxide shall be an industrial chemical, marketed under the name DMSO. Discolored solution shall be discarded, or filtered before reuse (Note 2). The volume of the solution in which samples are immersed shall be at least five times the volume of the sample immersed at one time.
- Note 2**— To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed.

---

## 5. SAMPLES

- 5.1. *Coarse Aggregate* — Coarse aggregate for the test shall consist of material from which the sizes finer than the 4.75 mm (No. 4) sieve have been removed. The sample obtained shall be of such a size that it will yield the amounts indicated in Table 1.

**Table 1**— Coarse Aggregate Sample

Sieve Size	Mass, g
63 mm to 37.5 mm (2-1/2 inch to 1-1/2 inch)	5000 ± 300
Consisting of:	
50-mm to 37.5-mm (2 inch to 1-1/2 inch) material	2000 ± 200
63-mm to 50-mm (2-1/2 inch to 2 inch) material	3000 ± 300
37.5 mm to 19.0 mm (1-1/2 inch to 3/4 inch)	1500 ± 50
Consisting of:	
25.0-mm to 19.0-mm (1 inch to 3/4 inch) material	500 ± 30
37.5-mm to 25.0-mm (1-1/2 inch to 1 inch) material	1000 ± 50
19.0 mm to 9.5 mm (3/4 inch to 3/8 inch)	1000 ± 10
Consisting of:	
12.5-mm to 9.5-mm (1/2 inch to 3/8 inch) material	330 ± 5
19.0-mm to 12.5-mm (3/4 inch to 1/2 inch) material	670 ± 10
9.5 mm to 4.75 mm (3/8 inch to No. 4)	300 ± 5

- 5.1.1. Should the samples contain less than 5 percent of any of the sizes specified in Section 5.1, that size shall not be tested, but, for the purpose of calculating the test results, it shall be considered to have the same loss as the average of the next smaller and the next larger size, or if one of these sizes is absent, it shall be considered to have the same loss as the next larger or next smaller size, whichever is present. When the 63 to 37.5 mm (2-1/2 to 1-1/2 inch), 37.5 to 19.0 mm (1-1/2 to 3/4 inch), or 19.0 to 9.5 mm (3/4 to 3/8 inch), test samples specified in Section 5.1 cannot be prepared due to absence of one of the two sizes of aggregate shown for each, the size available shall be used to prepare the sample tested.

---

## 6. PREPARATION OF TEST SAMPLE

- 6.1. *Coarse Aggregate* — Thoroughly wash and dry the sample of coarse aggregate to constant mass (Note 3) at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ) and separate into the different sizes in Section 5.1 by hand sieving to refusal until none of the particles being sieved are passed in one minute's time (Note 4). Weigh quantities of the different sizes within the tolerances of Section 5.1 and place them in separate containers. Record the masses of the test samples and their fractional components. In the case of sizes larger than 19.0 mm (3/4 inch), record the number of particles in the test samples.
- Note 3**—Constant mass shall be defined as the mass at which further drying at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ) does not alter the mass by more than 0.1 percent.
- Note 4**—Finger manipulation of the particles may be used to determine refusal.
- 6.2. Test samples of coarse aggregate shall be weighed to the nearest 1 g.

---

## 7. PROCEDURE

- 7.1. *Storage of Samples in Solution* — Immerse the samples in the solution for not less than 112 hours nor more than 120 hours in such a manner that the solution covers them to a depth of at least 12.5 mm (1/2 inch). Cover the containers to reduce evaporation and prevent the accidental addition of extraneous substances. Maintain the samples immersed in the solution at a temperature of  $21 \pm 3^\circ\text{C}$  ( $70 \pm 5^\circ\text{F}$ ) for the immersion period.
- 7.2. *Drying Samples after Immersion* — After the immersion period, remove the aggregate sample from the solution, permit it to drain for  $15 \pm 5$  minutes and wash with tap water.

---

## 8. QUANTITATIVE EXAMINATION

- 8.1. After the solution has been removed, each fraction of the sample shall be dried to constant mass (Note 4) at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ), and weighed. Hand-sieve the coarse aggregate over the sieve shown below for the appropriate size of particle.

Size of Aggregate	Sieve Used to Determine Loss
63 mm to 37.5 mm (2-1/2 to 1-1/2 inch)	31.5 mm (1-1/4 inch)
37.5 mm to 19.0 mm (1-1/2 to 3/4 inch)	16.0 mm (5/8 inch)
19.0 mm to 9.5 mm (3/4 to 3/8 inch)	8.0 mm (5/16 inch)
9.5 mm to 4.75 mm (3/8 inch to No. 4)	4.00 mm (No. 5)

---

## 9. REPORT

- 9.1. The report shall include the following data:
- 9.1.1. Mass of each fraction of each sample before and after testing.
- 9.1.2. The material from each fraction of the sample passing the sieve used to determine the loss expressed as a mass percent of the fraction as shown in Table 2.

**Table 2— Suggested Form for Recording Test Data (with Illustrative Test Values)**

Sieve Size		Grading of Original Sample, percent	Mass of Test Fractions before Test, g	Percent Passing Sieve Used to Determine Loss	Weighted Average (Corrected Percent Loss)
Passing	Retained on				
63 mm (2-1/2 inch)	3.75 mm (1-1/2 inch)	20.0	3000	4.8	1.0
3.75 mm (1-1/2 inch)	19.0 mm (3/4 inch)	45.0	1500	8.0	3.6
19.0 mm (3/4 inch)	9.5 mm (3/8 inch)	23.0	1000	9.6	2.2
9.5 mm (3/8 inch)	4.75 mm (No. 4)	12.0	300	11.2	1.3
Totals		100.0	5800		8.1

9.1.3. Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative.

9.1.4. The weighted average loss shall be computed to the nearest 0.1 percent.

Standard Method of Test for  
Humphres Method for Granular Soils  
WFL Designation: W Humphres-19

## HIGHWAY RESEARCH BOARD

Bulletin 319

# *Factors Influencing Compaction Test Results*

A. W. JOHNSON, Engineer of Soils and Foundations  
Highway Research Board

and

J. R. SALLBERG, Highway Research Engineer  
Division of Physical Research  
Bureau of Public Roads

National Academy of Sciences—  
National Research Council  
Washington, D. C.  
1962

*Start*

—————→ ~~THE HUMPHRES METHOD FOR GRANULAR SOILS~~

The Humphres method (102) consists of establishing the maximum obtainable (that is, with current construction equipment) unit weight of a granular material for different percentages of fine aggregate (portion passing the No. 4 sieve). The method is intended for use with ballast, base course, and surfacing materials with specified gradations. The maximum unit weight curve developed, which relates maximum unit weight and percentage of fine aggregate, can be used by the compaction inspector to determine the proper "control" unit weight of material whose gradation fluctuates between fairly wide specification limits. To determine the proper "control" value, the inspector need only determine the percentage of fine aggregate in his sample and refer to the maximum unit weight curve for the material sampled.

To establish the maximum unit weight curve, for one material, the following 12 steps are necessary:

1. Oven-dry a representative sample of the granular material at 110 to 120 F.
2. Divide a sample into two parts: coarse aggregate, retained on No. 4 sieve; fine aggregate, passing No. 4 sieve.
3. Determine the maximum compacted dry unit weight of each part by using a combination of vibratory and static loading. (The vibratory spring load compactor unit is described in detail in HRB Bull. 159 (1957). Other methods of vibratory compaction (120) that yield comparable unit weights can also be used in determining maximum unit weight.) The maximum compacted dry unit weight of the fine aggregate is represented by  $\gamma_f^c$  ( $\gamma_{\text{fine}}^{\text{compacted}}$ ) and the maximum compacted dry unit weight of the coarse aggregate by  $\gamma_c^c$  ( $\gamma_{\text{coarse}}^{\text{compacted}}$ ).
4. Determine the loose dry unit weight of each part ( $\gamma_f^l$ ;  $\gamma_c^l$ ) by gently pouring each through an appropriately-sized funnel into a container of known volume, weighing, and calculating dry unit weight. The size of sample, pouring device, and volume of measure based on maximum particle size given in Table 27 may be used (121).
5. Determine the solid unit weight of each part ( $\gamma_f^s$ ;  $\gamma_c^s$ ). First determine the specific gravity of each (for fine aggregate, test ASTM D 854-52 or AASHTO T 100-54; for coarse aggregate, apparent specific gravity ASTM C 124-42 or AASHTO T 85-45), then multiply each specific gravity by 62.4.

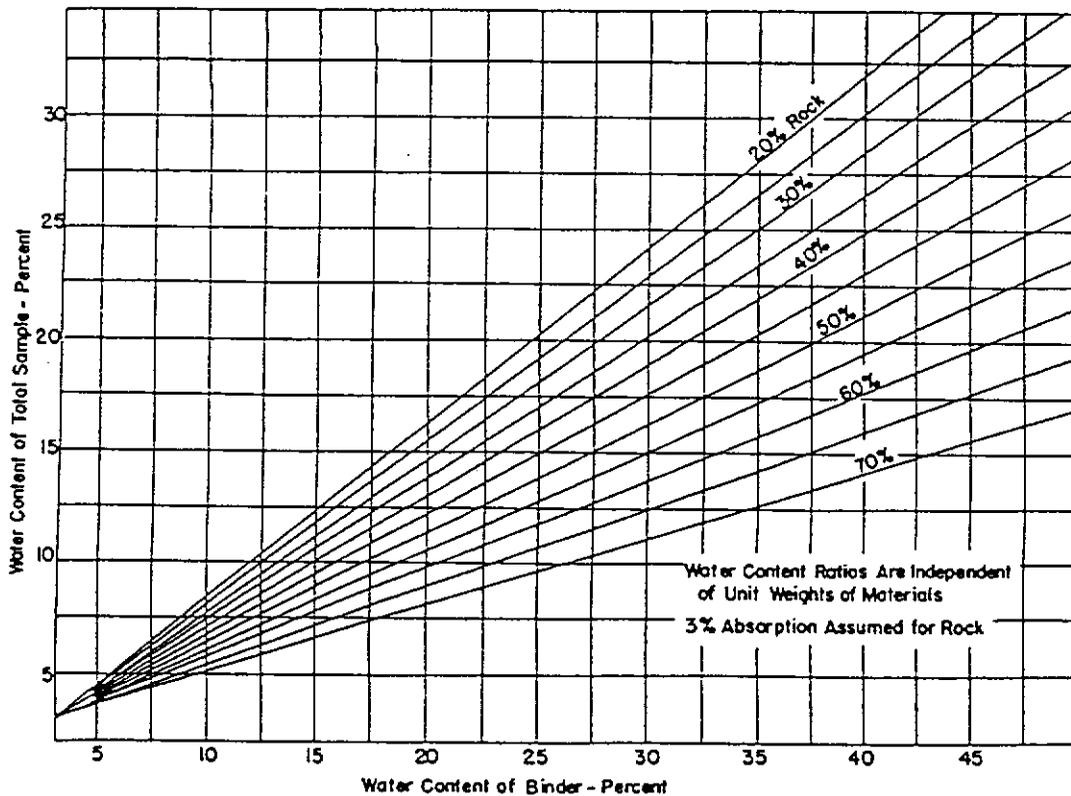


Figure 82. Chart for determining relation between water content of portion passing  $\frac{1}{4}$ -in. sieve and total sample (26).

