Designation: D4546 – 14

Standard Test Methods for One-Dimensional Swell or Collapse of Soils[1]

This standard is issued under the fixed designation D4546; 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 standard covers two laboratory test methods for measuring the magnitude of one-dimensional wetting-induced swell or collapse of unsaturated soils and one method for measuring load-induced compression subsequent to wetting-induced deformation.

1.1.1 Test Method A is a procedure for measuring one-dimensional wetting-induced swell or hydrocompression (collapse) of reconstituted specimens simulating field condition of compacted fills. The magnitude of swell pressure (the minimum vertical stress required to prevent swelling), and free swell (percent swell under a pressure of 1 kPa or 20 lbf/ft^2) can also be determined from the results of Test Method A.

1.1.2 Test Method B is a procedure for measuring one-dimensional wetting-induced swell or collapse deformation of intact specimens obtained from a natural deposit or from an existing compacted fill. The magnitude of swell pressure and free swell can also be determined from the results of Test Method B.

1.1.3 Test Method C is a procedure for measuring load-induced strains on a reconstituted or intact specimen after the specimen has undergone wetting-induced swell or collapse deformation.

1.2 In Test Method A, a series of reconstituted specimens duplicating compaction condition of the fine fraction of the soil in the field (excluding the oversize particles) are assembled in consolidometer units. Different loads corresponding to different fill depths are applied to different specimens and each specimen is given access to free water until the process of primary swell or collapse is completed (Fig. 1) under a constant vertical total stress (Fig. 2). The resulting swell or collapse deformations are measured. This test method can be referred to as *wetting-after-loading tests* on multiple reconstituted specimens. The data from these tests can be used to estimate one-dimensional ground surface heave or settlement that can occur due to full wetting after fill construction. In addition, the magnitude of swell pressure and the magnitude of free swell can be interpreted from the test results.

1.3 Test Method B is commonly used for measuring one-dimensional wetting-induced swell or hydrocompression of individual intact samples. This method can be referred to as *single-point wetting-after-loading test*. The vertical pressure at wetting for the specimen is chosen equal to the vertical in-situ stress (overburden stress plus structural stress, if any) corresponding to the sampling depth. The test result indicates the amount of heave or hydrocompression that can result when the soil at a given fill depth is wetted from the current moisture condition to full inundation condition. If intact specimens from various depths are tested, the swell or collapse strain data can be used to estimate heave or settlement of the ground surface. If the objective of the test is to measure swell pressure for an expansive soil, a series of intact specimens from a given depth zone can be wetted under a range of pressures (similar to Test Method A) and the results interpreted to determine the magnitude of the swell pressure.

1.4 Test Method C is for measuring load-induced strains after wetting-induced swell or collapse deformation has occurred. This method can be referred to as *loading-after-wetting test*. The test can be performed on either intact or reconstituted specimens, and can be on one specimen or a series of specimens. The results would apply to situations where new fill, additional structural loads, or both, are applied to the ground that has previously gone through wetting-induced heave or settlement. The first part of the test is the same as in Test Method A or B. After completion of the swell or collapse under a given vertical load, additional vertical load increments are applied to the specimen in the same manner as in a consolidation test (Test Methods D2435) and the load-induced strains are measured.

1.5 It shall be the responsibility of the agency requesting this test to specify the magnitude of each load for Test Method A and Test Method B. For Test Method C, the agency requesting the test should specify the magnitude of the stress under which the specimen is wetted, and the magnitudes of the additional stress increments subsequent to wetting.

1.6 These test methods do not address the measurement of soil suction and suction-controlled swell-collapse tests. The addition of suction-controlled wetting does not constitute nonconformance to these test methods.

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.05 on Strength and Compressibility of Soils.

