INTERNATIONAL

Designation:D 4186–89 (Reapproved 1998)[ε1] Designation: D4186 – 06

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; 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—Sections 1.3 and 13, and a Summary of Changes were added editorially in January 1999.

1. Scope*

1.1This test method covers the determination of the rate and magnitude of consolidation of soil when it is restrained laterally and drained axially and subjected to controlled-strain loading.

NOTE1—The determination of the rate and magnitude of consolidation of soil when it is subjected to incremental loading is covered by Test Method D 2435D 2435

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, 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 5.4 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.

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.

1.2The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate.

1.3This test method is currently undergoing extensive review.

1.4*This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.*

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

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.

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] This test method is under the jurisdiction of ASTM Committee D-18 D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Structural Properties of Soils.

Current edition approved June 30, 1989. Published October 1989. Originally published as D4186–82. Last previous edition D4186–82.on Strength and Compressibility of Soils.

Current edition approved Sept. 1, 2006. Published December 2006. Originally approved in 1982. Last previous edition approved in 1998 as D4186 – 89 (1998) ε[1]. DOI: 10.1520/D4186-06.

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

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 This standard is written using SI units. Inch-pound units are provided for convenience. The values stated in inch-pound units may not be exact equivalents; therefore, they shall be used independently of the SI system. Combining values from the two systems may result in non-conformance with the this standard.

1.10.1 The gravitational system of inch-pound units is used when dealing 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 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]

D~~422Test Method for Particle-Size Analysis of Soils~~ 653 Terminology Relating to Soil, Rock, and Contained Fluids

D~~653Terminology Relating to Soil, Rock, and Contained Fluids~~[2] 854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D~~854Test Method for Specific Gravity of Soils~~[2] 1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

D~~1587Practice for Thin-Walled Tube Sampling of Soils~~[2] 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D~~2216Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures~~[2] 2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D~~2435Test Method for One-Dimensional Consolidation Properties of Soils~~[2] 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D~~3550Practice for Ring-Lined Barrel Sampling of Soils~~[2] 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D~~4220Practices for Perserving and Transporting Soil Samples~~[2] 3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D~~4318~~3740 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 Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils~~[2] 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

D6026 Practice for Using Significant Digits in Geotechnical Data

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*—The definitions of terms used in this method shall be in accordance with Terminology D 653D 653~~

3.1 *Definitions*:

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

~~3.2*Definitions of Terms Specific to This Standard:*~~

3.2 *Definitions of Terms:*

3.2.1 ~~*back pressure*—the pore-water pressure at the drainage boundary.~~ 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.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* ~~, Vol 04.08.~~volume information, refer to the standard's Document Summary page on the ASTM website.

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 ~~*excess pore-water pressure,* u_b—the pore-water pressure developed at the impervious end of the specimen (usually the base of the specimen) in excess of the back pressure.~~ consolidometer—an apparatus containing a specimen under conditions of no lateral deformation while allowing one-dimensional axial deformation and one directional axial flow.

3.2.3 ~~*applied vertical stress,* σ_v— the axial stress applied at the drainage boundary in excess of the back pressure.~~ 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 ~~*pore pressure ratio*—the excess pore water pressure divided by the applied vertical stress.~~ total axial stress, σ_a *(FL^{-2})—in effective stress testing*, the total stress applied to the free draining surface of the specimen in excess of the back pressure.

3.3 *Definitions of Terms Specific to This Standard:*

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

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

3.3.3 *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 during constant strain rate conditions.

3.3.4 *base excess pressure,* Δu_m *(FL^{-2})*—the fluid pressure in excess of the back pressure that is measured at the impervious boundary of the specimen under conditions of one way drainage.

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

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

3.3.7 *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.

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

3.3.9 *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.

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

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

3.3.12 *linear theory (calculation method)*—a set of equations derived based on the assumption that the coefficient of volume compressibility (m_v) is constant.

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

3.3.14 *nonlinear theory (calculation method)*—a set of equations derived based on the assumption that the compression index (C_c) is constant.

