
Standard Method of Test for One-Dimensional Consolidation Properties of Soils

AASHTO Designation: T 216-22

Technically Revised: 2022

Technical Subcommittee: 1a, Soil and Unbound Recycled Materials

ASTM Designation: D2435-04



**American Association of State Highway and Transportation Officials
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1. SCOPE

- 1.1. This test method covers 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.
- 1.1.2. *Test Method B*—Time-deformation readings are required on all load increments. Successive load increments are applied after 100 percent primary consolidation is reached, or at constant time increments as described in Test Method A.
- Note 1**—The determination of the rate and magnitude of consolidation of soil when it is subjected to controlled-strain loading is covered by ASTM D4186/D4186M.
- 1.2. This test method is most commonly performed on undisturbed samples of fine grained soils naturally sedimented in water; however, the basic test procedure is applicable as well to specimens of compacted soils and undisturbed samples of soils formed by other processes such as weathering or chemical alteration. Evaluation techniques specified in this test method are generally applicable to soils naturally sedimented in water. Tests performed on other soils, such as compacted and residual (weathered or chemically altered) soils, may require special evaluation techniques.
- 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.
- 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 load increment (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. The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate and given for guidance only. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.



- 1.4.1. 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.
- 1.5. *This standard does not purport to address the safety concerns 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.*
- 1.6. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

2.1. AASHTO Standards:

- M 339M/M 339, Thermometers Used in the Testing of Construction Materials
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 100, Specific Gravity of Soils
- T 207, Thin-Walled Tube Sampling of Soils
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. ASTM Standards:

- D653, Standard Terminology Relating to Soil, Rock, and Contained Fluids
- D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D3550/D3550M, Standard Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
- D4186/D4186M, Standard Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading
- D4220/D4220M, Standard Practices for Preserving and Transporting Soil Samples
- D4452, Standard Practice for X-Ray Radiography of Soil Samples
- D4546, Standard Test Methods for One-Dimensional Swell or Collapse of Soils
- D6026, Standard Practice for Using Significant Digits in Geotechnical Data
- E1, Standard Specification for ASTM Liquid-in-Glass Thermometers

- E230/E230M, Standard Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
- E2877, Standard Guide for Digital Contact Thermometers

2.3. *International Electrotechnical Commission Standard:*

- IEC 60584-1: 2013 Thermocouples - Part 1: EMF Specifications and Tolerances

2.4. *Other Document:*

- Casagrande, A. "The Determination of the Pre-Consolidation Load and its Practical Significance." *Proceedings*, 1st ICSMFE, III, 1936, p. 60.

3. TERMINOLOGY

- 3.1. *Definitions*—The definitions of terms used in this test method shall be in accordance with ASTM D653.

4. SUMMARY OF TEST METHOD

- 4.1. In this test method, a soil specimen is restrained laterally and loaded axially with total stress increments. Each stress increment is maintained until excess pore water pressures are completely dissipated. During the consolidation process, measurements are made of change in the specimen height and these data are used to determine the relationship between the effective stress and void ratio or strain, and the rate at which consolidation can occur by evaluating 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 minimize disturbance.
- 5.3. Consolidation test results are dependent on the magnitude of the load increments. Traditionally, the load is doubled for each increment resulting in a load-increment ratio of one. For undisturbed samples, this load procedure has provided data from which estimates of the preconsolidation pressure also referred to as the maximum past pressure, using established evaluation techniques, compare directly with field measurement. Other load 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 simulate the response. Smaller than standard load increment ratios may be desirable for soils that are highly sensitive or whose response is highly dependent on strain rate. The test method specified to estimate the preconsolidation pressure provides a simple technique to verify that one set of time readings are taken after the preconsolidation pressure. Several other evaluation techniques exist and may yield different estimates of the preconsolidation pressure. Therefore, the requesting agency may specify an alternate technique to estimate the preconsolidation pressure.
- 5.4. Consolidation test results are dependent on 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 that indirectly determines that consolidation is complete. This test method specifies two techniques; however, the requesting agency may specify an alternative technique and still be in conformance with this test method.

- 5.5. The apparatus in general use for this test method does not have provisions for verification of saturation. Most undisturbed 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. 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.
- 5.6. This test method uses conventional consolidation theory based on Terzaghi's consolidation equation to compute the coefficient of consolidation, c_v . The analysis is based on the following assumptions:
 - 5.6.1. The soil is saturated and has homogeneous properties;
 - 5.6.2. The flow of pore water is in the vertical direction;
 - 5.6.3. The compressibility of soil particles and pore water is negligible compared to the compressibility of the soil skeleton;
 - 5.6.4. The stress-strain relationship is linear over the load increment;
 - 5.6.5. The ratio of soil permeability to soil compressibility is constant over the load increment; and
 - 5.6.6. Darcy's law for flow through porous media applies.

6. APPARATUS

- 6.1. *Load Device*—A suitable device for applying vertical loads or total stresses to the specimen. The device should be capable of maintaining specified loads for long periods of time with an accuracy of ± 0.5 percent of the applied load and should permit quick application of a given load increment without significant impact.

