
Standard Method of Test for

Particle Size Analysis of Soils

AASHTO Designation: T 88-10



**American Association of State Highway and Transportation Officials
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1. SCOPE

- 1.1. This method describes a procedure for the quantitative determination of the distribution of particle sizes in soils.
- 1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.
- 1.3. The values stated in SI units are to be regarded as the standard.
- 1.4. Refer to R 16 for regulatory information for chemicals.

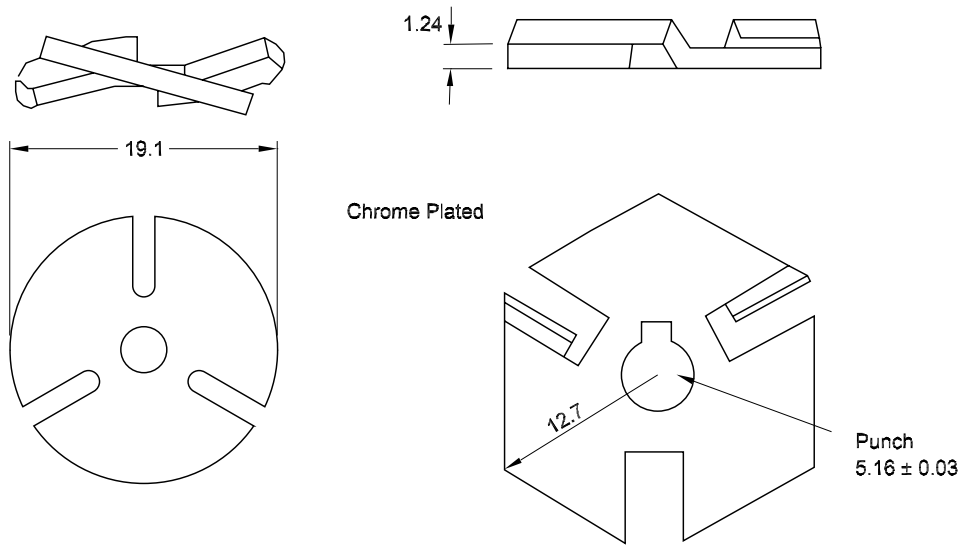
2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
 - M 92, Wire-Cloth Sieves for Testing Purposes
 - M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
 - M 147, Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses
 - M 231, Weighing Devices Used in the Testing of Materials
 - R 16, Regulatory Information for Chemicals Used in AASHTO Tests
 - R 58, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
 - T 100, Specific Gravity of Soils
 - T 146, Wet Preparation of Disturbed Soil Samples for Test
 - T 265, Laboratory Determination of Moisture Content of Soils
- 2.2. *ASTM Standards:*
 - C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
 - E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
 - E 100, Standard Specification for ASTM Hydrometers

3. APPARATUS

- 3.1. *The apparatus shall consist of the following:*

- 3.1.1. *Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$) for drying the sieve analysis samples.
- 3.1.2. *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 M 231.
- 3.1.3. *Stirring Apparatus*—A mechanically operated stirring apparatus consisting of an electric motor suitably mounted to turn a vertical shaft at a speed not less than 10,000 revolutions per minute without load, a replaceable stirring paddle made of metal, plastic, or hard rubber similar to one of the designs shown in Figure 1. The shaft shall be of such length that the stirring paddle will operate not less than 19.0 mm ($\frac{3}{4}$ in.) nor more than 38 mm (1.5 in.) above the bottom of the dispersion cup. A dispersion cup conforming to either of the designs shown in Figure 2.

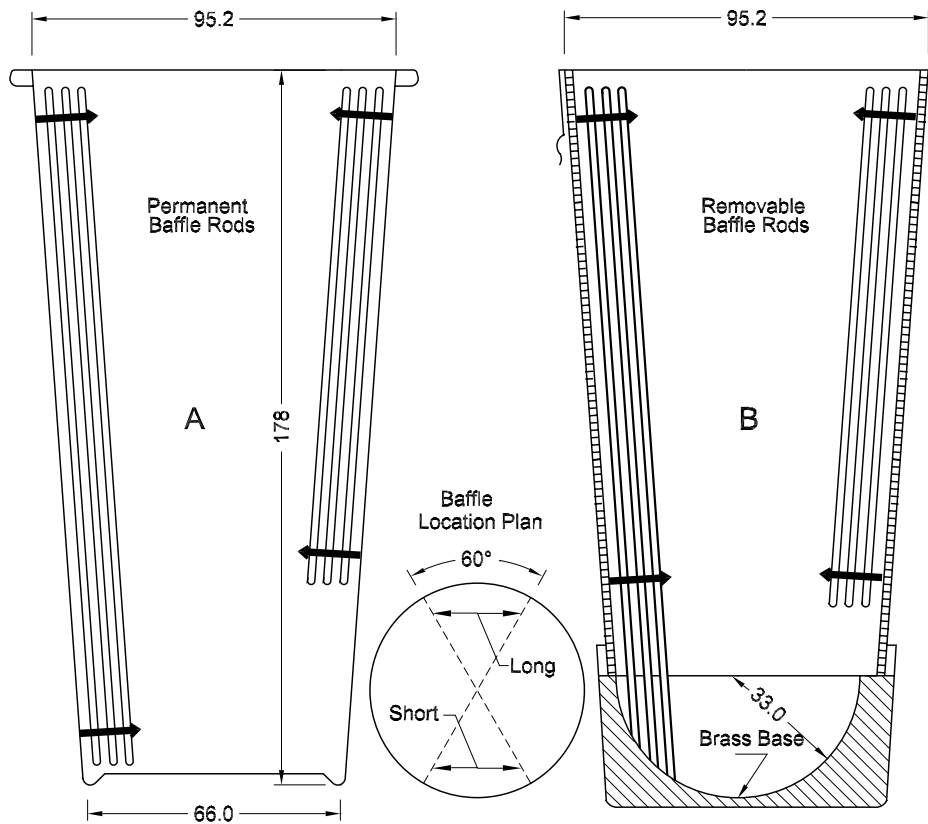


Dimensional Equivalents

mm	in.
19.1	$\frac{3}{4}$
12.7	$\frac{1}{2}$
5.16 ± 0.025	0.203 ± 0.001
1.24	0.049 (No. 18 BW Ga.)

Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 1—Details of Stirring Paddles



Dimensional Equivalents

mm	in.
33.0	1.3
66.0	2.6
95.2	3.75
178	7.0

Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 2—Dispersion Cups

3.1.3.1. (Alternate B)—An air-jet type dispersing device similar to either of the designs shown in Figure 3.

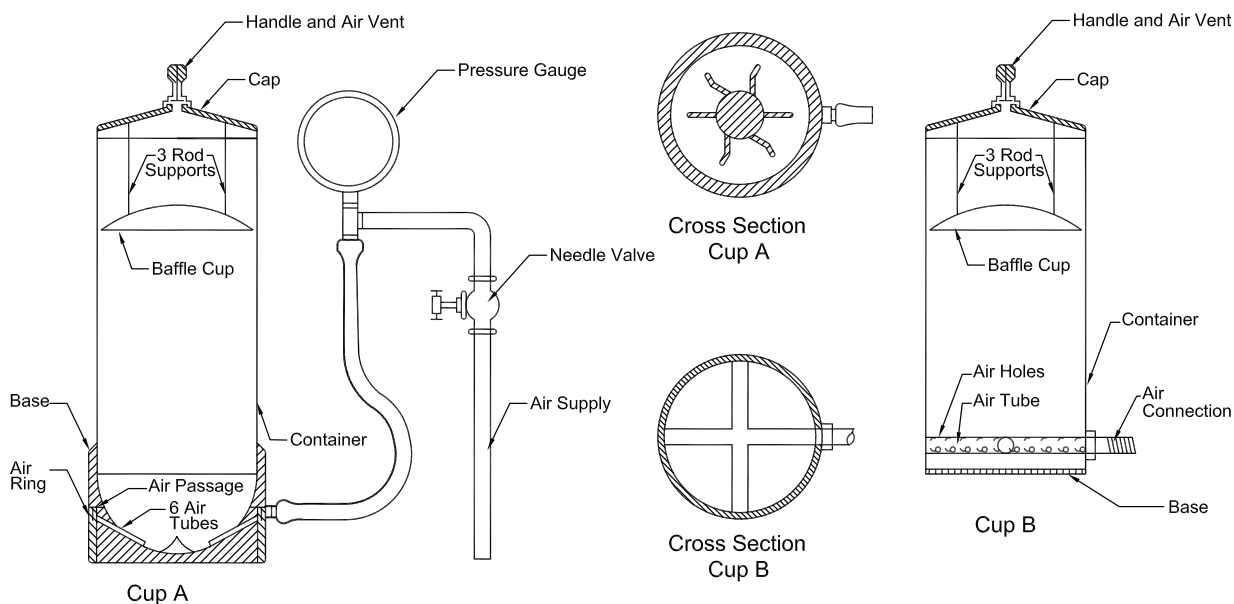


Figure 3—The Wintromyer Soil Dispersion Cups

Note 1—The amount of air required by an air-jet dispersion cup is of the order of $0.06 \text{ m}^3/\text{min}$ (2 cfm); some small air compressors are not capable of supplying sufficient air to operate a cup.

Note 2—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

Note 3—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.1.4. *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per liter of suspension, and conforming to the requirements for hydrometers 151 H or 152 H in ASTM E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.1.5. *Sedimentation Cylinders*—A glass cylinder approximately 460 mm (18 in.) in height and 60 mm ($2\frac{1}{2}$ in.) in diameter and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000 mL mark is 360 ± 20 mm (14 ± 1.0 in.) from the bottom on the inside.

3.1.6. *Thermometer*—A calibrated thermometer readable to 0.5°C (1°F).

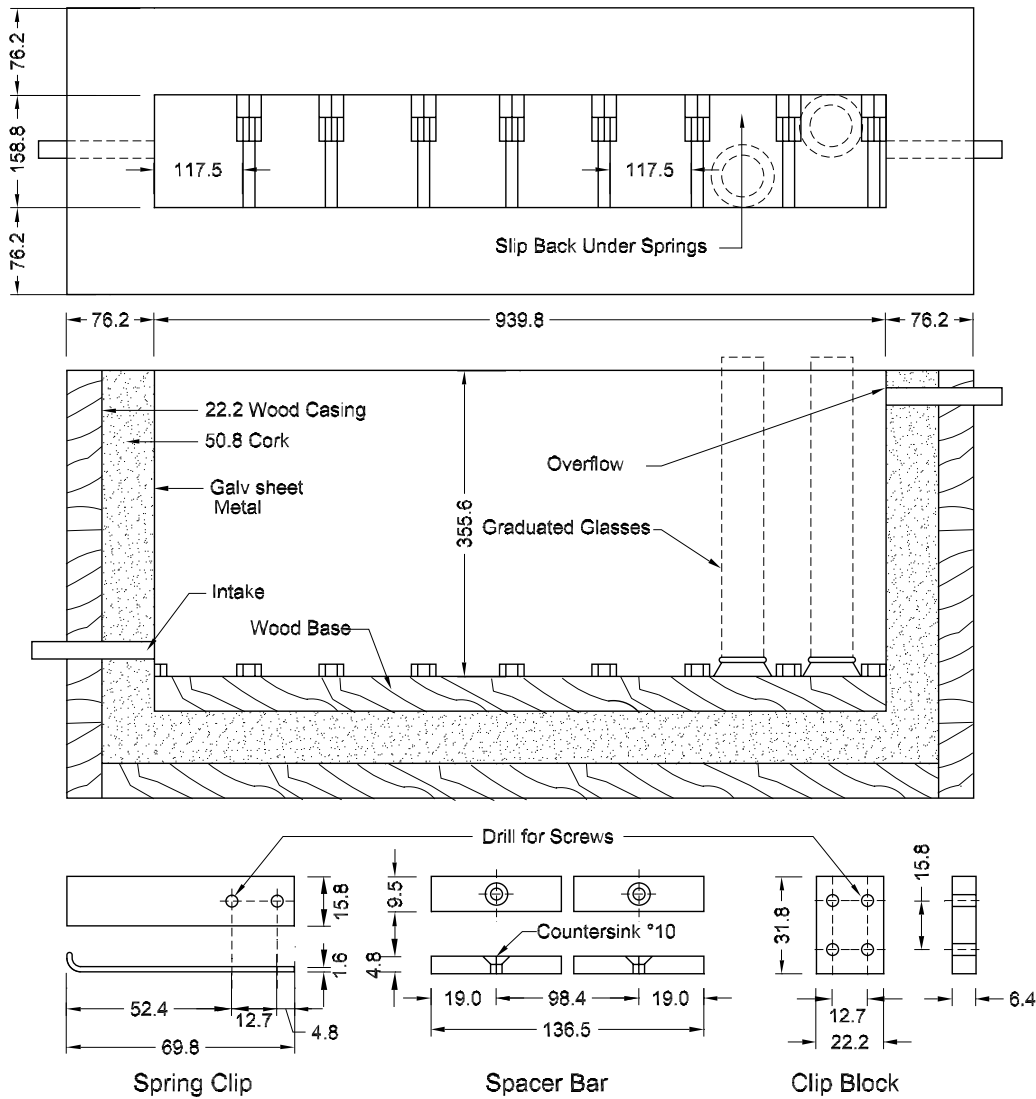
3.1.7. *Sieves*—A series of sieves of square mesh woven cloth, conforming to the requirements of M 92. The sieves normally required are as follows:

Standard Designation, mm	Alternate Designation
75	3 in.
50	2 in.
25	1 in.
9.25	$\frac{3}{8}$ in.
4.75	No. 4
2.00	No. 10
0.425	No. 40
0.075	No. 200

Note 4—The above sieves fulfill the requirements of M 145 and M 147. If desired, intermediate sieve sizes may be used in such sizes as:

Standard Designation, mm	Alternate Designation
75	3 in.
37.5	1 $\frac{1}{2}$ in.
19	$\frac{3}{4}$ in.
9.5	$\frac{3}{8}$ in.
4.75	No. 4
2.36	No. 8
1.18	No. 16
0.60	No. 30
0.30	No. 50
0.15	No. 100
0.075	No. 200

- 3.1.8. *Water Bath or Constant Temperature Room*—A water bath or constant temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water bath is an insulated tank that maintains the suspension at a convenient constant temperature as near 20°C (68°F) as the room and faucet-water temperature will permit. Such a device is illustrated in Figure 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary and subsequent reference to a constant temperature bath shall be interpreted as meaning either a water bath or a constant temperature room.
- 3.1.9. *Beaker*—A glass beaker having a capacity of at least 250 mL and not greater than 500 mL.
- 3.1.10. *Timing Device*—A watch or clock with a sweep second hand.
- 3.1.11. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.
- 3.1.12. *Glass Rod*—Suitable for stirring the sample mixture.



Dimensional Equivalents

mm	in.	mm	in.
939.8	37	31.8	1 ¹ / ₄
355.6	14	22.2	⁷ / ₈
158.8	6 ¹ / ₄	19.0	³ / ₄
136.5	5 ³ / ₈	15.8	⁵ / ₈
117.5	4 ⁵ / ₈	12.7	¹ / ₂
98.4	3 ⁷ / ₈	9.5	³ / ₈
76.2	3	6.4	¹ / ₄
69.8	2 ³ / ₄	4.8	³ / ₁₆
52.4	2 ¹ / ₁₆	1.6	¹ / ₁₆
50.8	2		

Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 4—Tank for Maintaining Soil Suspension at Constant Temperature During Hydrometer Analysis

4. DISPERSING AGENT

- 4.1. A solution of sodium hexametaphosphate shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate per liter of solution.
- 4.1.1. Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersing action. Solutions shall be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions shall have the date of preparation marked on them.

5. GENERAL REQUIREMENTS FOR WEIGHING

- 5.1. The masses of subsamples and size fractions in the hydrometer analysis and hygroscopic moisture determination shall be determined to the nearest 0.01 g. The mass of the subsample for mechanical analysis of the fraction retained on the 4.75-mm sieve, the 2.00-mm sieve, or the 0.425-mm sieve for coarse sieve analysis, and each size fraction in the coarse sieve analysis, shall be determined to within 0.1 percent of the mass of the subsample. For example, a subsample with a mass of 1000 g, its size fractions in the coarse sieve analysis, must be weighed to the nearest gram.

6. SAMPLES

- 6.1. The test sample for particle size analysis shall be prepared in accordance with either R 58 for Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test, or T 146 for Wet Preparation of Disturbed Soil Samples for Test. The representative portion of the original air-dry sample selected for test shall be weighed. The mass of this sample shall be sufficient to yield quantities for particle size analysis as follows:
- 6.1.1. The minimum amount required of material retained on the 4.75-mm sieve, the 2.00-mm sieve, or the 0.425-mm sieve depends on the maximum particle size, but shall not be less than the amount shown in the following table:

Normal Size of Largest Particles Standard (Alternate)		Approximate Minimum Weight of Portion
mm	in.	kg
9.5	$\frac{3}{8}$	0.5
25	1	2
50	2	4
75	3	5

- 6.1.2. The size of the portion passing the 2.00-mm (No. 10) or 0.425-mm (No. 40) sieve shall be: (a) for the hydrometer test, approximately 100 g for sandy soil and approximately 50 g for silty or clayey soils, and (b) for hygroscopic moisture determination, at least 10 g.
- 6.2. The test sample selected in Section 5.1 shall be processed by one of the following methods:
- 6.2.1. *Alternate Method Using 4.75-mm and 2.00-mm (No. 4 and No. 10) Sieves*—After separating the test sample on the 4.75-mm sieve as described in Section 5.2.2 of R 58, the two fractions shall be

weighed. A representative portion of the passing 4.75-mm sieve fraction adequate for mechanical analysis shall be selected and separated into two fractions using a 2.00-mm sieve. Each of these fractions shall be weighed and the subsamples for hydrometer analysis and hygroscopic moisture determination shall be obtained from the passing 2.00-mm sieve fraction by use of a riffle sampler or sample splitter, and either weighed immediately or placed in air-tight containers until tested.