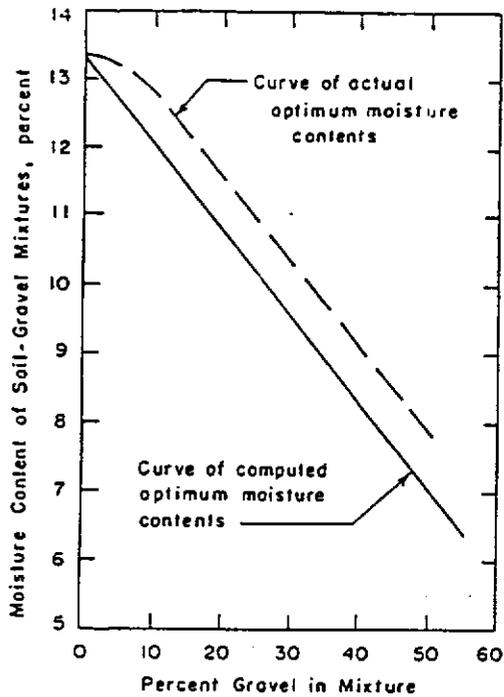


Figure 83. Effect of coarse aggregate (gravel) content on optimum moisture content (28).

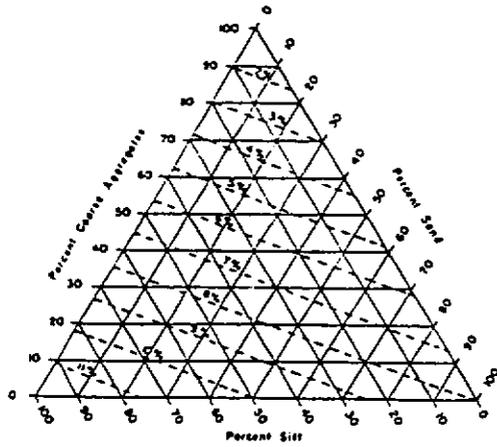


Figure 84. Triangular chart showing optimum moisture content of total material for various proportions of coarse aggregate, sand, and silt (58).

TABLE 27

Max. Size of Soil Particle (in.)	Size of Sample (lb)	Pouring Device	Volume of Measure (cu ft)
3	150	Shovel	1.0
1½	150	Scoop	0.5
¾	100	1¼-in. spout	0.5
⅜	25	1-in. spout	0.1
¼	25	½-in. spout	0.1

6. Plot the three unit weights (loose, compacted, and solid) for the coarse aggregate and the fine aggregate on a chart (as in Fig. 85) relating unit weight to percentage of fine aggregate. The three unit weights for coarse aggregate are plotted on the left side of the chart on the zero percent vertical line. The three unit weights for the fine aggregate are plotted on the right side, on the 100 percent vertical line.

The data used in the example in Figure 85 are, as follows:

Coarse aggregate:

$$\gamma_c^S = (2.73)(62.4) = 170.3 \text{ pcf}$$

$$\gamma_c^C = 107 \text{ pcf}$$

$$\gamma_c^L = 89 \text{ pcf}$$

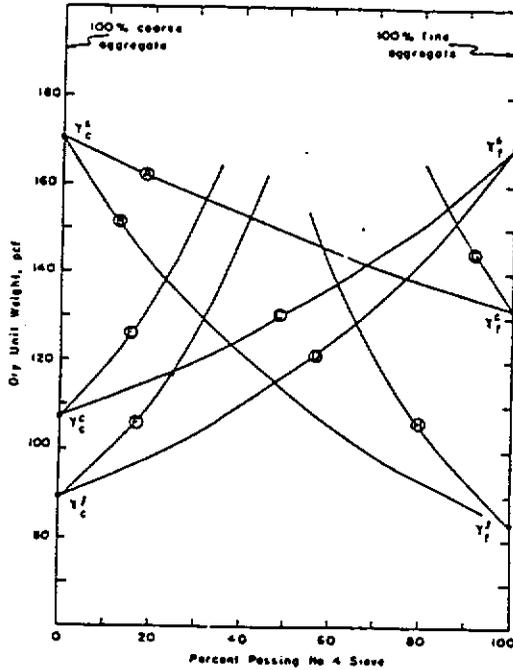


Figure 85. Sample theoretical curves for various combinations of coarse and fine aggregate and for solid, compacted, and loose unit weights (102).

Fine aggregate:

$$\begin{aligned} \gamma_f^s &= (2.71)(62.4) = 169.0 \text{ pcf} \\ \gamma_f^c &= 132 \text{ pcf} \\ \gamma_f^l &= 84 \text{ pcf} \end{aligned}$$

7. Determine sufficient points to plot each of the curves A, B, C, . . . .H, as shown in Figure 85, with the aid of the nomographs in Figures 86 and 87 or by using the following equations, and plot the curves. These curves will be used as guides in establishing the maximum unit weight curve. The equations for each curve, A through H, are as follows:

Curve A (theoretical unit weight formula)

$$\gamma_p = \frac{\gamma_c^s \gamma_f^s}{\left(\frac{p}{100}\right) \gamma_c^s + \left(\frac{1-p}{100}\right) \gamma_f^c}$$

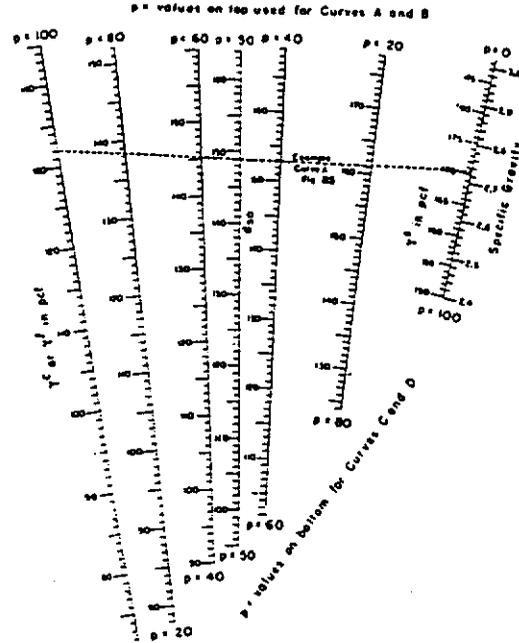


Figure 86. Nomograph for determining unit weight values ( $\gamma_p$ ) for curve A, B, C, or D for different values of p, the percentage passing the No. 4 sieve (102).

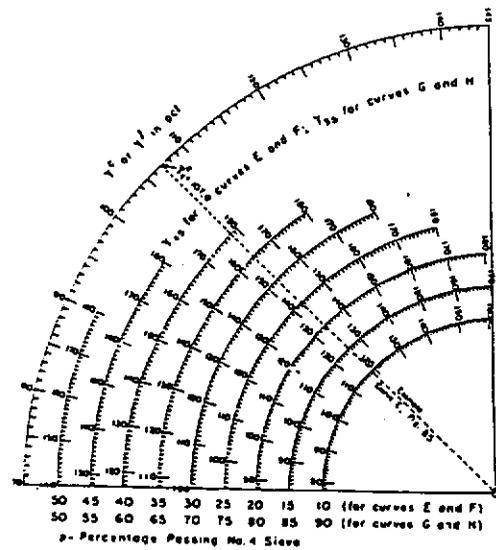


Figure 87. Nomograph for determining unit weight values ( $\gamma_p$ ) for curve E, F, G, or H for different values of p, the percentage passing the No. 4 sieve (102).

in which

- $p$  = percentage of fine aggregate;  
 $\gamma_p$  = unit weight of combination with  $p$  percent fine aggregate, pcf;  
 $\gamma_c^s$  = solid unit weight of coarse aggregate, pcf; and  
 $\gamma_f^c$  = compacted unit weight of fine aggregate, pcf.

For example, the ordinate ( $\gamma_p$ ) on curve A (Fig. 85) for a given mixture (with 20 percent fine aggregate,  $\gamma_c^s = 170$  pcf and  $\gamma_f^c = 132$  pcf) is

$$\gamma_{20} = \frac{(170)(132)}{\left(\frac{20}{100}\right)(170) + \left(1 - \frac{20}{100}\right)(132)} = \frac{(170)(132)}{(0.2)(170) + (0.8)(132)}$$

$$\gamma_{20} = 160.8 \text{ pcf}$$

Curve B:

$$\gamma_p = \frac{\gamma_c^s \gamma_f^l}{\left(\frac{p}{100}\right)(\gamma_c^s) + \left(1 - \frac{p}{100}\right)\gamma_f^l}$$

Curve C:

$$\gamma_p = \frac{\gamma_c^c \gamma_f^s}{\left(\frac{p}{100}\right)(\gamma_c^c) + \left(1 - \frac{p}{100}\right)(\gamma_f^s)}$$

Curve D:

$$\gamma_p = \frac{\gamma_c^l \gamma_f^s}{\left(\frac{p}{100}\right)(\gamma_c^l) + \left(1 - \frac{p}{100}\right)(\gamma_f^s)}$$

Curve E:

$$\gamma_p = \frac{\gamma_c^c}{1 - \frac{p}{100}}$$

Curve F:

$$\gamma_p = \frac{\gamma_c^l}{1 - \frac{p}{100}}$$

Curve G:

$$\gamma_p = \frac{\gamma_f^c}{\frac{p}{100}}$$

Curve H:

$$\gamma_p = \frac{\gamma_f^l}{\frac{p}{100}}$$

8. Label intersections of the curves (as shown in Figure 88) as follows: Curves B and E intersect at point a, G and D at b, A and D at c, B and D at d, A and F at e, and C and H at f.

9. Calculate the coordinates of point r (Fig. 88) between points  $\gamma_c^c$  and e as shown in the following equation and plot point r.

$$p_r = 0.5 p_e$$

$$\gamma_r = \frac{\gamma_c^c \gamma_e}{0.5\gamma_c^c + 0.5\gamma_e}$$

in which

- $P_r$  = percentage of fine aggregate in mixture represented by point r;
- $P_e$  = percentage of fine aggregate in mixture represented by point e;
- $\gamma_r$  = unit weight of mixture represented by point r, pcf;
- $\gamma_e$  = unit weight of mixture represented by point e, pcf; and
- $\gamma_c^c$  = compacted unit weight of coarse aggregate, pcf.

If, for example,  $P_e = 41.5$  percent  $\gamma_e = 152.0$  pcf, and  $\gamma_c^c = 107.0$  pcf,

$$P_r = -(0.5) (41.5) = 20.75 \text{ percent}$$

$$\gamma_r = \frac{(107) (152)}{(0.5) (107) + (0.5) (152)} = \frac{16270}{53.7 + 76} = 125.6 \text{ pcf}$$

10. Draw a smooth curve from  $\gamma_c^c$  through point r to e; label intersection with curve B, point o.
11. Draw straight lines ab and de and label their intersection point m; draw straight lines ac and df and label their intersection n.
12. Draw the maximum unit weight curve through  $\gamma_c^c$ , r, o, m, n, and  $\gamma_f^c$  as shown in Figure 89.