Note 3—Load application generally should be completed in a time corresponding to $0.01 t_{100}$ or less. For soils where primary consolidation is completed in 3 min, load application should be 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 periphery of specimen) with porous disks on each face of the specimen. The inside diameter of the ring shall be determined to a tolerance of 0.075 mm (0.003 in.). The consolidometer shall also provide a means of submerging the specimen, for transmitting the concentric vertical load to the porous disks, and for measuring the change in height of specimen.
 - 6.2.1. *Minimum Specimen Diameter*—The minimum specimen diameter shall be 50 mm (2.00 in.). The diameter of the sample in the tube shall be greater than the diameter of the consolidation test ring. The diameter of the sample must be greater than the test ring to reduce sampling disturbance and prevent lateral displacement.
 - 6.2.2. *Minimum Specimen Height*—The minimum initial specimen height shall be 12 mm (0.5 in.), but shall not be less than 10 times the maximum particle diameter.

Note 4—If large particles are found in the specimen after testing, include in the report this visual observation or the results of a particle-sized analysis in accordance with T 88 (except the minimum sample-sized requirement shall be waived).

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 sides of the specimen and ring, a diameter-to-height ratio greater than four is preferable.

6.2.4. *Specimen Ring Rigidity*—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 0.03 percent of the diameter under the greatest load applied.

6.2.5. *Specimen Ring Material*—The ring shall be made of a material that is noncorrosive in relation to the soil tested. 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 non-sandy soils.

6.3. *Porous Disks*—The porous disks shall be of silicon carbide, aluminum oxide, or similar noncorrosive material. The grade of the disks shall be fine enough to prevent intrusion of soil into the pores. If necessary, a filter paper (Note 6) may be used to prevent intrusion of the soil into the disks; however, the permeability of the disks, and filter paper, if used, must be at least one order of magnitude higher than that of the specimen.

Note 6—Whatman No. 54 filter paper has been found to meet requirements for permeability and durability.

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 have the same diameter as the top disk.

Note 7—The use of tapered disks is recommended, with the larger diameter in contact with the soil.

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 other defects. New porous disks should be boiled for at least 10 min 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 to remove clay particles that may reduce their permeability. It is recommended that porous disks be stored in a jar with de-aired water between tests.

6.4. *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 a minimum of disturbance. A cutter having the same inside diameter 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.

6.5. *Deformation Indicator*—To measure change in specimen height, with a readability of 0.0025 mm (0.0001 in.).

6.6. *Miscellaneous Equipment*—Including timing device with 1-s readability, distilled or demineralized water, spatulas, knives, and wire saws, used in preparing the specimen.

- 6.7. *Balances*, in accordance with T 265.
- 6.8. *Drying Oven*, in accordance with T 265.
- 6.9. *Water Content Containers*, in accordance with T 265.
- 6.10. *Environment*—Tests shall be performed in an environment where temperature fluctuations are less than $\pm 4^{\circ}\text{C}$ ($\pm 7^{\circ}\text{F}$) and there is no direct exposure to sunlight. The thermometer for measuring ambient temperature shall meet the requirements of M 339M/M 339 with a temperature range of at least 16 to 34°C (61 to 93°F) and an accuracy of $\pm 0.5^{\circ}\text{C}$ ($\pm 1.0^{\circ}\text{F}$) (see Note 8).
- Note 8**—Thermometer types suitable for use include ASTM E1 mercury thermometers; ASTM E230/E230M thermocouple thermometer, Type T, Class Special; IEC 60584 thermocouple thermometer, Type T, Class 1; or ASTM E2877 digital metal stem thermometer.

7. STANDARDIZATION

- 7.1. The measured vertical deformations must be corrected for apparatus flexibility whenever the calibration correction determined in Section 7.4 exceeds 5 percent of the measured deformation and in all tests where filter paper disks are used.
- 7.2. 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 sample. Moisten the porous disks. If filter papers are to be used (Section 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.
- 7.3. Load and unload the consolidometer as in the test and measure the deformation for each load applied. When filter papers are used, it is imperative that calibration be performed following the exact loading and unloading schedule to be used. This is due to the inelastic deformation characteristics of filter paper. Recalibration for tests without filter paper need be done only on an annual basis, or after replacement and reassembly of apparatus components.
- 7.4. At each load applied, plot or tabulate the corrections to be applied to the measured deformation of the test specimen. Note that the metal disk will deform also; however, the correction due to this deformation will be negligible for all but extremely stiff soils. If necessary, the compression of the metal disk can be computed and applied to the corrections.

8. SAMPLING

- 8.1. AASHTO T 207 and ASTM D3550/D3550M cover procedures and apparatus that may be used to obtain undisturbed samples generally satisfactory for testing (Note 9). Specimens may also be trimmed from large undisturbed block samples 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.
- Note 9**—Not all tube diameters specified may be of sufficient size for testing.
- 8.2. Undisturbed samples destined 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 ASTM D4220/D4220M. Bulk samples for remolded specimens should be handled and transported in accordance with the practice for Group B samples.