Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading[1]

This standard is issued under the fixed designation D2435/D2435M; 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 procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. Two alternative procedures are provided as follows:

1.1.1 *Test Method A*—This test method is performed with constant load increment duration of 24 h, or multiples thereof. Time-deformation readings are required on a minimum of two load increments. This test method provides only the compression curve of the specimen and the results combine both primary consolidation and secondary compression deformations.

1.1.2 *Test Method B*—Time-deformation readings are required on all load increments. Successive load increments are applied after 100 % primary consolidation is reached, or at constant time increments as described in Test Method A. This test method provides the compression curve with explicit data to account for secondary compression, the coefficient of consolidation for saturated materials, and the rate of secondary compression.

NOTE 1—The determination of the rate and magnitude of consolidation of soil when it is subjected to controlled-strain loading is covered by Test Method D4186.

1.2 These test methods are most commonly performed on saturated intact samples of fine grained soils naturally sedimented in water, however, the basic test procedure is applicable, as well, to specimens of compacted soils and intact samples of soils formed by other processes such as weathering or chemical alteration. Evaluation techniques specified in these test methods assume the pore space is fully saturated and are generally applicable to soils naturally sedimented in water. Tests performed on other unsaturated materials such as compacted and residual (weathered or chemically altered) soils may require special evaluation techniques. In particular, the rate of consolidation (interpretation of the time curves) is only applicable to fully saturated specimens.

1.3 It shall be the responsibility of the agency requesting this test to specify the magnitude and sequence of each load increment, including the location of a rebound cycle, if required, and, for Test Method A, the load increments for which time-deformation readings are desired. The required maximum stress level depends on the purpose of the test and must be agreed on with the requesting agency. In the absence of specific instructions, Section 11 provides the default load increment and load duration schedule for a standard test.

NOTE 2—Time-deformation readings are required to determine the time for completion of primary consolidation and for evaluating the coefficient of consolidation, c_v. Since c_v varies with stress level and loading type (loading or unloading), the load increments with timed readings must be selected with specific reference to the individual project. Alternatively, the requesting agency may specify Test Method B wherein the time-deformation readings are taken on all load increments.

1.4 These test methods do not address the use of a back pressure to saturate the specimen. Equipment is available to perform consolidation tests using back pressure saturation. The addition of back pressure saturation does not constitute non-conformance to these test methods.

1.5 *Units*—The values stated in either SI units or inch-pound units [given in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5.1 In the engineering profession it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ($F = Ma$) are involved. This implicitly combines two separate systems of units, that is, the absolute system and the gravimetric system. It is scientifically undesirable to combine two separate systems within a single standard. This test method has been written using SI units; however, inch-pound conversions are given in the gravimetric system, where the pound (lbf) represents a unit of force (weight). The use of balances or scales recording pounds of mass (lbm), or the recording of density in lb/ft^3 should not be regarded as nonconformance with this test method.

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock .

Current edition approved May 1, 2011. Published July 2011. Originally approved in 1965. Last previous edition approved in 2004 as D2435–04. DOI: 10.1520/D2435_D2435M-11.

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

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

1.6.1 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. How one applies the results obtained using this standard is beyond its scope.

1.7 *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]

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
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
D4186 Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4452 Practice for X-Ray Radiography of Soil Samples
D4546 Test Methods for One-Dimensional Swell or Collapse of Cohesive 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
D6027 Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes

[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. Terminology

3.1 For definitions of technical terms used in these test methods, see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *axial deformation (L, L, %, or -)*, *n*—the change in axial dimension of the specimen which can be expressed in terms of length, height of specimen, strain or void ratio.

3.2.2 *estimated preconsolidation stress (F/L^2)*, *n*—the value of the preconsolidation stress determined by the technique prescribed in these test methods for the purpose of aiding the laboratory in the performance of the test. This estimation should not be considered equivalent to an engineering interpretation of the test measurements.

3.2.3 *load (F)*, *n*—in the context of soil testing, the act of applying force or deformation to the boundary of a test specimen. In the incremental consolidation test this is generally performed using weights on a hanger.

3.2.4 *load increment*, *n*—one individual step of the test during which the specimen is under a constant total axial stress.

3.2.5 *load increment duration (T)*, *n*—the length of time that one value of total axial stress is maintained on the specimen.

3.2.6 *load increment ratio, LIR (-)*, *n*—the change (increase or decrease) in total axial stress to be applied to the specimen in a single step divided by the current total axial stress.

3.2.6.1 *Discussion*—Load Increment Ratio is historically used in consolidation testing to reflect the fact that the test was performed by adding weights to apply the total axial stress to the specimen.

3.2.7 *total axial stress (F/L^2)*, *n*—the force acting on the specimen divided by the specimen area. Once consolidation is complete, the effective axial stress is assumed to equal the total axial stress.

3.2.8 *total axial stress increment (F/L^2)*, *n*—the change (increase or decrease) in total axial stress applied in one single step. The change may be an increase or a decrease in stress.

4. Summary of Test Methods

4.1 In these test methods a soil specimen is restrained laterally and loaded axially with total stress increments. Each stress increment is maintained until excess pore water pressures are essentially dissipated. Pore pressure is assumed to be dissipated based on interpretation of the time deformation under constant total stress. This interpretation is founded on the assumption that the soil is 100% saturated. Measurements are made of change in the specimen height and these data are used to determine the relationship between the effective axial stress and void ratio or strain. When time deformation readings are taken throughout an increment, the rate of consolidation is evaluated with the coefficient of consolidation.

5. Significance and Use

5.1 The data from the consolidation test are used to estimate the magnitude and rate of both differential and total settlement of a structure or earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

5.2 The test results can be greatly affected by sample disturbance. Careful selection and preparation of test specimens is required to reduce the potential of disturbance effects.

NOTE 3—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 suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 generally are considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D3740 does not assure reliable testing. Reliable testing depends on many factors, and Practice D3740 provides a means of evaluation some of these factors.

5.3 Consolidation test results are dependent on the magnitude of the load increments. Traditionally, the axial stress is doubled for each increment resulting in a load increment ratio of 1. For intact samples, this loading procedure has provided data from which estimates of the preconsolidation stress, using established interpretation techniques, compare favorably with field observations. Other loading schedules may be used to model particular field conditions or meet special requirements. For example, it may be desirable to inundate and load the specimen in accordance with the wetting or loading pattern expected in the field in order to best evaluate the response. Load increment ratios of less than 1 may be desirable for soils that are highly sensitive or whose response is highly dependent on strain rate.

5.4 The interpretation method specified by these test methods to estimate the preconsolidation stress provides a simple technique to verify that one set of time readings are taken after the preconsolidation stress and that the specimen is loaded to a sufficiently high stress level. Several other evaluation techniques exist and may yield different estimates of the preconsolidation stress. Alternative techniques to estimate the preconsolidation stress may be used when agreed to by the requesting agency and still be in conformance with these test methods.

5.5 Consolidation test results are dependent upon the duration of each load increment. Traditionally, the load duration is the same for each increment and equal to 24 h. For some soils, the rate of consolidation is such that complete consolidation (dissipation of excess pore pressure) will require more than 24 h. The apparatus in general use does not have provisions for formal verification of pore pressure dissipation. It is necessary to use an interpretation technique which indirectly determines that consolidation is essentially complete. These test methods specify procedures for two techniques (Method A and Method B), however alternative techniques may be used when agreed to by the requesting agency and still be in conformance with these test methods.