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*A Summary of Changes section appears at the end of this standard

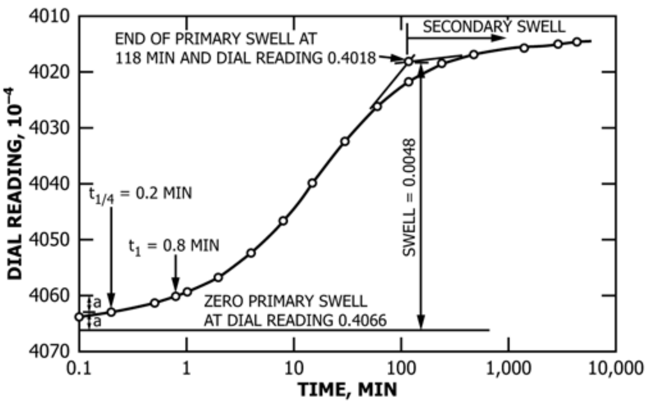

FIG. 1 Time-Swell Curve

1.7 These test methods have a number of limitations and their results can be affected by one or a combination of factors including the effect of significant amounts of oversize particles (in Test Method A), sampling disturbance (in Test Method B) and differences between the degree of wetting in the laboratory test specimens and in the field. For details of these and other limitations, see Section 6.

1.8 *Units*—The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate equivalent values provided for information purposes only and are not considered standard. Test results recorded in units other than SI shall not be regarded as nonconformance with this standard. Figures depicting the test results can be either in SI units or in inch-pound units.

1.8.1 The converted inch-pound units use the gravitational system of units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The slug unit is not given, unless dynamic (F = ma) calculations are involved.

1.8.2 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as nonconformance with this standard.

1.8.3 The terms density and unit weight are often used interchangeably. Density is mass per unit volume whereas unit weight is force per unit volume. In this standard density is given only in SI units. After the density has been determined, the unit weight is calculated in SI or inch-pound units, or both.

1.9 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.9.1 The procedures used to specify how data are collected/recorded, or calculated, in this 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 consideration 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 standard to consider significant digits used in analysis methods for engineering design.

1.10 *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]

C127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
D422 Test Method for Particle-Size Analysis of Soils
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
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 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
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
D6027 Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes (Withdrawn 2013)[3]
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

[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.

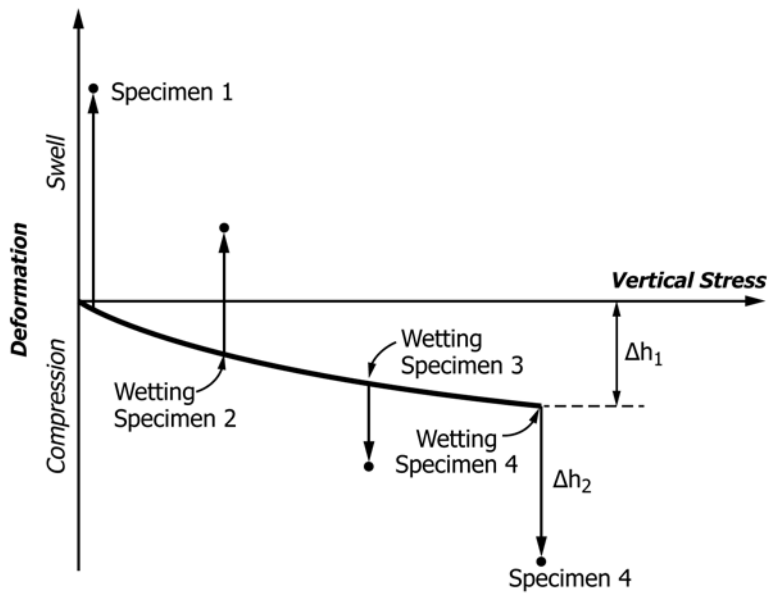

FIG. 2 Deformation Versus Vertical Stress, Test Method A

3. Terminology

3.1 *Definitions*—For definitions of common technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *collapse or hydrocompression (L)*—wetting-induced decrease in height of a soil element or test specimen.

3.2.2 *collapse or hydrocompression strain*—%-wetting-induced change in height divided by the height immediately prior to wetting.

3.2.3 *compression (L)*—decrease in height of a soil element or test specimen due to wetting (synonymous with hydrocompression or collapse) or due to increase in total stress.

3.2.4 *free swell, %*—percent swell following absorption of water at the seating pressure of 1 kPa (20 lbf/ft^2).

3.2.5 *intact specimen*—a test specimen obtained from a natural deposit or from an existing compacted fill or embankment using undisturbed sampling equipment.

