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Standard Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading[1]

This standard is issued under the fixed designation D4186/D4186M; 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.

ε[1] NOTE—Editorially corrected Eq X1.3 in June 2014.

1. Scope*

1.1 This test method is for the determination of the magnitude and rate-of-consolidation of saturated cohesive soils using continuous controlled-strain axial compression. The specimen is restrained laterally and drained axially to one surface. The axial force and base excess pressure are measured during the deformation process. Controlled strain compression is typically referred to as constant rate-of-strain (CRS) testing.

1.2 This test method provides for the calculation of total and effective axial stresses, and axial strain from the measurement of axial force, axial deformation, chamber pressure, and base excess pressure. The effective stress is computed using steady state equations.

1.3 This test method provides for the calculation of the coefficient of consolidation and the hydraulic conductivity throughout the loading process. These values are also based on steady state equations.

1.4 This test method makes use of steady state equations resulting from a theory formulated under particular assumptions. Section 5.5 presents these assumptions.

1.5 The behavior of cohesive soils is strain rate dependent and hence the results of a CRS test are sensitive to the imposed rate of strain. This test method imposes limits on the strain rate to provide comparable results to the incremental consolidation test (Test Method D2435).

1.6 The determination of the rate and magnitude of consolidation of soil when it is subjected to incremental loading is covered by Test Method D2435.

1.7 This test method applies to intact (Group C and Group D of Practice D4220), remolded, or laboratory reconstituted samples.

1.8 This test method is most often used for materials of relatively low hydraulic conductivity that generate measurable excess base pressures. It may be used to measure the compression behavior of essentially free draining soils but will not provide a measure of the hydraulic conductivity or coefficient of consolidation.

1.9 All recorded and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026, unless superseded by this test method. The significant digits specified throughout this standard are based on the assumption that data will be collected over an axial stress range from 1% of the maximum stress to the maximum stress value.

1.9.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.9.2 Measurements made to more significant digits or better sensitivity than specified in this standard shall not be regarded a non-conformance with this standard.

1.10 *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.

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

1.10.2 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two

[1] This test method is 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**

separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as non-conformance with this standard.

1.11 *This standard may involve hazardous materials, operations, and equipment. 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]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3213 Practices for Handling, Storing, and Preparing Soft Intact Marine Soil
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4452 Practice for X-Ray Radiography of Soil Samples
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D5720 Practice for Static Calibration of Electronic Transducer-Based Pressure Measurement Systems for Geotechnical Purposes
D6026 Practice for Using Significant Digits in Geotechnical Data
D6027 Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes (Withdrawn 2013)[3]
D6519 Practice for Sampling of Soil Using the Hydraulically Operated Stationary Piston Sampler
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
D7015 Practices for Obtaining Intact Block (Cubical and Cylindrical) Samples of Soils

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of technical terms used in this Test Method, see Terminology D653.

3.2 *Definitions of Terms:*

3.2.1 *back pressure,* $(u_b$ *(FL^{-2}))*—a fluid pressure in excess of atmospheric pressure that is applied to the drainage boundary of a test specimen.

3.2.1.1 *Discussion*—Typically, the back pressure is applied to cause air in the pore spaces to pass into solution, thus saturating the specimen.

3.2.2 *consolidometer*—an apparatus containing a specimen under conditions of negligible lateral deformation while allowing one-dimensional axial deformation and one directional axial flow.

3.2.3 *excess pore-water pressure,* Δ_u *(FL^{-2})—in effective stress testing*, the pressure that exists in the pore fluid relative to (above or below) the back pressure.

3.2.4 *total axial stress,* σ_a *(FL^{-2})—in effective stress testing*, the normal stress applied to the axial boundary of the specimen in excess of the back pressure.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *average effective axial stress,* σ'_a *(FL^{-2})*—the effective stress calculated using either the linear or nonlinear theory equations to represent the average value at any time under steady state constant strain rate conditions.

3.3.2 *axial deformation reading, AD (volts)*— readings taken during the test of the axial deformation transducer.

3.3.3 *axial force reading, AF (volts)*—readings taken during the test of the axial force transducer.

3.3.4 *base excess pressure,* Δu_m *(FL^{-2})*—the fluid pressure in excess (above or below) of the back pressure that is measured at the sealed boundary of the specimen under conditions of one way drainage. The base excess pressure will be positive during loading and negative during unloading.

3.3.5 *base excess pressure ratio,* R_u *(D)* —the ratio of *(1)* the base excess pressure to *(2)* the total axial stress. This value will be positive during loading and negative during unloading.

3.3.6 *base excess pressure reading, BEP (volts)*—readings taken during the test of the base excess pressure transducer when using a differential pressure transducer which is referenced to the chamber pressure.

[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.

3.3.7 *base pressure, u_m (FL^{-2})*—the fluid pressure measured at the sealed boundary (usually at the base of the consolidometer) of the specimen under conditions of one way drainage.