5.6 The apparatus in general use for these test methods do not have provisions for verification of saturation. Most intact samples taken from below the water table will be saturated. However, the time rate of deformation is very sensitive to degree of saturation and caution must be exercised regarding estimates for duration of settlements when partially saturated conditions prevail. Inundation of the test specimen does not significantly change the degree of saturation of the test specimen but rather provides boundary water to eliminate negative pore pressure associated with sampling and prevents evaporation during the test. The extent to which partial saturation influences the test results may be a part of the test evaluation and may include application of theoretical models other than conventional consolidation theory. Alternatively, the test may be performed using an apparatus equipped to saturate the specimen.

5.7 These test methods use conventional consolidation theory based on Terzaghi's consolidation equation to compute the coefficient of consolidation, c_v. The analysis is based upon the following assumptions:

5.7.1 The soil is saturated and has homogeneous properties;

5.7.2 The flow of pore water is in the vertical direction;

5.7.3 The compressibility of soil particles and pore water is negligible compared to the compressibility of the soil skeleton;

5.7.4 The stress-strain relationship is linear over the load increment;

5.7.5 The ratio of soil permeability to soil compressibility is constant over the load increment; and

5.7.6 Darcy's law for flow through porous media applies.

6. Apparatus

6.1 *Load Device*—A suitable device for applying axial loads or total stresses 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 and shall permit quick application of a given load increment without significant impact. Load application should be completed in a time corresponding to 0.01 times t_{100} or less.

NOTE 4—As an example, for soils where primary consolidation is completed in 3 min, the applied load should be stable in less than 2 s.

6.2 *Consolidometer*—A device to hold the specimen in a ring that is either fixed to the base or floating (supported by friction on the periphery of specimen) with porous disks on each face of the specimen. The inside diameter of the ring shall be fabricated to a tolerance of at least 0.1 % of the diameter. The consolidometer shall also provide a means of submerging the specimen in water, for transmitting the concentric axial load to the porous disks, and for measuring the axial deformation of specimen.

6.2.1 *Minimum Specimen Diameter*—The minimum specimen diameter or inside diameter of the specimen ring shall be 50 mm [2.0 in.].

6.2.2 *Minimum Specimen Height*—The minimum initial specimen height shall be 12 mm [0.5 in.], but shall be not less than ten times the maximum particle diameter.

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

NOTE 5—The use of greater diameter-to-height ratios is recommended. To minimize the effects of friction between the periphery of the specimen and the inside of the ring, a diameter-to-height ratio greater than four is preferable.

6.2.4 *Specimen Ring Rigidity*—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.

NOTE 6—For example, a ring thickness (for metallic rings) of 3.2 mm [1/8 in.] will be adequate for stresses up to 6000 kPa [900 lbf/in^2] for a specimen diameter of 63.5 mm [2.5 in.].

6.2.5 *Specimen Ring Material*—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. Silicone grease or molybdenum disulfide is recommended; polytetrafluoroethylene is recommended for nonsandy soils.

6.3 *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. Exact criteria have not been established but the disk thickness and hydraulic conductivity should result in an impedance factor of at least 100.

NOTE 7—The impedance factor is defined as the ratio of the hydraulic conductivity of the stones times the drainage thickness of the soil to the hydraulic conductivity of the soil times the thickness of the stone. Bishop and Gibson (1963) provides further information on the calculation and importance of the impedance factor.

6.3.1 *Diameter*—The diameter of the top disk shall be 0.2 to 0.5 mm [0.01 to 0.02 in.] less than the inside diameter of the ring. If a floating ring is used, the bottom disk shall meet the same requirement as the top disk.

NOTE 8—The use of tapered disks is recommended to prevent the disk from binding with the inside of the ring. The surface matching l, the larger diameter should be in contact with the soil or filter screen.

6.3.2 *Thickness*—Thickness of the disks shall be sufficient to prevent breaking. The top disk shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the disk.

6.3.3 *Maintenance*—The disks shall be clean and free from cracks, chips, and nonuniformities. New porous disks should be boiled for at least 10 minutes and left in the water to cool to ambient temperature before use. Immediately after each use, clean the porous disks with a nonabrasive brush and boil or sonicate to remove clay particles that may reduce their permeability.

NOTE 9—It is recommended that porous disks be stored in clean test water between tests. Each drying cycle has the potential to draw particles into the pores of the stone causing a progressive reduction in hydraulic conductivity. When performing tests that require dry stones during the setup procedure, the stones can be blotted dry just prior to the test.

6.4 *Filter Screen*—To prevent intrusion of material into the pores of the porous disk, a filter screen may be placed between the porous disk and the specimen. The screen must be included when evaluating the impedance factor. Monofilament-nylon filter screen or hardened, low ash, grade 54 filter paper may be used for the filter screen material.

NOTE 10—Filters should be cut to approximately the same dimension as the cross section of the test specimen. When following the wet setup procedure, soak the filter paper, if used, in a container of water to allow it to equilibrate before testing.

6.5 *Specimen Trimming Device*—A trimming turntable or a cylindrical cutting ring may be used for trimming the sample down to the inside diameter of the consolidometer ring with minimal disturbance. A cutter having the same inside diameter (or up to 0.05 mm larger) as the specimen ring shall attach to or be integral with the specimen ring. The cutter shall have a sharp edge, a highly polished surface and be coated with a low-friction material. Alternatively, a turntable or trimming lathe may be used. The cutting tool must be properly aligned to form a specimen of the same diameter as that of the ring.

6.6 *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.

6.7 *Recess Spacer Plate*—A plate usually of acrylic with a flat raised circular surface that fits inside the specimen ring and used to depress the top surface of the specimen about 2 mm [0.08 in] into the ring. A second plate that produces about twice the recess will be required when using a floating ring. The spacer plate(s) is not required if the consolidometer provides a means to center the porous disks.

6.8 *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 Specification D4753. The mass of specimens shall be determined to at least four significant digits.

6.9 *Drying Oven*—in accordance with Method D2216.

6.10 *Water Content Containers*—in accordance with Method D2216.

6.11 *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 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.

6.12 *Test Water*—Water is necessary to saturate the porous stones and fill the submersion reservoir. Ideally, this water would be similar in composition to the specimen pore fluid. Options include extracted pore water from the field, potable tap water, demineralized water, or saline water. The requesting agency should specify the water option. In the absence of a specification, the test should be performed with potable tap water.

6.13 *Miscellaneous Equipment*—Including timing device with 1 s readability, spatulas, knives, and wire saws, used in preparing the specimen.

7. Sampling

7.1 *Collection*—Practices D1587 and D3550 cover procedures and apparatus that may be used to obtain intact samples generally satisfactory for testing. Specimens may also be trimmed from large intact block samples which have been fabricated and sealed in the field. Finally, remolded specimens may be prepared from bulk samples to density and moisture conditions stipulated by the agency requesting the test.

7.2 *Transport*—Intact samples intended for testing in accordance with this test method shall be preserved, handled, and transported in accordance with the practices for Group C and D samples in Practices D4220. Bulk samples for remolded specimens should be handled and transported in accordance with the practice for Group B samples.

7.3 *Storage*—Storage of sealed samples should be such that no moisture is lost during storage, that is, no evidence of partial drying of the ends of the samples or shrinkage. Time of storage should be minimized, particularly when the soil or soil moisture is expected to react with the sample tubes.

7.4 *Disturbance*—The quality of consolidation test results diminishes greatly with sample disturbance. No sampling procedure can ensure completely undisturbed samples. Therefore, careful examination of the sample is essential in selection of specimens for testing.