3.3.15 *pore-water pressure 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.

3.3.16 *pore-water pressure ratio,* R_u *(D)* —the base excess pressure divided by the total axial stress.

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 *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.

4. Summary of Test Method

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

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, 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 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 pore pressure ratio that is between 3 % and 15 % at the end of the loading phase.

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

5. Significance and Use

4.1Information concerning rate and magnitude of consolidation settlement of soil is essential in the design of earth and earth-supported structures. The results of this method may be used to analyze or estimate one-dimensional consolidation settlements and rates.

4.2*Strain Rate*

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.

5.2 *Strain Rate Effects*:

4.2.1It is recognized that consolidation test results are strain-rate dependent. Strain rates recommended in this standard are within the range usually encountered in Test Method D 2435D 2435

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 pore-water pressure ratio. This specification provides comparable results to the 100 % consolidation compression behavior obtained using Test Method D2435.

4.2.2Field strain rates vary greatly with time, depth below the loaded area, and radial distance from the loaded area. Because field rates cannot be accurately determined or predicted, it is not feasible to relate the laboratory-test strain rate to the field strain rate. However, it may be feasible to relate field pore pressure ratios ($u_b \sigma_v$) to laboratory pore pressure ratios. Further research is needed in this area.

4.2.3The constant-rate-of-strain consolidation test does not address the problem of strain-rate effects but does provide a means for studying strain rate effects.

4.3This method is not applicable to soils of high permeability, such as sands and other coarse-grained soils, or to partially saturated soils.

4.4This method makes the following assumptions:

4.4.1The ratio of soil permeability to soil compressibility is constant,

4.4.2Flow of soil pore water occurs only in the vertical direction,

4.4.3Darcy's law for flow through porous media applies,

4.4.4The soil is saturated,

4.4.5The soil is homogeneous,

4.4.6The compressibility of the soil grains and water is negligible,

4.4.7The log stress versus strain relationship is linear during a short-time interval of loading, and

4.4.8The distribution of excess pore-water pressures across the specimen is parabolic.

5.

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 This test method may not be used to measure the properties of partially saturated soils because the method requires the material to be back pressure saturated prior to consolidation.

5.4 *Test Interpretation Assumptions*—The equations used in this test method are based on the following assumptions:

5.4.1 The soil is saturated.

5.4.2 The soil is homogeneous.

5.4.3 The compressibility of the soil particles and water is negligible.

5.4.4 Flow of pore water occurs only in the vertical direction.

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

5.4.6 The ratio of soil hydraulic conductivity to compressibility is constant throughout the specimen during the time interval between individual readings.

5.4.7 The compressibility of the base excess pressure measurement system is negligible compared to that of the soil.

5.5 *Theoretical Solutions*:

5.5.1 Solutions for constant rate of strain consolidation are available for both linear and nonlinear soil models.

5.5.1.1 The linear model assumes that the soil has a constant coefficient of volume compressibility (m_v). These equations are presented in 13.4.

5.5.1.2 The nonlinear model assumes that the soil has a constant compression index (C_c). These equations are presented in Appendix X1.

NOTE 1—The base excess pressure measured at the boundary of the specimen is assumed equal to the maximum excess pore-water pressure in the specimen. The distribution of excess pore-water pressure throughout specimen is unknown. Each model predicts a different distribution. As the magnitude of the base excess pressure increases, the difference between the two model predictions increases.

5.5.2 The equations for the linear case are used for this test method. This test method limits the maximum time interval between readings and the maximum pore-water pressure ratio to values that yield similar results when using either theory. However, it is more precise to use the model that most closely matches the shape to the compression curve.

5.5.3 The nonlinear equations are presented in Appendix X1 and their use is not considered a non-conformance with this test method.

5.5.4 The equations used in this test method apply only to steady state conditions. The transient strain distribution at the start of the test is insignificant after the pore-water pressure factor (*F*) exceeds 0.4. Data corresponding to lower pore-water pressure factors are not used in this test method.

