INTERNATIONAL

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Standard Test Methods for One-Dimensional Swell or Settlement PotentialCollapse of Cohesive Soils[1]

This standard is issued under the fixed designation D 4546; 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*

1.1These test methods cover three alternative laboratory methods for determining the magnitude of swell or settlement of relatively undisturbed or compacted cohesive soil.

1.1 These test methods cover three alternative laboratory methods for measuring free swell, swell pressure, and the magnitude of one-dimensional swell or collapse of compacted or intact cohesive soils.

NOTE1—Refer to Section 1—Refer to Sections 4, 5, 6 and 13.8 to determine the best method for a particular application.

1.2The test methods can be used to determine (*a*) the magnitude of swell or settlement under known vertical (axial) pressure, or (*b*) the magnitude of vertical pressure needed to maintain no volume change of laterally constrained, axially loaded specimens.

1.2 The test methods can be used to measure the magnitude of one-dimensional wetting-induced swell or collapse (hydrocompression) under different vertical (axial) pressures, as well as the magnitude of swell pressure and the magnitude of free swell. It can also be used to obtain data for stress-induced compression following wetting-induced swell or collapse.

1.3 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate.

1.4All observed1.4 All measured and calculated values shall conform to the guidelines for significant digits and rounding established in Practive D6026.Practice D 6026.

1.4.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both.uses. How one applies the results obtained using this standard is beyond its scope.

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]

D 422 Test Method for Particle-Size Analysis of Soils

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D698Test Method 698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12.400(12 400 ft-lbf/ft^3(600 kN-m/m^3))

D 854Test Method for Specific Gravity of Soils[2]

D1557Test Method for Laboratory Compaction Characteristics of Soils Using Modified Effort (56.000 ft-lbf/ft Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D 1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2.700 kN-m/m (2,700 kN-m/m^3))

D 1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 2435Test Method for One-Dimensional Consolidation Properties of Soils[2] Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D 3550Practice for Ring-Lined Barrel Sampling of Soils[2] Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

[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 Structural Properties Strength and Compressibility of Soils.

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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*, Vol. 04.08. volume information, refer to the standard's Document Summary page on the ASTM website.

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

D 3740 Practice for Minimum Requirements for Agencies Engaged ~~In the~~ in Testing and/or Inspection of Soil and Rock as Used ~~In~~in Engineering Design and Construction
D~~3877Test~~ 3877 Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures
D 4220 Practices for Preserving and Transporting Soil Samples
D 4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D 6026~~Practice for Using Significant Digits in Geotechnical Data[2]~~ Practice for Using Significant Digits in Geotechnical Data
E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens

3. Terminology

3.1 *Definitions*—~~—Refer~~Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 ~~*heave (L)*—increase in vertical height, Δ *h*, of a column of in situ soil of height *h* following absorption of water.~~ collapse or hydrocompression, L—wetting-induced decrease in height of a soil element or test specimen, Δ*h*.

3.2.2 ~~*percent heave or settlement, %*— increase or decrease in the ratio of the change in vertical height, Δ *h*, to the original height of a column of in situ soil; *h* × 100 or Δ *h*/ *h* × 100.~~ collapse or hydrocompression strain—%-wetting-induced change in height divided by the height immediately prior to wetting, (Δ*h*/*h*) × 100.

3.2.3 ~~*settlement, L*—decrease in vertical height, Δ *h*, of a column of in situ soil of height *h*.~~ compression, L—decrease in height of a soil element or test specimen, Δ*h*, due to wetting (synonymous with hydrocompression or collapse), or due to increase in total stress.

3.2.4 ~~*swell, L*—increase in elevation or dilation of soil column following absorption of water.~~

~~3.2.5~~*free swell, %*~~—percent heave, Δ *h*/*h* × 100, following absorption of water at the seating pressure σ_{se}.~~

~~3.2.6*primary swell, L*—an arbitrary short-term swell usually characterized as being completed at the intersection of the tangent of reverse curvature to the curve of a dimensional change-logarithm of time plot with the tangent to the straight line portion representing long-term or secondary swell (Fig. 1~~—percent swell, (Δ*h*/*h*) × 100, following absorption of water at the seating pressure of 1 kPa (20 lbf/ft^2).