This maximum unit weight curve shows how the maximum obtainable dry unit weight of a particular material varies with the percentage of fine aggregate in the mixture. In Figure 89 it can be seen that for the sample material, the maximum unit weight increases rapidly as the fine aggregate content increases from 0 to about 35

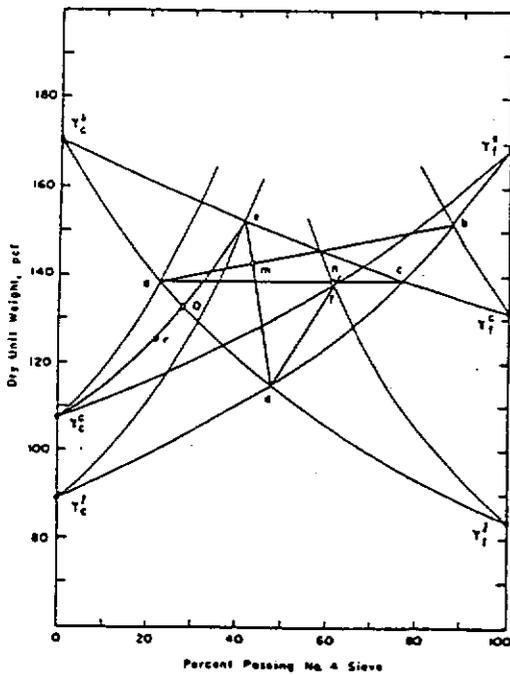


Figure 88. Determination of points (r, o, m, n) for maximum unit weight curve for mixtures of sample materials (102).

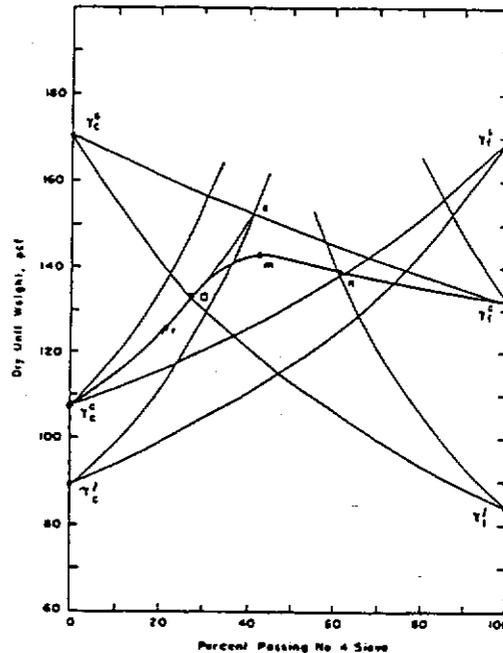


Figure 89. Derived maximum unit weight curve for mixtures of sample materials (102).

percent of the mixture. For the higher percentages of fine aggregate, fluctuations in gradation would have less effect on maximum unit weight.

The Humphres method is complex and lengthy, but has proved very useful in the State of Washington.

If several points on the Humphres maximum dry unit weight curve could be obtained by simply compacting several mixtures of coarse and fine aggregate, much time could be saved. James and Larew (133) investigated this possibility. They performed a series of impact compaction tests on two materials: a crushed limestone and a natural gravel. For each material, they first established the Humphres maximum unit weight curve. Then, they determined the compaction effort required to compact the fine aggregate (100 percent passing the No. 4 sieve) to the same unit weight as obtained in the Humphres method. Finally, they determined the maximum unit weight for each of several mixtures. The resulting maximum unit weight curve for the crushed limestone matched the Humphres curve very closely; the curve for the natural gravel generally fell below the Humphres curve. James and Larew concluded that the Humphres maximum unit weight curve represents a single level of compaction effort for some soil materials. It was also evident that a simple impact compaction test could not be used to duplicate the Humphres method for all soil-aggregate mixtures.

# A Method for Controlling Compaction Of Granular Materials

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This paper presents a method for establishing the proper maximum density values to be used for controlling the compaction of granular materials which eliminates the inconsistencies frequently encountered with methods now in use. The proposed method accounts for variations of the maximum obtainable density of a given material, for a given compactive effort, due to fluctuations in gradation.

It is proposed that by splitting the material on the No. 4 U.S. standard sieve and determining the specific gravity, the compacted density and the loose density of each of the two fractions, a curve of maximum density versus percent passing No. 4 sieve curve can be plotted, which curve values will correlate closely with the densities obtainable in the field; using modern compaction equipment.

As the density curve can be established in the laboratory prior to construction, the actual field control phase is reduced to performing field density tests only, freeing the field inspector from performing time-consuming standard maximum density tests.

Data accumulated while applying the method to more than 30 highway projects have been summarized and typical results are presented. The method is applicable either to specifications requiring compacting to a given percent of maximum density or to specifications requiring compaction to a given compaction ratio.

Use of this method eliminates the danger of applying the wrong "standard" to compaction control of gravelly soils.

● THE problem of exercising realistic field control over the compaction of granular base course and surfacing materials has perplexed both laboratory and field engineers for many years. The importance of such control becomes more apparent with each passing construction season. With the continued improvement of construction practices and control methods applied to the foundation and subgrade soils has come recognition of the fact that many roadway failures heretofore attributed to failure in the subgrade soils must be attributed to the granular base course and surfacing materials not fulfilling their structural assignment.

As density greatly affects the stability and strength properties of granular materials, and as density can be determined easily and rapidly in the field by improved methods developed for that purpose (1), it follows that, as with fine-grained soils, adequate field compaction control of the granular soils should be of considerable value to the engineer in determining that full structural value is built into the base and surfacing courses.

The primary deterrent to such control in the past has been the lack of a reliable standard with which to compare field results. A number of different procedures for establishing "maximum density" values for gravels have been applied and found inadequate. Those procedures using laboratory test results from tests performed on the fine fraction of the granular soil and applying a correction formula for the percent gravel content of the whole material are often in serious error when the gravel content exceeds 25 to 30 percent (2). Those procedures using the whole material compacted by a specific procedure are cumbersome and slow and require an excessive number of repeat tests on very large samples because minor variations in gradation often have a large effect upon obtainable density.

As a result, the wrong "standard" or "maximum density" value often has been applied, and the resulting frequent incompatibility with field results has caused the field

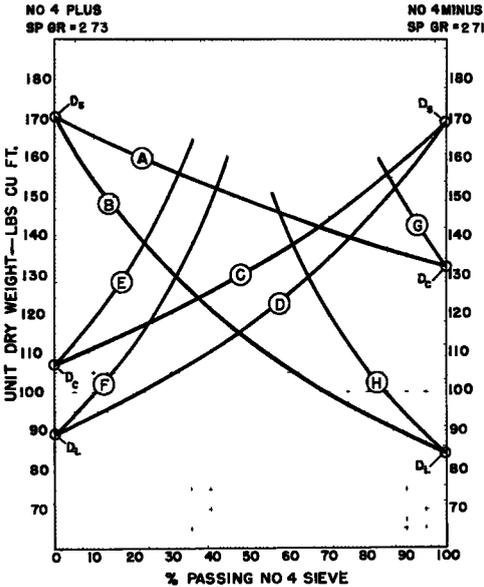


Figure 1. Theoretical curves.

experimental basis to more than thirty projects. The range of granular materials to which it has been applied covers the entire group of specification ballast, base course, and surfacing materials described in the Washington Department of Highways Standard Specifications. In addition, the method has been applied to a number of special ballast, cement-treated base, and selected roadway borrow materials. Special field correlation studies were conducted on most projects to insure complete and adequate data, and normal field control practices were used on other projects to evaluate the practicality of this method of compaction control.

The excellent results achieved with the method during the past three years has led to its adoption as a standard control method by the Washington Department of Highways. Acceptance by field personnel has been excellent.

A theoretical concept of the effects that gradation, grain size and shape, fracture and hardness have upon the maximum density obtainable from a given aggregate is undoubtedly very complex. One approach to analysis of these effects is to attempt to determine the extreme limits of possible results and then to determine if actual results follow a definable pattern in relation to these limits.

By splitting a granular material into a fine fraction and a coarse fraction, we obtain two distinctly different materials whose characteristics can be assumed to represent extremes which will encompass the characteristics of any combination of the two fractions.

In relation to unit weight characteristics

engineer to view with suspicion and distrust any attempts to apply compaction control to the base course and surfacing materials on his job.

The need exists, then, for a reliable method for determining the proper maximum density value for granular materials. As the gradation of a given granular material, such as a base course gravel, may fluctuate between rather wide specification limits, and, as gradation seriously affects the density obtainable with any given compaction procedure, the maximum density values must be correlated to gradation.

To be of practical value the maximum density-vs-gradation relationships should be established prior to construction so that the field inspector can devote his time during construction to the performance of field density tests and to giving adequate attention to the actual compaction process on the job.

The purpose of this paper is to present a method developed to fulfill the above requirements. During the past three years, this method has been applied on an experi-

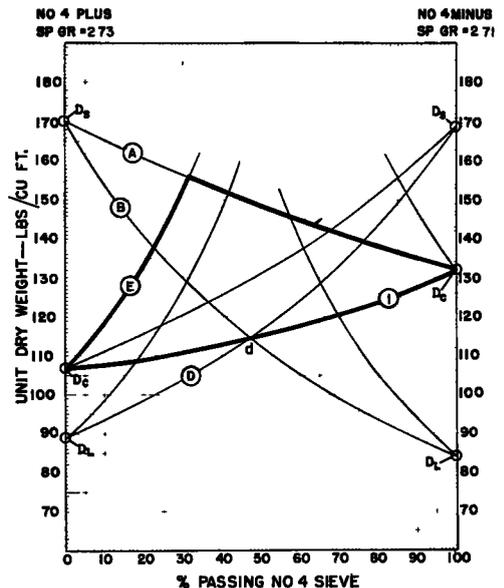


Figure 2. Theoretical limits of maximum density.

of a granular material, there are three values of density which can be determined by tests, as follows:

1. Solid density,  $D_s$ ; the density of a given material considered as a solid having zero void content. This value is determined by multiplying the specific gravity of the material by the unit weight of water.

2. Compacted density,  $D_c$ ; the density obtained by compacting the material by a specified method to the highest unit weight possible using that method of compaction. This value varies, depending on the type of test selected. The test selected should give results compatible with actual field results with modern compaction procedures.

3. Loose density,  $D_L$ ; the loosest condition possible for a material to exist unaffected by "bulking" influences of moisture. This value can be obtained from Figure 22 in Appendix B, or from the nomograph of Figure 7, both of which show the correlation between  $D_c$  (or  $D_{max}$ ) and  $D_L$  as determined by the procedure described in Appendix B. The procedure represents a new approach to the matter of loose density determination which should eliminate much of the present confusion about what loose density value should be used for a given material.

The effects of gradation are reflected in the  $D_c$  and  $D_L$  values. Specific gravity is reflected in the  $D_s$  value. Particle size and shape, texture, and fracture are reflected in the  $D_c$  and  $D_L$  values. By using these three values of density, all characteristics of a material that affect the actual obtainable density are accounted for. In this report unit weight and density shall mean pcf dry weight.