NOTE 11—Examination for sample disturbance, stones, or other inclusions, and selection of specimen location is greatly facilitated by x-ray radiography of the samples (see Methods D4452).

8. Calibration

8.1 *Apparatus Deformation*—The measured axial deformations shall be corrected for apparatus compressibility whenever the equipment deformation exceeds 0.1 % of the initial specimen height or when using paper filter screens. If the correction is warranted at any point during the test, then a correction should be applied using the calibration data to all measurements throughout the test.

8.1.1 Assemble the consolidometer with a copper, aluminum, or hard steel disk of approximately the same height as the test specimen and at least 1 mm [0.04 in.] smaller in diameter than the ring, but no more than 5 mm smaller in diameter than the ring, in place of the specimen. Moisten the porous disks. If paper filter screens are to be used (see 6.3), they should be moistened and sufficient time (a minimum of 2 min.) allowed for the moisture to be squeezed from them during each increment of the calibration process.

8.1.2 Load and unload the consolidometer as in the test and measure the deformation for each load applied. When using paper filter screens, it is imperative that calibration be performed following the exact loading and unloading schedule to be used in the test. This is due to the inelastic deformation characteristics of filter paper. Recalibration should be done on an annual basis, or after replacement and reassembly of apparatus components.

8.1.3 At each load applied, plot or tabulate the apparatus deformations (corrections) to be applied to the measured deformation of the test specimen. The metal disk will also deform; however, modification of the apparatus deformation due to this deformation will be negligible for all but extremely large stress levels. If necessary, the compression of the metal disk can be computed and added to the corrections.

8.1.4 When using nylon filter screens it may be possible to represent the corrections with a mathematical equation.

8.2 *Miscellaneous Loading Elements*—Determine the cumulative mass (to the nearest 0.001 kg) of the top porous disk plus any other apparatus components that rest on the specimen and are not counterbalanced by the load frame, M_a.

8.3 *Apparatus Constants*—The following measurements must be made on an annual schedule or after replacement or alteration.

8.3.1 Determine the height of the ring, H_r, to the nearest 0.01 mm [0.0005 in], the diameter of the ring, D_r, to the nearest 0.01 mm [0.0005 in], and the mass of the ring, M_r, to the nearest 0.01 gm.

8.3.2 Determine the thickness of the filter screen, H_{fs}, to the nearest 0.01 mm [0.0005 in].

8.3.3 Determine the thickness of the step in the recess spacer(s), H_{rs}, to the nearest 0.01 mm [0.0005 in].

9. Specimen Preparation

9.1 Reduce as much as practical any disturbance of the soil or changes in moisture and density during specimen preparation. Avoid vibration, distortion, and compression.

9.2 Prepare test specimens in an environment where soil moisture change during preparation is minimized.

NOTE 12—A high humidity environment is often used for this purpose.

9.3 Trim the specimen and insert it into the consolidation ring. The specimen must fit tightly in the ring without any perimeter gaps. When specimens come from intact soil collected using sample tubes, the inside diameter of the tube shall be at least 5 mm [0.25 in.] greater than the inside diameter of the consolidation ring, except as noted in 9.4 and 9.5. It is recommended that either a trimming turntable or cylindrical cutting ring be used to cut the soil to the proper diameter. When using a trimming turntable, make a complete perimeter cut, reducing the specimen diameter to the inside diameter of the consolidation ring. Carefully insert the specimen into the consolidation ring, by the width of the cut, with a minimum of force. Repeat until the specimen protrudes from the bottom of the ring. When using a cylindrical cutting ring, trim the soil to a gentle taper in front of the cutting edge. After the taper is formed, advance the cutter a small distance to form the final diameter. Repeat the process until the specimen protrudes from the ring.

9.4 Fibrous soils, such as peat, and those soils that are easily damaged by trimming, may be transferred directly from the sampling tube to the ring, provided that the ring has the same or slightly smaller inside diameter as the sample tube.

9.5 Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of Practice D3550 and the rigidity requirement of 6.2.4.

9.6 Trim the specimen flush with the plane ends of the ring. For soft to medium soils, a wire saw should be used for trimming the top and bottom of the specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soils, a sharpened straightedge alone should be used for trimming the top and bottom. If a small particle is encountered in any surface being trimmed, it should be removed and the resulting void filled with soil from the trimmings.

NOTE 13—If large particles are found in the material during trimming or in the specimen after testing, include in the report this visual observation or the results of a particle size analysis in accordance with Method D422 (except the minimum sample size requirement shall be waived).

9.6.1 Unless the consolidometer provides a means to center the porous disks, the specimen must be recessed slightly below the top of the ring and also the bottom of the ring when using a floating ring geometry. This is to facilitate centering of the top (and bottom) porous disk. After trimming the top surface flush with the ring cover the specimen surface with the filter screen and then use the recess spacer to partially extrude the specimen from the bottom of the ring. Trim the bottom surface flush with the bottom of the ring. If using a floating ring configuration, cover the surface with the second filter screen and use the recess space with the smaller dimension to push the specimen back into the ring.

NOTE 14—If, at any stage of the test, the specimen swells beyond its initial height, the requirement of lateral restraint of the soil dictates the use of a recessed specimen or the use of a specimen ring equipped with an extension collar of the same inner diameter as the specimen ring. At no time during the test should the specimen extend beyond the specimen ring or extension collar.

9.7 Determine the initial wet mass of the specimen, M_{To}, to the nearest 0.01 g, in the consolidation ring by measuring the mass of the ring with specimen and subtracting the tare mass of the ring, M_r.

9.8 Determine the initial height of the specimen, H_o, to the nearest 0.01 mm [0.001 in.] using one of the following techniques.

9.8.1 Take the average of at least four evenly spaced measurements over the top (and bottom) surface(s) of the specimen using a dial comparator or other suitable measuring device. Subtract the thickness of the filter screens when appropriate.

9.8.2 Calculate the height based on the thickness of the specimen ring, H_r, minus the thickness of the recess spacer(s), H_{rs} and the filter screen(s), Hfs, as appropriate.

9.9 Compute the initial volume of the specimen, V_o, to the nearest 0.01 cm^3 [0.01 $in.^3$] from the diameter of the ring and the initial specimen height.

9.10 If sufficient material is available, obtain at least two natural water content determinations of the soil in accordance with Method D2216 from material trimmed adjacent to the test specimen.

9.11 When index properties are specified by the requesting agency, store the remaining trimmings taken from around the specimen and determined to be similar material in a sealed container for determination as described in Section 10.

10. Soil Index Property Determinations

10.1 The determination of index properties is an important adjunct to but not a requirement of the consolidation test. These determinations when specified by the requesting agency shall be made on the most representative material possible. When testing uniform materials, all index tests may be performed on adjacent trimmings collected in 9.11. When samples are heterogeneous or trimmings are in short supply, index tests should be performed on material from the test specimen as obtained in 11.6, plus representative trimmings collected in 9.11.

10.2 *Specific Gravity*—The specific gravity shall be determined in accordance with Test Method D854 on material from the sample as specified in 10.1. The specific gravity from another sample judged to be similar to that of the test specimen may be used for calculation in 12.2.4 whenever an accurate void ratio is not needed.

10.3 *Atterberg Limits*—The liquid limit, plastic limit and plasticity index shall be determined in accordance with Test Method D4318 using material from the sample as specified in 10.1. Determination of the Atterberg limits are necessary for proper material classification but are not a requirement of this test method.