3.2.6 *percent heave or settlement, %*—change in vertical height divided by the height of a column of soil immediately before wetting.

3.2.7 *primary swell or collapse (L)*—amount of swell or collapse characterized as being completed at the intersection of the two tangents to the curve shown in Fig. 1.

3.2.8 *reconstituted specimen*—a test specimen compacted into a mold.

3.2.9 *secondary swell or collapse (L)*—long-term swell or collapse characterized as the linear portion of the plot shown in Fig. 1 following completion of primary swell or collapse.

3.2.10 *settlement (L)*—decrease in vertical height of a column of soil.

3.2.11 *swell (L)*—increase in thickness of a soil element or a soil specimen following absorption of water.

3.2.12 *swell pressure (FL^{-2})*—the minimum stress required to prevent swelling.

4. Summary of Test Methods

4.1 In these test methods a soil specimen is restrained laterally in a rigid mold and loaded vertically (axially) in increments up to a load that depends on the purpose of the test. Subsequent to reaching equilibrium under the applied load, the specimen is inundated with test water and the one-dimensional wetting-induced swell or collapse strain is measured. Test Method A is specified for specimens that are reconstituted using the fill material excluding the oversize fraction. Test Method B is for intact samples of a natural soil or an existing fill. In both cases, the measured strains are wetting-induced, not load-induced. Test Method C is used for measuring load-induced compression subsequent to wetting-induced swell or collapse

5. Significance and Use

5.1 The wetting-induced swell/collapse strains measured from Test Methods A and B can be used to develop estimates of heave or settlement of a confined soil profile (**1 and 2**).[4] They can also be used to estimate the magnitudes of the swell pressure and the free swell strain. The load-induced strains after wetting from Test Method C can be used to estimate stress-induced settlement following wetting-induced heave or settlement. Selection of test method, loading, and inundation sequences should, as closely as possible, simulate field conditions because relatively small variations in density and water content, or sequence of loading and wetting can significantly alter the test results (**3 and 4**).

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

NOTE 1—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. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depends on several factors; Practice D3740 provides a means of evaluating some of these factors.

6. Limitations

6.1 When using data from these test methods, the following limitations should be considered:

6.1.1 Laboratory one-dimensional tests simulate vertical deformation with full lateral restraint; they do not simulate lateral collapse or lateral swell.

6.1.2 Inundation of specimens in the laboratory represent an extreme case of wetting and the results represent upper bound values for swell/collapse strains, and the degrees of saturation typically rise to 90–95 % (not 100 %, (**1**)). The wetting situation in the field rarely produces inundation; wetting is often caused by water percolation. In-situ water contents and degrees of saturation typically end up being somewhat lower than those caused by inundation in the laboratory. Consequently, the magnitudes of swell/collapse strains in the field might be somewhat smaller than those measured in the laboratory. Partial wetting tests can be performed for estimating a partial wetting reduction factor for use in conjunction with heave/settlement calculations (**1**, **2**, **and 5**).

6.1.3 Because laboratory tests are usually performed in small molds, gravels and other granular inert particles (oversize) are excluded from the specimen. The specimen is reconstituted using water content and dry density of the fine fraction. Because of limitations on the accuracy of the oversize correction equations 1 and 2 (Practice D4718), tests in large molds would be necessary for soils that have more than 40 % oversize particles larger than 4.75 mm (No. 4) sieve.

6.1.4 Disturbance and variability in composition of intact specimens can affect the test results. The effect of disturbance can be particularly significant for soils of low plasticity that have some cementation in their natural state (**5**).

6.1.5 Rates of swell or collapse as measured by laboratory time rate curves are not always reliable indicators of field rates of heave/settlement due to soil nonuniformity, fissures or localized permeable layers within the soil mass, variability in percentage of oversize particles, and non-uniform wetting (different sources of water, concurrent vertical downward percolation and lateral percolation from canyon sides, localized wetting anomalies due to leaking buried utility lines, cyclic wetting episodes).

6.1.6 Secondary long-term swell/collapse may be significant for some soils and estimates of slow time-dependent secondary heave/settlement can be added if necessary. This can be done based on the slope of plot of strain versus Log time line in Fig. 1.