3.2.5 *heave (L)*—increase in vertical height, Δ*h*, of a column of soil of height *h* following absorption of water.

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

3.2.7 ~~*secondary swell, L*—an arbitrary long-term swell usually characterized as the linear portion of a dimensional change-logarithm of time plot following completion of short-term or primary swell (Fig. 1).~~ percent heave or settlement, %—change in vertical height divided by the height of a column of soil immediately before wetting; (Δ*h*/*h*) × 100.

3.2.8 ~~*swell index*—slope of the rebound pressure - void ratio curve on a semi-log plot.~~ 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.

3.2.9 *remolded or compacted specimen*—a test specimen compacted into a mold.

3.2.10 *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.

3.2.11 *settlement, L*—decrease in vertical height, Δ*h*, of a column of soil of height *h*.

3.2.12 *swell, L*—increase in thickness of a soil element or a soil specimen following absorption of water.

3.2.13 *swell pressure, FL*$^{-2}$— (*1*) a pressure which prevents the specimen from swelling as obtained in Method C, or (*2*) that ~~pressure which is required to return the specimen back to its original state (void ratio, height) after swelling in Method A or B.~~

~~NOTE2—Swell pressures by Method C corrected for specimen disturbance may be similar to or slightly greater than those by Method A.~~ -2—the

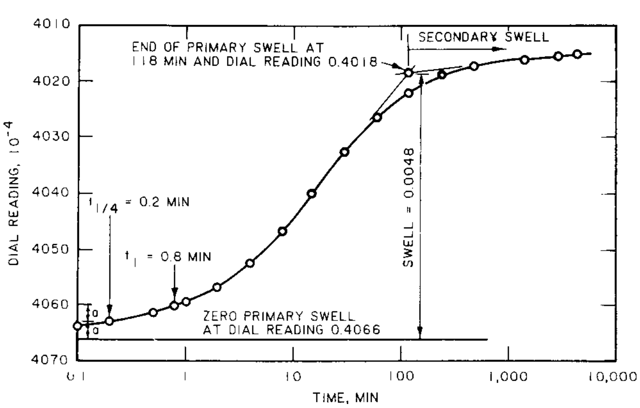

FIG. 1 Time-Swell Curve

minimum stress required to prevent swelling.

4. Summary of Test Methods

4.1 The following three alternative test methods require that ~~a~~ soil specimens be restrained laterally and loaded ~~axially~~vertically in a consolidometer, with access to free water.

4.1.1 *Method A*~~—The specimen is inundated and allowed to swell vertically at the seating pressure (pressure of at least 1 kPa (20 lbf/ft~~—This method can be used for measuring one-dimensional wetting-induced swell or collapse (hydrocompression) strains of compacted or natural soils over a range of vertical stresses. Four or more identical specimens are assembled in consolidometer units. Different loads are applied to different specimens and each specimen is given access to free water until the process of primary swell or collapse is completed under a constant vertical total stress. The resulting swell or collapse deformations are measured. The final water contents and dry densities are also measured. This method can be referred to as *wetting-after-loading tests on multiple specimens*. The data from these tests can be used to estimate one-dimensional ground surface heave or settlement. In addition, the magnitude of "Swell Pressure," the minimum vertical stress required for preventing swell, and the magnitude of free swell, the swell strain corresponding to a near zero stress of 1 kPa (20 lbf/ft ^{2} ~~) applied by the weight of the top porous stone and load plate) until primary swell is complete. The specimen is loaded after primary swell has occurred until its initial void ratio/height is obtained.~~

