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Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, or Centrifuge[1]

This standard is issued under the fixed designation D6836; 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 These test methods cover the determination of soil water characteristic curves (SWCCs) for desorption (drying). SWCCs describe the relationship between suction and volumetric water content, gravimetric water content, or degree of water saturation. SWCCs are also referred to as soil water retention curves, soil water release curves, or capillary pressure curves.

1.2 This standard describes five methods (A-E) for determining the soil water characteristic curve. Method A (hanging column) is suitable for making determinations for suctions in the range of 0 to 80 kPa. Method B (pressure chamber with volumetric measurement) and Method C (pressure chamber with gravimetric measurement) are suitable for suctions in the range of 0 to 1500 kPa. Method D (chilled mirror hygrometer) is suitable for making determinations for suctions in the range of 500 kPa to 100 MPa. Method E (centrifuge method) is suitable for making determinations in the range 0 to 120 kPa. Method A typically is used for coarse soils with little fines that drain readily. Methods B and C typically are used for finer soils, which retain water more tightly. Method D is used when suctions near saturation are not required and commonly is employed to define the dry end of the soil water characteristic curve (that is, water contents corresponding to suctions >1000 kPa). Method E is typically used for coarser soils where an appreciable amount of water can be extracted with suctions up to 120 kPa. The methods may be combined to provide a detailed description of the soil water characteristic curve. In this application, Method A or E is used to define the soil water characteristic curve at lower suctions (0 to 80 kPa for A, 0 to 120 kPa for E) near saturation and to accurately identify the air entry suction, Method B or C is used to define the soil water characteristic curve for intermediate water contents and suctions (100 to 1000 kPa), and Method D is used to define the soil water characteristic curves at low water contents and higher suctions (>1000 kPa).

1.3 All observed and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026. The procedures in Practice D6026 that are used to specify how data are collected, recorded, and calculated are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the objectives of the user. Increasing or reducing the significant digits of reported data to be commensurate with these considerations is common practice. Consideration of the significant digits to be used in analysis methods for engineering design is beyond the scope of this standard.

1.4 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants (Withdrawn 2016)[3]

D425 Test Method for Centrifuge Moisture Equivalent of Soils

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

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[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.04 on Hydrologic Properties and Hydraulic Barriers.

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[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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D6026 Practice for Using Significant Digits in Geotechnical Data

2.2 *API Standard:*

API RP 40 Recommended Practice for Core-Analysis Procedure[4]

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air entry pressure*—the air pressure required to introduce air into and through the pores of a saturated porous plate.

3.2.2 *air entry suction, ψ_a*—the suction required to introduce air into and through the pores of a saturated porous material.

3.2.3 *axis translation*—the principle stating that a matric suction ψ can be applied to a soil by controlling the pore gas pressure, u_g, and the pore water pressure, u_w, so that the difference between the pore gas pressure and pore water pressure equals the desired matric suction, that is, $\psi = u_g - u_w$.

3.2.4 *gravimetric water content, w*—the ratio of the mass of water contained in the pore spaces of soil or rock to the mass of solid particles.

3.2.5 *matric suction, ψ*—the negative gauge pressure, relative to an external gas pressure acting on the soil water, that must be applied to a solution identical in composition to the soil water to maintain equilibrium through a porous membrane existing between the solution and the soil water. Matric suction is also referred to as matric potential, capillary suction, and capillary potential. By definition, matric suction is the difference between the pore gas pressure, u_g, and the pore water pressure, u_w, that is, $\psi = u_g - u_w$. In most cases the pore gas is air.

3.2.6 *osmotic suction, ψ_o*—the negative gauge pressure derived from the measurement of the vapor pressure of water in equilibrium with a solution identical in composition with the soil water, relative to the vapor pressure of water in equilibrium with free pure water. Osmotic suction is also referred to as osmotic potential.

3.2.7 *porous membrane*—a porous polymeric membrane that can transmit water and has a air entry pressure exceeding the highest matric suction to be applied during a test.

3.2.8 *porous plate*—a plate made of metal, ceramic, or other porous material that can transmit water and has an air entry pressure exceeding the highest matric suction to be applied during a test.

3.2.9 *pressure chamber*—a vessel used to apply a gas pressure on the specimen and the soil pores to induce a specified matric suction.

3.2.10 *saturated water content*—volumetric or gravimetric water content when the specimen is saturated.

3.2.11 *soil water characteristic curve*—a graph of suction (matric or total) versus water content (gravimetric or volumetric) or saturation. The soil water characteristic curve is also referred to as the soil water retention curve, the soil water release curve, and the capillary pressure curve.

3.2.12 *total suction, ψ_t*—the negative gauge pressure derived from the measurement of the vapor pressure of water in equilibrium with water in the soil pores, relative to the vapor pressure of water in equilibrium with free pure water. Total suction is the sum of matric and osmotic suction, $\psi_t = \psi + \psi_o$. Total suction is also referred to as total potential.

3.2.13 *volumetric water content, θ*—the ratio of the volume of water contained in the pore spaces of soil or rock to the total volume of soil and rock.

3.2.14 *water activity, a_w*—the ratio of vapor pressure of water in the soil gas to the saturated vapor pressure at the existing soil temperature. Water activity is also referred to as the relative humidity.

4. Summary of Methods

4.1 *Methods A-C*—Methods A-C yield soil water characteristic curves in terms of matric suction. Various suctions are applied to the soil and the corresponding water contents are measured. Two different procedures are used to apply the suction. In Method A, the matric suction is applied by reducing the pore water pressure while maintaining the pore gas pressure at the atmospheric condition. In Methods B and C, the pore water pressure is maintained at atmospheric pressure, and the pore gas pressure is raised to apply the suction via the axis translation principle.