5.6 This test method may be used to measure the compression behavior of free draining soils. For such materials, the base excess pressure will be zero and it will not be possible to compute the coefficient of consolidation or the hydraulic conductivity. In this case, the average effective axial stress is equal to the total stress and the results are independent of model.

5.7 The procedures presented in this test method assume a high permeability porous disk is used in the base pressure measurement system. Use of a low permeability porous disk or high-air entry (> 1 bar) disk will require modification of the equipment specifications and procedures. These modifications are beyond the scope of this test method and are not considered a non-conformance.

NOTE 2—The quality of the results produced by application of this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

~~5.1~~

6.1 *Electronics*—This test method requires the use of electronic transducers along with the necessary apparatus to energize (power supply) and read (digital voltmeter) these transducers. In addition, automatic data acquisition will be necessary to achieve the required reading frequency.

6.1.1 Transducers are required to measure the base pressure (or base excess pressure), the back pressure, the axial deformation, and the axial force. Each transducer must meet the accuracy and capacity requirement specified for the particular measurement. The capacity of the force and pressure transducers will depend on the stiffness of the soil and magnitude of the back pressure.

6.1.2 A power supply is required to energize each transducer. The specific type of power supply will depend on the details of the individual transducers. Ideally, all the transducers will operate using the same power supply. Some data acquisition systems provide transducer power.

6.1.3 *Recording Devices*:

6.1.3.1 A digital voltmeter is useful in setting up tests and obtaining zero readings but the actual test requires far too many readings to be collected manually.

6.1.3.2 A data acquisition system is required to collect and store data during the test. The specifications (bit precision and voltage range) of the data acquisition system must be matched to the individual transducers in order to obtain the capacity necessary for the individual test and readability requirement for each device. These requirements will depend on the stiffness of the soil, the magnitude of the back pressure and the specific transducers.

6.1.3.3 A reading set must contain a measurement of base pressure (or base excess pressure), back pressure, axial force, axial deformation, excitation voltage, and elapsed time (or time). Time must be recorded to three significant digits of the reading interval. The reading set must be completed within 0.1 s if the measurements are made sequentially.

6.2 *Axial Loading Device*~~—The axial compression device may be a screw jack driven by an electric motor through a geared transmission, a platform weighing scale equipped with a screw-jack activated yoke, a hydraulic or pneumatic loading device, or any other compression device with sufficient capacity and control to axially compress the specimen at the constant rate of strain prescribed in 9.6. If the axial loading device is outside the consolidometer, see 5.8.~~

~~5.2*Axial Load-Measuring Device*—The axial load-measuring device may be a load ring, strain-gage load cell, hydraulic load cell, or any other load-measuring device capable of the accuracy prescribed in this paragraph and may be a part of the axial loading device. The axial load-measuring device shall be capable of measuring the axial load to an accuracy of 0.25% of the maximum load applied to the specimen.~~ —This device may be a screw jack driven by an electric motor through a geared transmission, a hydraulic or pneumatic loading device, or any other compression device with sufficient force and deformation capacity. It must be able to apply a constant rate of deformation as well as maintain a constant force. During a single loading or unloading phase of the test, the deformation rate should be monotonic and should not vary by more than a factor of 5. The rate can gradually change due to the system stiffness but should not have more than ±10 % cyclic variation. During a constant load phase of the test, the load must be maintained to ±2 % of the target value. Vibration due to the operation of the loading device shall be considered sufficiently small when there are no visible ripples in a glass of water placed on the loading platform when the device is operating at the typical test speed.

6.3 *Axial Load Measuring Device*—This device may be a load ring, strain-gage load cell, hydraulic load cell, or any other load-measuring device capable of the accuracy prescribed in this paragraph and may be a part of the axial loading device. The axial load-measuring device shall be capable of measuring the axial load to 0.1 % of full range and a readability of at least 5 significant digits at the maximum load applied to the specimen.

6.3.1 For a constant rate-of-deformation to be transmitted from the axial loading device through the load-measuring device, it is important that the load-measuring device be relatively stiff. Most electronic load cells are sufficiently stiff, while load rings are typically not stiff (that is, they are compressible).