6.2.2. *Alternate Method Using 2.00-mm (No. 10) Sieve*—The sample shall be separated on the 2.00-mm sieve as described in Section 5.2.1 of R 58. The portion retained on the 2.00-mm sieve after the second sieving shall be processed in accordance with Section 7, Sieve Analysis of Fraction Retained on 2.00-mm (No. 10) Sieve. The portion passing the 2.00-mm sieve in both sieving operations shall be weighed and prepared as described in Section 6.2 of R 58. Subsamples for hygroscopic moisture, hydrometer analysis, and sieve analysis shall be weighed immediately or placed in air-tight containers until tested.

6.2.3. *Alternate Method Using 0.425-mm (No. 40) Sieve*—The sample shall be processed as described in T 146, the portions retained on and passing the 0.425-mm sieve shall be weighed, and the subsamples for hydrometer analysis and hygroscopic moisture determination shall be obtained by use of a riffle sampler or sample splitter, and either weighed immediately or placed in air-tight containers until tested.

Note 5—Most laboratories prepare the sample in accordance with Section 5.2.1 of R 58, which provides for splitting the original sample on the 2.00-mm sieve. Hereafter in this method the triple designation, 4.75-mm, or 2.00-mm, or 0.425-mm sieve, is not used. When reference to the fraction retained or passing the 2.00-mm sieve is used, the 4.75-mm sieve is implied if the sample was processed in accordance with Section 6.2.1, and the 0.425-mm sieve is implied if the sample was processed in accordance with Section 6.2.3.

7. SIEVE ANALYSIS OF FRACTION RETAINED ON 2.00-MM (NO. 10) SIEVE

- 7.1. The portion of the sample retained on the 2.00-mm (No. 10) sieve shall be separated into a series of sizes by the use of the 75, 50, 25.0, 9.5, and 4.75-mm (3 in., 2 in., 1 in., $\frac{3}{8}$ in., and the No. 4) sieves, and using other sieves as may be needed depending on the sample or upon the specification for the material being tested. The 2.00-mm sieve shall be used if the sample was prepared in accordance with T 146.
- 7.2. The sieving operation shall be conducted by means of a lateral and vertical motion of the sieve, accomplished by jarring action so as to keep the sample moving continuously over the surface of the sieve. In no case shall fragments in the sample be turned or manipulated through the sieve by hand. Sieving shall be continued until not more than 1 percent by mass of the residue passes any sieve during 60 seconds. When sieving machines are used, their thoroughness of sieving shall be tested by comparison with hand methods of sieving as described in this paragraph.
- 7.3. The portion of the sample retained on each sieve shall be weighed and the mass recorded, although it shall be permissible to record the accumulated masses as the contents of each successive sieve are added to the fractions previously deposited on the scales pan.

HYDROMETER AND SIEVE ANALYSIS OF FRACTION PASSING THE 2.00-MM SIEVE

8. DETERMINATION OF COMPOSITE CORRECTION FOR HYDROMETER READING

- 8.1. Equations for percentages of soil remaining in suspension, as given in Section 16.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.
- 8.1.1. Both soil hydrometers are calibrated at 20°C (68°F); variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.
- 8.1.2. Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.
- 8.1.3. The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.
- 8.2. For convenience, a graph or table of composite corrections for a series of 1-degree temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight line relationship between the two observed values.
- 8.3. Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the selected dispersing agent specified in Section 4. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151 H the composite correction is the difference between this reading and one; for hydrometer 152 H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before. (See Figure 5.)

9. HYGROSCOPIC MOISTURE

- 9.1. Determine the mass of the sample for the hygroscopic moisture determination. Dry the sample according to T 265, to determine the moisture content, and record the results.

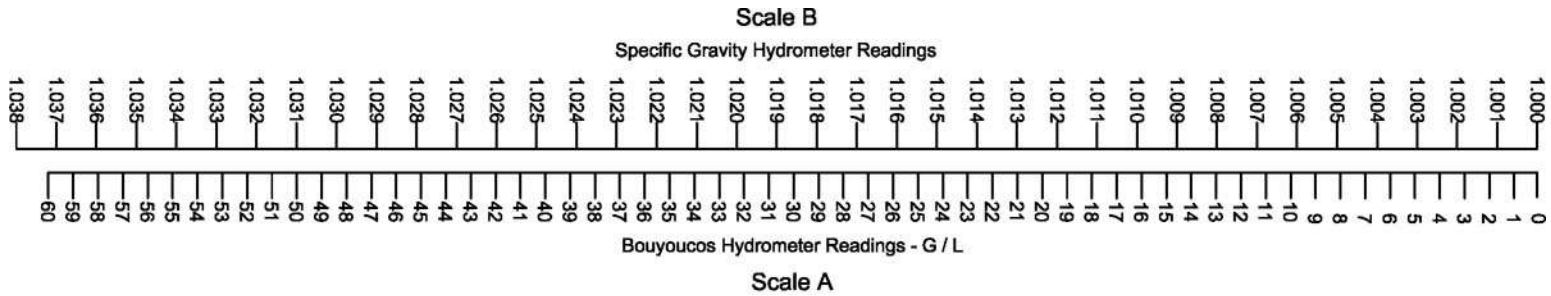
10. DISPERSION OF SOIL SAMPLE

- 10.1. The approximately 100 or 50-g sample for hydrometer analysis shall be weighed, placed in a 250-mL beaker, covered with 125 mL of stock solution of the selected dispersing agent specified in Section 4, stirred thoroughly with a glass rod, and allowed to soak for a minimum of 12 hours. The contents of the beaker shall then be washed into one of the dispersion cups shown in Figure 2,

distilled or demineralized water added until the cup is more than half full, and the contents dispersed for a period of 60 seconds in the mechanical stirring apparatus.