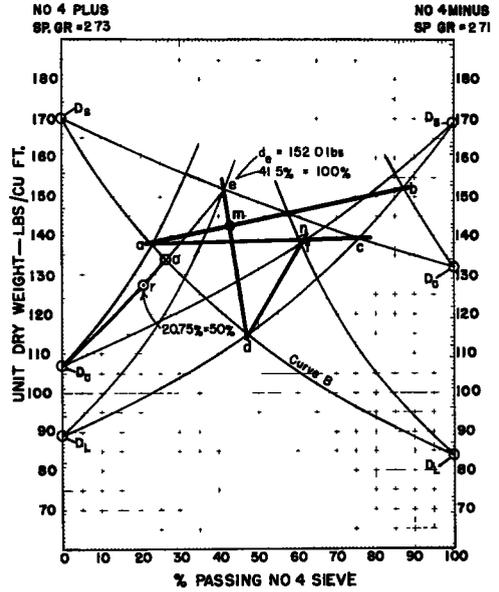


Figure 3. Points for maximum density curve.

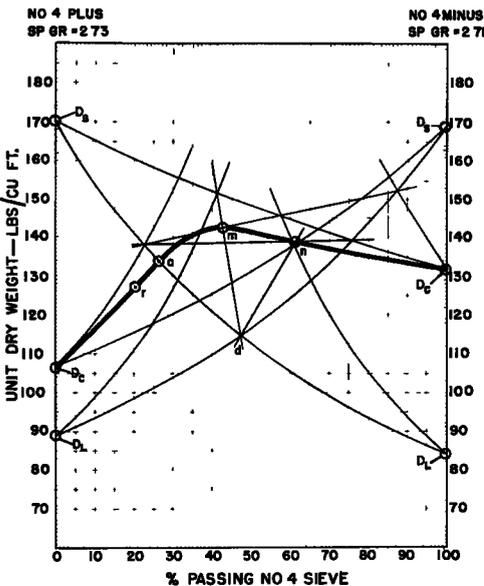
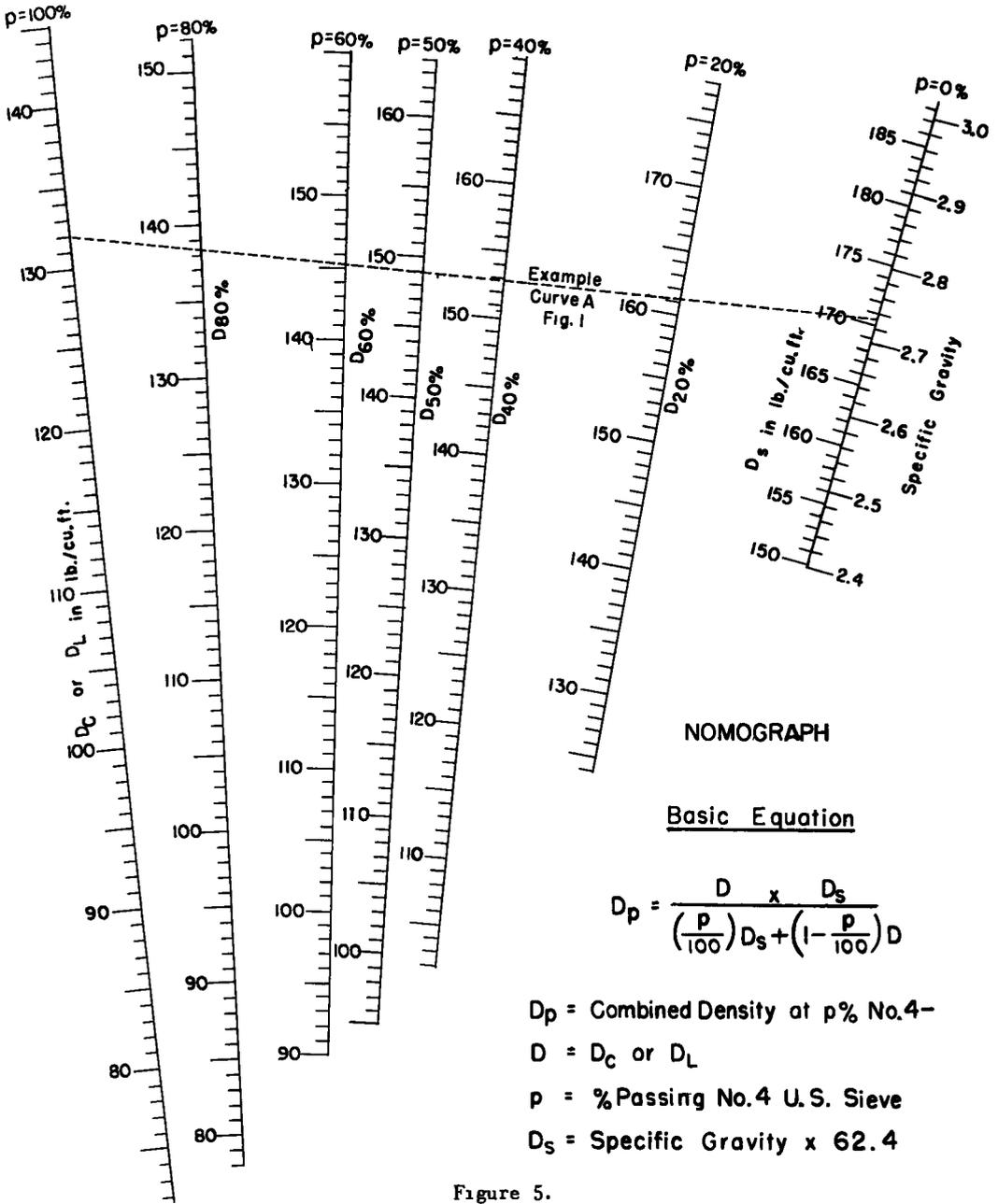


Figure 4. Derived maximum density curve.

### DERIVATION OF THEORETICAL CURVES FOR DENSITY VERSUS PERCENT PASSING NO. 4 SIEVE

As the gradation of a given specified surfacing or base course material will vary significantly on a given project, and as the actual obtainable density will vary with the gradation, a plotted curve showing the relationship of the density and the gradation is required for realistic control of compaction in the field. Such a curve can be established. The values of loose density,  $D_L$ , compacted density,  $D_c$ , and solid density,  $D_s$ , for each of the two fractions are determined and are plotted on the respective left and right ordinates, as shown in Figure 1.

By establishing certain assumptions and imposing certain conditions, several theoretical curves can be established which describe the gradation-density relationship that would occur should those assumptions and conditions hold true. To establish the true relationship curve, it has been reasoned



**NOMOGRAPH**

Basic Equation

$$D_p = \frac{D \times D_s}{\left(\frac{p}{100}\right) D_s + \left(1 - \frac{p}{100}\right) D}$$

$D_p$  = Combined Density at p% No.4-

$D$  =  $D_c$  or  $D_L$

$p$  = % Passing No.4 U.S. Sieve

$D_s$  = Specific Gravity x 62.4

Figure 5.

that each of the relationships shown by the theoretical curves derived from limited assumptions and conditions hold true to a certain extent, and that the inter-relationship of these curves establishes the correct position of the true maximum density curve.

These theoretical curves are shown in Figure 1, and are derived under the following conditions and assumptions.

Curve A

1. The No. 4-minus material is compacted to its dense condition,  $D_c$ , and remains in that state.

2. Increasing amounts of solid No. 4-plus material replace part of the No. 4-minus material, until the final product is 0 percent No. 4-minus and 100 percent No. 4-plus

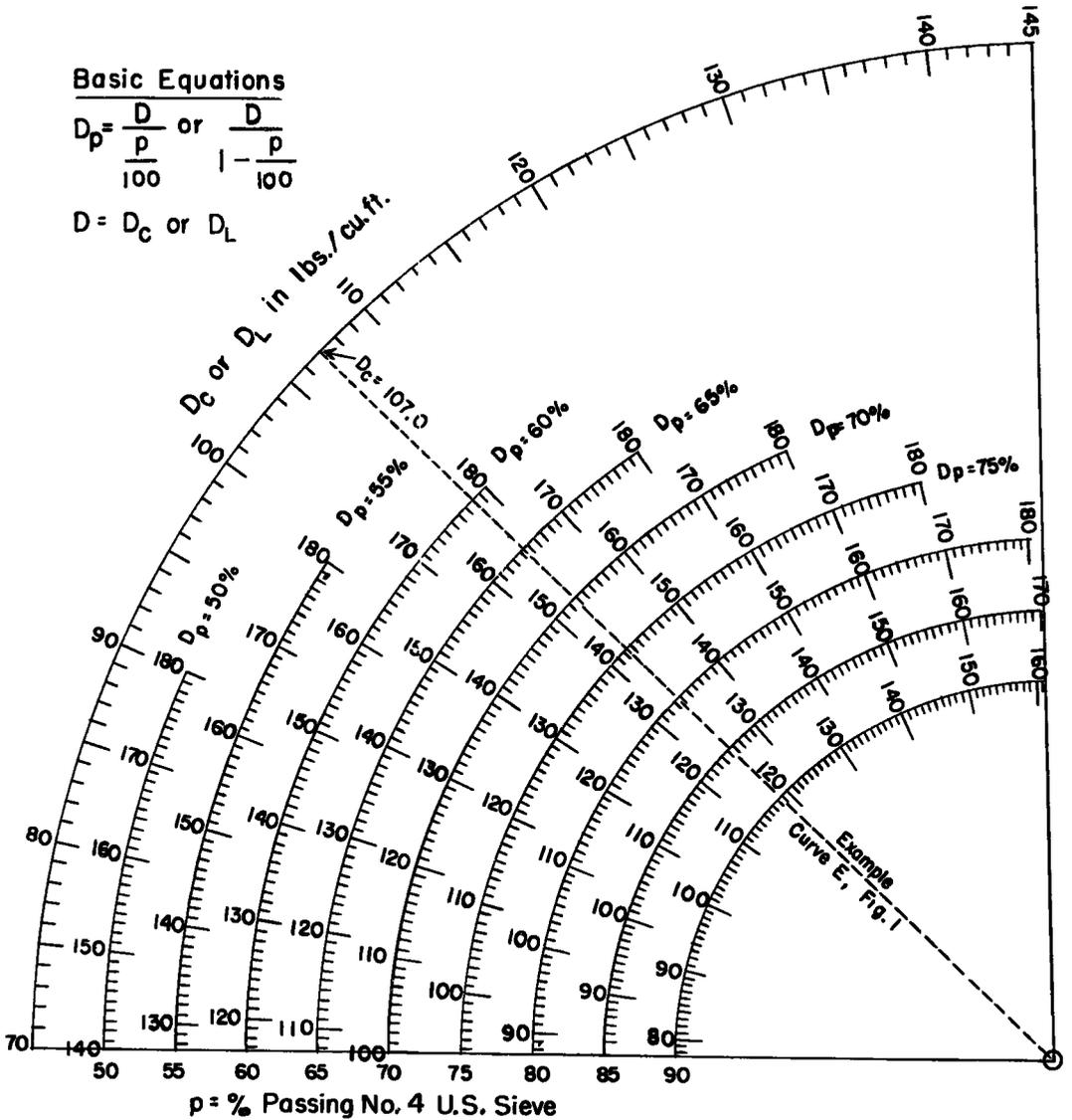


Figure 6. Nomograph for points on curves E F G and H.

in its solid condition,  $D_S$ . As percentages are based on dry weight of total sample, the density at any specific percent content of No. 4-minus can be calculated by:

$$d_p = \frac{(D_S \text{ No. 4-plus}) (D_C \text{ No. 4-minus})}{\frac{p}{100} D_S \text{ No. 4-plus} + \left(1 - \frac{p}{100}\right) D_C \text{ No. 4-minus}} \tag{1}$$

in which  $p$  = percent of No. 4-minus.