3.3.8 *base pressure reading, BP (volts)*—readings taken during the test of the base pressure transducer.

3.3.9 *chamber pressure, σ_c (FL^{-2})*—the fluid pressure inside the consolidometer. In most CRS consolidometers, the chamber fluid is in direct contact with the specimen. For these devices (and this test method), the chamber pressure will be equal to the back pressure.

3.3.10 *chamber pressure reading, CP (volts)*—readings taken during the test of the chamber pressure transducer.

3.3.11 *constant rate-of-strain, CRS*—a method of consolidating a specimen in which the surface is deformed at a uniform rate while measuring the axial deformation, axial reaction force, and induced base excess pressure.

3.3.12 *dissipation*—change over time of an excess initial condition to a time independent condition.

3.3.13 *equilibrated water*—test water that has come to equilibrium with the current room conditions including temperature, chemistry, dissolved air, and stress state.

3.3.14 *linear theory (calculation method)*—a set of equations derived based on the assumption that the coefficient of volume compressibility (m_v) is constant (the soil follows a linear strain versus effective stress relationship).

3.3.15 *monofilament nylon screen*—thin porous synthetic woven fabric made of single untwisted filament nylon.

3.3.16 *nonlinear theory (calculation method)*— a set of equations derived based on the assumption that the compression index (C_c) is constant (the soil follows a linear strain versus log effective stress relationship).

3.3.17 *steady state condition—in CRS testing* , a time independent strain distribution within the specimen that changes in average value as loading proceeds.

3.3.18 *steady state factor, F (D)*—a dimensionless number equal to the change in total axial stress minus the base excess pressure divided by the change in total axial stress.

3.3.19 *transient condition—in CRS testing*, a time dependent variation in the strain distribution within the specimen that is created at the start of a CRS loading or unloading phase or when the strain rate changes and then decays with time to a steady state strain distribution.

3.3.20 *unit conversion factor*—a constant used in an equation to unify the system of units (eg, SI to inch pound) or prefix of variables (eg. cm to m) within the same system of units.

4. Summary of Test Method

4.1 In this test method the specimen is constrained axially between two parallel, rigid boundaries and laterally such that the cross sectional area remains essentially constant. Drainage is provided along one boundary (typically the top) and the fluid pressure is measured at the other sealed boundary (typically the base) of the consolidometer.

4.2 A back pressure is applied to saturate both the specimen and the base pressure measurement system.

4.3 The specimen is deformed axially at a constant rate while measuring the time, axial deformation, reaction force, chamber pressure, and base pressure. A standard test includes one loading phase, one constant load phase, and one unloading phase. The constant load phase allows the base excess pressure to return to near zero prior to unloading. More extensive tests can be performed by including more phases to obtain unload-reload cycle(s).

4.4 The rate of deformation is selected to produce a base excess pressure ratio that is between about 3 % and 15 % at the end of the loading phase.

NOTE 1—The base excess pressure ratio typically decreases during loading. The lower limit provides sufficient pressure to compute the rate parameters and the upper limit reduces the differences between the linear and non linear model calculations. It also helps constrain differences in the compression behavior when testing rate sensitive materials.

4.5 During loading and unloading, the measurements are first evaluated in order to be sure transient effects are small as defined by the steady state factor. Steady state equations are then used to compute the one-dimensional effective axial stress versus strain relationship. During the loading phase, when base excess pressures are significant and transient effects are small, the measurements are used to compute both the coefficient of consolidation and hydraulic conductivity throughout the test.

4.6 It is possible to interpret measurements made during the test when transient effects are significant but these equations are complicated and beyond the scope of this standard test method. Interpretation of transient conditions does not constitute non-conformance of this test method.

5. Significance and Use

5.1 Information concerning magnitude of compression and rate-of-consolidation of soil is essential in the design of earth structures and earth supported structures. The results of this test method may be used to analyze or estimate one-dimensional settlements, rates of settlement associated with the dissipation of excess pore-water pressure, and rates of fluid transport due to hydraulic gradients. This test method does not provide information concerning the rate of secondary compression.

5.2 *Strain Rate Effects:*

5.2.1 It is recognized that the stress-strain results of consolidation tests are strain rate dependent. Strain rates are limited in this test method by specification of the acceptable magnitudes of the base excess pressure ratio during the loading phase. This specification provides comparable results to the 100 % consolidation (end of primary) compression behavior obtained using Test Method D2435.

5.2.2 Field strain rates vary greatly with time, depth below the loaded area, and radial distance from the loaded area. Field strain rates during consolidation processes are generally much slower than laboratory strain rates and cannot be accurately determined or predicted. For these reasons, it is not practical to replicate the field strain rates with the laboratory test strain rate.

5.3 *Temperature Effects:*

5.3.1 Temperature affects the rate parameters such as hydraulic conductivity and the coefficient of consolidation. The primary cause of temperature effects is due to the changes in