10.4 *Particle Size Distribution*—The particle size distribution shall be determined in accordance with Method D422 (except the minimum sample size requirement shall be waived) on a portion of the test specimen as obtained in 11.6. A particle size analysis may be helpful when visual inspection indicates that the specimen contains a substantial fraction of coarse grained material but is not a requirement of this test method.

11. Procedure

11.1 Preparation of the porous disks and other apparatus will depend on the material being tested. The consolidometer must be assembled in such a manner as to prevent a change in water content or swelling of the specimen. Dry porous disks and filters must be used with dry, highly expansive soils and may be used for all other soils. Damp disks may be used for partially saturated soils. Saturated disks may be used only when the specimen is saturated and known to have a low affinity for water. The disks should be prepared using the test water. Assemble the ring with specimen, porous disks, filter screens (when needed) in the consolidometer. If the specimen will not be inundated shortly after application of the seating load (see 11.2), enclose the consolidometer in a loose fitting plastic or rubber membrane to prevent change in specimen volume due to evaporation.

NOTE 15—In order to meet the stated objectives of this test method, the specimen must not be allowed to swell in excess of its initial height prior to being loaded beyond its preconsolidation stress. Detailed procedures for the determination of one-dimensional swell or settlement potential of cohesive soils is covered by Test Method D4546.

11.2 Place the consolidometer in the loading device and apply a seating load that results in a total axial stress of about 5 kPa [100 lbf/ft^2]. Immediately after application of the seating load, adjust the deformation indicator and record the initial deformation reading, d_o. If necessary, add additional load to keep the specimen from swelling. Conversely, if it is anticipated that a total axial stress of 5 kPa [100 lbf/ft^2] will cause significant consolidation of the specimen, reduce the seating load to produce a total axial stress of about 3 kPa [50 lbf/ft^2] or less. If necessary, allow time for the consolidometer temperature to reach the test temperature range (± 2 °C).

11.3 If the test is performed on an intact specimen that was either saturated under field conditions or obtained below the water table, inundate with the test water shortly after application of the seating load. As inundation and specimen wetting occur, quickly increase the load as required to prevent swelling. Record the applied load required to prevent swelling and the resulting deformation reading. If specimen inundation is to be delayed to simulate specific conditions, then inundation must occur at a total axial stress that is sufficiently large to prevent swell. In such cases, apply the required load and inundate the specimen. Take deformation readings during the inundation period as specified in 11.5. In such cases, note in the test report the total axial stress at inundation and the resulting axial deformation.

NOTE 16—Inundation is necessary to eliminate the air water interface at the soil boundary which can cause negative pore pressures to exist in the pore space. Inundation will not significantly increase the degree of saturation of the test specimen and should not be used as the basis to claim a specimen is fully saturated.

11.4 The specimen is to be subjected to load increments of constant total axial stress. The duration of each load increment shall conform to guidelines specified in 11.5. The specific loading schedule will depend on the purpose of the test, but should conform to the following guidelines.

11.4.1 The standard loading schedule shall consist of a load increment ratio (LIR) of one which is obtained by approximately doubling the total axial stress on the soil to obtain values of about 12, 25, 50, 100, 200, etc. kPa [250, 500, 1000, 2000, 4000, etc. lbf/ft ^{2}].

11.4.2 If the slope and the shape of the virgin compression curve or determination of the preconsolidation stress is required, the maximum total axial stress shall be sufficiently high to provide either a) three points which define a straight line when plotted in log stress space, b) three points which define a concave up curve when plotted in log stress space or c) a stress level which is eight times the estimated preconsolidation stress. In other circumstances, the maximum total axial stress should be agreed on with the requesting agency.

11.4.3 The standard unloading (or rebound) schedule should be selected by approximately halving the total axial stress on the soil (that is, use the same stress levels as 11.4.1, but in reverse order). However, if desired, each successive stress level can be only one-fourth as large as the preceding stress level, that is, skip every other stress level.

11.4.4 In the case of overconsolidated clays, a better evaluation of recompression parameters may be obtained by imposing an unload-reload cycle once the preconsolidation stress has been exceeded. Specification of the stress level and the magnitude of an unload-reload cycle is the option of the agency requesting the test (see 1.3), however, unloading shall always include at least two decrements of total axial stress.

11.4.5 An alternative loading, unloading, or reloading schedule may be employed that reproduces the construction stress changes or allows better definition of some part of the stress-strain (compression) curve, or aids in interpreting the field behavior of the soil, or is specified by the requesting agency.

NOTE 17—Small increments may be desirable on highly compressible soils or when it is desirable to determine the preconsolidation stress with more precision. It should be cautioned, however, that load increment ratios less than 0.7 and load increments very close to the preconsolidation stress may preclude evaluation for the coefficient of consolidation, c_v, and the end-of-primary consolidation as discussed in Section 12.

11.5 Before each load increment is applied, record the height or change in height, d_f, of the specimen. Two alternative procedures are available that specify the time sequence of readings during the load increment and the required minimum load increment duration. Longer durations are often required during specific load increments to define the slope of the characteristic straight line secondary compression portion of the axial deformation versus log of time graph. For such increments, sufficient readings should be taken near the end of the load increment to define this straight line portion. It is not necessary to increase the duration of other load increments during the test.

11.5.1 *Test Method A*—The standard load increment duration shall be approximately 24 h. For at least two load increments, including at least one load increment after the preconsolidation stress has been exceeded, record the axial deformation, *d*, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15 and 30 min, and 1, 2, 4, 8 and 24 h (or 0.09, 0.25, 0.49, 1, 4, 9 min etc. if using 12.5.2 to present time-deformation data), measured from the time of each load increment application. Take sufficient readings near the end of the load increment duration to verify the completion of primary consolidation. For some soils, a period of more than 24 h may be required to reach the end-of-primary consolidation (as determined in 12.5.1.1 or 12.5.2.3). In such cases, load increment durations greater than 24 h are required. The load increment duration for these tests is usually taken at some multiple of 24 h and should be the standard duration for all load increments of the test. The decision to use a load increment duration greater than 24 h is usually based on experience with particular types of soils. If, however, there is a question as to whether a 24 h period is adequate, a record of axial deformation with time should be made for the initial load increments in order to verify the adequacy of a 24 h period. Load increment durations other than 24 h shall be noted in the report. For load increments where time versus deformation data are not required, leave the load on the specimen for about the same length of time as when time versus deformation readings are taken.

11.5.2 *Test Method B*—For each increment, record the axial deformation, *d*, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 min, and 1, 2, 4, 8 and 24 h (or 0.09, 0.25, 0.49, 1, 4, 9, min, etc. if using 12.5.2 to present time deformation data), measured from the time of each load increment application. The standard load increment duration shall exceed the time required for completion of primary consolidation as determined by 12.5.1.1, 12.5.2.3, or a criterion set by the requesting agency. For any load increment where it is impossible to verify the end of primary consolidation (for example, low LIR, high overconsolidation during recompression increments, or rapid consolidation), the load increment duration shall be constant and exceed the time required for primary consolidation of an increment applied after the preconsolidation stress and along the virgin compression curve. Where secondary compression must be evaluated, increase the load increment duration as necessary to define the rate of secondary compression.

NOTE 18—The suggested time intervals for recording the axial deformation are for typical soils and load increments. It is often desirable to change the reading frequency to improve interpretation of the data. More rapid consolidation will require more frequent readings. For most soils, primary consolidation during the first load decrements will be complete in less time (typically one-tenth) than would be required for a load increment along the virgin compression curve. However, at very low stresses the rebound time can be longer.