~~4.1.2~~*) can be interpreted from the test results.*

4.1.2 *Method B*~~—A vertical pressure exceeding the seating pressure is applied to the specimen before placement of free water into the consolidometer. The magnitude of vertical pressure is usually equivalent to the in situ vertical overburden pressure or structural loading, or both, but may vary depending on application of the test results. The specimen is given access to free water. This may result in swell, swell then contraction, contraction, or contraction then swell. The amount of swell or settlement is measured at the applied pressure after movement is negligible.~~ —This method can be used for measuring one-dimensional wetting-induced swell or collapse strain of a single "intact" specimen of natural soil, or a single "intact" specimen of compacted soil obtained from an existing fill or embankment. The specimen is loaded to a specific vertical stress, typically the in-situ vertical overburden stress or a particular design pressure, or 1 kPa (20 lbf/ft ^{2}) for measuring the free swell strain, and then inundated to measure the wetting induced strain under that particular stress. This method can be referred to as *single point wetting-after- loading test on a single specimen*.

4.1.3 *Method C*~~—The specimen is maintained at constant height by adjustments in vertical pressure after the specimen is inundated in free water to obtain swell pressure. A consolidation test is subsequently performed in accordance with Test Method D2435. Rebound data is used to estimate potential heave.~~ —This method 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 results would apply to situations where new fill and/or additional structural loads 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 Method A or B. After completion of the swell or collapse phase, increments of additional vertical loads are applied to the specimen in the same manner as in a consolidation test, Test Methods D 2435, and the load-induced deformations are measured.

5. ~~Significance and Use~~

~~5.1The relative swell/settlement potential of soil determined from these test methods can be used to develop estimates of heave or settlement for given final moisture and loading conditions. The initial water content and void ratio should be representative of the in situ soil immediately prior to construction. Selection of test method, loading, and inundation sequences should, as closely as possible, simulate any construction and post-construction wetting and drying effects and changes in loading conditions.~~

~~5.2Soils containing montmorillonites (Smectite) are likely to have a significant potential for swell and are commonly tested by these test methods.~~ Significance and Use

5.1 The soil swell/collapse strains measured from these test methods can be used to develop estimates of heave or settlement for a confined soil profile subject to one-dimensional heave or settlement, or stress-induced settlement following wetting-induced heave/settlement. They can also be used to estimate the pressure that would be necessary to prevent swelling. Selection of test method, loading, and inundation sequences should, as closely as possible, simulate field conditions because relatively small variations in unit weight and water content, or sequence of loading and wetting can significantly alter the test results. (See 6.1.8 and Refs **(1-5)**.)[3]

NOTE ~~3—Montmorillonites with divalent cations usually swell less than with monovalent cations. It is useful to know the type of cation as well as the cation exchange capacity of montmorillonite.~~

~~5.3Laboratory-prepared test specimens should duplicate the in situ soil or field-compacted soil conditions as closely as possible because relatively small variations in unit weight and water content can significantly alter the measured heave and swell pressure. Differences in soil fabric of the compacted specimens, such as obtained by kneading or static compaction, could also have a significant impact on the swell/settlement behavior of cohesive soils.~~

~~5.4These test methods are applicable to undisturbed test or remolded specimens, or both, as follows:~~

~~5.4.1*Method A*—This test method measures (*a*) the free swell, (*b*) percent heave for vertical confining pressures up to the swell pressure, and (*c*) the swell pressure.~~

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

~~5.4.2 *Method B*—This test method measures (*a*) the percent heave or settlement for vertical pressure usually equivalent to the estimated in situ vertical overburden and other vertical pressure up to the swell pressure, and (*b*) the swell pressure.~~

~~5.4.3 *Method C*—This test method measures (*a*) the swell pressure, (*b*) preconsolidation pressure, and (*c*) percent heave or settlement within the range of applied vertical pressures.~~

