



Designation: D7928 – 21

Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis¹

This standard is issued under the fixed designation D7928; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes of the fine-grained portion of soils. The sedimentation by hydrometer method is used to determine the particle-size distribution (gradation) of the material that is finer than the No. 200 (75- μm) sieve and larger than about 0.2- μm . The test is performed on material passing the No. 10 (2.0-mm) or finer sieve and the results are presented as the mass percent finer of this fraction versus the log of the particle diameter.

1.2 This method can be used to evaluate the fine-grained fraction of a soil with a wide range of particle sizes by combining the sedimentation results with results from a sieve analysis using D6913 to obtain the complete gradation curve. The method can also be used when there are no coarse-grained particles or when the gradation of the coarse-grained material is not required or not needed.

NOTE 1—The significant digits recorded in this test method preclude obtaining the grain size distribution of materials that do not contain a significant amount of fines. For example, clean sands will not yield detectable amounts of silt and clay sized particles, and therefore should not be tested with this method. The minimum amount of fines in the sedimentation specimen is 15 g.

1.3 When combining the results of the sedimentation and sieve tests, the procedure for obtaining the material for the sedimentation analysis and calculations for combining the results will be provided by the more general test method, such as Test Methods D6913 (Note 2).

NOTE 2—Subcommittee D18.03 is currently developing a new test method “Test Method for Particle-Size Analysis of Soils Combining the Sieve and Sedimentation Techniques.”

1.4 The terms “soil” and “material” are used interchangeably throughout the standard.

1.5 The sedimentation analysis is based on the concept that larger particles will fall through a fluid faster than smaller

particles. Stokes’ Law gives a governing equation used to determine the terminal velocity of a spherical particle falling through a stationary liquid. The terminal velocity is proportional to the square of the particle diameter. Therefore, particles are sorted by size in both time and position when settling in a container of liquid.

1.5.1 Stokes’ Law has several assumptions which are: the particles are spherical and smooth; there is no interference between the particles; there is no difference between the current in the middle of the container and the sides; flow is laminar; and the particles have the same density. These assumptions are applied to soil particles of various shapes and sizes.

1.6 A hydrometer is used to measure the fluid density and determine the quantity of particles in suspension at a specific time and position. The density of the soil-water suspension depends upon the concentration and specific gravity of the soil particles and the amount of dispersant added. Each hydrometer measurement at an elapsed time is used to calculate the percentage of particles finer than the diameter given by Stokes’ Law. The series of readings provide the distribution of material mass as a function of particle size.

1.7 This test method does not cover procurement of the sample or processing of the sample prior to obtaining the reduced sample in any detail. It is assumed that the sample is obtained using appropriate methods and is representative of site materials or conditions. It is also assumed that the sample has been processed such that the reduced sample accurately reflects the particle-size distribution (gradation) of this finer fraction of the material.

1.8 *Material Processing*—Material is tested in the moist or as-received state unless the material is received in an air-dried state. The moist preparation method shall be used to obtain a sedimentation test specimen from the reduced sample. Air-dried preparation is only allowed when the material is received in the air-dried state. The method to be used may be specified by the requesting authority; however, the moist preparation method shall be used for referee testing.

1.9 This test method is **not** applicable for the following soils:

1.9.1 Soils containing fibrous peat.

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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1.9.2 Soils containing less than approximately 5 % of fine-grained material (**Note 1**).

1.9.3 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items (**Note 3**).

NOTE 3—If extraneous matter, such as wood, can be easily removed by hand, it is permissible to do so. However, there may be cases where the extraneous matter is being evaluated as part of the material and it should not be removed from the material.

1.9.4 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.10 This test method may not produce consistent test results within and between laboratories for the following soils. To test these soils, this test method must be adapted and these adaptations documented.

1.10.1 Soils that flocculate during sedimentation. Such materials may need to be treated to reduce salinity or alter the pH of the suspension.

1.10.2 Friable soils in which processing changes the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales, decomposed granites, and some weakly cemented soils.

1.10.3 Soils that will not readily disperse, such as glauconitic clays or some dried plastic clays.

1.11 Samples that are not soils, but are made up of particles may be tested using this method. The applicable sections above should be used in applying this standard.

1.12 *Units*—The values stated in SI units are to be regarded as standard. Except the sieve designations, they are identified using the “alternative” system in accordance with Practice **E11**, such as 3-in. and No. 200, instead of the “standard” designation of 75-mm and 75- μm , respectively. Reporting of test results in units other than SI shall not be regarded as non-conformance with this test method. The use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice **D6026**, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user’s objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this test method to consider significant digits used in analysis methods for engineering or other data.

1.14 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.15 *This international standard was developed in accordance with internationally recognized principles on standard-*

ization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:²

- D653** Terminology Relating to Soil, Rock, and Contained Fluids
- D854** Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
- D1140** Test Methods for Determining the Amount of Material Finer than 75- μm (No. 200) Sieve in Soils by Washing
- D2216** Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D2487** Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D2488** Practice for Description and Identification of Soils (Visual-Manual Procedures)
- D3740** Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- D4220/D4220M** Practices for Preserving and Transporting Soil Samples
- D4318** Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- D4753** Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
- D6026** Practice for Using Significant Digits in Geotechnical Data
- D6913** Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
- E11** Specification for Woven Wire Test Sieve Cloth and Test Sieves
- E100** Specification for ASTM Hydrometers
- E126** Test Method for Inspection, Calibration, and Verification of ASTM Hydrometers
- E177** Practice for Use of the Terms Precision and Bias in ASTM Test Methods

3. Terminology

3.1 Definitions:

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology **D653**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *reduced sample, n*—the minus $\frac{3}{8}$ -in. (9.5-mm) sieve or finer material that has been separated from the sample and then split to reduce the mass while still having sufficient quantity to meet the minimum mass requirements of **Table 1**.

3.2.2 *sample, n*—material collected without limitation on the total mass or size range of particles meeting the minimum mass requirements provided in **Table 1**.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

TABLE 1 Minimum Dry Mass Requirements

| Alternative Sieve Designation | Maximum Particle Size of Material (smallest sieve that 99% or more passes) | Minimum Dry Mass of Specimen (g or kg) |
|-------------------------------|---|---|
| | Maximum Particle Size, mm | |
| No. 40 | 0.425 | 50 g |
| No. 10 | 2.00 | 50 g |
| No. 4 | 4.75 | 75 g |
| 3/8 in. | 9.50 | 165 g |
| 3/4 in. | 19.0 | 1.3 kg |
| 1 in. | 25.4 | 3 kg |
| 1 1/2 in. | 38.1 | 10 kg |
| 2 in. | 50.8 | 25 kg |
| 3 in. | 76.2 | 70 kg |

3.2.3 *sedimentation sample, n*—the minus No. 10 (2.0-mm) or finer material separated from the reduced sample using the separation sieve which is then used to obtain the sedimentation specimen and a water content specimen.