4.1.1 For all three methods, saturated soil specimens are placed in contact with a water saturated porous plate or membrane. The matric suction is applied by one of the two aforementioned procedures. Application of the matric suction causes water to flow from the specimen until the equilibrium water content corresponding to the applied suction is reached. Equilibrium is established by monitoring when water ceases to flow from the specimen. Several equilibria are established at successive matric suctions to construct a soil water characteristic curve.

4.1.2 The water content corresponding to the applied suction is determined in one of two ways. For Methods A and B, the volume of water expelled is measured using a capillary tube. The water content is then determined based on the known initial water content of the specimen and the volume of water

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[4] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

expelled. For Method C, the water content is measured gravimetrically by weighing the specimen after removal from the apparatus.

4.2 *Method D*—Method D yields a soil water characteristic curve in terms of total suction. In contrast to Methods A-C, the water content of the soil is controlled in Method D, and the corresponding suctions are measured. Two different approaches are commonly used. In one approach, a set of specimens are prepared that are essentially identical, but have different water contents. Water contents are selected that span the range of water contents that will be used to define the soil water characteristic curve. In the other approach, a single specimen is used. The specimen is tested, dried to a lower water content, and then tested again. This process is repeated until suctions have been measured at all of the desired water contents.

4.2.1 In Method D, the water activity of the pore water is measured using a chilled mirror hygrometer (also known as a chilled mirror psychrometer) and then the total suction is computed using the Kelvin equation. In many cases, Method D is used to determine only that portion of the soil water characteristic curve corresponding to higher suctions (typically >1000 kPa) and lower water contents. Under these conditions, the osmotic component of total suction is generally small, and the matric and total suctions are comparable. Thus, the data from Methods A-C and Method D can be combined to form a single soil water characteristic curve. An example of this type of soil water characteristic curve is provided in Section 11.

4.3 *Method E*—Method E yields a soil water characteristic curve in terms of matric suction (or capillary pressure). The specimen is contained in a support chamber that is subjected to a centrifugal force in a centrifuge. Different matric suctions are applied by varying the angular velocity of the centrifuge. Water displaced from the soil at a given angular velocity is collected and measured in a calibrated cylinder at the base of the support chamber. A soil water characteristic curve is measured by subjecting the specimen to a series of angular velocities (each corresponding to a matric suction) and measuring the volume of water displaced from the soil at each velocity.

5. Significance and Use

5.1 The soil water characteristic curve (SWCC) is fundamental to hydrological characterization of unsaturated soils and is required for most analyses of water movement in unsaturated soils. The SWCC is also used in characterizing the shear strength and compressibility of unsaturated soils. The unsaturated hydraulic conductivity of soil is often estimated using properties of the SWCC and the saturated hydraulic conductivity.

5.2 This method applies only to soils containing two pore fluids: a gas and a liquid. The liquid is usually water and the gas is usually air. Other liquids may also be used, but caution must be exercised if the liquid being used causes excessive shrinkage or swelling of the soil matrix.

5.3 A full investigation has not been conducted regarding the correlation between soil water characteristic curves obtained using this method and soil water characteristics curves of in-place materials. Thus, results obtained from this method should be applied to field situations with caution and by qualified personnel.

NOTE 1—The quality of the result produced by this standard depends on the competence of the personnel performing the test 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 ensure reliable results. Reliable results depend on many factors. Practice D3740 provides a means of evaluating some of these factors.

6. Apparatus

6.1 *Hanging Column Apparatus (Method A)*—A hanging column apparatus consists of three parts: a specimen chamber, an outflow measurement tube, and a suction supply (Fig. 1). The specimen chamber consists of a glass or rigid plastic funnel containing a porous plate that is large enough to contain the specimen being tested. Such funnels are commonly referred to as "Buchner" funnels. A photograph of a funnel used for a hanging column apparatus is shown in Fig. 2. Water expelled from the specimen during the test is measuring using a capillary tube connected to the outflow end of the funnel. The other end of this capillary tube is connected to suction supply consisting of two reservoirs. The relative elevation of the two reservoirs is adjusted to develop a vacuum, which is transmitted to the capillary tube. The magnitude of the applied suction is measured with a manometer.

6.2 *Pressure Chamber (Methods B and C)*—Pressure chambers are used for the pressure extraction method to apply a gas pressure (typically air pressure) to the specimen and the gas in the pores. Typically the pressure chamber is a metallic vessel. The pressure chamber shall be pressure-rated, at the very least, for the maximum pressure to be applied to the vessel during the test. The pressure chamber shall have a sealed, non-collapsing outflow tube that connects the atmospheric pressure side of the porous plate (or membrane) to the outside of the pressure chamber. Schematics of two types of pressure chambers are shown in Figs. 4 and 5. Photographs of these pressure chambers are shown in Fig. 4. In some cases, the effects of overburden pressure may wish to be simulated. For these cases, the pressure vessel may be equipped with a piston or a triaxial cell may be used.

6.3 *Regulated Pressure Source (Methods B and C)*—A regulated pressure source is used to apply gas pressure to the pressure chamber. Compressed gas is typically provided by an air compressor or bottled gas. The pressure source and associated regulators shall be capable of maintaining the desired pressure with an accuracy of ±0.25 % or better.