11. ALTERNATE METHOD FOR DISPERSION

- 11.1. The approximately 100 or 50-g sample for hydrometer analysis shall be weighed, placed in a 250-mL beaker, covered with 125 mL of the stock solution of the selected dispersing agent specified in Section 4, stirred thoroughly with a glass rod, and allowed to soak for a minimum of 12 hours.
- 11.2. The air-jet dispersion apparatus shall be assembled as shown in Figure 3 without the cover cap in place. The needle valve controlling the line pressure shall be opened until the pressure gauge indicates 6.9-kPa (1-psi) air pressure. This initial air pressure is required to prevent the soil-water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup. After the apparatus is adjusted, the soil-water mixture shall be transferred from the beaker to the dispersion cup, using a wash bottle to assist in the transfer operation.
- 11.3. The volume of the soil-water mixture in the dispersion cup shall not exceed 250 mL. The cover containing the baffle plate shall be placed upon the dispersion cup and the needle valve opened until the pressure gauge reads 138 kPa (20 psi). The soil-water mixture shall be dispersed for 5, 10, or 15 minutes depending upon the plasticity index of the soil. Soils with a PI of five or less shall be dispersed for 5 minutes; soil with a PI between 6 and 20 for 10 minutes; and soils with a PI greater than 20 for 15 minutes. Soils containing large percentages of mica need be dispersed for 60 seconds only.
- 11.4. After the dispersion period is completed, the needle valve shall be closed until the pressure gauge indicates 6.9 kPa (1 psi). The cover shall be removed and all adhering soil particles washed back into the dispersion cup. The soil water suspension shall then be washed into the 1000-mL glass graduate and the needle valve closed.



The specific gravity scale (SP. G.) shall be calibrated to read 1.000 at 68° F and it shall extend beyond the limits shown, so as to read from 0.995 to 1.038. The grams per liter scale (G/L) shall be extended 5 G/L above zero (1.000 SP. G.) and down to 60 G/L. The bulb shall be symmetrical above and below the middle diameter, and shall be blown into a mold to assure uniformity of product.

* The diameter of the stem may be varied to adjust the length of the scale specified but the stem shall be uniform in diameter from top to bottom. The accuracy of the scale shall be ± 1 scale division. Distributed uniformly over the scale length.

Hydrometer equipped with Scale B shall be identified as No. 151 H.

Hydrometer equipped with Scale A shall be identified as No. 152 H.

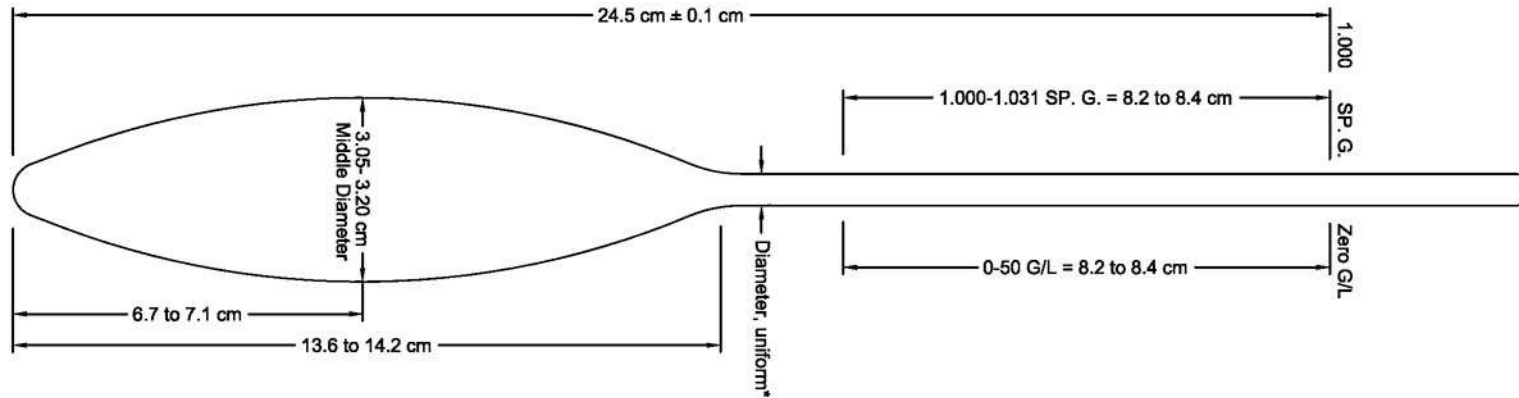


Figure 5—Hydrometer

12. HYDROMETER TEST

- 12.1. After dispersion, the mixture shall be transferred to the glass graduate and distilled or demineralized water having the same temperature as the constant temperature bath added until the mixture attains a volume of 1000 mL. The graduate containing the soil suspension shall then be placed in the constant temperature bath. Remove the graduate after the soil suspension attains the temperature of the bath. Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 60 seconds to complete the agitation of the slurry.
- Note 6**—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.
- Note 7**—Upon completion of the agitation period, if necessary, any material clinging to the inside walls of the top of the cylinder may be rinsed into the suspension with a small amount of water.
- 12.2. At the conclusion of this shaking, the time shall be recorded, the graduate placed in the bath, and readings taken with the hydrometer at the end of 120 seconds. The hydrometer shall be read at the top of the meniscus formed by the suspension around its stem. The hydrometer shall float freely and not touch the wall of the graduate or cylinder. If hydrometer with scale A is used, it shall be read to the nearest 0.5 g/L. Scale B shall be read to the nearest 0.0005 specific gravity. Subsequent readings shall be taken at intervals of 5, 15, 30, 60, 250, and 1440 minutes after the beginning of sedimentation. Readings of the thermometer placed in the soil suspension shall be made immediately following each hydrometer reading and recorded.
- 12.3. After each reading the hydrometer shall be very carefully removed from the soil suspension and placed with a spinning motion in a graduate of clean water. About 25 or 30 seconds before the time for a reading, it shall be taken from the clear water and slowly immersed in the soil suspension to assure that it comes to rest before the appointed reading time.