~~NOTE 4—Methods A and C have produced estimates of heave consistent with observed heave. Method B may lead to estimates of heave less than observed heave. Method A has not been recommended for evaluation of swell pressure and consolidation parameters for settlement estimates because sorption of water under practically no restraint may disturb the soil structure.~~

~~NOTE 5—Notwithstanding the statement on precision and bias contained in this standard: The precision of this test method is dependent on the competence of the personnel performing the test and the suitability of the equipment and facilities used. Agencies which meet the criteria of Practice D3740~~ 2—Notwithstanding the statement on precision and bias contained in this standard: The precision of this test method is dependent on the competence of the personnel performing the test and the suitability of the equipment and facilities used. Agencies which meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means of evaluating some of these factors.

6. ~~Interferences~~

~~6.1 Estimates of the swell and settlement of soil determined by these test methods are often of key importance in design of floor slabs on grade and evaluation of their performance. However, when using these estimates it is recognized that swell parameters determined from these test methods for the purpose of estimating in situ heave of foundations and compacted soils may not be representative of many field conditions because:~~

~~6.1.1 Lateral swell and lateral confining pressure are not simulated.~~

~~6.1.2 Swell in the field usually occurs under constant overburden pressure, depending on the availability of water. Swell in the laboratory is evaluated by observing changes in volume due to changes in applied pressure while the specimen is inundated with water. Method B is designed to avoid this limitation.~~

~~6.1.3 Rates of swell indicated by swell tests are not always reliable indicators of field rates of heave due to fissures in the in situ soil mass and inadequate simulation of the actual availability of water to the soil. The actual availability of water to the foundation may be cyclic, intermittent, or depend on in-place situations, such as pervious soil-filled trenches and broken water and drain lines.~~

~~6.1.4 Secondary or long-term swell may be significant for some soils and should be added to primary swell.~~

~~6.1.5 Chemical content of the inundating water affects volume changes and swell pressure; that is, field water containing large concentrations of calcium ions will produce less swelling than field water containing large concentrations of sodium ions or even rain water.~~

~~6.1.6 Disturbance of naturally occurring soil samples greatly diminishes the meaningfulness of the results.~~ Interferences and 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. Therefore, the results should not be used to estimate lateral extension of slopes, differential heave/settlement in the vicinity of slopes, or differential heave/settlement where ground surface is not relatively flat.

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)**.

6.1.3 Because laboratory tests are usually performed in small molds, gravels and other granular inert particles (oversize) are excluded from the specimen. This has two implications: *(1)* Laboratory specimens should be compacted at matrix (finer fraction) water content and matrix dry density as described in 9.1.2; and *(2)* Because the test results represent the volume change behavior of the soil's finer fraction, they should be applied only to the soil column consisting of the finer fraction of in the field (excluding the oversize inert particles.) This can be done by applying an oversize factor in calculating the magnitude of the net ground surface heave or settlement **(2)**.

6.1.4 Disturbance of naturally occurring soils, and variability in composition of "intact" specimens can affect the test results.

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 application of the 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) for cohesive soils depend