6.4 *Pressure Indicators (Methods A, B, and C)*—Pressure indicators are used to monitor the pressure applied in pressure chambers and the applied suction for the hanging column. Bourdon gauges, water manometers, and pressure transducers are acceptable devices for measuring pressure in the pressure chamber. The accuracy of the measuring device must be within ±0.25 % of the matric suction being applied. For cases where both very large and very small suctions are to be applied, multiple pressure indicators may be used to provide sufficient

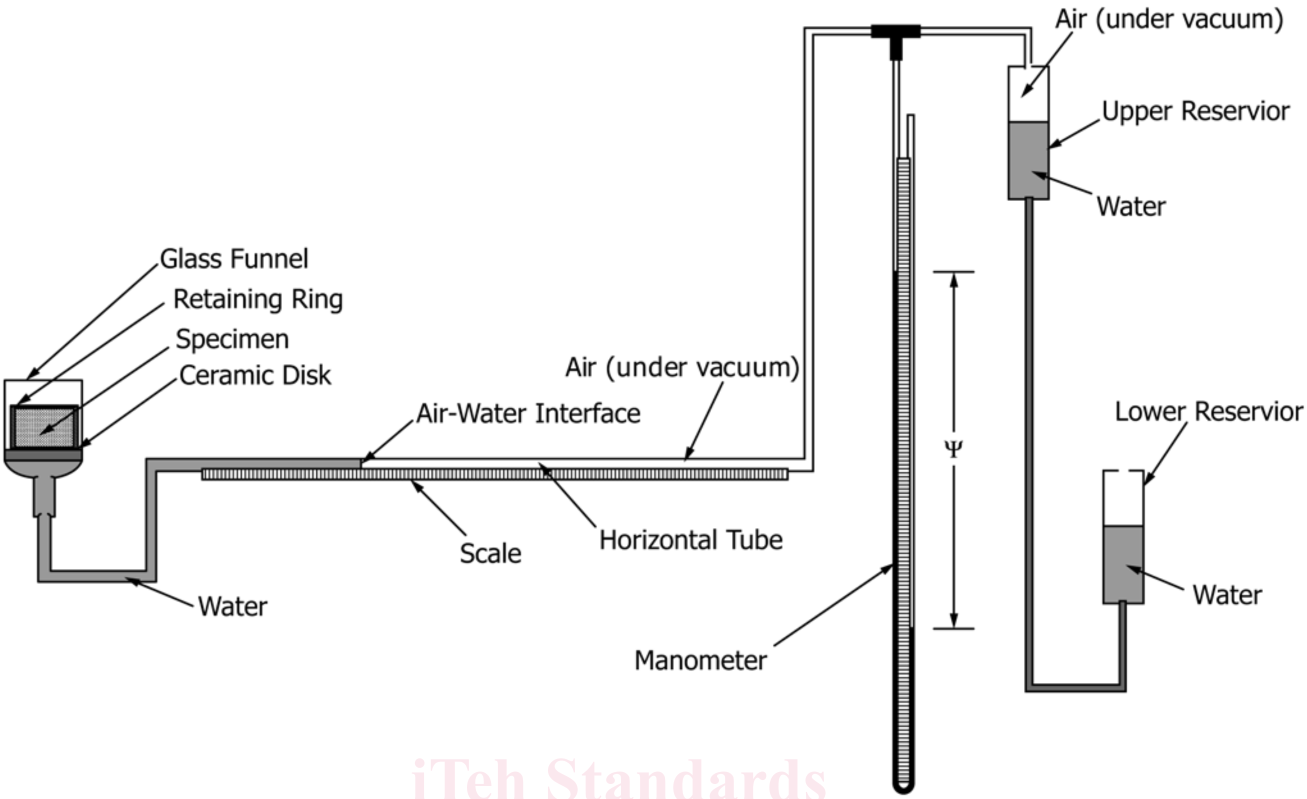


FIG. 1 Schematic of Hanging Column Apparatus

accuracy for the various pressures to be applied. The manometer used to measure the applied suction in Method A shall have a resolution of 1 mm of water.

6.5 *Porous Plate (Methods B and C)*—A porous plate is used in the hanging column and pressure extractor to provide a saturated interface between the pore water and the water in the volume measuring system. Porous plates shall be fabricated from material that is hydrophilic and has an air entry pressure greater than the maximum matric suction to be applied during the test. Porous ceramic plates are typically usually used as porous plates. Porous plates are shown in the photographs in Figs. 4 and 5.