11.6 To minimize swell during disassembly, rebound the specimen back to the seating load (corresponding to a total axial stress of about 5 kPa). Once the change in axial deformation has reduced to less than 0.2 % per hour (usually overnight), record the end-of-test axial deformation, d_{et} and remove the consolidometer from the load frame quickly after releasing the final small seating load on the specimen. Remove the specimen and the ring from the consolidometer and wipe any free water from the ring and specimen.

11.7 Measure the height of the specimen H_{et}, to the nearest 0.01 mm [0.001 in.] by taking the average of at least four evenly spaced measurements over the top and bottom surfaces of the specimen using a dial comparator or other suitable measuring device.

11.8 Determine the final total mass of the specimen, M_{T_f} to the nearest 0.01 g, by measuring the soil plus the ring and subtracting the tare mass of the ring.

11.9 The most accurate determination of the specimen dry mass and water content is found by drying the entire specimen at the end of the test in accordance with Method D2216. If the soil sample is homogeneous and sufficient trimmings are available for the specified index testing (see 9.11), then determine the final water content, w_f, and dry mass of solids, M_d, using the entire specimen. If the soil is heterogeneous or more material is required for the specified index testing, then determine the final water content, w_{f_p}, using a small wedge shaped section of the specimen. The remaining undried material should be used for the specified index testing.

12. Calculation

12.1 Calculations as shown are based on the use of SI units. Other units are permissible, provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations. See 1.5.1 for additional comments on the use of inch-pound units.

12.1.1 Equations and graphs are illustrated using a single and dimensionally consistent set of units. Each equation makes use of the most convenient unit (for example, percent or decimal, s or min, kg or g) for each variable in the calculation. The multiplier unit conversion factors are not provided in the equations for simplicity and may be required to provide dimensional consistency between equations. Other units may be used and still be in conformance with these test methods.

12.1.2 Variables used in the equations are specified with a maximum resolution. When working in different units it will be necessary to compute comparable values to achieve the same number of significant digits.

12.2 *Specimen Physical Properties*:

12.2.1 Obtain the dry mass of the total specimen by direct measurement or for the case where part of the specimen is used for index testing, calculate the dry mass as follows:

$$M_d = \frac{M_{T_f}}{1 + w_{f_p}} \quad (1)$$

where:

M_d = dry mass of total specimen, g (nearest 0.01),
M_{Tf} = moist mass of total specimen after test, g (nearest 0.01), and
w_{fp} = water content wedge of specimen taken after test, in decimal form (nearest 0.0001).

12.2.2 Calculate the initial and final water content of the specimen, in percent, as follows:

$$\text{initial water content: } w_0 = \frac{M_{To} - M_d}{M_d} \times 100 \quad (2)$$

$$\text{final water content: } w_f = \frac{M_{T_f} - M_d}{M_d} \times 100 \quad (3)$$

where:

w_o = initial water content, % (nearest 0.01),
w_f = final water content, % (nearest 0.01),
M_d = dry mass of specimen, g, and
M_{To} = moist mass of specimen before test, g.

12.2.3 Calculate the initial dry density of the specimen as follows:

$$\rho_d = \frac{M_d}{V_o} \quad (4)$$

where:

ρ_d = dry density of specimen, g/cm^3 (nearest 0.001), and
V_o = initial volume of specimen, cm^3 (nearest 0.01).

12.2.4 Compute the volume of solids as follows:

$$V_s = \frac{M_d}{G\rho_w} \quad (5)$$

where:

V_s = Volume of solids, cm^3 (nearest 0.01)
G = specific gravity of the solids (nearest 0.001), and
ρ_w = density of water filling the pore space, (nearest 0.0001) g/cm^3.

NOTE 19—Water density depends on salt concentration and temperature. Appropriate values should be obtained from standard tables.

12.2.5 Since the cross-sectional area of the specimen is constant throughout the test, it is convenient for subsequent calculations to introduce the term "equivalent height of solids," defined as follows:

$$H_s = \frac{V_s}{A} \quad (6)$$

where:

H_s = height of solids, cm (nearest 0.001), and
A = specimen area, cm^2.

12.2.6 Calculate initial and final void ratio as follows:

$$\text{initial void ratio: } e_o = \frac{H_o - H_s}{H_s} \quad (7)$$

$$\textit{final void ratio : } e_f = \frac{H_f - H_s}{H_s} \quad (8)$$

where:

e_o = initial void ratio, (nearest 0.01),
e_f = final void ratio (nearest 0.01),
H_o = initial specimen height, cm, and
H_f = final specimen height, cm.

12.2.7 Calculate the initial and final degree of saturation, in percent, as follows:

$$\text{initial degree of saturation: } S_o = \frac{M_{T_o} - M_d}{A\rho_w(H_o - H_s)} \times 100 \quad (9)$$

$$\text{final degree of saturation: } S_f = \frac{M_{T_f} - M_d}{A\rho_w(H_f - H_s)} \times 100 \quad (10)$$

where:

S_o = initial degree of saturation, % (nearest 0.1), and
S_f = final degree of saturation, % (nearest 0.1).

12.3 *Deformation Calculations*:

12.3.1 For each deformation reading, calculate the change in specimen height, in cm, as follows:

$$\Delta H = d - d_o - d_a \quad (11)$$

where:

ΔH = Change in specimen height, cm, (nearest 0.00025),
d = deformation reading at various times in test, cm (nearest 0.00025),
d_o = initial deformation reading, cm (nearest 0.00025), and
d_a = apparatus deformation correction, cm (nearest 0.00025).

NOTE 20—Refer to 8.1 for apparatus compressibility correction requirements.

12.3.2 Represent each deformation measurement in at least one of the following forms.

12.3.2.1 The change in specimen height as computed in 12.3.1.

12.3.2.2 Calculate the specimen height, in cm, as follows:

$$H = H_o - \Delta H \quad (12)$$

12.3.2.3 Calculate the void ratio as follows:

$$e = \frac{H - H_s}{H_s} \quad (13)$$

12.3.2.4 Calculate the axial strain, in percent, as follows:

$$\varepsilon = \frac{\Delta H}{H_0} \times 100 \quad (14)$$

12.3.2.5 Calculate the final height differential as follows:

$$H_d = H_f - H_{et} \quad (15)$$

where:

H_d = final height differential, cm, (nearest 0.001),
H_f = computed final height using d_{et}, cm (nearest 0.001), and
H_{et} = measured final height, cm (nearest 0.001).

12.4 Compute the axial total stress, in kPa, as follows:

$$\sigma_a = \left(\frac{P + M_a g}{A}\right) \times 10 \quad (16)$$

where:

σ_a = axial total stress in kPa (nearest 1),
P = applied force in N (nearest 1),
M_a = mass of apparatus resting on specimen, kg (nearest 0.01)
A = specimen area, cm^2, (nearest 0.01), and
g = acceleration due to gravity, 9.81 m/s^2.

12.5 *Time-Deformation Properties*—From those load increments where time-deformation readings are obtained, two alternative procedures (see 12.5.1 or 12.5.2) are provided to present the data, determine the end-of-primary consolidation and compute the rate of consolidation. Alternative techniques may be used when agreed to by the requesting agency and still be in conformance with these test methods. The deformation readings may be presented as measured deformation, specimen height, or axial strain (see 12.6). The following text and figures are presented in terms of axial strain. The bold letters in parentheses within the following text are linked to the associated figures.