3.2.4 *sedimentation specimen, n*—the material obtained from the sedimentation sample having a maximum particle-size no greater than the No. 10 (2.0-mm) sieve to be used in the sedimentation test and in sufficient quantity to satisfy the minimum mass requirements of **Table 1**.

3.2.5 *separation sieve, n*—the No. 10 (2.0-mm) sieve or finer (**Note 4**) used to separate the reduced sample to obtain the material for the sedimentation sample.

NOTE 4—The methodology for using a sieve finer than the No. 10 (2.0-mm) is not defined in this standard. The methodology used to obtain a representative sample using a sieve finer than the No. 10 (2.0-mm) is not the same as obtaining the representative sample using the No. 10 (2.0-mm) sieve as presented in this standard. Additional effort or steps are necessary to make sure the material passing the finer sieve adequately represents the sample. Such additional effort or steps should be documented if using a sieve finer than the No. 10 (2.0-mm) sieve to obtain the sedimentation specimen.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of material finer than the No. 200 (75- μ m) sieve as a percentage of the mass used in the sedimentation test.

4.2 When the source material contains particles larger than the 3/8-in. (9.5-mm) sieve, a reduced sample passing the 3/8-in. (9.5-mm) sieve shall be obtained using techniques presented in Test Methods **D6913** or another standard. This reduced sample shall meet the minimum mass requirements in **Table 1** for the 3/8-in. (9.5-mm) sieve. The material is processed using the moist (referee) preparation method unless the material is received in the air-dried state.

4.3 The reduced sample is separated using the separation sieve to obtain a sedimentation sample. The sedimentation sample is then split to obtain the appropriate mass for the sedimentation test specimen and a water content test specimen.

4.4 The sedimentation test specimen is mixed with a dispersing agent and test water. The slurry is allowed to condition and is then thoroughly mixed and placed in a cylinder with additional test water. Readings are taken with a hydrometer and thermometer over specific time intervals.

4.5 The mass of particles passing specified particle diameters are calculated and recorded. The results produce a tabulation of particle size versus percent passing the separation sieve size that can be graphically presented as a gradation curve. The plot is typically expressed as percent passing/finer than the separation sieve size versus the log of the particle size in millimeters. These results can then be combined with the results of a mechanical sieve analysis to obtain a complete particle size distribution.

5. Significance and Use

5.1 Particle-size distribution (gradation) is a descriptive term referring to the proportions by dry mass of a soil distributed over specified particle-size ranges. The gradation curve generated using this method yields the distribution of silt and clay size fractions present in the soil based on size definitions, not mineralogy or Atterberg limit classification.

5.2 Unless the sedimentation sample is representative of the entire sample, the sedimentation results must be combined with a sieve analysis to obtain the complete particle size distribution.

5.3 The clay size fraction is material finer than 2 μ m. The clay size fraction is used in combination with the Plasticity Index (Test Methods **D4318**) to compute the activity, which provides an indication of the mineralogy of the clay fraction.

5.4 The gradation of the silt and clay size fractions is an important factor in determining the susceptibility of fine-grained soils to frost action.

5.5 The gradation of a soil is an indicator of engineering properties such as hydraulic conductivity, compressibility, and shear strength. However, soil behavior for engineering and other purposes is dependent upon many factors, such as effective stress, mineral type, structure, plasticity, and geological origin, and cannot be based solely upon gradation.

5.6 Some types of soil require special treatment in order to correctly determine the particle sizes. For example, chemical cementing agents can bond clay particles together and should be treated in an effort to remove the cementing agents when possible. Hydrogen peroxide and moderate heat can digest organics. Hydrochloric acid can remove carbonates by washing and Dithionite-Citrate-Bicarbonate extraction can be used to remove iron oxides. Leaching with test water can be used to reduce salt concentration. All of these treatments, however, add

significant time and effort when performing the sedimentation test and are allowable but outside the scope of this test method.

5.7 The size limits of the sedimentation test are from about 100 μm to about 0.1 μm . The length of time required to obtain a stable initial reading on the hydrometer controls the upper range of results, and the test duration controls the lower range.

5.8 The shape and density of the grains are important to the results. Stokes' Law is assumed to be valid for spherical particles even though fine silt- and clay-sized particles are more likely to be plate-shaped and have greater mineral densities than larger particles.

5.9 High plasticity clays develop structured water layers on their surfaces. According to Zhang and Lu³ this near surface water can be as dense as 1.4 g/L. This high-density structured water causes an error in this test method and shifts the particle size distribution curve upwards. Correction for the structured water is beyond the scope of this standard but values of percent passing above 100 % are possible and should not be excluded from the report.

NOTE 5—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Hydrometer*—ASTM hydrometer type 151H or 152H. These hydrometers shall be in general conformance with the requirements in Specification E100 with the exception of dimensional specifications as indicated in Annex A1.

6.2 *Sedimentation Cylinder*—At least two glass cylinders having a height of about 457 mm, an inside diameter between 55 and 64 mm, and a capacity of 1,000 mL. The cylinders shall have an indication mark at $1,000 \pm 5$ mL. One cylinder is used for the soil suspension and the other one can be used as the control cylinder or the wash cylinder. The control cylinder shall have the same amount of dispersant as the soil suspension cylinder. See Annex A1.

6.3 *Separation Sieve*—No. 10 (2-mm) or finer sieve used to separate the reduced sample. This sieve is subjected to rough operation and shall not be used for quantitative grain size analysis.

6.4 *Thermometric Device*—A thermometric device capable of measuring the temperature range within which the test is being performed readable to 0.5°C or better and having an accuracy of at least $\pm 0.5^\circ\text{C}$. The thermometric device must be capable of being immersed in the suspension and reference solutions to a depth ranging between 25 and 80 mm. Full immersion, also known as complete or total immersion thermometers, shall not be used. The thermometric device shall be standardized by comparison to a nationally or internation-

ally traceable thermometric device and shall include at least one temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months. The same thermometric device shall be used for all measurements.

6.5 *Timing Device*—A clock, stopwatch, digital timer, or comparable device readable to one second or better.

6.6 *Balance*—Balances shall conform to the requirements of Specification D4753.