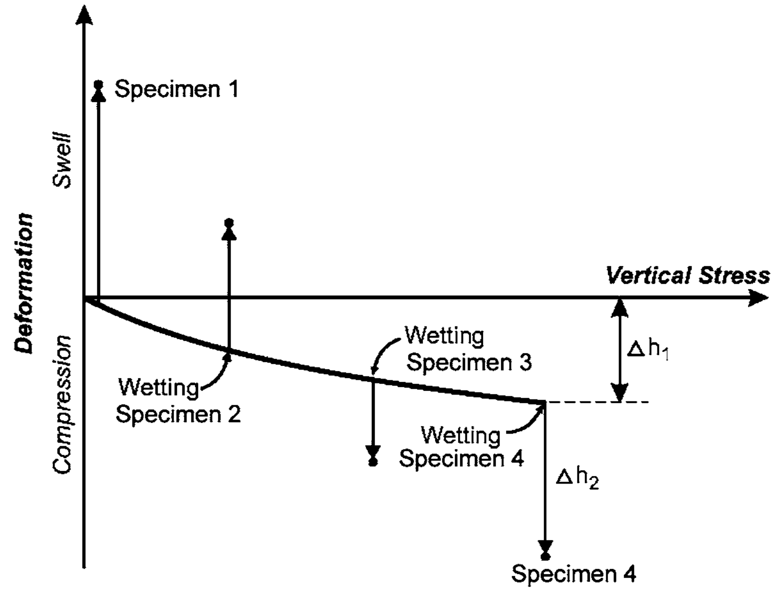

FIG. 2 Deformation versus Vertical Stress, Method A

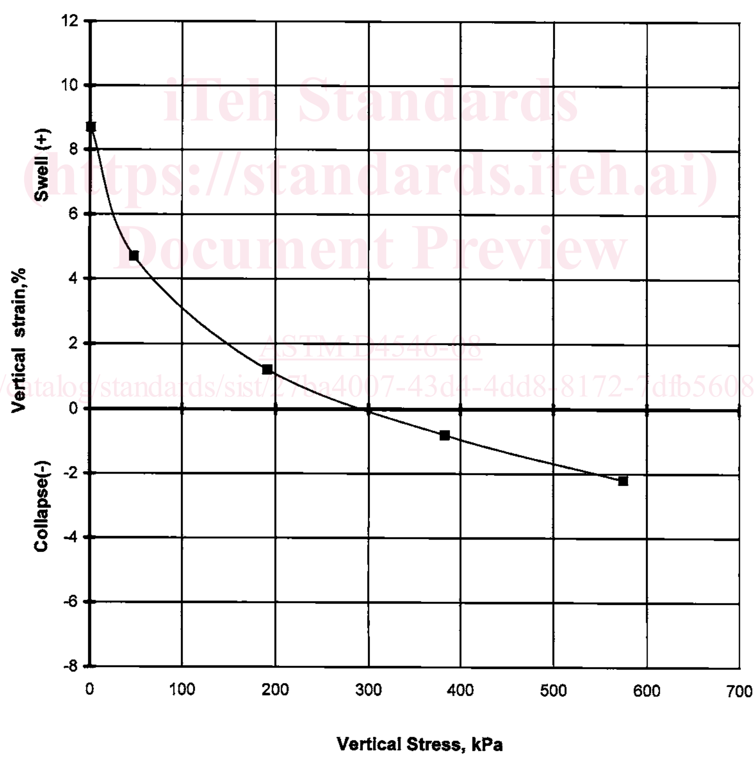

FIG. 3 Stress versus Wetting-Induced Swell/Collapse Strain, Method A

on the stress path and the wetting sequence, loading-after-wetting tests on a single specimen (Method C) should not be expected to give results applicable to wetting-after-loading cases (Method A) such as post-construction heave/settlement of compacted fills and embankments **(1-4)**. However, it has been found **(5)** that for noncohesive collapsible soils, loading-after-wetting tests on a single specimen can give a segment of the curve (in the vicinity of the stress level at wetting) that is close to the results of a Method A multiple specimen wetting-after-loading test.

7. Apparatus and Materials

7.1 *Consolidometer*~~—The apparatus shall comply with the requirements of Test Method D2435. The apparatus shall be capable of exerting a pressure on the specimen of (*1*) at least 200% of the maximum anticipated design pressure, or (*2*) the pressure required to maintain the original specimen height when the specimen is inundated (Method C), whichever is greatest.~~