To simplify the work involved in solving this equation for a sufficient number of points to establish the curve, the nomograph shown in Figure 5 may be used. From this nomograph,  $d_p$  for  $p = 20, 40, 50, 60,$  and  $80$  percent may be found for any combination of  $D_S$  and  $D_C$  or  $D_L$ .

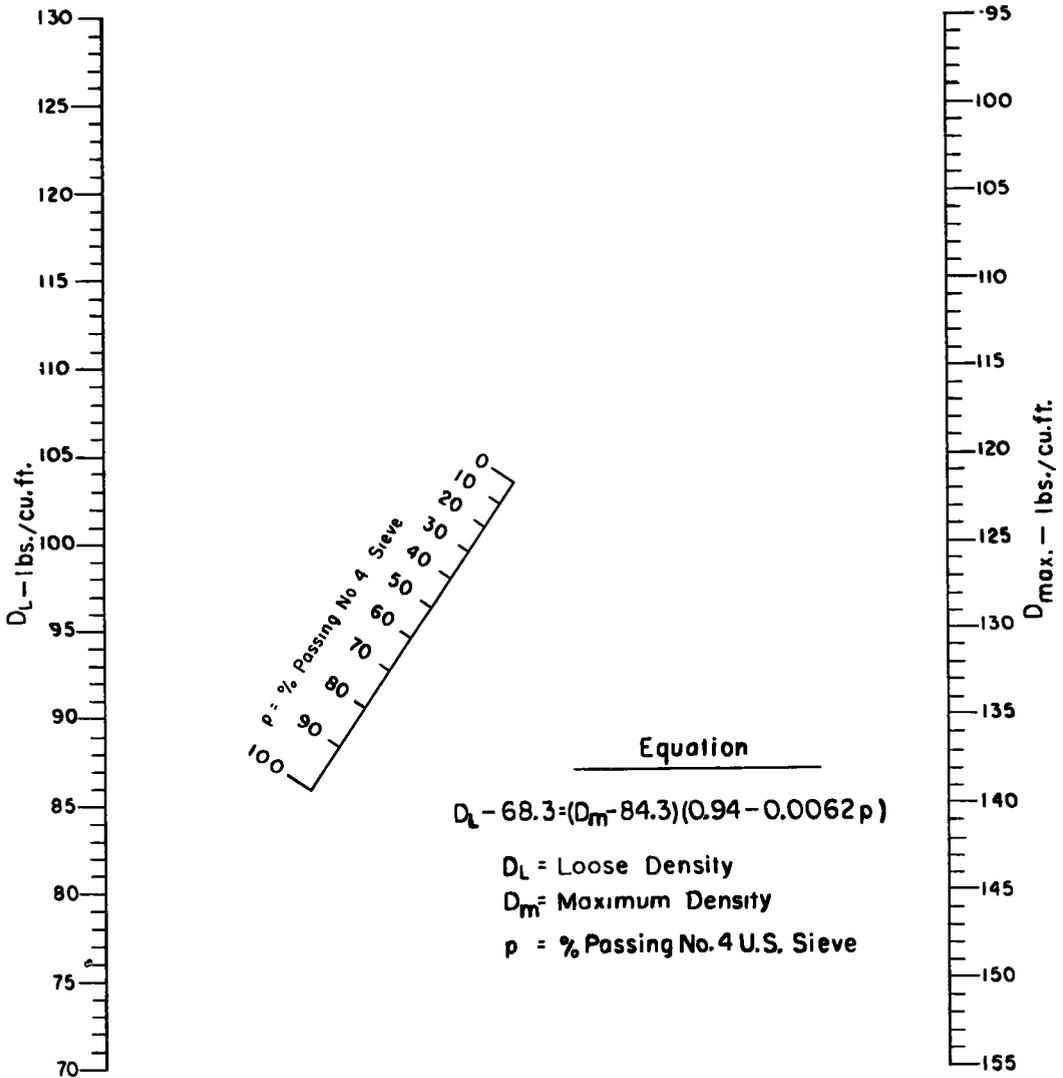


Figure 7. Nomograph for relationship of maximum density and loose density.

Curves B, C, and D

These curves are established in the same manner as Curve A, substituting the proper values in Eq. 1 or using the nomograph (Figure 5). For curves B and D,  $D_L$  is substituted for  $D_c$ . For Curves C and D, the percentage values  $p$  are reversed; that is, 80 percent = 20 percent, etc.

Curve E

1. The No. 4-plus material is compacted to its dense state,  $D_c$  (minimum void content), and remains in that condition.
2. The voids of the No. 4-plus aggregate are gradually filled with No. 4-minus material. Because the unit volume remains constant, the combined unit weight for increasing percentages by weight of No. 4-minus material can be calculated by:

$$d_p = \frac{D_c \text{ No. 4-plus}}{1 - \frac{p}{100}} \tag{2}$$

The nomograph (Figure 6) can be used to solve Eq. 2 for sufficient points to permit plotting the curve.

**Curve F**

This curve is established in the same manner, substituting  $D_L$  for  $D_C$  in Eq. 2. The No. 4-plus material is assumed to remain in its loose state while the voids are filled with No. 4-minus material.

**Curves G, H**

These curves are established in the same manner, except that the formula is changed to

$$d_p = \frac{D \text{ No. 4-minus}}{\frac{p}{100}} \quad (3)$$

and  $D = D_C$  or  $D_L$ . The nomograph (Figure 6) can be used to solve this equation, also.

The theoretical curves derived as stated and plotted as in Figure 1 form the basis for establishing theoretical extreme limits of maximum density.

If one starts with No. 4-minus material compacted to its dense condition,  $D_C$ , and add increasing amounts of No. 4-plus material, the maximum theoretical density will be that shown by Curve A. This relationship will hold until Curve A intersects Curve E. At this point the coarse fraction is compacted to its densest condition, and the voids are just filled with dense No. 4-minus material. Further increase in the proportion of No. 4-plus material will create more voids than the fines can fill, and the theoretical maximum density will follow Curve E (3). This is illustrated in Figure 2 by the heavy black lines on Curve A and Curve E.

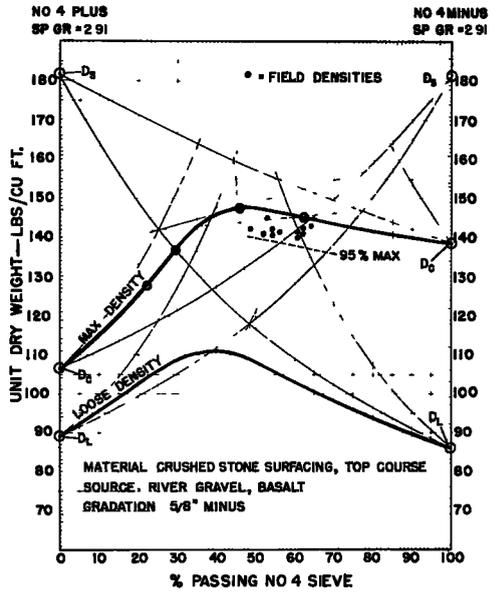


Figure 8.

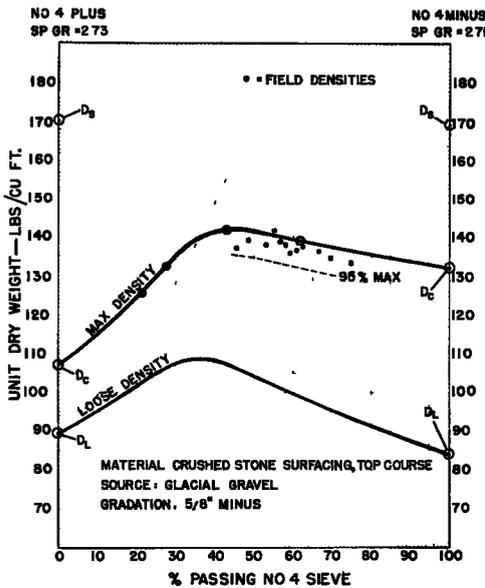


Figure 9.

Curves D and B represent theoretical density curves based on the loose, or minimum densities of the two fractions. The intercept of these curves at point d, therefore, can be said to be a point common to both fractions on the theoretical lower limiting density curve, which starts at  $D_C$  No. 4-plus and terminates at  $D_C$  No. 4-minus. The curve is shown in Figure 2 as Curve I. (The exact shape of Curve I is not important.)

The true maximum density curve must lie within the boundaries of Curves A, E, and I, and its location and shape should be determined by the inter-relationships of the theoretical curves. The following method is used to locate the maximum density curve.

It has been reasoned that when increasing amounts of No. 4-minus material are added to compacted No. 4-plus material, particle interference will cause the void content of the No. 4-plus material to progressively change from minimum to maximum. Therefore, the maximum density curve will tend to follow a curve from  $D_C$  No. 4-plus

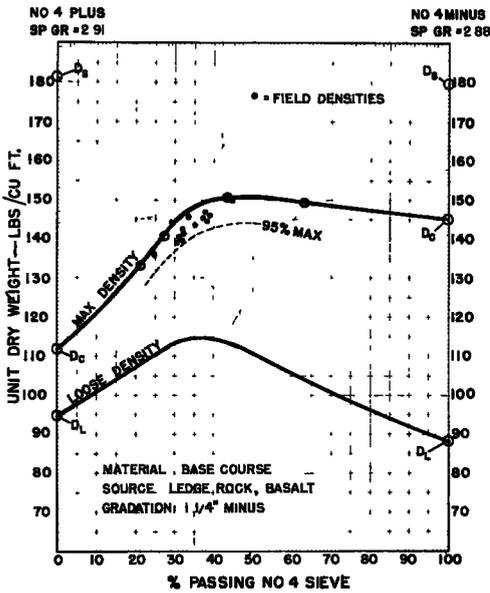


Figure 10.

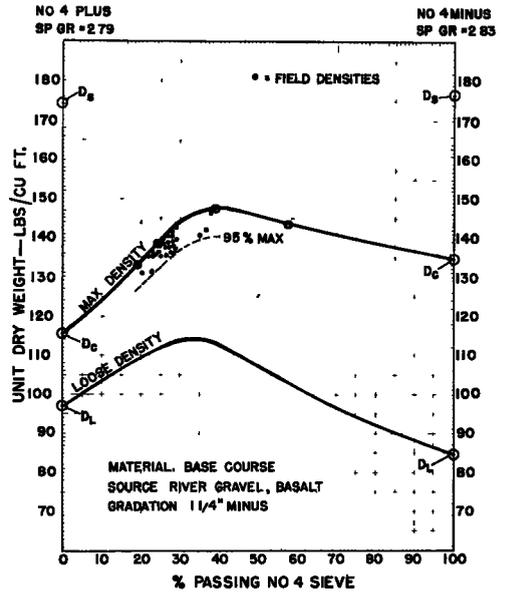


Figure 11.

toward point e (see Figure 3) until other factors divert it at or slightly past its intercept with Curve B (point o). The shape of this curve is determined by the basic equation in Figure 5 by substituting the unit weight of point e for  $D_s$ , and  $D_c$  No. 4-plus for  $D$ . The percent passing No. 4 sieve at point e is equated to 100 percent, and calculation of the mid-point (50 percent) value ( $r$ ) is sufficient to permit drawing the curve. The unit weight at point  $r$  can be obtained either from the equation or from the nomograph.

