This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

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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/D4186M.

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 and is the direct responsibility of Subcommittee D18.05 on Strength and Compressibility of Soils.

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

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

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D422 Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)[3]
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1587/D1587M Practice for Thin-Walled Tube Sampling of Fine-Grained 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 Procedures)
D3550/D3550M 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/D4186M Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading
D4220/D4220M 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 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/D6027M Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes

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

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

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

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.