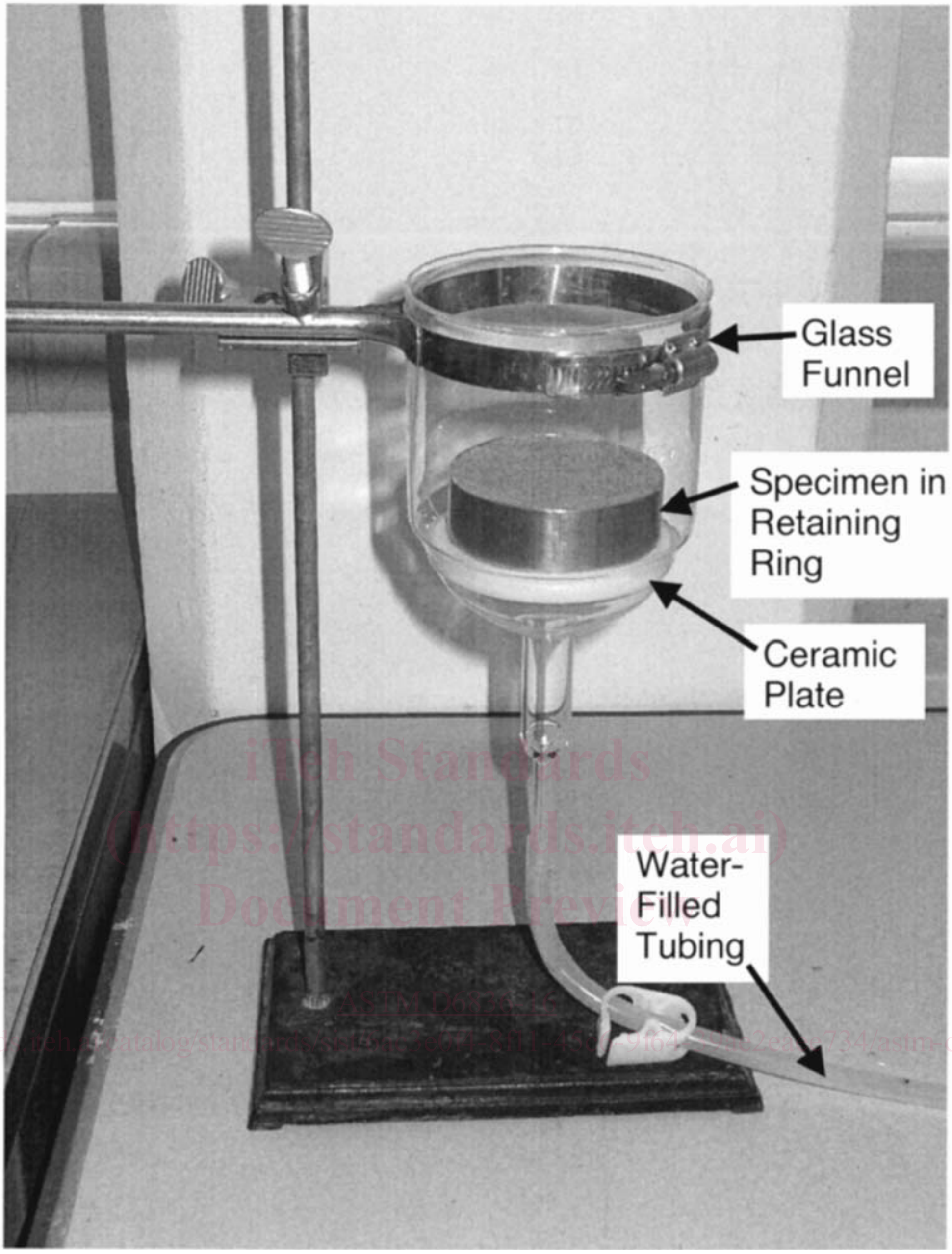
6.5.1 The porous plate shall be configured such that one side of the membrane is in contact with the specimen and is exposed to gaseous atmosphere in the pressure chamber. The other side of the plate shall be in contact with the outflow system (Fig. 3). A seal shall be provided that prevents gas in the chamber from contacting the side of the porous membrane in contact with the outflow system. This seal shall also prevent water from leaking from the outflow system and into the pressure chamber.

6.6 *Pressure Membrane (Methods B and C)*—A porous membrane is used in a pressure extractor to provide a saturated interface between the pore water and the water in the measuring system. The porous membrane shall be fabricated from a material that is hydrophilic and has an air entry pressure higher than the maximum suction to be applied during the test. A non-corroding porous material having sufficient strength and stiffness shall be used to support the porous material (a stainless steel screen typically is used). The pores in the supporting material shall be sufficiently large to preclude development of measurable capillary stresses. The membrane and supporting material shall be configured such that the unsupported side of the membrane is in contact with the specimen and is exposed to gaseous atmosphere in the pressure chamber. The support side of the membrane shall be in contact with the outflow system. A seal shall be provided that prevents gas in the chamber from contacting the side of the porous membrane in contact with the outflow system. This seal shall also prevent water from leaking from the outflow system and into the pressure chamber.

6.7 *Capillary Tube (Methods A and B)*—A capillary tube is used to measure the outflow from the specimen for Methods A and B. The capillary tube shall be free of dirt, oil, or other contaminants and include a scale that permits resolution of the volume expelled to 0.1 mL or better.

6.8 *Specimen Retaining Rings*—Specimens tested using Methods A, B, and C shall be retained on the porous plate or membrane using a retaining ring at least 5 mm in height and 25 mm in inside diameter. The wall thickness shall be sufficient to retain the soil without visible distortion. A photograph of a specimen in a typical retaining ring is shown in Fig. 6a. Retaining rings are typically constructed from stainless steel, acrylic, or polyvinyl chloride.

6.9 *Chilled Mirror Hygrometer (Method D)*—A chilled mirror hygrometer (also known as a chilled mirror psychrometer) shall be used to measure water activity to within 0.001. The chilled mirror hygrometer must be able to test specimens



Specimen is contained in a retaining ring.