6.4 *Back Pressure Maintaining Device*—A device capable of applying and controlling the back pressure to within ±2 % of the target back pressure throughout the test. This device may consist of a single unit or separate units connected to the top and bottom of the specimen. The device may be a pressurized hydraulic system or a partially filled reservoir with a gas/water interface. The bottom drainage lines shall be connected to the bottom drainage valve and shall be designed to minimize dead space in the lines. This valve, when open, shall permit the application of back pressure to the base of the specimen; when closed, it shall prevent the leakage of water from the specimen base and base pressure measuring device. However, if high air entry stones are used, then different means will be required to keep the system saturated.

6.4.1 A pressurized hydraulic system may be activated by deadweight acting on a piston, a gear driven piston with feedback control, a hydraulic regulator, or any other pressure-maintaining device capable of applying and controlling the back pressure within the specifications stated above. The system should be filled with equilibrated potable water.

6.4.2 A pressure reservoir partially filled with potable water and having a gas/water interface may be controlled by a precision pressure regulator. As much as practicable, the device should minimize the air diffusion into the back pressure water. All gas/water interfaces should be small in area relative to the area of the specimen and should be in reservoirs connected to the consolidometer by a length of small diameter tubing. Any water remaining in the reservoir should be flushed out after each test and replenished with equilibrated water.

6.4.3 The bottom drainage valve may be assumed to produce minimum volume change if opening or closing the valve in a closed, saturated pore-water pressure system does not induce a pressure change of greater that 0.7 kPa (±0.1 lbf/in.^{2}). All valves must be capable of withstanding applied pressures without leakage.

NOTE 2—For a constant rate of deformation to be transmitted from the axial loading device through the load-measuring device, it is important that the load-measuring device be relatively stiff. Some hydraulic load cells or proving rings may not provide sufficient stiffness.

5.3 *Pore-Water Pressure-Measuring Device*—The pore-water pressure-measuring device shall be a differential pressure transducer. Separate pressure transducers for measuring pore-water pressure at the base of the specimen and back pressures may be used if both have the required accuracy and both are monitored during the test. The device shall be constructed and located such that the pore-water pressure at the base of the specimen can be measured with negligible drainage of pore water from the base of the specimen on one side of the transducer. The other side of the transducer measures the back pressure applied to the specimen. Negligible drainage of pore water from the base of the specimen can be attained if the coefficient of volume change of the pore pressure-measuring device and de-aired, water-filled cavities connecting the device to the base of the specimen is less than 10^{-5} in.

3—Ball valves have been found to provide minimum volume-change characteristics; however, any other type of valve having suitable volume-change characteristics may be used.

6.5 *Back Pressure Measuring Device*—A pressure transducer arranged to measure the applied back pressure shall have an accuracy of ±0.25 % of full range, a capacity in excess of the applied back pressure, and a readability of at least 5 significant digits at the maximum applied axial stress.

6.6 *Base Pressure Measuring Device*—This device can be a differential pressure transducer referenced to the back pressure or a separate pressure transducer measuring pressure at the base of the specimen. If a separate pressure transducer is used, then it's zero value must be adjusted to give the same pressure reading as the back pressure transducer at the end of back pressure saturation and with the bottom drainage valve open. The device shall be constructed and located such that the water pressure at the base of the specimen can be measured with negligible drainage from the specimen due to changes in pore-water pressure. To achieve this requirement, a very stiff electronic pressure transducer must be used. The compliance of all the assembled parts of the base pressure measurement system relative to the total volume of the specimen shall satisfy the following requirement:

$$(\Delta V/V) / \Delta u_m < 3.2 \times 10^{-6} \text{ m}^2/\text{kN} \ (2.2 \times 10^{-5} \text{ in.}^2/\text{lbf}) \quad (1)$$

D4186-06_1

where:

ΔV = change in volume of the base measurement system due to a pressure change, mm^3/psi (10^{-8} m (in.^{3}/Pa). The pore pressure-measuring device shall be capable of measuring the pore-water pressure at the base of the specimen to an accuracy of 0.25 % of the maximum anticipated pore pressure.