6.1.7 Any differences between the chemical content of the field water and the water used in the laboratory tests might influence the amount of heave/settlement in the field.

6.1.8 For reliable test results, the stress path and the wetting sequence should as closely as possible simulate field conditions. Because the shape of the wetting-induced strain versus vertical stress curves (Figs. 3-5) depend on the stress path and the wetting sequence (**1**, **3**, and **4**), loading-after-wetting tests

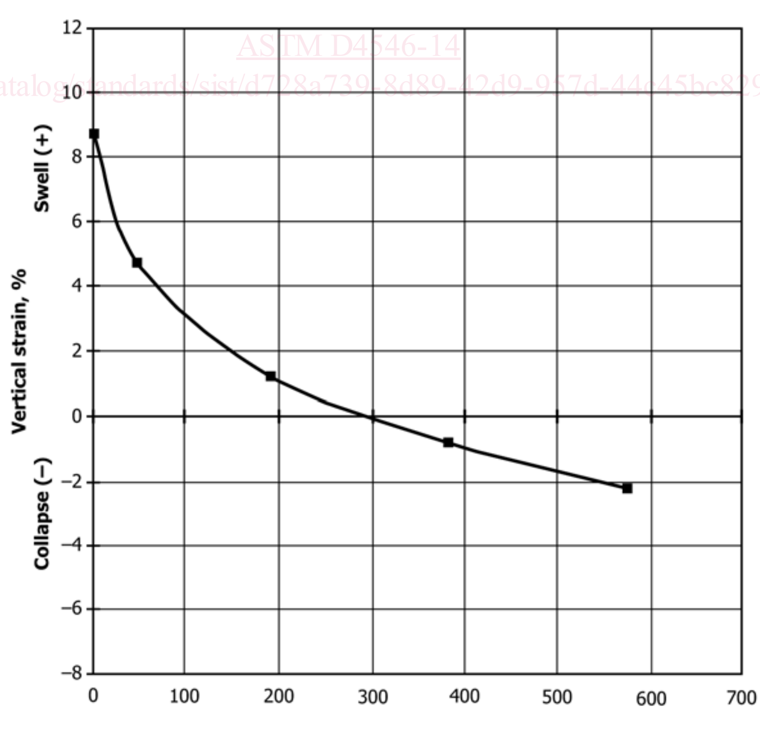

FIG. 3 Stress Versus Wetting-Induced Swell/Collapse Strain, Test Method A

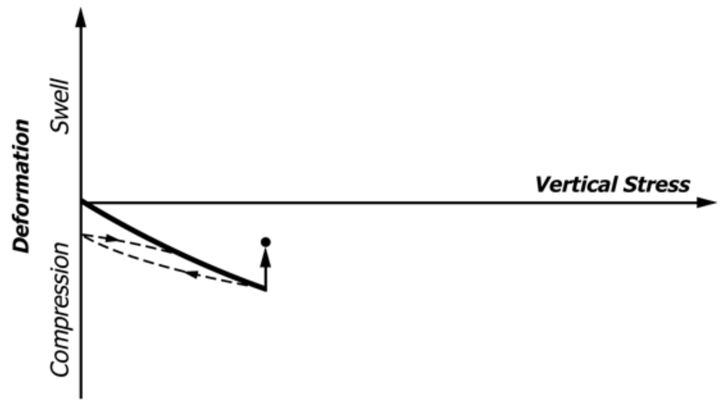

FIG. 4 Deformation Versus Vertical Stress, Single-Point Test Method B

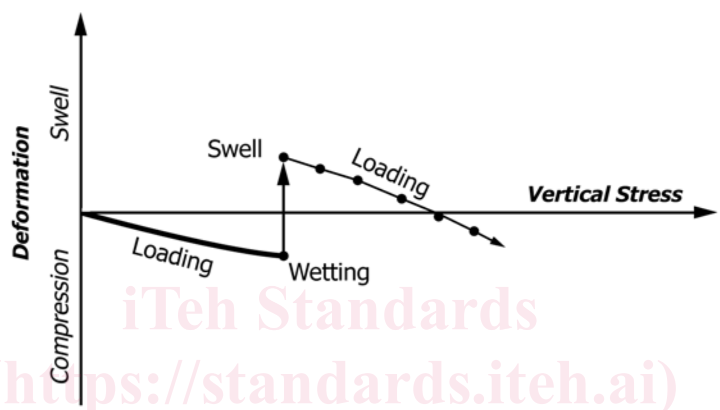

FIG. 5 Deformation Versus Vertical Stress, Loading-after-Wetting Test Method C

on a single specimen (Test Method C) should not be expected to give results applicable to wetting-after-loading cases (Test Methods A and B)

7. Apparatus

7.1 *Consolidometer*—A suitable device for applying axial loads to the specimen. The device shall be capable of maintaining the specified loads for long periods of time with a precision of ±0.5 % of the applied load.

7.1.1 *Specimen Ring*—The consolidation ring holding the specimen shall be fabricated to a tolerance of at least 0.1 %. The ring shall be stiff enough to prevent significant lateral deformation of the specimen throughout the test. The rigidity of the ring shall be such that, under hydrostatic stress conditions in the specimen, the change in diameter of the ring will not exceed 0.04 % of the diameter under the greatest load applied. The ring shall be made of a material that is noncorrosive in relation to the soil or pore fluid. The inner surface shall be highly polished or shall be coated with a low-friction material.

7.1.2 *Minimum Specimen Diameter*—The minimum specimen diameter or inside diameter of the specimen ring shall be 50 mm (2.00 in.).

7.1.3 *Minimum Specimen Height*—The minimum initial specimen height shall be 20 mm (0.8 in.), but shall be not less than six times the maximum particle diameter in the soil.

7.1.4 *Minimum Specimen Diameter-to-Height Ratio*—The minimum specimen diameter-to-height ratio shall be 2.5.