6.6.1 To determine the mass of the specimen, the balance shall have readability without estimation of 0.01 g. The capacity of this balance will need to exceed the mass of the container plus soil used to contain the soil suspension after the completion of the sedimentation test. In general, a balance with a minimum capacity of 1,800 g is sufficient.

6.7 *Drying Oven*—Vented, thermostatically controlled oven capable of maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$ throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.8 *Plate*—A clean, nonporous, smooth, solid surface that is large enough to pile and split about 500 g of material. The surface shall not be made of any type of paper product.

6.9 *Specimen-Mixing Container*—A glass beaker or equivalent inert container with enough capacity to hold the specimen, the test water, and dispersant. A container of about 250 mL is sufficient.

6.10 *Temperature Maintaining Device*—Unless otherwise specified by the requesting agency, the standard test temperature shall be in the range of $22 \pm 5^\circ\text{C}$. In addition, the temperature of the soil suspension shall not vary more than $\pm 2^\circ\text{C}$. Normally, this temperature maintenance is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the cylinders shall be placed in an automatically temperature controlled insulated chamber or water bath that maintains a temperature within the tolerance specified above.

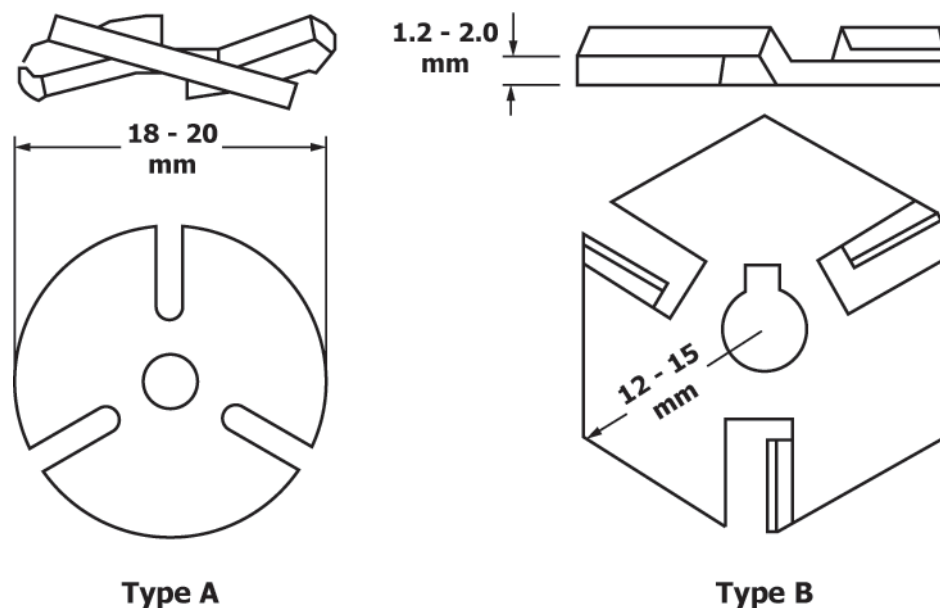
6.11 *Soil Suspension Oven-Drying Container (Optional)*—A container having smooth walls and capable of holding approximately 1.5-L of the soil suspension. This container shall have a tight fitting lid or fit into a desiccator, to prevent moisture gain during cooling of the oven-dried specimen. This is only required when there is insufficient material to obtain the initial water content from a companion specimen.

6.12 *Dispersion Apparatus*—Use one of the following devices to disperse the specimen; however for referee testing, the stirring apparatus shall be used.

6.12.1 *Stirring Apparatus (Referee)*—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a minimum speed of 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate between 19.0 mm and 37.5 mm above the bottom of the dispersion cup.

6.12.1.1 *Dispersion Cup*—A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be

³Zhang, C and Lu, N. "What is the Range of Soil Water Density? Critical Reviews with a Unified Model," *Reviews of Geophysics*, Vol 56, No. 3, July 2019, pp. 532–562.



Dimensions are provided to give a sense of scale and will vary depending on manufacturer specifications.

FIG. 1 Typical Detail of Stirring Paddles

provided to hold the sample while it is being dispersed. The cup shall contain two sets of three long baffle rods and two sets of three short baffle rods rigidly mounted to the interior sides of the cup. This cup is used with the stirring apparatus.

6.12.2 *Air Jet Dispersion Device (Optional)*—A tube type or other comparable device that uses compressed air to disperse the slurry (Note 6). The device requires an air source capable of providing up to 0.0024 m³/s of air to operate the device, such that pressures between about 70 and 170 kPa can be achieved. The device shall be fitted with a pressure gauge on the line between the device and the air source. Water may condense in the lines when not in use and this water must be removed. There are two ways to remove the water: use of a water trap or purging the lines before use. If a water trap is used, it shall be installed on the air line in such a manner to prevent condensed water from entering the slurry. This device shall not be used in referee testing.

NOTE 6—Use of this device or others, causes differing amounts of dispersion and should be used with caution. Information on how to appropriately use this device should be obtained from the manufacturer. 0.0024 m³/s is equivalent to 5 ft³/min. The device typically needs at least 0.0009 m³/s (2 ft³/min) to operate and therefore, some small air compressors are not capable of supplying sufficient air to operate the device.

6.13 *Agitator (Optional/Referee)*—A hand-held device to mix the soil suspension in the sedimentation cylinder prior to testing, as shown in Fig. 3. The agitator must not have any type of metal, such as a screw head, protruding from the bottom of the disk. To aid in strengthening the connection between the rod and the disk, a smaller disk (about 25 mm or less) having similar thickness and material as the larger disk, may be inserted on top of and in the center of the larger disk. This device shall be used for referee testing.

6.14 *Agitation of the Soil Slurry*—Any of the following items may be used to break up the soil aggregations as described in 11.1:

6.14.1 *Erlenmeyer Flask*—A glass flask having a capacity between 250 mL and 500 mL.

6.14.2 *Dispersion Shaker*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

6.14.3 *Ultrasonic Water Bath*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the soil slurry to be agitated for use in the sedimentation test. The water level in the bath should be equal to or higher than the water level in the specimen container.

6.15 *Desiccator (Optional)*—A desiccant containing device of suitable size used to prevent moisture gain during cooling of the oven-dried specimen.

6.16 *Mortar and Rubber-Covered Pestle (Optional)*—Apparatus suitable for breaking up aggregations of air-dried soil particles without breaking individual particles.

6.17 *Miscellaneous Items*—Items such as a wash/rinse bottle (squirt bottle), rubber scraper, spatula, and stirring rod may be useful.