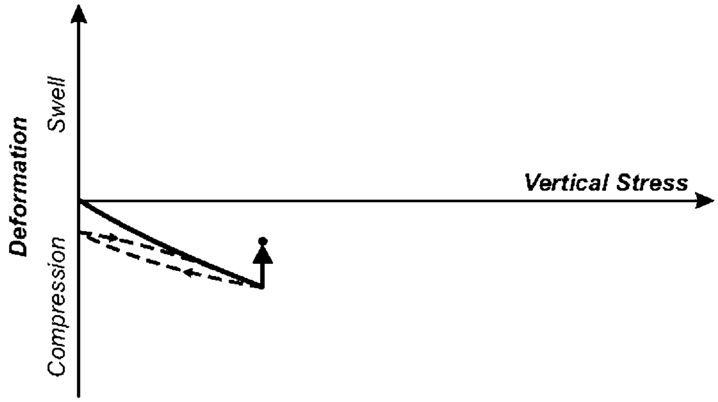

FIG. 4 Deformation versus Vertical Stress, Single-Point Test Method B

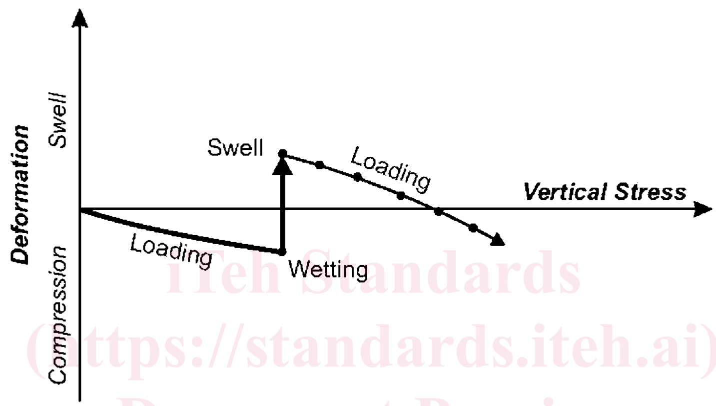

FIG. 5 Deformation versus Vertical Stress, Loading-after-Wetting Test Method C

~~7.1.1Consolidometer rigidity influences the observed swell, particularly with Method C. Therefore, consolidometers of high rigidity should be used with Method C (see Test Method D2435).~~

NOTE~~6—Small increases in soil volume can significantly relieve swell pressures. Therefore, variations in displacements that occur during determination of swell pressures by Method C should be as small as possible to reduce the magnitude of correction required in 13.2.5. The measurements, especially swell pressure measurements, should be based on corrections for compression of members.~~ —The apparatus shall comply with the requirements of Test Methods D 2435. The apparatus shall be capable of exerting a pressure on the specimen of *(1)* at least 200 % of the maximum anticipated design pressure, or *(2)* the swell pressure, whichever is greatest.

7.1.1 Consolidometer rigidity influences the test results. Therefore, consolidometers of high rigidity should be used.

7.2 *Porous Stones*—The stones shall be smooth ground and fine enough to minimize intrusion of soil into the stones if filter paper is not used and shall reduce false displacements caused by seating of the specimen against the surface of porous stones (Note ~~7~~3). Such displacements may be significant, especially if displacements and applied vertical pressures are small.

7.2.1 Porous stones shall be air dry.

7.2.2 Porous stones shall fit close to the consolidometer ring to avoid extrusion or punching of the soil specimen at high vertical pressures. Suitable stone dimensions are described in 5.3 of Test Methods D 2435.

NOTE~~7—A~~ 3—A suitable pore size is 10 μm if filter paper is not used. Filter paper is not recommended because of its high compressibility and should not be used when measuring the ~~swell/settlement~~swell/collapse of stiff natural clays and ~~when measuring swell pressure by Method C.~~ compacted soils.

7.3 *Plastic ~~Membrane,~~Wrap, Aluminum Foil, or Moist ~~Paper Towel~~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.

8. Sampling and Storage of Naturally Occurring Soils

8.1 Disturbance of the soil sample from which specimens are to be obtained can greatly ~~diminishes the meaningfulness of~~influence results and should be minimized. Practice D 1587 and Practice D 3550 cover procedures and apparatus that may be used to obtain satisfactory ~~undisturbed~~intact samples. Practices D 4220 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. ~~Water and~~