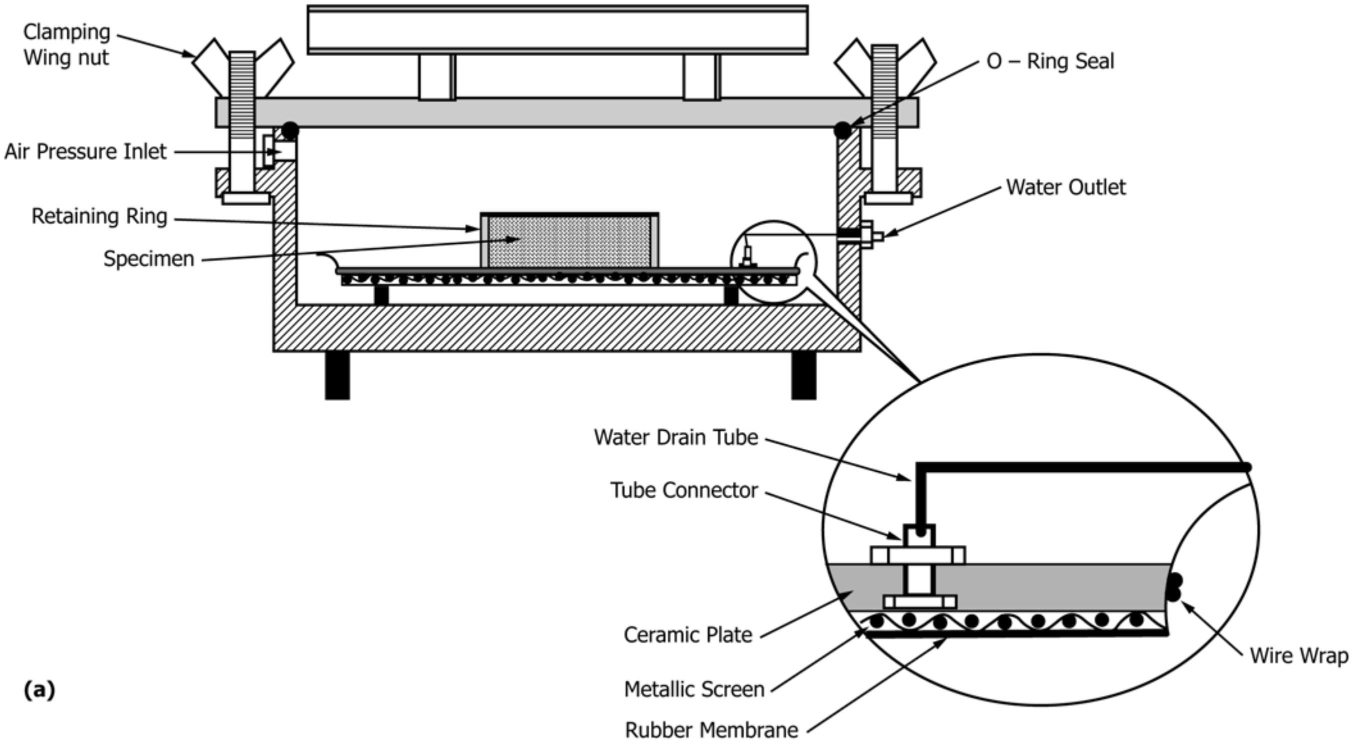
FIG. 2 Photograph of Funnel Used for Hanging Column Apparatus.

with a diameter of at least 20 mm and height of at least 5 mm. Water activity obtained from the chilled mirror hygrometer shall be converted to total suction using the Kelvin equation. A photograph of a chilled mirror hygrometer is shown in Fig. 7.

6.10 *Specimen Retaining Dish (Method D)*—Specimens tested using Method D shall be contained in a specimen retaining dish with a diameter of at least 20 mm and height of at least 5 mm. The dish shall be made of a non-porous and non-corroding material such as stainless steel or plastic. A photograph of a specimen in a retaining dish is shown in Fig. 6b.

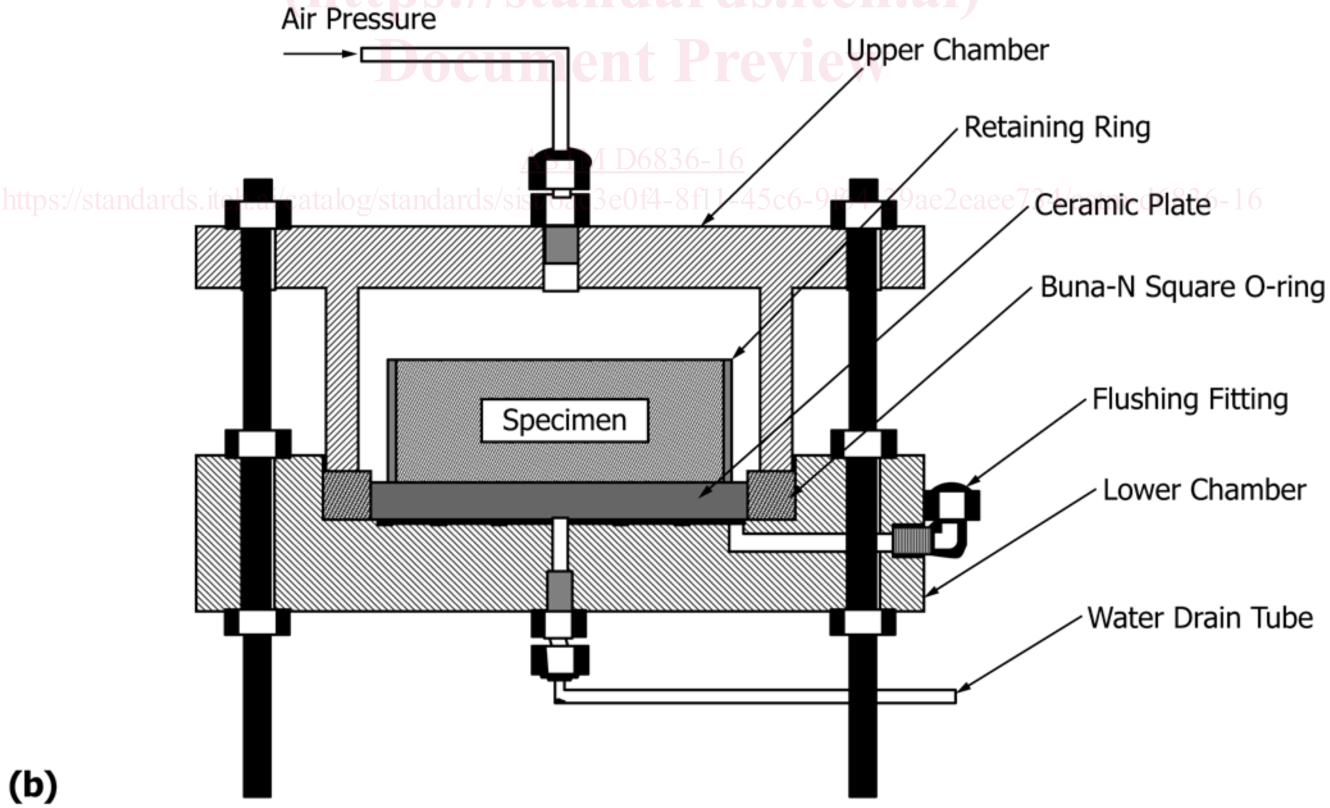
6.11 *Moisture Content Container*—A container meeting the requirements outlined in Method D2216 shall be provided for determination of water content.