13. SIEVE ANALYSIS

- 13.1. At the conclusion of the final reading of the hydrometer, the suspension shall be washed on a 0.075-mm (No. 200) sieve. That fraction retained on the 0.075-mm sieve shall be dried in an oven at $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$) and a sieve analysis made using the 0.425-mm and 0.075-mm sieves and such other sieves as may be required by the material under test.
- Note 8**—Following washing of the sample and flushing of any materials retained on the 75- μm (No. 200) sieve back into the container, no water should be decanted from the container except through the 75- μm (No. 200) sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

CALCULATIONS

14. PERCENTAGE OF HYGROSCOPIC MOISTURE

- 14.1. The hygroscopic moisture shall be expressed as a percentage of the mass of the oven-dried soil and shall be determined as follows:

$$\text{Percentage of hygroscopic moisture} = \frac{W - W_1}{W_1} \times 100 \quad (1)$$

where:

W = mass of air-dried soil, and

W_1 = mass of oven-dried soil.

To correct the mass of the air-dried sample for hygroscopic moisture, the given value shall be multiplied by the expression:

$$\frac{100}{100 + \text{percentage of hygroscopic moisture}} \quad (2)$$

- 14.2. Calculate the percentage of moisture to the nearest 0.001 as described in Section 14.1.

15. COARSE MATERIAL

- 15.1. The percentage of coarse material shall be calculated from the masses of the fractions recorded during the sieving of the material retained on the 2.00-mm sieve, in accordance with Section 7.3, and the total mass recorded in Section 6.1. The calculations shall be made as follows:

- 15.1.1. From the mass of the air-dried sample, obtained in Section 6.1, subtract the mass of the fraction retained on the 2.00-mm sieve. The difference is assumed to equal the mass of the air-dried fraction passing the 2.00-mm sieve (Note 5).

- 15.1.2. Correct the mass of the fraction passing the 2.00-mm sieve for hygroscopic moisture, determined in Section 14.1.

- 15.1.3. To the corrected mass obtained in Section 15.1.2, add the mass of the fraction retained on the 2.00-mm sieve to obtain the mass of the total test sample corrected for hygroscopic moisture.

- 15.1.4. The fractions retained on the 2.00-mm and coarser sieves shall be expressed as percentages of the corrected mass obtained in Section 15.1.3.

Note 9—According to this assumption, no hygroscopic moisture is contained in the air-dried particles retained on the 2.00-mm sieve, when as a matter of fact a small percentage of moisture may be present in this fraction. This amount of moisture, compared with that held in the pores of the fraction passing the 2.00-mm sieve, is relatively small. Therefore, any error produced by the assumption as stated may be considered negligible in amount.

Note 10—Somewhat different computations are required when the test sample is processed in accordance with Section 6.2.1 (Alternate Method Using 4.75-mm and 2.00-mm sieves). In Section 15.1, substitute the 4.75-mm sieve for the 2.00-mm sieve. The percentage passing the 2.00-mm sieve shall be calculated as follows: (1) correct the mass of the test fractions passing the 4.75-mm and 2.00-mm sieves for hygroscopic moisture; (2) divide the dry mass of the fraction passing the 2.00-mm sieve by the dry mass of the subsample passing the 4.75-mm sieve, and multiply this value by 100, giving the percent passing the 2.00-mm sieve in the selected subsample (Section 6.2.1); and (3) multiply this percentage by the percentage of the total sample passing the 4.75-mm sieve, to give the percentage passing the 2.00-mm sieve in the total sample.

16. PERCENTAGE OF SOIL IN SUSPENSION

16.1. Hydrometer readings shall be corrected by applying the approximate composite correction as determined by Section 8 to account for the dispersing agent used, temperature of the suspension, and height of the meniscus on the stem of the hydrometer.

16.2. The percentage of the dispersed soil in suspension represented by different corrected hydrometer readings depends upon both the amount and the specific gravity of the soil dispersed. The percentage of dispersed soil remaining in suspension shall be calculated as follows:

For hydrometer 152 H

$$P = \frac{Ra}{w} \times 100 \quad (3)$$

For hydrometer 151 H

$$P = \frac{1606(R-1)a}{w} \times 100 \quad (4)$$

where:

P = percentage of originally dispersed soil remaining in suspension,

R = corrected hydrometer reading,

w = mass in grams of soil originally dispersed minus the hygroscopic moisture, and

a = constant depending on the density of the suspension.

For an assumed value of G for the specific gravity of the soil, and a water density of 1.000 at 20.0°C (68°F), the value of “ a ” may be obtained by the formula:

$$a = \frac{2.6500 - 1.000}{2.6500} \times \frac{G}{G - 1.000}$$

The values of “ a ,” given to two decimal places, are shown in Table 1.

Table 1—Values of a , for Different Specific Gravities

Specific Gravity, G	Constant, a
2.95	0.94
2.85	0.96
2.75	0.98
2.65	1.00
2.55	1.02
2.45	1.05
2.35	1.08

16.2.1. It is sufficiently accurate for ordinary tests to select the constant for the specific gravity nearest to that of the particular soil tested.