5.4 *Back Pressure-Maintaining Device* , capable of applying and controlling the back pressure to within± 2.0 %. This device may consist of a reservoir, it may have reservoirs connected to the top and bottom of the specimen and partially filled with de-aired water; the upper part of the reservoir shall be connected to a compressed gas supply, the gas pressure being controlled by a pressure regulator and measured by a pressure gage. (See Note 3.) However, a hydraulic system pressurized by a deadweight acting on a piston or any other pressure-maintaining device capable of applying and controlling the back pressure to the tolerance prescribed in this paragraph may be used. A low volume-change valve shall be provided in the back-pressure measuring device as near as possible to the base of the specimen. This valve, when open, shall permit the application of back pressure to the base of the specimen; when closed, shall prevent the drainage of water from the specimen base and pore-water pressure-measuring device to the reservoir of the back pressure-maintaining device.),

V = total volume of the specimen, mm^3 (in.^{3}), and

Δu_m = change in base excess pressure, kPa (lbf/in.^{2}).

NOTE3—All gas-water interfaces should be small in area relative to the area of the specimen and should be in reservoirs connected to the consolidometer by a length of small diameter tubing.

5.5*Deformation Indicator*—The deformation indicator shall be a dial indicator or displacement transducer having a sensitivity of 0.002 mm (0.0001 in.) and a range of at least 50% of the specimen height, or other measuring device meeting these requirements for sensitivity and range.

5.6*Timer*, indicating the elapsed testing time to the nearest 1 s for establishing the rates of strain application prescribed in 9.6 4—To meet this compressibility requirement, tubing between the specimen and the measuring device should be short and thick-walled with small bores. Thermoplastic, copper, and stainless steel tubing have been used successfully.

6.6.1 A differential pressure transducer shall have an accuracy of ±0.25 % of full range, a capacity of at least 50 % of the maximum applied axial stress, a burst pressure that exceeds the applied back pressure plus 50 % of the maximum applied axial stress, and a readability of at least 5 significant digits at the maximum applied axial stress.

6.6.2 A separate pressure transducer shall have an accuracy of ±0.25 % of full range, a capacity of at least the applied back pressure plus 50 % of the maximum applied axial stress, and a readability of at least 5 significant digits at the maximum applied axial stress.

NOTE 5—Typically, pressure transducers with a capacity of 1500 kPa (200 lbf/in.^{2}) will meet these requirements.

6.7 *Deformation Measuring Device*—The axial deformation of the specimen is usually determined from the travel of the piston acting on the top platen of the specimen. The deformation measuring device may be a linear variable differential transformer (LVDT), extensometer, or other electronic measuring device and shall have a range of at least 50 % of the initial height of the specimen. The device shall have an accuracy of at least 0.25 % of full range and a readability of at least 5 significant digits at the initial specimen height.

6.8 *Consolidometer*—This device must hold the specimen in a confinement ring to a rigid base, with porous disks on each face of the specimen and apply a back pressure to the specimen. A high air entry stone can be used in place of the porous disk on the bottom of the specimen provided that the high air entry stone is always kept saturated. The top platen should be rigid enough to uniformly distribute the load to the top stone. Any potentially submerged parts of the consolidometer shall be made of a material that is noncorrosive in relation to the soil or other parts of the consolidometer. The bottom of the confinement ring shall form a leak proof seal with the rigid base capable of withstanding internal pressures of 1500 kPa (200 lbf/in.^{2}). The consolidometer shall be constructed such that placement of the confinement ring (with specimen) into the consolidometer will not entrap air at the base of the specimen. The axial loading device and back pressure maintaining device may be an integral part of the consolidometer. A schematic drawing of a typical CRS consolidometer is shown in Fig. 1.

5.7

6.8.1 The axial load piston seal must be designed so the variation in axial load due to friction does not exceed 0.05 % of the maximum axial load applied to the specimen.