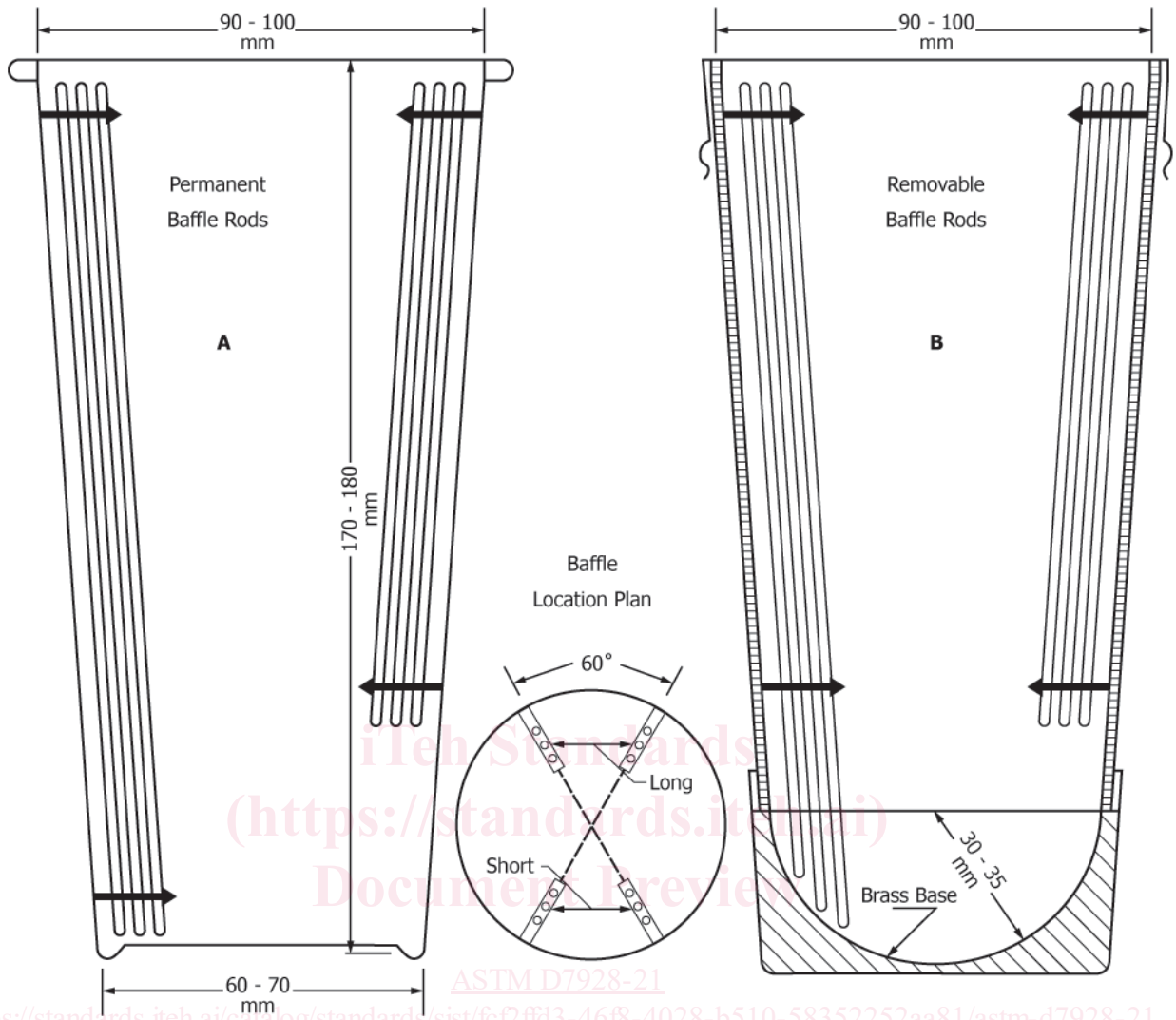
7. Reagents and Materials

7.1 *Sodium Hexametaphosphate (NaPO₃)₆*—Also referred to as sodium metaphosphate is the dispersion agent (deflocculant) required to prevent the fine particles in suspension from coalescing or flocculating (Note 7). Consult the Safety Data Sheet (SDS) for specific information regarding this chemical.

7.2 *Isopropyl Alcohol*—Also referred to as isopropanol alcohol or rubbing alcohol is used as a foam inhibitor. Commercially available in concentrations ranging from 70 % to 99 %.

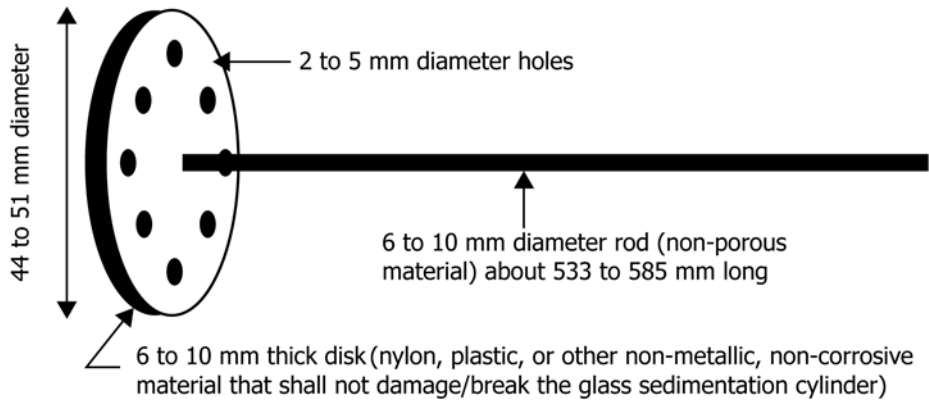
7.3 *Test Water*—Distilled or demineralized water is the only permissible test fluid. The use of tap water is not permitted.

NOTE 7—Fine-grained soils requiring the use of a dispersant are those



Dimensions are provided to give a sense of scale and will vary depending on manufacturer specifications.

FIG. 2 Typical Geometry of the Dispersion Cup



Dimensions are provided to give a sense of scale and will vary depending on manufacturer specifications.

FIG. 3 Detail of Agitator

that do not readily slake in water, such as some highly plastic clays and most tropical soils. Typically, 5 grams per test of dispersant is used to

prevent flocculation and is added directly to the soil, such that the concentration will equal 5 g/L in the final soil suspension volume. The

chemical formula for the dispersant shown above is approximate.

8. Sampling

8.1 *General*—This test method does not address, in any detail, procurement of the sample. It is assumed the sample is obtained using appropriate methods and is representative of the material under evaluation. However, the testing agency shall preserve all samples in accordance with Practice **D4220/D4220M**, Group B, except if the as-received sample does not meet those requirements. In which case, the water content of the material does not have to be maintained.