12.5.1 *Alternative Interpretation Procedure 1*—Referring to Fig. 1, plot the axial strain, ε, versus the log time (typically in minutes) for each applicable load increment.

12.5.1.1 Draw a straight line through the points representing the late time readings which exhibit a straight line trend and constant slope **(C)**. Draw a second straight line tangent to the steepest part of the axial strain-log time curve **(D)**. The intersection of these two lines represents the axial strain **(E)**, ε_{100}, and time **(F)**, t_{100}, corresponding to 100 % primary consolidation. Compression in excess of the above estimated 100 % primary consolidation is defined as secondary compression.

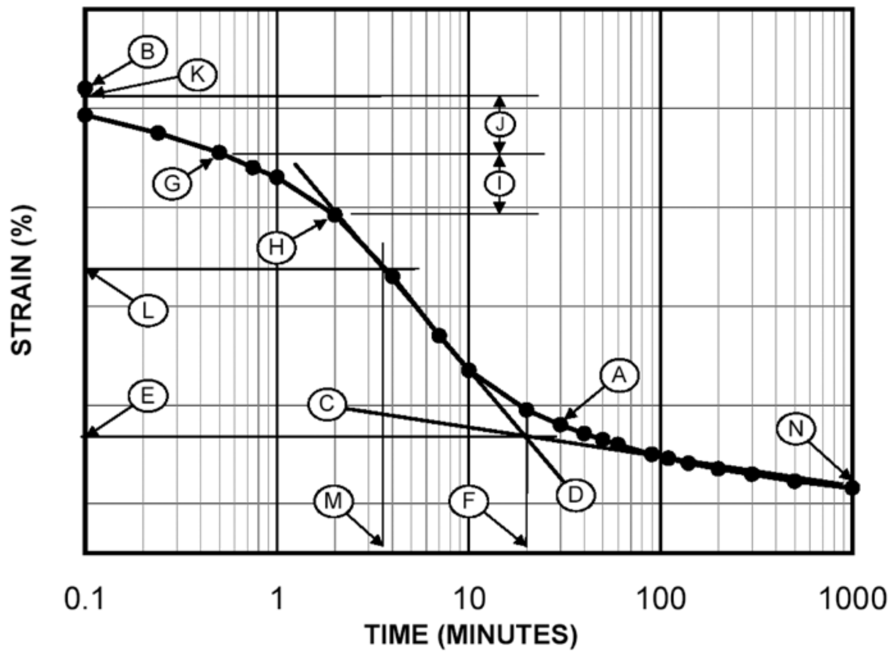
12.5.1.2 Find the axial strain representing 0 % primary consolidation **(K)** by selecting any two points that have a time ratio of 1 to 4 **(points G and H in this example)**. The axial strain increment at the larger of the two times should be greater than ¼ , but less than ½ of the total axial strain increment for the load increment. The axial strain corresponding to 0 % primary consolidation is equal to the axial strain at the smaller time, less the difference in axial strain **(I = J)** between the two selected points.

12.5.1.3 The axial strain **(L)**, ε_{50}, corresponding to 50 % primary consolidation is equal to the average of the axial strains corresponding to the 0 and 100 %. The time **(M)**, t_{50}, required for 50 % consolidation may be found graphically from the axial strain-log time curve by observing the time that corresponds to 50 % of the primary consolidation on the curve.

12.5.2 *Alternative Interpretation Procedure 2*—Referring to Fig. 2, plot the axial strain, ε, versus the square root of time (typically in minutes) for each applicable load increment.

12.5.2.1 Draw a straight line through the points representing the early time readings that exhibit a straight line trend **(A)**. Extrapolate the line back to $t = 0$ and obtain the axial strain ordinate representing 0 % primary consolidation **(B)**.

12.5.2.2 Draw a second straight line through the 0 % ordinate so that the abscissa of this line **(C)** is 1.15 times the abscissa of the first straight line through the data. The intersection of this second line with the axial strain-square root of time data curve gives the axial strain, ε_{90}, **(D)**, and time, t_{90}, **(E)**, corresponding to 90 % primary consolidation.



A – STRAIN-TIME BASED ON DATA POINTS AND INTERPRETED CURVE
B – STRAIN AT TIME = 0 MINUTES
C – LINEAR FIT OF ENDING PORTION OF MEASURED CURVE
D – LINEAR FIT OF STEEPEST PORTION OF MEASURED CURVE
E – STRAIN AT INTERSECTION OF LINES 'C' AND 'D' CORRESPONDING TO 100% CONSOLIDATION
F – TIME AT INTERSECTION OF LINES 'C' AND 'D' CORRESPONDING TO 100% CONSOLIDATION
G – FIRST DATA POINT SELECTED FOR INTERPRETATION OF 0% CONSOLIDATION
H – SECOND INTERPRETATION POINT CORRESPONDING TO FOUR TIMES LATER THAN POINT 'G'
I – INCREMENT OF STRAIN BETWEEN POINTS 'H' AND 'G'
J – INCREMENT OF STRAIN EQUAL TO 'I'
K – INTERPRETED STRAIN AT THE START OF CONSOLIDATION
L – STRAIN AT 50% CONSOLIDATION EQUAL TO MEAN OF 'K' AND 'E'
M – TIME CORRESPONDING TO 50% CONSOLIDATION
N – STRAIN AND TIME FOR LAST READING OF INCREMENT

NOTE—Strain scale omitted intentionally to make plot generic.

FIG. 1 Time-Deformation Curve Using Log Time Method

12.5.2.3 The axial strain at 100 % consolidation **(F)** is $\frac{1}{9}$ more than the difference in axial strain between 0 and 90 % consolidation. The time of primary consolidation **(G)**, t_{100}, may be taken at the intersection of the axial strain-square root of time curve and this axial strain ordinate. The axial strain **(H)**, ε_{50}, corresponding to 50 % consolidation is equal to the axial strain at $\frac{5}{9}$ of the difference between 0 and 90 % consolidation. The time for 50 % consolidation **(I)**, t_{50}, corresponds to the intersection of axial strain-square root time curve and the 50 % strain ordinate.

12.5.3 Compute the coefficient of consolidation for each applicable load increment using the following equation and values appropriate to the chosen method of interpretation:

$$c_v = \frac{TH_{D_{50}}^2}{t} \tag{17}$$

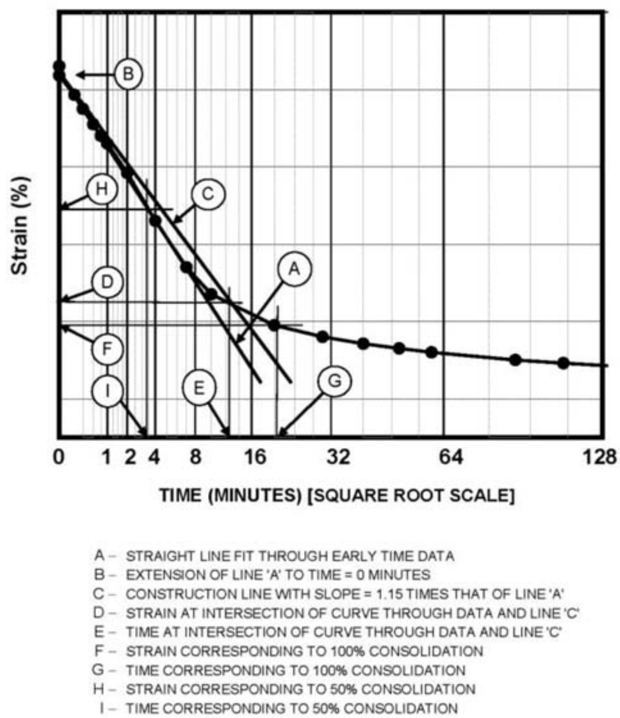
where:

c_v = coefficient of consolidation, cm^2/s (3 significant digits),

T = a dimensionless time factor: for method 12.5.1 use 50 % consolidation with T = $T_{50} = 0.197$, for method 12.5.2 use 90 % consolidation with $T = T_{90} = 0.848$,

t = time corresponding to the particular degree of consolidation, s; for method 12.5.1 use $t = t_{50}$, for method 12.5.2 use $t = t_{90}$, and

$H_{D_{50}}$ = length of the drainage path at 50 % consolidation, cm, for double-sided drainage $H_{D_{50}}$ is half the specimen height at the appropriate increment and for one-sided drainage $H_{D_{50}}$ is the full specimen height.