NOTE 6—The use of two linear ball bushings to guide the piston is recommended to minimize friction and maintain alignment.

6.8.2 The confinement ring shall be made of a material that is noncorrosive in relation to the soil and pore fluid. The inner surface shall be polished and coated with a low-friction material (silicone/vacuum grease). The ring shall be stiff enough to prevent significant lateral deformation of the specimen throughout the test.

6.8.2.1 The thickness of the ring (for metallic rings) shall be no less than 3.2 mm (⅛ in.) for stresses up to 3000 kPa (400 lbf/in.^{2}) or 6.4 mm (¼ in.) for stresses up to 6000 kPa (800 lbf/in.^{2}).

6.8.3 The test specimen dimensions shall conform to the following specifications.

6.8.3.1 The minimum diameter shall be about 50 mm (2.0 in.).

6.8.3.2 The minimum height shall be about 20 mm (0.75 in.), but shall not be less than 10 times the maximum particle diameter as determined in accordance with Test Method D6913. If, after completion of a test, it is found based on visual observation that oversize (> 2 mm; 0.075 in.) particles are present, indicate this information in the report of test data.

6.8.3.3 The maximum height-to-diameter ratio shall be 0.5.

6.9 *Porous Disks*—The porous disks at the top and bottom of the specimen shall be made of silicon carbide, aluminum oxide, or other material of similar stiffness that is not corroded by the specimen or pore fluid. The disks shall have plane and smooth surfaces and be free of cracks, chips, and nonuniformities. They shall be checked regularly to ensure that they are not clogged. For fine-grained soils, fine-grade porous disks shall be used. 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 disc should be at least 10 times more permeable than the soil.)

6.9.1 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 confinement ring.

6.9.2 The surfaces of the disks, as well as the bearing surfaces in contact with them, shall be flat and rigid enough to prevent breakage of these disks.

6.9.3 The disks shall be regularly cleaned by ultrasonification or boiling and brushing and checked routinely for signs of clogging. Disks will last longer if stored in water between testing.

6.10 *Filter Screen*—To prevent intrusion of material into the pores of the porous disk, a filter screen must be placed between