8.2 Where data from this test are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible and as much is practical.

8.3 The sample can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for particle-size analysis are obtained from the following sources: large bags or buckets, small bags, jar samples, tube samples, or specimens from other tests, such as consolidation, hydraulic conductivity or strength tests. In some cases, such as compaction testing, prior testing may have caused a reduction in particle sizes; therefore, it may be required to obtain a sample of the original material, the degraded sample, or both. Test Methods **D6913**, Section 9, gives additional information regarding sampling from the different sources.

8.3.1 Preserve the sample at its original moisture condition unless excluded above, and at no time shall the sample be allowed to undergo undesirable temperature changes such as freezing or heating.

8.4 When the sample contains particles larger than the $\frac{3}{8}$ -in. (9.5-mm) sieve, it shall be processed to obtain the reduced sample. If particle-size separation is necessary, process the sample to meet this requirement using the separation procedures provided in Test Methods **D6913**.

8.4.1 The reduced sample shall have a maximum particle size that passes through the $\frac{3}{8}$ -in. (9.5-mm) or smaller sieve.

8.4.2 The mass of the reduced sample shall meet or exceed the mass requirements given in **Table 1**.

9. Preparation of the Test Specimen

9.1 *Specimen Procurement*—This standard presents two preparation methods to obtain the sedimentation specimen from the reduced sample: moist and air-dried. In these preparation methods, moist and air-dried refers to the condition of the material or sample as it is being reduced to an appropriate particle size and mass. The test shall not be performed on oven-dried material. The moist preparation method shall be used for referee testing and for samples not received in the air-dried state. The air-dried method shall only be used on materials received in the air-dried state (**Note 8**). Since some fine-grained, air-dried soils aggregate, a mortar and rubber covered pestle is used to break up aggregations. Care must be taken to avoid disintegration or reduction of individual particles. Use only enough force as necessary to break up the aggregations without destroying the individual particles. Additional guidance for splitting material to obtain a representative specimen using a splitter, quartering, or moist stockpile sampling is given in Test Methods **D6913**, Annex A2.

NOTE 8—Air drying causes irreversible changes to some clay particles that cause permanent flocculation and decreases the fine fraction.⁴

9.2 *Moist Preparation (Referee)*—This preparation method shall be used for materials not received in the air-dried state. This method is especially important for any soil whose properties are altered due to drying such as, most organic soils, many highly plastic fine-grained soils, tropical soils and soils containing halloysite. The material is thoroughly mixed to obtain a uniform reduced sample. Intact fine-grained samples should be chopped/reduced into small pieces, less than approximately 10 mm, and mixed to make uniform. There is no need to process the fine-grained materials through a sieve.

9.3 *Air-Dried Preparation*—This preparation method shall only be used if the sample is received in the dried condition. In order to obtain a uniform reduced sample, the sample is blended at room temperature.

9.4 If the reduced sample contains particles which are larger than the No. 10 (2.0-mm) sieve, the material shall be separated using a No. 10 (2.0-mm) or finer sieve. Process the entire reduced sample over the No. 10 (2.0-mm) or finer sieve using a rubber scraper and, if needed, test water to aid in working the material through the sieve. Check that the material retained on the sieve does not contain aggregations of finer particles. Any aggregations should be broken and passed through the sieve. It is not necessary that the separation be totally complete but the material passing the sieve shall be representative of the passing fraction. The material passing the separation sieve is termed the sedimentation sample and shall meet the minimum mass requirement of **Table 1**. Record the separation sieve size that is used to separate the sample.

9.5 Estimate the maximum amount of moist mass that can be used for the sedimentation test using the following equation (**Note 9**):

$$M_{mest} = H_c \times \left(\frac{100}{\%est} \right) \times \left(1 + \left(\frac{w_{cest}}{100} \right) \right) \quad (1)$$

where:

- M_{mest} = estimated maximum moist mass, nearest 1 g,
- H_c = hydrometer capacity, g (either 45 for 151H or 55 for 152H),
- $\%est$ = estimated percentage of material passing the No. 200 (75- μ m) sieve, nearest 1 %, and
- w_{cest} = estimated water content, nearest 1 %.

NOTE 9—The mass of the sedimentation test specimen should be selected based on the amount of material that will be in suspension at the time of the first reading. Using the maximum capacity of the hydrometer provides the highest resolution but is not a requirement. Exceeding the capacity will make it impossible to obtain the initial readings. The capacity of the 152H hydrometer is about 55 g of dry soil and the capacity of the 151H is about 45 g. The wet mass should be adjusted to account for the water content and the fraction of particles smaller than the No. 200 (75- μ m) sieve. For example, if the water content is estimated at 20 %, using a 151H hydrometer, and an estimated percent passing the No. 200 (75- μ m) sieve of 95 %, the estimated moist mass is 57 g.

⁴ Sridharan, A., Jose, B.T., and Abraham, B.M., Technical Note on “Determination of Clay Size Fraction of Marine Clays,” *Geotechnical Testing Journal*, GTJODJ, Vol. 14, No. 1, March 1991, pp. 103-107.

9.6 If the sedimentation sample contains sufficient material, then split or quarter the sedimentation sample into at least two portions: one for the water content determination and one for the sedimentation test. The water content specimen shall contain 50 ± 10 g of material. The sedimentation specimen should be less than the limit computed in 9.5.

9.7 If the sedimentation sample has limited material, do not obtain a water content specimen. Obtain the dry mass, M_d , of the sedimentation specimen at the end of the sedimentation test as discussed in 11.12 and calculated in 12.1.2. Reduce the mass to be less than the limit computed in 9.5.

NOTE 10—If there is enough material after splitting/quartering to obtain the necessary masses for both the sedimentation and water content specimens, the sedimentation sample is considered to have sufficient material. If there is not enough material to obtain both the necessary masses of the specimens, the sedimentation sample is considered to have limited material.

9.8 Record the mass of the moist soil, M_m , used for the sedimentation test to the nearest 0.01 g.

9.9 Place the sedimentation specimen in the specimen-mixing container and record the identification of the specimen-mixing container.

9.10 If sufficient material is available, immediately use the other specimen for determination of the water content in accordance with Test Methods D2216, and record the water content, w_c , to the nearest 0.1 %.