Other points on the maximum density curve are located by establishing relationships between critical intercepts of the theoretical curves. Points a and b are graphically opposite intercepts. Points a and c are similar points on opposing boundary

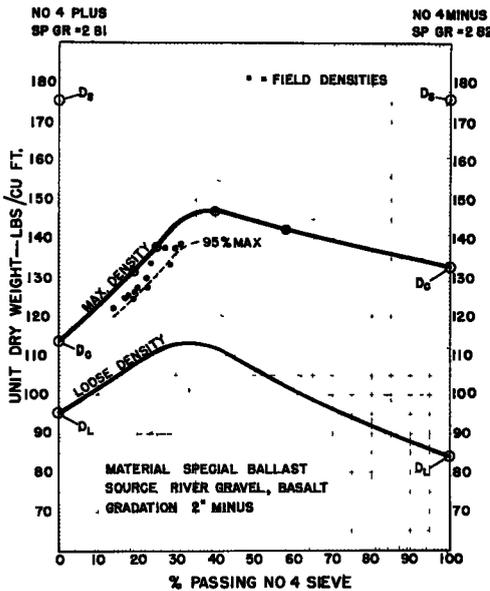


Figure 12.

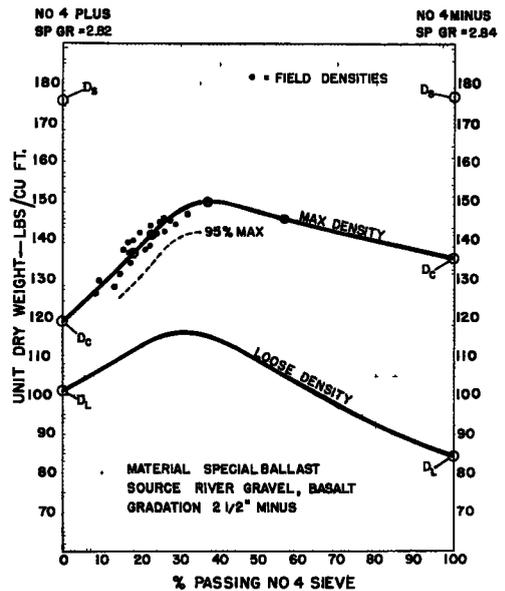


Figure 13.

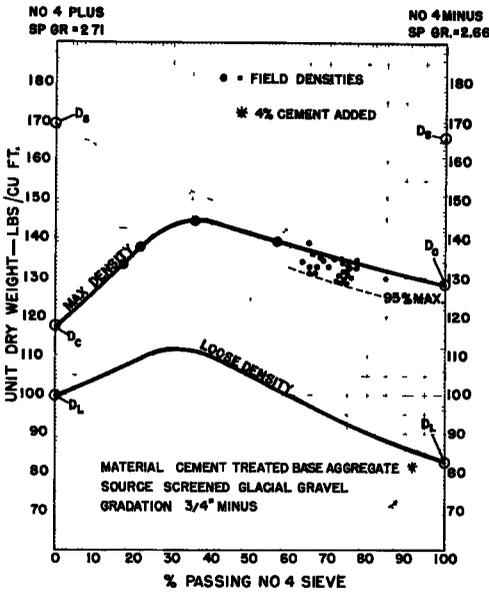


Figure 14.

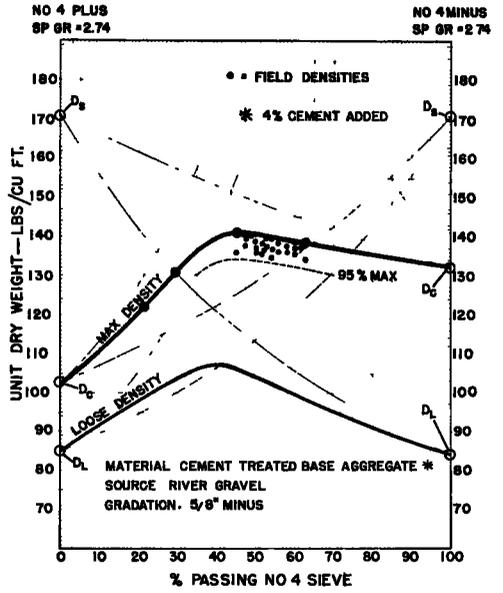


Figure 15.

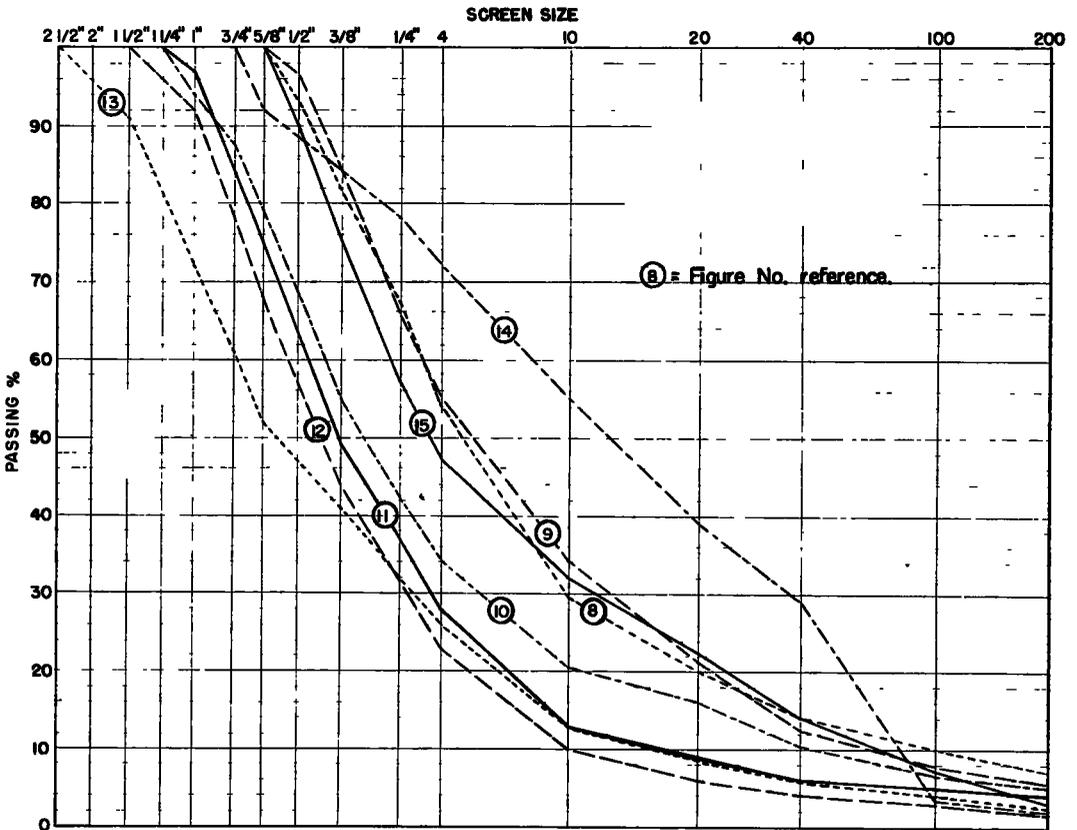


Figure 16. Gradation curves for aggregates illustrated by Figures 8 through 15.

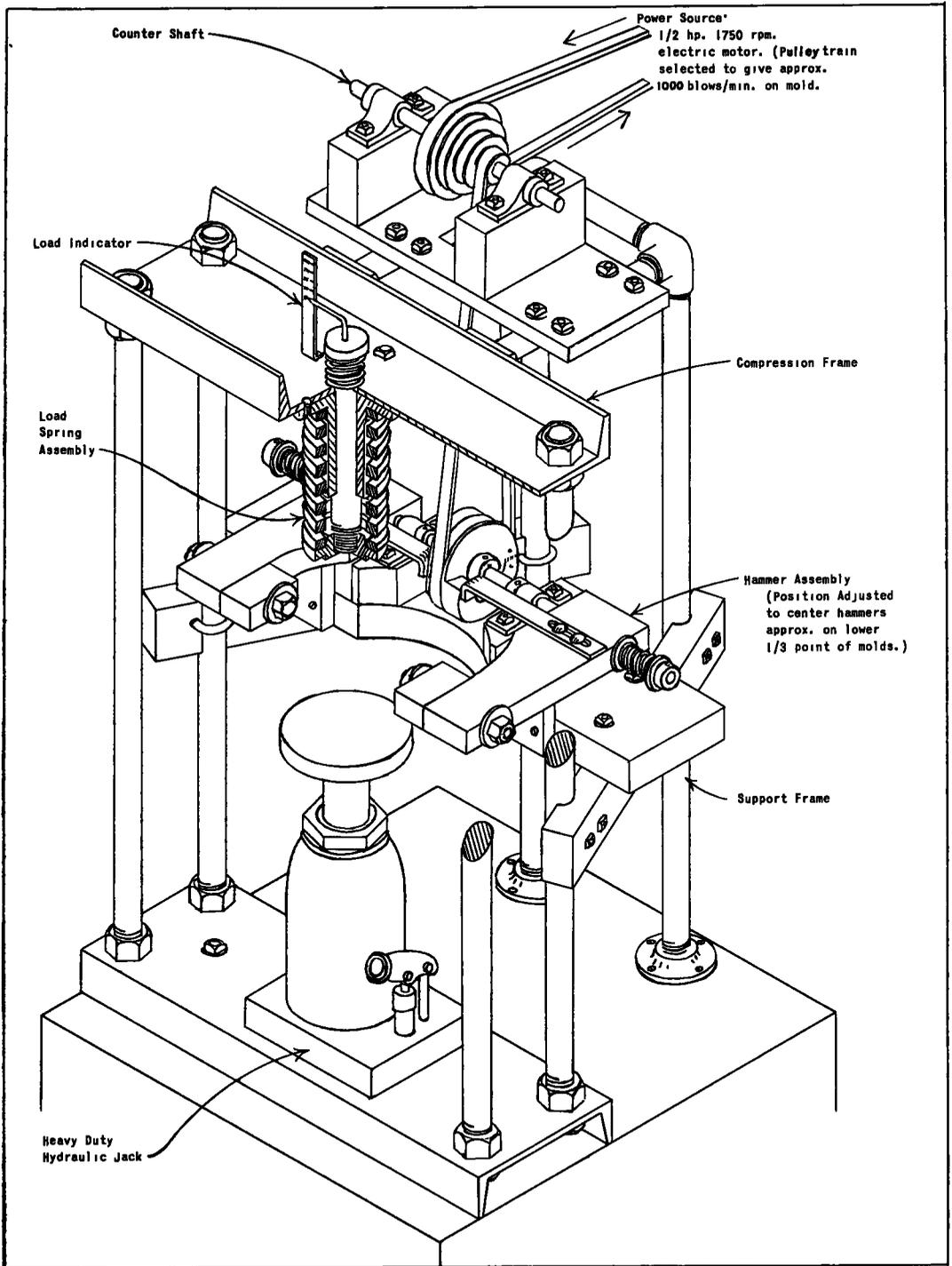


Figure 17. Pilot model -- vibratory spring-load compactor.