16.3. To convert the percentages of soil in suspension to percentages of the total test sample including the fraction retained on the 2.00-mm (No. 10) sieve, the percentage of originally dispersed soil remaining in suspension shall be multiplied by the expression:

$$\frac{100 - \text{the percentage retained on 2.00-mm sieve}}{100} \quad (5)$$

17. DIAMETER OF SOIL PARTICLES IN SUSPENSION

17.1. The maximum diameter, d , of the particles in suspension, corresponding to the percentage indicated by a given hydrometer reading, shall be calculated by the use of Stokes' law.

According to Stokes' law:

$$d = \sqrt{\frac{30 nL}{980(G - G_1)T}} \quad (6)$$

where:

d = maximum grain diameter in millimeters;

n = coefficient of viscosity of the suspending medium (in this case water) in Pa·s. Varies with changes in temperature of the suspending medium;

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, mm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (see Table 2).);

T = interval of time from beginning of sedimentation to the taking of the reading, min;

G = specific gravity of soil particles; and

G_1 = specific gravity of the suspending medium (approximately 1.0 for water).

Note 11—As Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

Table 2—Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes^a

Hydrometer 151 H		Hydrometer 152 H			
Actual Hydrometer Reading	Effective Depth, <i>L</i> , mm	Actual Hydrometer Reading	Effective Depth, <i>L</i> , mm	Actual Hydrometer Reading	Effective Depth, <i>L</i> , mm
1.000	163	0	163	31	112
1.001	160	1	161	32	111
1.002	158	2	160	33	109
1.003	155	3	158	34	107
1.004	152	4	156	35	106
1.005	150	5	155		
1.006	147	6	153	36	104
1.007	144	7	152	37	102
1.008	142	8	150	38	101
1.009	139	9	148	39	99
1.010	137	10	147	40	97
1.011	134	11	145	41	96
1.012	131	12	143	42	94
1.013	129	13	142	43	92
1.014	126	14	140	44	91
1.015	123	15	138	45	89
1.016	121	16	137	46	88
1.017	118	17	135	47	86
1.018	115	18	133	48	84
1.019	113	19	132	49	83
1.020	110	20	130	50	81
1.021	107	21	129	51	79
1.022	105	22	127	52	78
1.023	102	23	125	53	76
1.024	100	24	124	54	74
1.025	97	25	122	55	73
1.026	94	26	120	56	71
1.027	92	27	119	57	70
1.028	89	28	117	58	68
1.029	86	29	115	59	66
1.030	84	30	114	60	65
1.031	81				
1.032	78				
1.033	76				
1.034	73				
1.035	70				
1.036	68				
1.037	65				
1.038	62				

^a Values of effective depth are calculated from the equation:

$$L = L_1 + \frac{1}{2}[L_2 - (V_B/A)] \quad (7)$$

where:

L = effective depth, mm;

*L*₁ = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, mm;

*L*₂ = overall length of hydrometer bulb, mm;

*V*_{*B*} = volume of hydrometer bulb, mm³; and

A = cross-sectional area of sedimentation cylinder, mm².

For both hydrometers, 151 H and 152 H:

L_2 = 140 mm

V_B = 67000 mm³

A = 2780 mm²

For hydrometer 151 H:

L_1 = 105 mm for a reading of 1.000

L_2 = 23 mm for a reading of 1.031

For hydrometer 152 H:

L_1 = 105 mm for a reading of 0 g/L

L_2 = 23 mm for a reading of 50 g/L

17.2. For convenience in calculations the above equation may be written as follows:

$$D = K \sqrt{\frac{L}{T}} \quad (8)$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K may not change for a series of readings constituting a test, while values of L and T do vary.

Table 3—Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature deg C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.004838	0.004759	0.004683	0.004607	0.004538	0.004471	0.004408	0.004345	0.004288
17	0.004778	0.004699	0.004623	0.004551	0.004481	0.004415	0.004351	0.004288	0.004231
18	0.004718	0.004639	0.004563	0.004494	0.004424	0.004358	0.004298	0.004234	0.004177
19	0.004661	0.004582	0.004506	0.004437	0.004370	0.004304	0.004244	0.004184	0.004127
20	0.004604	0.004525	0.004452	0.004383	0.004317	0.004250	0.004190	0.004133	0.004076
21	0.004547	0.004471	0.004399	0.004329	0.004263	0.004200	0.004139	0.004083	0.004026
22	0.004494	0.004418	0.004345	0.004279	0.004212	0.004149	0.004092	0.004035	0.003978
23	0.004440	0.004367	0.004294	0.004228	0.004165	0.004101	0.004045	0.003988	0.003931
24	0.004389	0.004317	0.004244	0.004177	0.004114	0.004054	0.003997	0.003940	0.003886
25	0.004339	0.004266	0.004196	0.004130	0.004067	0.004007	0.003950	0.003896	0.003842
26	0.004291	0.004218	0.004149	0.004083	0.004022	0.003962	0.003905	0.003852	0.003798
27	0.004244	0.004171	0.004101	0.004038	0.003978	0.003918	0.003861	0.003807	0.003757
28	0.004196	0.004124	0.004057	0.003997	0.003934	0.003875	0.003820	0.003766	0.003716
29	0.004149	0.004079	0.004013	0.003950	0.003890	0.003833	0.003779	0.003725	0.003675
30	0.004105	0.004035	0.003972	0.003909	0.003848	0.003792	0.003738	0.003684	0.003633

18. FINE SIEVE ANALYSIS

18.1. The percentage of the dispersed soil sample retained on each of the sieves in the sieve analysis of the material washed on the 0.075-mm (No. 200) sieve shall be obtained by dividing the mass of fraction retained on each sieve by the oven-dry mass of the dispersed soil and multiplying by 100.

- 18.2. The percentages of the total test sample, including the fraction retained on the 2.00-mm (No. 10) sieve, shall be obtained by multiplying these values by the expression:

$$\frac{100 - \text{the percentage retained on 2.00-mm sieve}}{100}$$

19. PLOTTING

- 19.1. The accumulated percentages of grains of different diameters shall be plotted on semilogarithmic paper to obtain a “grain size accumulation curve,” such as that shown in Figure 6.