NOTE—Strain scale omitted intentionally to make plot generic.

FIG. 2 Time-Deformation Curve Using Square Root of Time Method

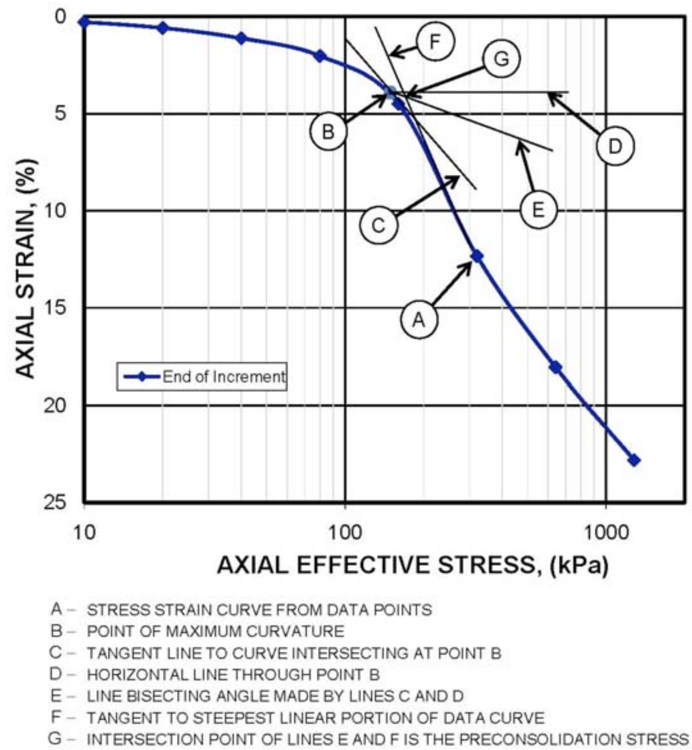


FIG. 3 Evaluation for Preconsolidation Stress From Casagrande Method

12.6 *Load-Deformation Properties*:

12.6.1 Tabulate the deformation or change in deformation, d_f, readings corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation, d_{100}.

12.6.2 Plot the deformation results (Fig. 3 is in terms of strain) corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation versus the stress on a log scale.

NOTE 21—In some cases, it may be preferable to present the load-deformation curve in arithmetic scale.

12.6.3 Referring to Fig. 3, determine the value of the preconsolidation stress using the following procedure.

NOTE 22—Any other recognized method of estimating preconsolidation stress (see references) may also be used, provided the method is identified in the report.

12.6.3.1 Draw a smooth curve through the measurements.

12.6.3.2 Estimate the point of maximum curvature on the compression curve **(B)**.

12.6.3.3 Draw the tangent to the compression curve at this point **(C)**, and a horizontal line through the point **(D)**, both extended towards increasing values on the abscissa.

12.6.3.4 Draw the line bisecting the angle between these lines **(E)**.

12.6.3.5 Extend the tangent to the steep, linear portion of the compression curve (virgin compression branch) **(F)** upwards to intersection with the bisector line **(E)**. The stress **(G)** (abscissa) corresponding to this point of intersection is the estimated preconsolidation stress.

12.6.4 Complete evaluation often includes consideration of information not generally available to the laboratory performing the test. For this reason further evaluation of the test is not mandatory. Many recognized methods of evaluation are described in the literature. Some of these are discussed in the Refs. (**1**) through (**9**).[3]

13. Report: Test Data Sheet(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the data sheet(s)/form(s), as given below, is covered in 1.6 and Practice D6026.

13.2 Record as a minimum the following general information (data):

13.2.1 Project name and location, boring number, sample number, and depth.

13.2.2 Test number, starting date, apparatus, and technician.

13.2.3 Description and classification of the soil in accordance with Practice D2488 or Test Method D2487 when Atterberg limit data are available. Specific gravity of solids, Atterberg limits and grain size distribution shall also be reported when available plus the source of such information if other than measurements obtained on test specimen. Also note occurrence and approximate size of isolated large particles.

13.2.4 *Soil Condition*:

13.2.4.1 Average water content of trimmings when available,

13.2.4.2 Initial and final water content of specimen,

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

13.2.4.3 Initial dry density of specimen,

13.2.4.4 Initial and final void ratio of specimen,

13.2.4.5 Initial and final degree of saturation of specimen,

13.2.4.6 Final differential height, and

13.2.4.7 Estimated preconsolidation stress.

13.2.5 *Test Procedure*:

13.2.5.1 Preparation procedure used relative to trimming; state whether the specimen was trimmed using a trimming turntable, trimmed using a cutting shoe, or tested directly in a ring from a ring lined sampler.

13.2.5.2 Condition of test (natural moisture or inundated, stress at inundation, test water).

13.2.5.3 Method of testing (A or B).

13.2.5.4 Interpretation procedure (1 or 2 or both) used to compute coefficient of consolidation.

13.2.5.5 Listing of loading increments, and load increment duration, if differing from 24 h; end of increment deformation results and, for Test Method B, end-of-primary deformation results and coefficient of consolidation (see Table 1).

13.2.5.6 All departures from the procedure outlined, including special loading sequences.

13.2.6 *Graphical Presentations*:

13.2.6.1 Graph of deformation versus log time (see Fig. 1) or square root of time (see Fig. 2) for those load increments where time rate readings were taken.

13.2.6.2 Graph of void ratio versus axial stress (on a log scale) curve or percent compression versus axial stress (on a log scale) curve (see Fig. 3).

13.2.6.3 In cases where time rate of deformation readings have been taken for several load increments, prepare a graph of the log of coefficient of consolidation versus average void ratio or average percent compression for the respective load increments (see Fig. 4). Alternatively, a graph of coefficient of consolidation or log of coefficient of consolidation versus log of average axial stress may be used. If time rate readings were obtained for only two load increments, simply tabulate the values of $c_v$versus the average axial stress for the increment.

NOTE 23—The average stress between two load increments is chosen because it is a convenient coordinate for plotting the result. Unless the rate of pore pressure dissipation is measured, it is not possible to determine the actual effective stress at the time of 50 % consolidation. Furthermore, some ambiguity may arise in cases where the test has been carried through one or more intermediate load-rebound cycles.

14. Precision and Bias

14.1 *Statement of Precision*—Due to the nature of the soil materials tested by this test method it is either not feasible or too costly at this time to produce multiple specimens which have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.05 welcomes proposals that would allow for development of a valid precision statement.