6.12 *Balance*—For Methods A-C, a balance shall be used that has a minimum capacity of 200 g and a sensitivity of 0.01



Schematic of pressure chambers with ceramic porous plates: (a) conventional chamber for single or multiple specimens and (b) chamber for single specimen

FIG. 3 Schematic of Pressure Chambers With Ceramic Porous Plates



Schematic of pressure chambers with ceramic porous plates: (a) conventional chamber for single or multiple specimens and (b) chamber for single specimen

FIG. 3 Schematic of Pressure Chambers With Ceramic Porous Plates *(continued)*

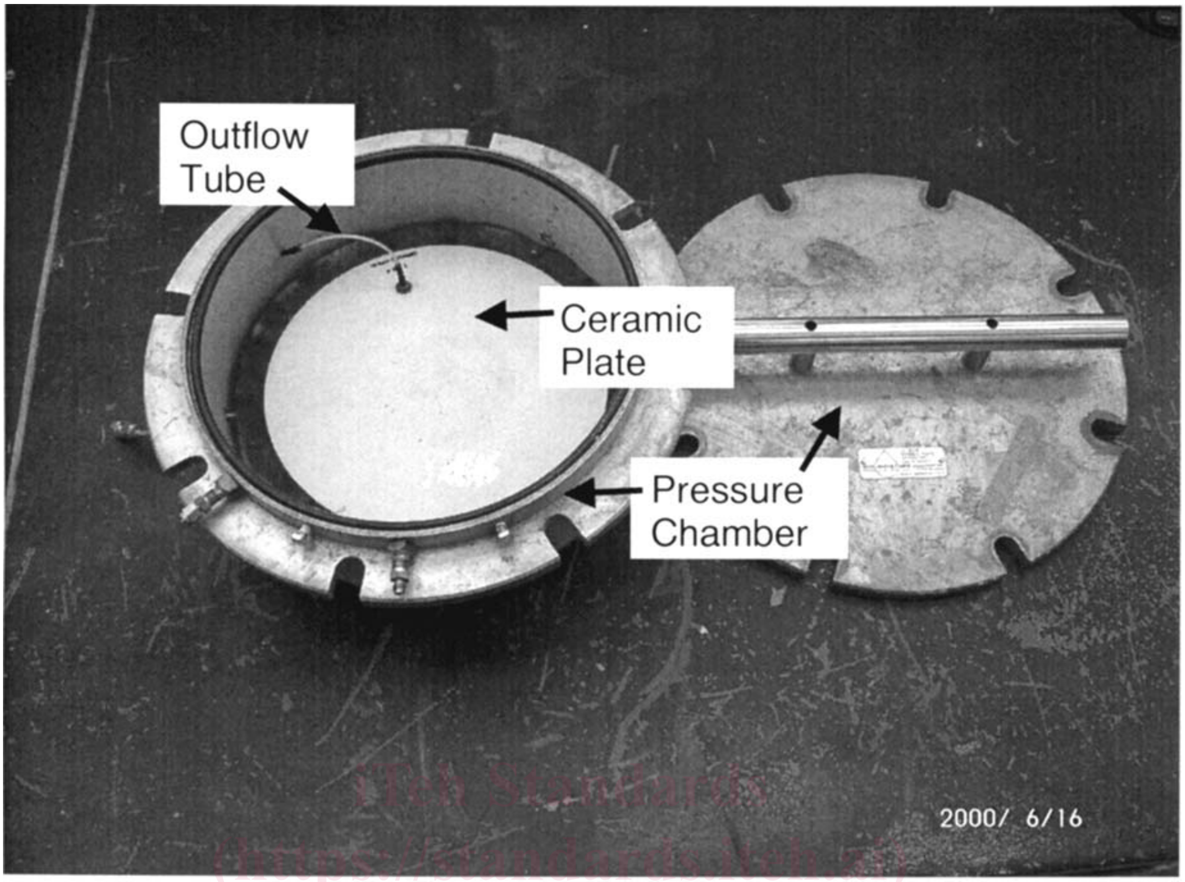


FIG. 4 Photographs of a Multiple-Specimen Pressure Chamber

g. For Method D, a balance shall be used that has a minimum capacity of 50 g and a sensitivity of 0.001 g. All balances shall meet the requirements of Specification D4753.

6.13 *Desiccator*—A desiccator shall be provided that has suitable size to hold specimens for cooling after removal from the oven. A desiccator is only recommended when moisture containers having close-fitting lids are not used (see Method D2216).

6.14 *Drying Oven*—A thermostatically controlled drying oven capable of maintaining temperature at 110 ± 5°C as per requirements of Method D2216.

6.15 *Temperature Controlled Centrifuge (Method E)*—A thermostatically controlled centrifuge capable of maintaining a temperature of 20 ± 3°C when operated between 0-10 000 RPM. A photograph of a centrifuge is shown in Fig. 8 with sealed sample support chamber and calibrated water collection tube. The centrifuge shall include a measurement device for recording outflow in the support chamber to the nearest 0.1 mL while the specimen is under centrifugation. A strobe light apparatus is normalized used for this purpose.

6.16 *Specimen Support Chamber (Method E)*—A chamber used to retain the specimen and the calibrated cylinder used to collect the displaced water. A schematic of a specimen support chamber is shown in Fig. 9.