7.2 *Porous Disks*—The porous disks shall be of silicon carbide, aluminum oxide, or other material of similar stiffness that is not corroded by the specimen or pore fluid. The disks shall be fine enough that the soil will not penetrate into their pores, but have sufficient hydraulic conductivity so as not to impede the flow of water from the specimen. Porous disks shall be smooth ground and fine enough to minimize intrusion of soil into the disk if filter paper is not used, and shall reduce false displacements caused by seating of the specimen against the surface of porous disk. Errors due to such false displacements may be significant, especially if displacements and applied vertical pressures are small.

NOTE 2—A suitable pore size is 10 µm if filter paper is not used.

7.2.1 Porous disks shall be air-dried. New porous disks should be boiled in water for about 10 minutes before air-drying to ambient temperatures. Immediately after each use, clean the porous disks with a non-abrasive brush and wash or boil to remove any soil particles.

7.2.2 Porous disks shall fit close to the consolidometer ring to avoid extrusion or punching of the soil specimen under high vertical pressures. Suitable porous disk dimensions are described in Test Methods D2435.

7.2.3 If filter paper is used with porous disks, the paper should be included when the system is being calibrated in both dry and wet conditions (see Section 9).

NOTE 3—Filter paper is not recommended because of its high compressibility after wetting.

7.3 *Plastic Wrap, Aluminum Foil, or Moist Filter Paper,* a loose fitting cover to enclose the specimen, ring, and porous stones prior to inundating the specimen, used to minimize evaporation from the specimen.

7.4 *Micrometer or Other Suitable Device*—To measure the inside diameter of the mold and the height of the specimen to the nearest 0.025 mm (0.001 in.).

7.5 *Deformation Indicator*—To measure the axial deformation of the specimen with a resolution of 0.0025 mm (0.0001 in.) or better. Practice D6027 provides details on the evaluation of displacement transducers

7.6 *Balances*—The balance(s) shall be suitable for determining the mass of the specimen plus the containment ring and for making the water content measurements. The balance(s) shall be selected as discussed in Guide D4753. The mass of specimens shall be determined to at least four significant digits.

7.7 *Drying Oven,* in accordance with Test Methods D2216.

7.8 *Water Content Containers,* in accordance with Test Methods D2216.