10. Verification/Preparation of Apparatus

10.1 *Hydrometer*—Check and record the dimensions of the 151H or 152H hydrometers as presented in Annex A1 in accordance with the interval listed in the Annex. The hydrometer shall be free of cracks and chips, which can compromise the integrity of the hydrometer. The body and stem of a hydrometer seldom change over time, unless they have been subjected to corrosive materials or have been damaged, that is, chipped or cracked. They only need to be checked before initial use or after damage has been suspected or seen. Since it is possible for the paper scale inside the hydrometer stem to slide down, the hydrometer reading in the test water, shall be checked and documented according to the interval presented in Annex A1 to make sure the scale has remained in its proper place. If the scale has moved, the hydrometer shall be replaced.

10.1.1 *Hydrometer Readings*—Hydrometer readings are taken to the nearest $\frac{1}{4}$ division (Note 11). Reading the hydrometer can be difficult. A properly placed hydrometer should neither bob nor rotate appreciably when released in the soil suspension. It is important for the stem to be dry and clean when inserting it into the soil suspension. If the stem is wet above the reading point it will add mass to the hydrometer causing the reading to be too low. If the stem is not clean, variations in the meniscus rise will result. In this application, the hydrometers are always read at the top of the meniscus for the reason stated in 10.3.

NOTE 11—Reading the hydrometer to the nearest $\frac{1}{4}$ division during the first 5 to 8 minutes of the test can be difficult. During that time it is acceptable to read the hydrometer to the nearest $\frac{1}{2}$ division.

10.1.2 To insert the hydrometer correctly do the following: First, make sure the stem is dry. Then, gently hold it by the

stem with one or both hands and slowly lower it to the depth slightly below the point at which it just floats. The hydrometer should then rise slightly and become stable. This insertion process should take between 5 to 15 seconds.

10.2 *Temperature-Density Correction*—During a test, the suspension fluid density changes, therefore calculations for the quantity of particles in suspension must account for fluid density changes due to temperature, presence of dispersant, and the meniscus rise. The temperature-density correction is shifting the hydrometer scale, which is factory set for distilled water at 20°C. There are two ways to determine this correction: take companion measurements in a control cylinder filled with the reference solution during the testing or generate a reusable, calibration relationship. Both options require the use of a reference solution composed of test water and the same amount of dispersant used in the sedimentation test cylinder. The meniscus correction is automatically accounted for in the temperature-density correction for both options by consistently reading the hydrometer at the top of the meniscus as described in 10.3.

10.2.1 *Reference Solution*—The reference solution shall be prepared with the same amount of dispersant as the soil suspension. Fill a control cylinder to the 1,000 mL mark with a mixture of test water and the same amount of dispersant used in the soil suspension cylinder. The test water and dispersant shall be well mixed such that no visible crystals can be seen, and the reference solution shall be agitated to make sure the dispersant is adequately mixed throughout the control cylinder.

10.2.1.1 *Companion Measurements*—Use a control cylinder filled with the reference solution in conjunction with the soil suspension cylinder to obtain the correction. Position the control cylinder in the same temperature-controlled location as the test cylinders so that all cylinders are at or near the same temperature. For each hydrometer and temperature reading taken in the soil suspension cylinder, take a corresponding hydrometer and temperature reading in the control cylinder. However, it is permissible for one control cylinder reading to be used in conjunction with readings in the soil suspension for up to 30 minute intervals. Record the elapsed time and the hydrometer and temperature readings of the control cylinder on the data sheet(s) only when measured (Note 12).

NOTE 12—Readings taken in one control cylinder may be used for multiple test cylinders. Therefore, if the hydrometer and temperature readings in the control cylinder are only taken once during the first 30 minutes of the test, only that reading is recorded on each of the data sheet(s) to which it applies. These measured readings are not to be written in for the other times during the first 30 minutes when a measurement was not actually determined.

10.2.2 *Calibration Relationship*—This option generates a general calibration relationship between the hydrometer reading of a control cylinder filled with the reference solution and the temperature, which eliminates the need for companion measurements during the test. A temperature-based general calibration relationship is required and established for each hydrometer. A sedimentation cylinder is filled to the 1,000 mL mark with test water with the same amount of dispersant used in the soil suspension. Be sure the solution is thoroughly mixed, and the temperature is allowed to equilibrate. Then

insert the hydrometer as described in 10.1.2. Take the reading at the top of the meniscus and record this reading and the temperature of the solution. Rinse the hydrometer well with test water between readings and dry it prior to taking the next reading. Increase/Decrease the temperature of the cylinder, allow it to come to temperature equilibrium and repeat the measurement process. Take at least five different hydrometer and temperature readings within the range of temperatures expected during the sedimentation test. Calculate the constant A or B as discussed below.

10.2.2.1 The 151H hydrometer measures the specific gravity of the fluid relative to distilled water at 20°C. The calibration measurements are used to compute the constant A in the following equation. The standard deviation of the five computed “A” values shall be less than 0.0005. The average value of A is used when computing the temperature-density correction.

$$A_n = R_{151,n} + (7.784 \times 10^{-6} \times T_n) + (4.959 \times 10^{-6} \times T_n^2) \quad (2)$$

where:

- A = average specific gravity shift (151H hydrometer), nearest 0.0001,
- $R_{151,n}$ = 151H specific gravity hydrometer at reading, n , in reference solution, readable to 0.00025 or better,
- T = temperature at reading, n , readable to 0.5°C or better, and
- n = subscript indicating the reading number during calibration.

10.2.2.2 The 152H hydrometer measures the mass of particles (specific gravity of 2.65) in a suspension of distilled water at 20°C. The temperature-density correction provides the offset mass reading for the hydrometer for a specific temperature and dispersant concentration. The calibration measurements are used to compute the constant B in the following equation (Note 13). The standard deviation of the five computed “B” values shall be less than 0.5 g/L. The average value of B is used when computing the temperature-density correction.

$$B_n = R_{152,n} + (1.248 \times 10^{-2} \times T_n) + (7.950 \times 10^{-3} \times T_n^2) \quad (3)$$

where:

- B = average mass reading shift (152H hydrometer), nearest 0.1,
- $R_{152,n}$ = mass in reference solution hydrometer at reading, n , readable to 0.25 g/L or better,
- T = temperature at reading, n , readable to 0.5°C or better, and
- n = subscript indicating the reading number during calibration.

NOTE 13—The equations relating the hydrometer readings to temperature are based on the same water density-temperature expression as used in Test Methods D854. For the 151H specific gravity hydrometer, the constants in the water density-temperature equation from Test Methods D854 are divided by the density of water at 20°C (0.99821 g/mL). For the 152H mass in suspension hydrometer, the constants are multiplied by 1606 setting the scale to read mass of solids in solution for a particle specific gravity of 2.65.