6.17 *Saturation Tray, Chamber, or Apron (Methods A-E)*—Plates, membranes and specimens are saturated in a saturation tray, a saturation chamber, or directly in pressure chamber using a saturation apron. Trays shall have a depth greater than the sum of the specimen height and thickness of the porous plate (or membrane). Saturation chambers are vessels filled with water in which a specimen in a retaining ring can be inundated for saturation. A vacuum is applied to the water in a saturation chamber using an external device. A saturation apron in the pressure chamber may be used to impound water around a specimen for saturation. Aprons are only used for saturating specimens.

6.18 *Miscellaneous Tools*—wire saw, beveled straightedge, spatula, and other small tools for trimming test specimens, 10 mL and 100 mL graduated cylinders, 25 mL syringe.

6.19 *Laboratory Environment*—The laboratory temperature shall be maintained within ± 3°C during the test. The apparatus shall be shielded from directly sunlight or other sources of heat that may cause variations in temperature. If very precise measurements are required, the hanging column or pressure chamber may be isolated in a thermally insulated box.

7. Reagents

7.1 *Saturating Liquid:*

7.1.1 The saturating liquid is used to saturate the porous plates and membranes, the specimen, and the outflow measuring components of the apparatus.

7.1.2 The saturating liquid should be specified by the requestor. If no specific type of saturating water is specified by

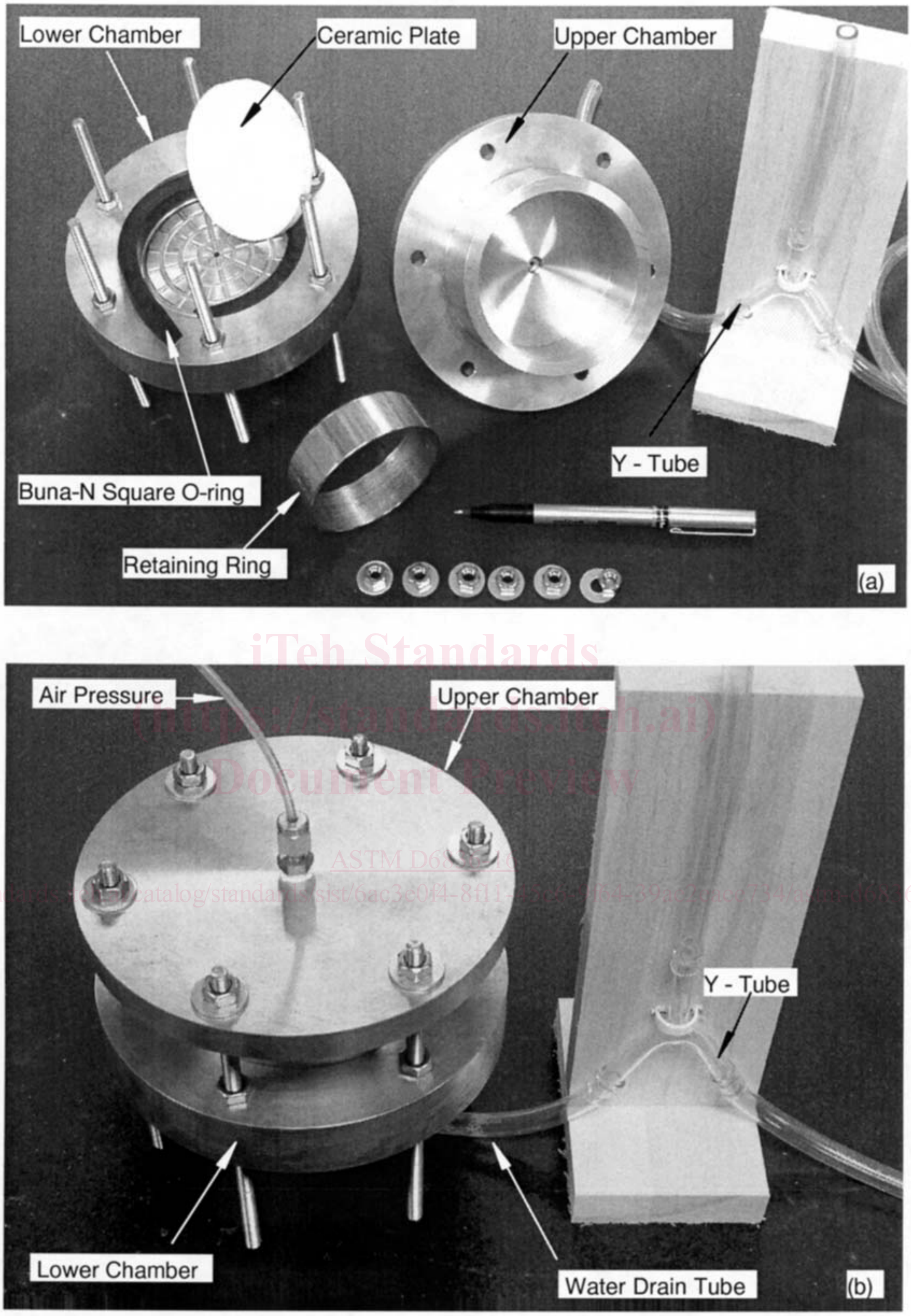
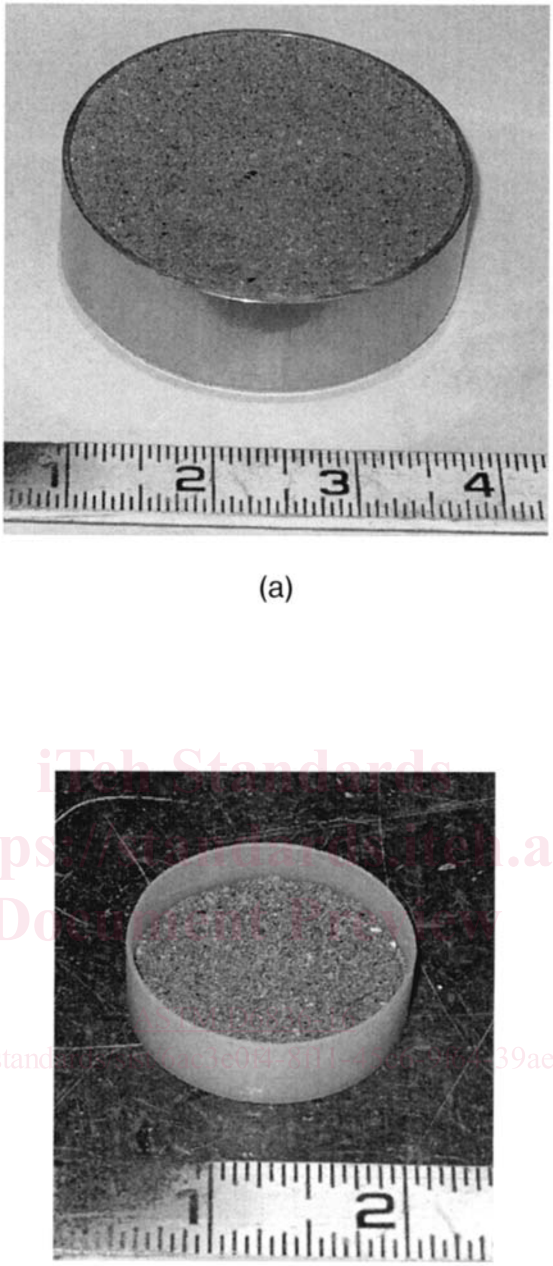