7.9 *Environment*—Unless otherwise specified by the requesting agency, the standard test temperature shall be in the range of 22 ± 5°C. In addition, the temperature of the consolidometer, test specimen, and submersion reservoir shall not vary more than ±2°C throughout the duration of the test. Normally, this control is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the apparatus shall be placed in an insulated chamber or other device that maintains the temperature within the tolerance specified above. The apparatus should be located in an area that does not have direct exposure to sunlight.

7.10 *Test Water*—Water used to inundate the specimens shall be similar in composition to the water that is the main source of wetting in the field. In the absence of the field water, the test should be performed with potable tap water.

7.11 *Miscellaneous Equipment*—Including timing device, spatulas, knives, and wire saws, used in preparing the specimen. Including devices for evacuating the water surrounding the mold at the end of the test before the specimen is unloaded and removed for weighing and oven-drying.

8. Sampling and Storage of Naturally Occurring Soils

8.1 Disturbance of the intact samples can greatly influence results and should be minimized. Practice D1587 and Practice D3550 cover procedures and apparatus that may be used to obtain satisfactory intact samples. Practices D4220 covers procedures for preserving and transporting soil samples.

8.2 Storage in sampling tubes is not recommended for swelling soils even though stress relief may be minimal. The influence of rust and penetration of drilling fluid or free water into the sample may adversely influence laboratory test results. Sampling tubes should be brass, stainless steel, or galvanized or lacquered inside to inhibit corrosion in accordance with Practice D1587.

8.3 If samples are to be stored prior to testing, they should be thoroughly sealed to minimize stress relief and moisture change. The sample should be extruded from the sampling tube in the same direction as sampled, to minimize further sample disturbance. If the sample cannot be extruded from the tubes immediately, they should be handled and shipped in accordance with Practices D4220, Group D.

8.4 Drilling with drilling fluid should be avoided to prevent any changes in sample's water content and density.

8.5 Containers for storage of extruded samples may be either cardboard or metal and should be approximately 25 mm (1 in.) greater in diameter and 40 to 50 mm (1.5 to 2.0 in.) greater in length than the sample to be encased.

8.6 Soil samples stored in containers should be completely sealed in wax. The temperature of the wax should be 8 to 14°C (15 to 25°F) above the melting point when applied to the soil sample; wax that is too hot will penetrate pores and cracks in the sample and render it useless and will also dry the sample. Aluminum foil, cheese cloth, or plastic wrap may be placed around the sample to prevent penetration of molten wax into open fissures. A small amount of wax about 12.7-mm (0.5-in.) thickness should be placed in the bottom of the container and allowed to partly congeal. The sample should subsequently be placed in the container, completely immersed and covered with molten wax, and then allowed to cool before moving.

NOTE 4—A good wax for sealing expansive soils consists of a 1 to 1 mixture of paraffin and microcrystalline wax or 100 % beeswax.

8.7 Examine and test samples as soon as possible after receipt; however, samples required to be stored should be kept in a humidity controlled room and may require re-waxing and relabeling before storage. Samples encased in wax or sampling tubes may be cut using a band-saw. The soil specimen should be adequately supported while trimming to size using sharp clean instruments. The specimen may be extruded from a section of sampling tube and trimmed in one continuous operation to minimize sampling disturbance.

9. Specimen Preparation

9.1 Reconstituted or intact specimens may be used for testing. The specimens shall have a minimum diameter of 50 mm (2.0 in.) and a minimum height of 20 mm (0.8 in.). The height of specimen and diameter of mold shall be measured to the nearest 0.025 mm (0.001 in.) or better (7.4). The height of the specimen shall be at least 6 times greater than the largest particle size within the specimen. Variations in length or diameter shall not exceed 5 %. Compute the initial and final specimen volumes to the nearest 0.001 cm^3 or 0.001 in^3.

9.1.1 Reconstituted specimens should be prepared using the soil's fine fraction (excluding the oversize), and should duplicate field conditions in terms of water content, dry density, and method of compaction (kneading, moist-tamping, or static). The desired density can be obtained by mass and volume control. Measured masses of soil can be placed in layers and compacted to a pre-determined volume for each layer. The