10.3 *Meniscus Correction*—Hydrometers are designed to be read at the fluid surface, however, the fluid is wetting to the glass such that the soil suspension will rise up the hydrometer

stem making a reading at the fluid surface impossible at times. It is common practice to read the hydrometer at the top of the meniscus and it must be taken there even when it is possible to see through the soil suspension. The meniscus rise has a small impact on the effective depth determination since the reading is taken slightly above the surface of the suspension. This rise causes a change to the third significant digit in the computed particle size. The meniscus correction is performed before initial use of the hydrometer and after damage has been suspected or noticed.

10.3.1 The meniscus correction, C_m , as shown in Fig. 4, is determined by inserting the hydrometer with a clean and dry stem and without bobbing into the test water with the proper amount of dispersant. The reading at the top of the meniscus and the reading where the plane of water surface intersects the stem are recorded. The difference between these two readings (top of meniscus minus plane of water surface) is the meniscus correction, C_m . Therefore, the meniscus correction is a negative value and has units of the hydrometer scale. In accordance with Test Method E126, the plane of water surface reading shall be obtained using the following guidance. Observe a point slightly below the plane of the water surface and raise the line of vision until this surface, seen as an ellipse, becomes a straight line. The point where this line cuts the hydrometer scale is the hydrometer reading. Holding a white card behind the cylinder just below the water level will improve the visibility of the surface. The hydrometer readings shall be recorded to the nearest 1/4 division.

10.4 *Effective Depth*—The effective depth, also referred to as “true depth,” is used in the calculation of the particle fall distance for each reading. The effective depth is defined as the distance from the center of (volume) buoyancy of the hydrometer to the surface of the soil suspension. The equation to calculate the effective depth when the hydrometer is inserted and removed between readings requires certain dimensional measurements in order to do the calculation. Refer to Fig. 5.

10.4.1 Determine and record the volume of the hydrometer bulb, V_{hb} , to the nearest 1 cm³ using the procedure given in Annex A1.3.4. The bulb includes everything from the bottom tip up to the base of the stem.

10.4.2 Determine and mark the center of (volume) buoyancy, c_b , using the procedure given in A1.3.5.

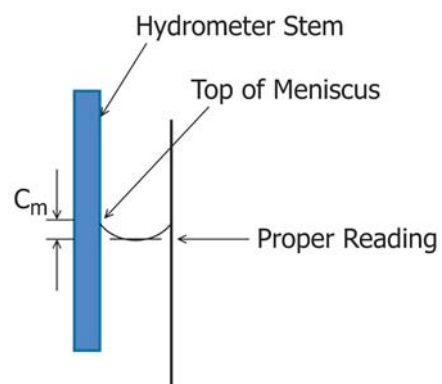


FIG. 4 Meniscus Correction Diagram

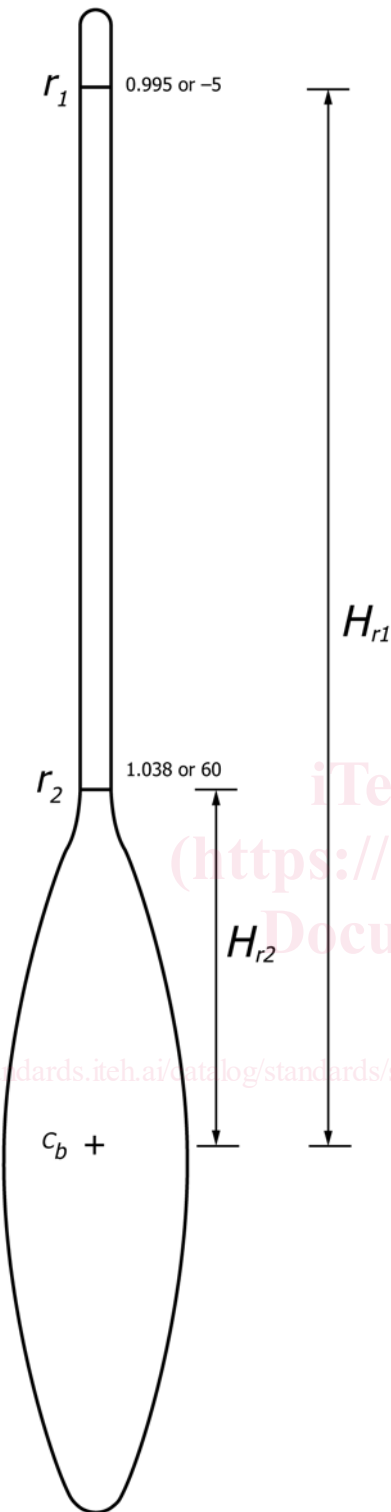


FIG. 5 Effective Depth Dimensional Measurements

10.4.3 Measure the distance between the center of (volume) buoyancy, c_b , and the maximum hydrometer reading H_{r2} , as well as the minimum hydrometer reading, H_{r1} . Record both values to the nearest 0.1 cm. Refer to Fig. 5.

10.4.4 Measure and record the inside cross-sectional area of the sedimentation cylinder, A_c , to the nearest 0.1 cm² using the procedure given in A1.4.2.1.

10.5 *Sedimentation Cylinder*—Check and record the dimensions of the sedimentation cylinders as presented in Annex A1 in accordance with the interval presented in Annex A1.

10.6 *Sieves*—See Practice E11 for the verification requirements of the sieves used in this test method.

10.7 *Miscellaneous*—The ancillary equipment used in conjunction with these test methods shall be calibrated/verified/checked according the intervals listed in Practice D3740 and performed in accordance with their applicable standards.

11. Procedure

11.1 Add 5.0 ± 0.1 g of sodium hexametaphosphate to the sedimentation specimen in the specimen-mixing container obtained in 9.9 or dissolve this amount of dispersant in about 100 mL of test water and add it to the sedimentation specimen. Record to the nearest 0.01 g the actual amount of dispersant, M_{disp} , placed in the container or dissolved in the test water. If added directly to the sedimentation specimen, first add at least 100 mL of test water to the specimen and then the dispersant to form a slurry of milkshake consistency. The amount of test water to be added during this step should be sufficient enough only to facilitate the process of breaking apart the soil aggregations. Mix the contents with a spatula or similar device until all of the soil aggregations are broken-up (Note 14).

NOTE 14—If hand mixing is not efficient, use a 250 to 500 mL Erlenmeyer flask along with either a wrist or orbital dispersion (mechanical) shaker to vigorously agitate the soil slurry in a minimum of 150 mL of test water for a few hours or until all the soil aggregations are broken-up. Be aware the dispersion cup has a capacity of about 400 mL and the stirring apparatus is only efficient in dispersing soil aggregations that will pass between the baffle rods. An ultrasonic water bath, along with the flask, may also be used to agitate the slurry.