FIG. 5 Photographs of a Single-Specimen Pressure Chamber and Associated Equipment: (a) Open and (b) Assembled



(a)

(b)

FIG. 6 Specimen in Retaining Ring (Methods A-C) (a) and Retaining Dish (Method D) (b)

the requestor, the water shall be deaired 0.0025 M $CaCl_2$ solution or tap water. Distilled or deionized water shall not be used unless specified by the requestor. A biocide may be added to the water to minimize microbial growth during the test. If a biocide is added, the type and concentration of the biocide shall be included in the report.

7.1.3 *Deaired Water*—Deaired water shall be used. Water is usually deaired by boiling, spraying a fine mist of water into an evacuated vessel attached to a vacuum source, or by forceful agitation of water in a container attached to a vacuum source. To prevent dissolution of air back into the water, deaired water shall not be exposed to the atmosphere for prolonged periods.

8. Preparation

8.1 *Preparation of Specimens:*

8.1.1 *Specific Gravity*—Measure the specific gravity of solids on a sub-sample of the material to be tested following the method in Test Method D854.

8.1.2 *Retaining Ring, Dish, or Mold*—Measure the inside diameter of the retaining ring, dish, or mold to the nearest 0.1

FIG. 7 Photograph of a Chilled Mirror Hygrometer With Open Sample Drawer and Specimen to be Inserted for Testing

mm at three locations and record the average of these measurements as the diameter. Measure the height of the retaining ring, dish (inside height for dish), or mold to the nearest 0.1 mm at three locations and record the average of these measurements as the height. Determine the mass of the retaining ring, dish, or mold and record its mass to the nearest 0.01 g (ring) or 0.001 g (dish).

8.1.3 *Specimens Prepared from Disturbed Samples*—Air dry and crush a representative sub-sample that has a mass at least twice that required to fill the specimen retaining ring. The sample may be crushed following the procedure described in Practice D421. Remove all particles from the crushed sub-sample having a diameter exceeding one-half the height of the retaining ring. If requested, moisten the sample to the gravimetric water content specified using tap water. Prepare a specimen by placing a known mass of the moistened sub-sample into the retaining ring (Methods A-D) or a specimen mold (Method E). Tap or compact the soil to the density specified by the requestor. Trim the upper surface of the specimen so that it is level with the top of the retaining ring or mold. Determine the mass of the specimen in the retaining ring or mold and record the mass to the nearest 0.01 g. Measure the gravimetric water content of the remaining material using Method D2216.

8.1.4 *Specimens Prepared from Undisturbed Samples*—For Methods A-D, place the undisturbed sample on the bench and gently place a retaining ring on the surface of soil. Use trimming tools to gently remove soil that protrudes beyond the edge of the retaining ring so that the ring can slide over the soil specimen with little effort. Continue trimming until the soil fills the retaining ring. Trim the top of the specimen flush with the top of the retaining ring. Determine the mass of the specimen in the retaining ring and record the mass to the nearest 0.01 g. Measure the gravimetric water content of the remaining material using Method D2216. This procedure is also used to prepare specimens for testing in the chilled mirror hygrometer after being tested in the hanging column or pressure extractor.

8.1.4.1 A similar procedure is followed to prepare specimens for Method E, except no trimming ring or dish is employed. Specimens are trimmed from the undisturbed sample to form a right circular cylinder that fits inside the specimen support chamber. Typically specimens are 38 mm in diameter and 51 mm long (Fig. 9). When trimming is complete, measure the height of the specimen at three locations to the nearest 0.1 mm, and record the average of these measurements as the height. Similarly, measure the diameter of the specimen at three locations to the nearest 0.1 mm, and record the average of these measurements as the diameter. Determine the mass of the specimen to the nearest 0.01 g. The sides of the trimmed specimen are wrapped in unsintered teflon tape. Stainless steel screens (220 mesh) are placed on the ends of the specimen.

8.1.5 *Specimens Compacted in the Laboratory*—Compact the specimen to the specified water content and density using the method of compaction specified by the requestor. For