14.2 *Statement of Bias*—There is no acceptable reference value for this test method, therefore, bias cannot be determined.

15. Keywords

15.1 compressibility; compression curves; consolidation; consolidation coefficient; consolidation test; consolidometer; preconsolidation pressure; preconsolidation stress; primary consolidation; rebound; secondary compression; settlement; swelling

TABLE 1 Example of a Consolidation Test Summary

Load Incr.	Axial Stress σ_a (kPa)	Corrected Deformation ΔH (mm)	Specimen Height H (mm)	Axial Strain ε_a (%)	Void Ratio e (--)	Corrected Deformation ΔH_{50} (mm)	Specimen Height H_{50} (mm)	Axial Strain $\varepsilon_{a,50}$ (%)	Void Ratio e_{50} (--)	Time t_{50} (sec)	Coef. of Consolidation c_v (mm^2/sec)	Time t_{90} (sec)	Coef. of Consolidation c_v (mm^2/sec)
seating	seating	0.0000	19.0500	0.00	1.231					Log Time Method		Root Time Method	
1	5	0.0288	19.0212	0.15	1.228								
2	10	0.0557	18.9943	0.29	1.225								
3	20	0.1133	18.9367	0.59	1.218								
4	40	0.2139	18.8361	1.12	1.206	0.2696	18.7804	1.42	1.200	52	3.34E-01	10	3.34E-01
5	80	0.3867	18.6633	2.03	1.186	0.5355	18.5145	2.81	1.169	144	1.17E-01	30	1.17E-01
6	160	0.8560	18.1940	4.49	1.131	1.5439	17.5061	8.10	1.050	516	2.93E-02	102	2.93E-02
7	320	2.3496	16.7004	12.33	0.956	2.8317	16.2183	14.86	0.900	282	4.59E-02	53	4.59E-02
8	640	3.4392	15.6108	18.05	0.828	3.8223	15.2277	20.06	0.784	156	7.32E-02	31	7.32E-02
9	1280	4.3440	14.7060	22.80	0.722								
10	320	4.2553	14.7947	22.34	0.733								
11	80	3.9300	15.1200	20.63	0.771								
12	20	3.5131	15.5369	18.44	0.820								
13	5	3.0981	15.9519	16.26	0.868								

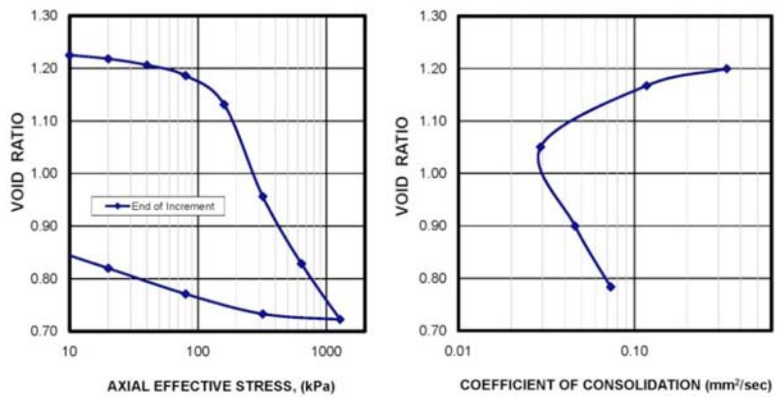


FIG. 4 Example of Consolidation Test Summary Plots

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(**9**) Bishop A.W. and Gibson, R.E., "The Influence of the Provisions for Boundary Drainage on Strength and Consolidation Characteristics of Soils Measured in the Triaxial Apparatus," *Laboratory Shear Testing of Soils*, ASTM STP No 361, pp. 273-328, ASTM 1963.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to these test methods since the last issue, D2435–04, that may impact the use of these test methods. (Approved May 1, 2011)

(*1*) Throughout Standard extensive edits for clarification.
(*2*) Renumbered Notes.
(*3*) Sections 1.1.1 and 1.1.2 added clarification to each method.
(*4*) Section 1.2 and beyond change undisturbed to intact.
(*5*) Section 1.2 added saturation and last sentence.
(*6*) Section 1.3 specify default test conditions.
(*7*) Added Section 1.4 on saturation.
(*8*) Section 1.5 change unit specification.
(*9*) Section 2.1 add reference to D 4753 and D 6027.
(*10*) Section 3.2 add definitions of terms specific to standard.
(*11*) Section 3.2 added all definitions in this section.
(*12*) Section 4.1 and beyond change method to methods.
(*13*) Section 4.1 added discussion relative to saturation.
(*14*) Section 5.4 and 5.5 changed wording relative to requesting agency.
(*15*) Section 5.6 added clarification on inundation.
(*16*) Section 6.1 move note 4 information in standard.
(*17*) Section 6.2 and beyond put dual units in brackets.
(*18*) Section 6.2 and beyond use axial deformation as height measurement.
(*19*) Section 6.2 change in ring specification.
(*20*) Section 6.2.4 change specimen ring specification.
(*21*) Add Note 6.
(*22*) Section 6.3 change porous disk specification.
(*23*) Change note 7.
(*24*) Change note 8.
(*25*) Change note 9.
(*26*) Add Section 6.4, Note 10, and Section 6.7.
(*27*) Section 6.8 change balance specification.
(*28*) Section 6.11 change environment specification.
(*29*) Add Section 6.12 on test water specification.
(*30*) Add Section 6.13.
(*31*) Section 7 insert subsection titles.
(*32*) Section 8.1 change specification of apparatus deformation.
(*33*) Section 8.2 and 8.3 new sections.
(*34*) Add Note 13.
(*35*) Add Section 9.6.1 on providing recess of specimen into ring.
(*36*) Section 9.7 add tolerance on mass measurement
(*37*) Restructured Section 9.8.
(*38*) Section 11.2 add temperature requirement.
(*39*) Add Note 16.

(*40*) Section 11.4 change specifications and restructure subsections.
(*41*) Section 11.4.2 change maximum stress specification.
(*42*) Section 11.4.4 add option to load schedule.
(*43*) Section 11.5.2 add clarification.
(*44*) Section 11.6 change specification.
(*45*) Section 11.7 add section with new requirement.
(*46*) Section 11.8 add specification.
(*47*) Added Section 12.1.1 and Section 12.1.2 for guidance on equations.
(*48*) Section 12.2 changed title.
(*49*) Section 12 added definition of all terms in appropriate subsections.
(*50*) Section 12 added maximum resolution values to terms were appropriate.
(*51*) Section 12 changed example units to one option using SI system.
(*52*) Rearranged several of the subsections with in Section 12.
(*53*) Eliminated old Section 12.2.4 relative to dry unit weight.
(*54*) Section 12.2.4 increased significant digits of water density.
(*55*) Added Note 19.
(*56*) Section 12.3 changed title.
(*57*) Added Section 12.3.1 and 12.3.2 and removed old Section 12.4.
(*58*) Added Section 12.3.2.5 with new calculation.
(*59*) Added Note 20.
(*60*) Section 12.5 examples use strain to represent axial deformation.
(*61*) Section 12.5 separated into two alternative interpretation procedures.
(*62*) Section 12.5.1 and 12.5.2 added letters to better link to figures
(*63*) Section 12.6.2 added title.
(*64*) Added Section 13.2.2.
(*65*) Section 13.2.4 changed requirements.
(*66*) Section 13.2.4.6 new requirement.
(*67*) Renamed Figure 1 to Table 1 and replaced it with a new table.
(*68*) New Log Time and Square Root of Time Figures.