11.2 Prior to the overnight conditioning period, disperse the slurry using either the stirring apparatus or an air jet device.

11.2.1 If using the stirring apparatus, transfer the slurry to the dispersion cup. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the dispersion cup. Add additional test water as necessary such that the cup is about half full, then use the stirring apparatus to blend the soil for about 1 minute (Note 15).

NOTE 15—Subsection 11.2.1.1 provides the referee procedure to disperse the soil. However, the stirring apparatus is known to create fines by breaking fragments off weak grains. Alternative methods of dispersion should be considered when testing friable materials.

11.2.1.1 Transfer all the dispersed slurry into the sedimentation cylinder. Use the wash/rinse bottle filled with test water as necessary to make sure all of the slurry is transferred to the cylinder. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to within ± 1 mm of the 1,000 mL mark.

11.2.2 If using the tube type air jet device, transfer the slurry to the sedimentation cylinder. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the cylinder. Add additional test water as necessary to bring the volume to no more than 250 mL in the sedimentation cylinder.

11.2.2.1 Before placing the device into the cylinder, slowly allow air to flow until the gauge reads about 7 kPa. This initial pressure is needed to prevent the slurry from entering the air jets when the device is inserted into the cylinder and to remove any water that has condensed in the lines. Then, slowly lower the device into the slurry. Make sure the rubber stopper is securely in place at the top of the cylinder to prevent the slurry from being ejected from the cylinder.

11.2.2.2 For clayey soils increase the pressure to about 170 kPa and for sandy soils increase the pressure to about 70 kPa. Once the pressure is reached, disperse the slurry for five minutes. At the end of five minutes, reduce the pressure to about 7 kPa and lift the air jets out of the slurry and wash any slurry remaining on the device back into the cylinder. Once the device is washed off, turn off the air flow to the device and add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to within ± 1 mm of the 1,000 mL mark.

11.3 Mix the slurry using the agitator (referee) or the tipping method (Note 16). The agitator device is the preferred/referee method for mixing. Check for the presence of foam on top of the slurry after mixing. If a significant amount of foam is present, it may be necessary to reduce the foam using isopropyl alcohol just prior to the start of testing (See 11.7.1).

11.3.1 To use the agitator, insert the paddle to the lower $\frac{1}{4}$ of the cylinder. Stroke the agitator at a rate of about one cycle per second over a distance of several centimeters to dislodge any material stuck to the bottom of the cylinder. After the material is dislodged, the agitator should be rapidly moved downwards until the paddle almost comes into contact with the bottom of the cylinder and then upwards with a slower motion. The downward stroke should take about one to two seconds while the upward stroke should take about two to three seconds. As this process is repeated, the elevation of the starting position of the agitation cycle is raised until the bottom of the agitator is significantly above the mid-height of the soil suspension. Keep the paddle submerged at all times during mixing. Mix for about one minute or until the suspension appears uniform.

11.3.2 To use the tipping method, first place a rubber stopper in the open end of the cylinder or use the palm of the hand to cover the opening. Then turn the cylinder upside down and back for a period of one minute to complete the agitation of the slurry (Note 17). Using the cylinder tipping method is not very efficient and tipping for more than one minute will typically be required when testing highly plastic clays. This method of agitation may leave some soil aggregations. Use of the agitator is greatly encouraged.

NOTE 16—When using the tipping method, there will likely be some soil particles remaining on the rubber stopper or hand and on the sides of the sedimentation cylinder above the 1,000 mL mark. Be careful not to lose much material by scraping the material adhering to the rubber stopper or hand off onto the rim of the cylinder. Do not rinse these particles back into the cylinder. The minor loss of mass (~ 0.02 g or less, if care is taken) is less critical with respect to the calculations than the addition of water (~ 5 mL) to the cylinder.

NOTE 17—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 vigorously shaking of the cylinder while it is inverted.

11.4 If using a companion measurement to obtain the temperature-density correction, prepare the reference solution in a control cylinder by dissolving the same amount (5.0 ± 0.1 g) of sodium hexametaphosphate as used in the soil suspension cylinder in test water. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the solution to ± 1 mm of the 1,000 mL mark.

11.5 Cover the cylinder(s) to prevent evaporation and allow the cylinder(s) to sit overnight either in a temperature controlled insulated chamber or water bath or in an area of relatively constant temperature. This conditioning period allows the temperature to equilibrate and for the specimen to deflocculate (Note 18). The soil slurry is now referred to as a soil suspension.

11.6 At the end of the conditioning period, check the suspension for indications of flocculation (Note 19). If the suspension has indications of flocculation, then the test is invalid and the suspension should be discarded since it has been contaminated with dispersant. A new specimen would need to be treated to prevent flocculation. Such treatment is beyond the scope of this test method.

NOTE 18—Strong interparticle bonding can occur in suspensions having high salt concentrations. The dispersant will not be effective in breaking these bonds. In such circumstances the salt should be leached from the soil before proceeding with the sedimentation test. This leaching results in a considerable increase in effort and difficulty to process the material and is not discussed in this standard.

NOTE 19—Flocculation of clay particles can be difficult to detect. Minor flocculation will shift the particle-size distribution (gradation) towards a coarser fraction. Moderate flocculation will cause a plateau in the curve as the sedimentation process stops. Major flocculation will completely halt sedimentation at an early stage. Only major flocculation is visually detectable showing a lack of material collected at the bottom of the cylinder, a surface layer of clear fluid, or horizontal cracks in the suspension.

11.7 Once the suspension has temperature equilibrated and deflocculated, the suspension shall once again be mixed to create a uniform suspension. Repeat the mixing procedure as described in 11.3. Upon completion of agitation, make sure the cylinder is on a stable surface and in a location where it will not be subjected to any jarring or disturbance and immediately start the timer as directed in either 11.7.2 or 11.7.3. If using a temperature controlled water bath, immediately place the cylinder back into the water bath after agitation.

11.7.1 If significant foam develops on top of the suspension after mixing, immediately add up to three drops of isopropyl alcohol to the suspension to reduce or eliminate the foam.

11.7.2 If using the agitator, start the timer when the paddle of the agitator breaks the surface of the soil suspension. After removing the agitator allow the “free” liquid on it to drain back into the sedimentation cylinder.

11.7.3 If using the tilting method, start the timer after completion of the last inversion.

11.8 Hydrometer readings shall be taken at elapsed times of approximately, 1, 2, 4, 8, 15, 30, 60, 240, and 1440 minutes. Additional readings can be taken to better define the particle-size distribution (gradation) relationship.