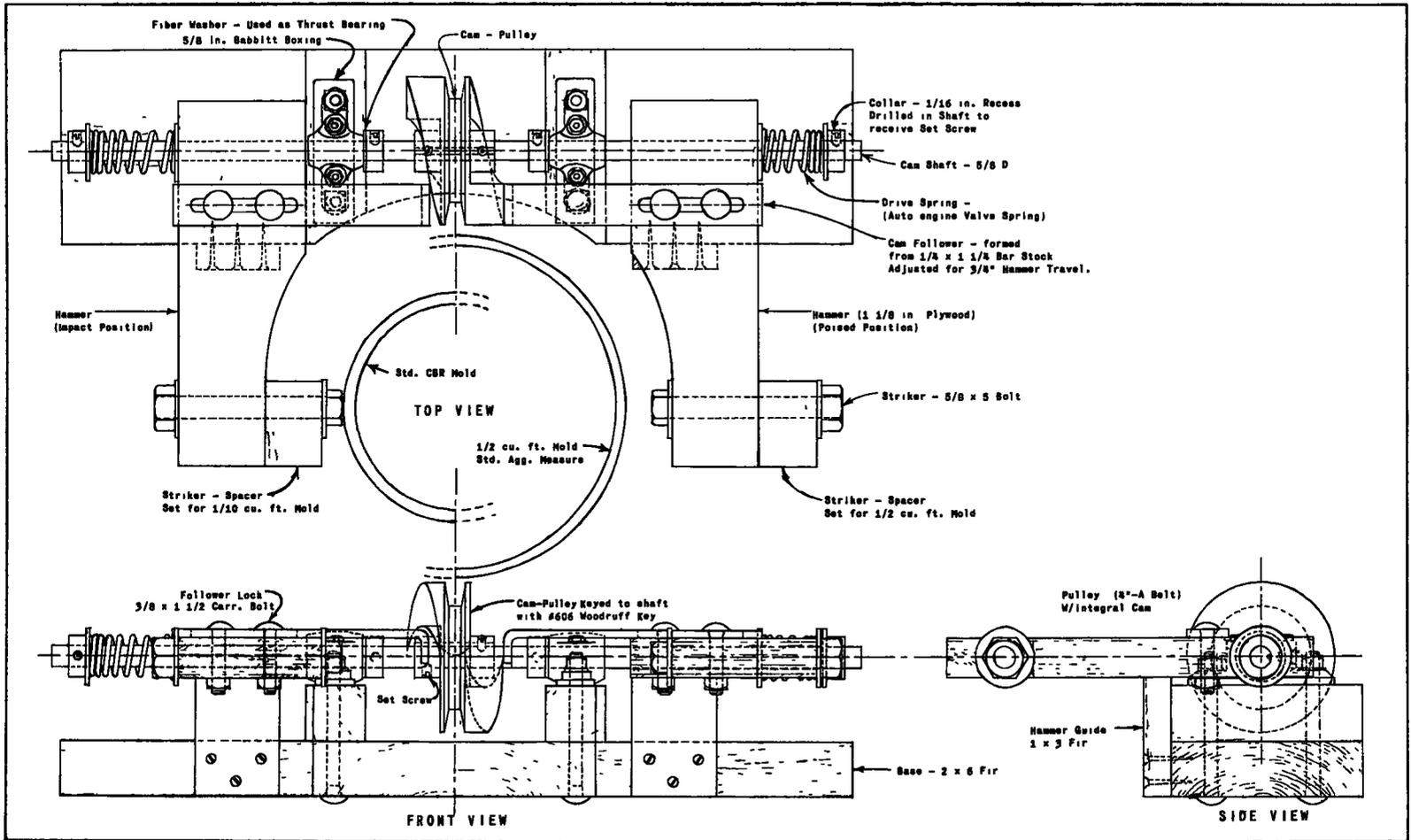


Figure 18. Hammer assembly. Pilot model -- vibratory spring-load compactor.

curves. Points e and f have opposing graphical position, and point d has a neutral position in relation to the two gravel fractions. From these critical points the locations of points m and n on the maximum density curve are determined. Point m is the intercept of  $\bar{a}b$  and  $\bar{d}e$ , and point n is the intercept of  $\bar{a}c$  and  $\bar{d}f$  or its extension. The maximum density curve is a smooth curve starting at  $D_c$  No. 4-plus, passing through points r, o, m, and n and terminating at  $D_c$  No. 4-minus as shown in Figure 4.

PRACTICAL APPLICATION

On first reading, the foregoing procedure may appear somewhat involved. However, in actual practice the process is quite simple and direct. The nomographs furnished eliminate the mathematical work involved in locating the curves. The laboratory tests required consume a minimum of time. The over-all economy of time inherent to this method is obvious when one considers that the maximum density curve established for a given material eliminates the need of performing any further standard density tests with which to compare field densities obtained with that material.

A representative sample of the material to be used on a given project is submitted to the laboratory prior to the time of actual use in construction. The sample is graded and divided into two fractions separated on the No. 4 U.S. standard sieve. The specific gravity and the compacted density  $D_c$  are determined for each of the two fractions as described in Appendix A. The loose density  $D_L$  for each fraction is obtained by using the relationships established for  $D_c$  and  $D_L$  in Appendix B. The nomograph (Figure 7) was derived from Figure 23, Appendix B, and may be used for obtaining the  $D_L$  values.

The respective values for  $D_s$ ,  $D_c$ , and  $D_L$  are used as described heretofore to determine the maximum density vs percent passing No. 4 U.S. sieve curve, and this curve is submitted to the field inspector for

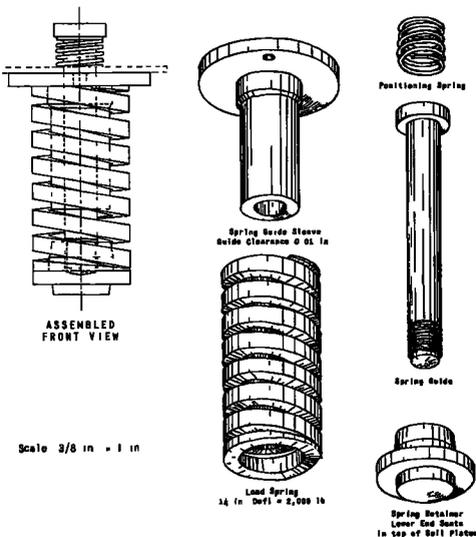


Figure 19. Load spring assembly. Pilot model -- vibratory spring-load compactor.

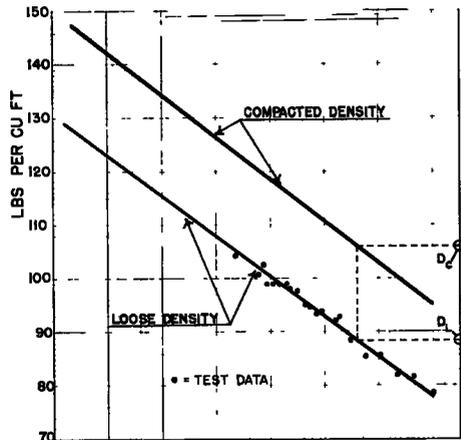


Figure 20. No. 4 plus fraction compacted density ( $D_c$ ) vs. loose density ( $D_L$ ).

use in controlling compaction of the subject material.

When a field density test is made, a representative sample is separated from the total sample excavated from the test hole for moisture determination. After drying and weighing, this portion is screened through a No. 4-sieve and the percent passing the No. 4-sieve is calculated. The calculated value is used to obtain the proper maximum density value for that particular sample from the maximum density curve. The field density value is compared to the maximum density value and the degree of compaction is evaluated.

Some agencies prefer to use compaction ratio as a control standard rather than percent maximum density. Those agencies will find further use of Figure 7 or Figure 23, Appendix B. From either of these graphs, the loose density corresponding to the maximum density for each successive 10 percent increase of percent passing No. 4-minus can be determined, and the loose density curve corresponding to the maximum density curve can be drawn. From these curves, the  $D_{max}$  and  $D_L$  values can be determined for any specific sample gradation.

Typical actual field results are illustrated by Figures 8 through 15. The material is described, the maximum density and loose density curves are plotted, and actual field density test values obtained during construction are plotted in relation to the curves. The gradation curves of the samples used to establish the maximum density curves are shown in Figure 16. As the compaction effort was regulated to yield 95 percent of maximum density or more, the 95 percent curve is drawn also. The Washington Dens-O-Meter, as described in HRB Bulletin No. 93, was used for obtaining field densities.

The range of gradations found in the field tests should be noted. All of these materials were manufactured to meet specifications, and control samples during production verified that specifications were satisfied. These data indicate that segregation during construction is a problem and that the gradation as finally found in the roadbed may sometimes exceed specification limits. From the standpoint of compaction control, the variation in gradation is not extremely serious for the finer materials (such as shown in Figure 8 and 9), because the maximum density does not change excessively for minor changes in gradation. However, radical changes in maximum density occur for minor variations of gradation for the coarse materials illustrated in Figures 10 through 13. For these materials, it is obvious that an "average maximum density" value would be useless for realistic control.

The method has been applied to a number of cement-treated base courses. In Washington, this is a high-quality base constructed by adding cement and water to a graded gravel meeting relatively high standards of quality and gradation. As compaction is rigorously controlled to yield better than 95 percent compaction, these projects serve as excellent measures of the suitability of the compaction control method. Typical results are illustrated in Figures 14 and 15. When performing the basic tests to establish the specific gravity and compacted density values, the proper proportion of cement must be added to the fine fraction.

### CONCLUSIONS

1. Maximum density values obtained in the manner described correlate well with maximum densities obtainable in the field and furnish a satisfactory standard for controlling compaction of granular materials.
2. Elimination of the need to perform continual maximum density tests on the aggregates during construction is of particular advantage and improves the quality of inspection and the efficiency of the inspector.
3. The method is applicable to a wide range of granular soils, ranging from fine aggregates having up to 80 percent passing the No. 4 sieve to coarse aggregates having a maximum size of about 3 in. and as little as 10 percent passing the No. 4 sieve.

### ACKNOWLEDGMENTS

The author is indebted to Laurence J. Gadbois, Junior Materials Engineer, for his critical assistance in developing the new test procedures described, and to both him

and Kenneth Gaw, Engineering Aide, for obtaining and compiling the large volume of field and laboratory test data necessary to the development of this report. Appreciation is expressed to Roger V. LeClerc, Senior Materials Engineer, for his contribution of the nomographs in Figures 5 and 7.

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# Appendix A

## TEST PROCEDURES

The following are descriptions of test procedures developed for use in evaluating compaction characteristics of granular materials. For illustrations of the vibratory, spring load compactor unit specified, see Figures 17, 18 and 19.

**TEST NO. 1: Compaction Test for Granular Material, Fine Fraction (100 percent passing No. 4 U. S. standard sieve).**

This test was developed for the sandy, non-plastic, highly permeable soils which normally occur as the fine fraction of granular base course and surfacing materials. When the fine fraction is primarily a soil having some plasticity and low permeability, AASHO T99-38 (Standard Proctor Test) may be used. With borderline soils, both tests should be applied, and the one yielding the highest density value should be used. Applying shock vibrations to the sides of the mold while using a light vertical compression load has the primary effect of reducing wall friction and thus increasing the efficiency of the vertical compression load. This greater efficiency allows use of the moderate compression load, which reduces sample degradation and particle distortion and closely duplicates actual field compaction.