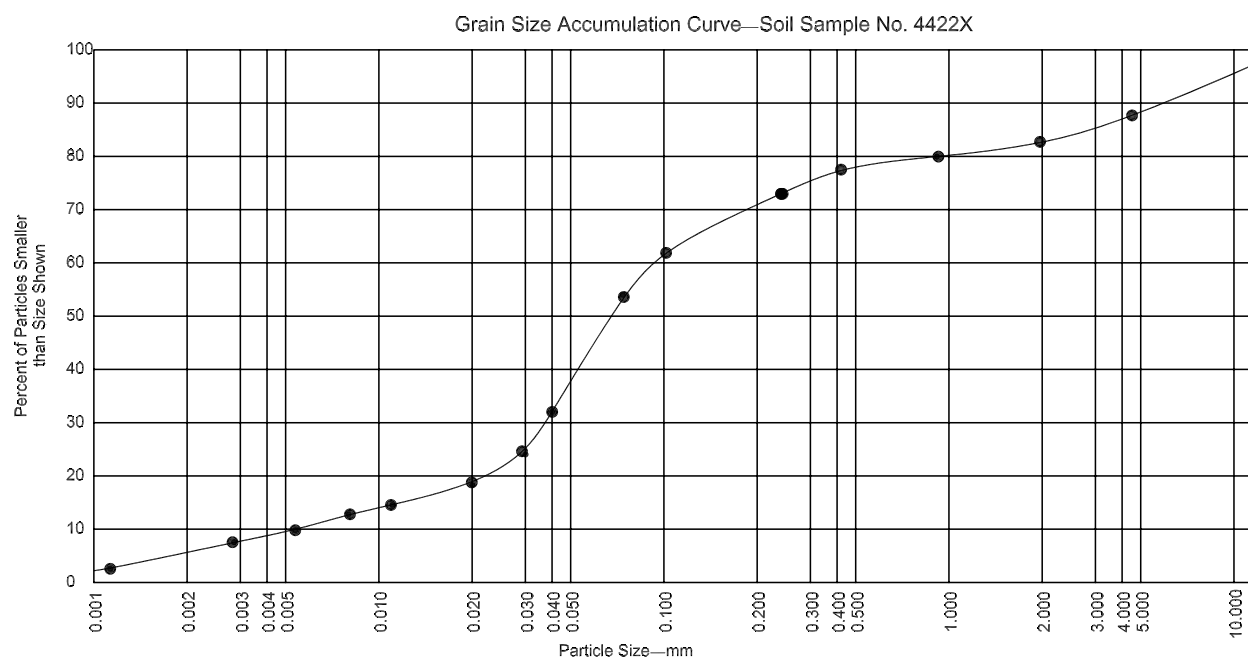


Figure 6—Grain Diameter Accumulation Curve for Soil Sample No. 4422X

20. REPORT

- 20.1. The results, read from the accumulation curve, shall be reported as follows:
- 20.1.1. Particles larger than 2-mm percent;
 - 20.1.2. Coarse sand, 2.0 to 0.42-mm percent;
 - 20.1.3. Fine sand, 0.42 to 0.074-mm percent;
 - 20.1.4. Silt, 0.074 to 0.002-mm percent;
 - 20.1.5. Clay, smaller than 0.002-mm percent; and

20.1.6. Colloids, smaller than 0.001-mm percent.

20.2. The results of complete mechanical analyses furnished by the combined sieve and hydrometer analysis shall be reported as follows:

Sieve Analysis		
Sieve Size		Percent Passing
Standard, mm	Alternate	
75	3 in.	_____
50	2 in.	_____
25	1 in.	_____
4.75	No. 4	_____
2.00	No. 10	_____
0.425	No. 40	_____
0.075	No. 200	_____

Hydrometer Analysis	
Smaller Than:	Percent
.02 mm	_____
.002 mm	_____
.001 mm	_____

For materials examined for any particular type of work or purpose, only such fractions shall be reported as are included in the specifications or other requirements for the work or purpose.

20.3. Report the Sieve Analysis to the nearest 0.1 percent passing.

20.4. Report the Hydrometer Analysis to the nearest 0.1 percent smaller than.

21. PRECISION

21.1. Criteria for judging the acceptability of the particle size analysis of soils is as follows:

Note 12—Colloids (smaller than 0.001 mm) are not normally required. However, if it is desired to obtain this size, it will then be necessary to extend the reading time to a minimum of 2880 minutes.

Note 13—The figures in Column 2 are the standard deviations that have been found to be appropriate for the tests described in Column 1. The figures in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

Table 4—Single-Operator Precision

<i>Single-Operator Precision:</i>		
Test Performed	Standard Deviation ^a	Acceptable Range of Two Results ^a
Hygroscopic Moisture in Percent Moisture:		
4.75 mm (No. 4)	0.15	0.4
2.00 mm (No. 10)	0.21	0.6
Sieve Analysis in Percent Passing:		
2.00 mm (No. 10)	0.66	1.9
0.425 mm (No. 40)	1.07	3.0
0.075 mm (No. 200)	1.19	3.4
Hydrometer Analysis in Percent Smaller Than:		
0.02 mm	1.98	5.6
0.002 mm	1.34	3.8
0.001 mm	1.45	4.1
<i>Multilaboratory Precision:</i>		
Test Performed	Standard Deviation ^a	Acceptable Range of Two Results ^a
Hygroscopic Moisture in Percent Moisture:		
4.75 mm (No. 4)	0.89	2.5
2.00 mm (No. 10)	0.88	2.4
Sieve Analysis in Percent Passing:		
2.00 mm (No. 10)	1.39	3.9
0.425 mm (No. 40)	1.98	5.6
0.075 mm (No. 200)	2.31	.5
Hydrometer Analysis in Percent Smaller Than:		
0.02 mm	4.32	12.2
0.002 mm	3.19	9.0
0.001 mm	3.16	8.9

^a These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.