**Equipment:** Vibratory, spring load compactor; standard CBR mold; piston to fit inside mold ( $\frac{1}{16}$ -in. clearance); height-measuring device accurate to 0.001 in.; and 5-lb tamping hammer with 3-sq. in. face area and  $\frac{3}{8}$ -in. diameter rod handle.

### Procedure:

1. Oven-dry (110 to 120 F) total original sample.
2. Separate sample, by screening, into two fractions divided on the No. 4 U. S. standard sieve. The coarse fraction shall be used in Test No. 2.
3. From the fine fraction (No. 4-minus) split or otherwise obtain a representative sample of approximately 13 lb. (This weight can be adjusted after the first compaction run to yield a final compacted sample approximately 6 in. high.)
4. Add amount of water estimated to produce a saturated sample when compacted.<sup>1</sup>

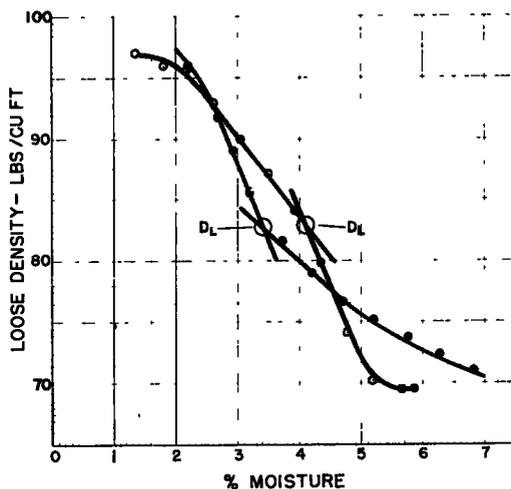


Figure 21. Percent moisture vs. loose density for No. 4 minus fraction.

<sup>1</sup> The moisture content should be adjusted so that free water will show at the base of the mold at about the 500-lb pressure point of the first compression run (step 7). Most

5. Place sample in mold in three layers. Rod each layer 25 times (use handle of tamping hammer) and tamp with 25 blows of the tamping hammer. The blows of the hammer should approximate that produced by a 12-in. free fall provided severe displacement of sample does not occur. In such cases adjust blow strength to produce maximum compaction. The surface of the top layer should be finished as level as possible.

6. Place piston on top of sample in mold and mount mold on jack in compactor. Elevate mold with jack until load-spring retainer seats on top of piston. Apply initial seating load of about 100 lb on sample.

7. Start compactor hammers and at same time gradually increase spring load on sample to 2,000-lb total pressure by elevating jack. The rate of load application is as follows:

0 to 500 lb	-	1 min
500 to 1,000 lb	-	$\frac{1}{2}$ min
1,000 to 2,000 lb	-	$\frac{1}{2}$ min

After reaching 2,000-lb pressure, stop hammer, release jack, and return to zero pressure.

8. Repeat step 7 four additional times. After last run, remove mold from compactor.

9. Determine height of compacted sample to nearest 0.001 in. and calculate volume.

10. Remove specimen from mold, determine weight accurately to nearest 0.01 lb and calculate wet density.

11. Determine moisture content of sample and calculate the dry density.

12. Repeat steps 3 through 11 at higher or lower moisture contents on fresh samples to obtain the maximum density value for material.<sup>1</sup> Three tests are usually sufficient.

**TEST NO. 2: Compaction Test for Granular Material, Coarse Fraction (0 percent passing No. 4 U.S. standard sieve).**

This test involves two separate procedures based on the maximum size aggregate being tested. When the maximum size is  $\frac{3}{4}$  in. or less, a 0.1-cu ft sample size is satisfactory. For material having a maximum size of 1 to 3 in., the sample size should be increased to about  $\frac{1}{2}$  cu ft for accuracy.

**A. Test for Coarse Aggregate having a maximum size of  $\frac{3}{4}$  in. or less.**

Equipment: See list for Test No. 1.

Procedure:

1. From the coarse fraction obtained in step 2, Test No. 1, separate a representative sample of 10 to 11 lb and weigh accurate to 0.01 lb.

2. Dampen sample with 2 $\frac{1}{2}$  percent moisture<sup>2</sup> and place in 0.1-cu ft mold in three lifts. Tamp each lift lightly with 25 blows of the tamping hammer (omit rodding). Avoid loss of material during placement.

3. Place piston on sample in mold and follow procedure outlined in steps 6, 7, 8 and 9 of Test No. 1.

4. Using original dry weight value, calculate dry density in pcf.

**B. Test for Coarse Aggregate having a maximum size greater than  $\frac{3}{4}$  in.**

Equipment: See list for Test No. 1 and add the following:

<sup>1</sup> (continued) materials will yield highest density at that moisture content. Some materials may continue to gain density on increasing the moisture above that specified; however, severe washing out of fines will occur, which will alter the character of the sample and void the results.

<sup>2</sup> It was found through experiment that moisture in excess of 2 $\frac{1}{2}$  percent has no effect on the final density obtained with these coarse, open-graded aggregates. For very coarse aggregate requiring the use of the  $\frac{1}{2}$ -cu ft mold, moisture has no effect on density and can be omitted.

$\frac{1}{2}$ -cu ft standard aggregate measure  
 $\frac{3}{4}$ -in. piston, plywood with bottom face covered  
 with 16-gage sheet steel and diameter  $\frac{1}{8}$  in.  
 less than I. D. of  $\frac{1}{2}$ -cu ft measure.

### Procedure:

1. From the coarse fraction obtained in step 2, Test No. 1, separate a representative sample of about 45 lb and weigh accurately to 0.1 lb.
  2. Divide the sample into five representative and approximately equal parts.
  3. Place the sample in the mold in five lifts. After each lift is placed in the mold, position piston on sample, mount mold in compactor, and compact as described in step 7, Test No. 1. Spacers between the load spring and piston must be used to adjust the elevation of the mold so the hammers strike the mold in the vicinity of the lift being compacted.
  4. After the final lift is compacted, remove the mold from the compactor, determine the height<sup>3</sup> of the compacted sample, and calculate the volume.
  5. Calculate the dry density value in pcf.
- TEST NO. 3. Specific Gravity Determination for Fine Fraction (100 percent No. 4-minus). Use ASTM Designation: D 854-52.
- TEST NO. 4. Specific Gravity Determination for Coarse Fraction (0 percent No. 4-minus). Use ASTM Designation: C 127-42 for Apparent Specific Gravity.

## Appendix B

### DETERMINATION OF COMPACTED DENSITY VS LOOSE DENSITY RELATIONSHIPS FOR GRANULAR SOILS

Extensive experimental work with the separate coarse and fine fractions (separated by No. 4 U.S. standard sieve) of granular base and surfacing materials has revealed that a definable relationship exists between the loose density,  $D_L$ , and the compacted

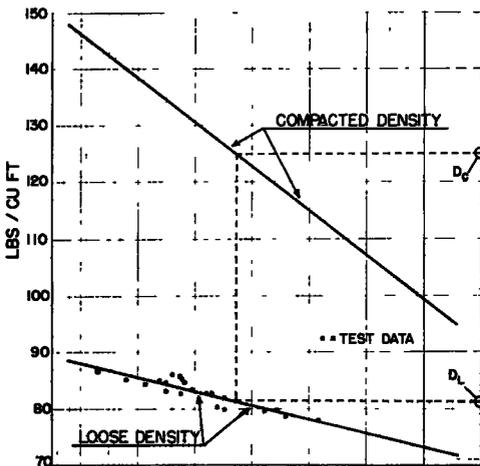


Figure 22. No. 4 minus fraction. Compacted density ( $D_C$ ) vs. loose density ( $D_L$ ).

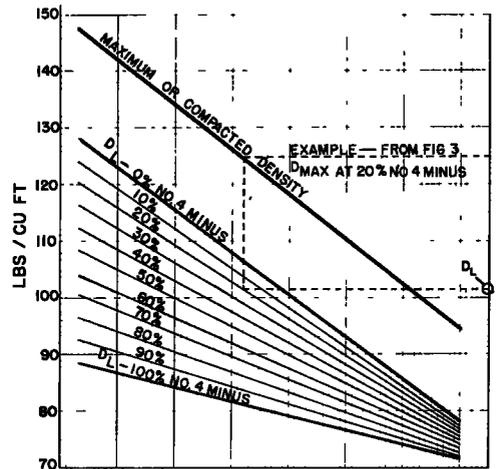


Figure 23. Relationship of maximum density and loose density.

<sup>3</sup> The procedure of measuring the average height of sample to the top surface of the piston, and then correcting for the piston is satisfactory for 1-in. maximum size aggregate. For larger material it is necessary to minimize the error introduced by the excessive void ratio obtained at the surface contact with the piston. By determining the total volume of the mold and using the Washington Dens-O-Meter to measure the unused volume above the sample, a more correct volume of sample can be obtained.

density  $D_C$ , inherent to these materials. For the range of materials examined, this relationship can be shown as a straight line.

The physical procedure used to determine the loose density was very similar to that proposed by Burmister. Appropriately sized funnels were used to place the aggregate in known-volume containers by gently pouring the aggregate through the funnel into the container. With No. 4-minus aggregate, the container was filled over-full and struck off level. With large, coarse aggregates, a funnel could not be used satisfactorily, and the material was placed from a scoop. The surface of these materials was leveled by hand-picking.

With the No. 4-plus fraction, it was found that moisture has no effect on the loose density obtainable, and oven-dried samples were used. When correlated with the compacted density ( $D_C$ ) obtained with Test No. 2 (Appendix A), Figure 20 was obtained. Data are shown for 21 different aggregates ranging from  $\frac{3}{8}$  to 3-in. max. sizes and varying in shape, fracture, and specific gravity.

With the No. 4-minus fraction, no rational correlation could be found with loose densities obtained with the dry aggregate. On adding moisture, the loose density generally followed one of two typical curves (Figure 21) to a minimum value, which also showed no correlation with the compacted density. It was found, however, that the loose density value located at the point of deviation from the upper tangent (point  $D_L$ , Figure 21) yielded the correlation shown in Figure 22, when plotted against the compacted density  $D_C$  obtained from Test No. 1 (Appendix A). Figure 22 shows the results obtained with 21 samples representing a wide range of aggregate types. Deviations from a straight line are within the accuracy limits of the test. It has been reasoned that low moisture contents assist in preventing sample segregation and stabilize the particle orientation during placement, and high moisture contents introduce bulking forces. Point  $D_L$  (Figure 21) is defined as the minimum loose density obtainable without bulking. The excellent correlation obtained indicates that this value should be the significant loose density value related to compactability.

As the relationship of  $D_C$  and  $D_L$  for both fractions is a straight line, it can be assumed that similar straightline relationships exist for all combinations of the two fractions. If a uniform rate of change of slope is established between the two limiting curves, Figure 22 can be produced, and from this the  $D_C$  vs  $D_L$  relationships for all combinations of No. 4-plus and No. 4-minus fractions can be determined. These data permit the application of "compaction ratio" as a method of field density control, and will eliminate the wide divergence of loose density values obtained by different agencies.