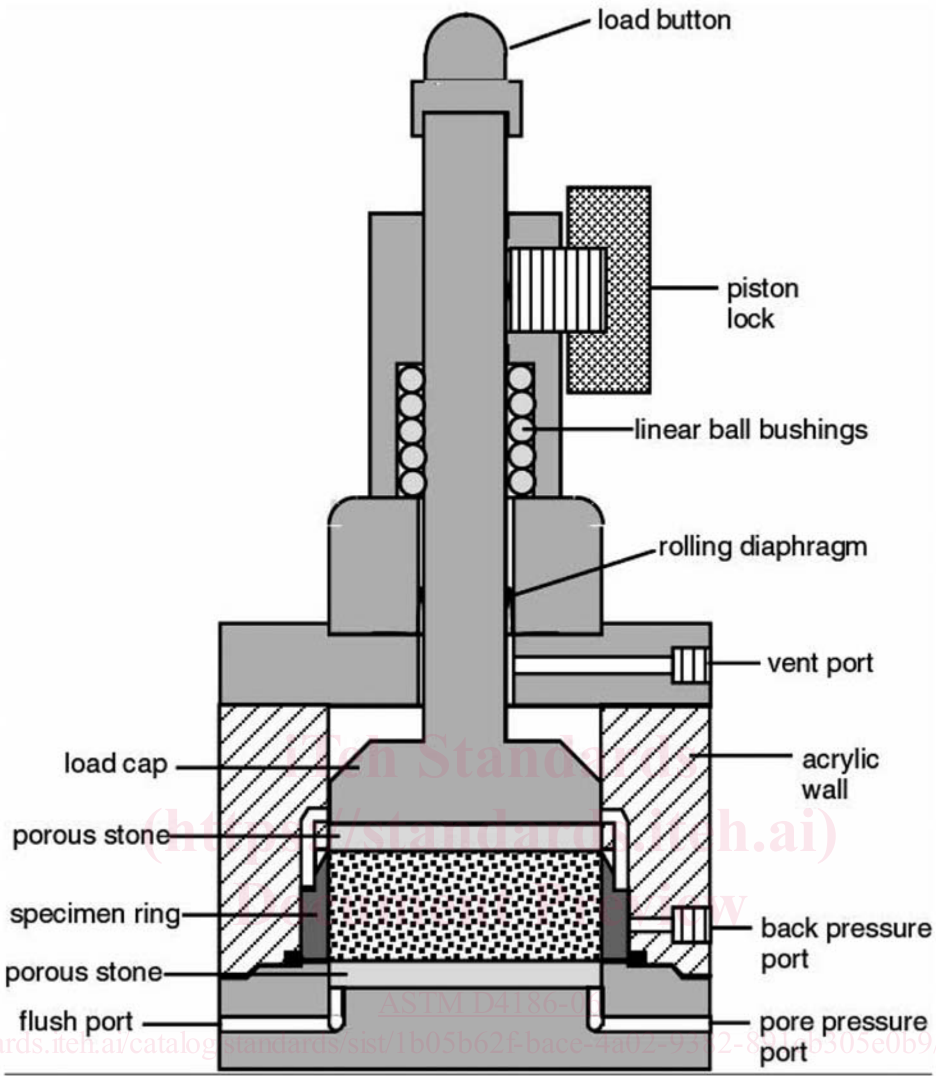

FIG. 1 Example of a CRS Consolidometer

the top porous disk and the specimen. The screen shall have negligibly small hydraulic impedance. A monofilament-nylon filter screen or Whatman No. 54 filter paper may be used for the top of the specimen.

NOTE 7—Filters should be cut to approximately the same shape as the cross section of the test specimen. Soak the filter paper, if used, in a container of water to allow it to equilibrate before testing.

6.11 *Balances*, devices for determining the mass of the soil specimens as well as portions of the apparatus. All measurements of mass should be accurate to 0.1%.

5.8*Consolidometer*, to hold the specimen in a ring that is fixed to a rigid base, with porous stones on each face of the specimen. Any potentially submerged parts of the consolidometer shall be made of a material that is noncorrosive in relation to the soil or other parts of the consolidometer. The bottom of the ring shall form a leakproof seal with the rigid base capable of withstanding internal pressures of 1400 kPa (200 psi). The consolidometer shall be constructed such that placement of the specimen into the ring and consolidometer will not entrap air at the base of the specimen. The axial loading device and back pressure-maintaining device may be an integral part of the consolidometer. If the design of the consolidometer is such that back pressures affect axial load readings (due to pressure pushing the piston from the consolidometer), the change in readings with changes in back pressure shall be determined by calibration. The consolidometer shall conform to the following requirements:

5.8.1*Minimum Specimen Diameter*shall be 50 mm (2.0 in.) and shall be at least 6 mm (0.25 in.) less than the diameter of the sample tube if using undisturbed samples, except as indicated in 7.2—The balance shall be suitable for determining the mass of the specimen and shall be selected as discussed in Specification D4753. The mass of specimens shall be determined to at least four significant digits.

6.12 *Sample Extruder*—When the material being tested is contained in a sampling tube, the soil shall be removed from the sampling tube with an extruder. The sample extruder shall be capable of extruding the soil from the sampling tube in the same direction of travel that the soil entered the tube and with minimum disturbance of the soil. If the soil is not extruded vertically, care should be taken to avoid bending stresses on the soil due to gravity. Conditions at the time of soil extrusion may dictate the direction of removal, but the principle concern is to avoid causing further sample disturbance.

NOTE 8—Removing the soil from a short section of the tube will reduce the amount of force required to extrude the sample and hence cause less disturbance. This can be done by cutting a section from the tube with a band saw or tube cutter prior to extrusion. This technique is very effective when combined with radiography to nondestructively examine the soil and select test locations.

6.13 *Specimen Trimming Devices*—A trimming turntable or a cylindrical cutting ring may be used for cutting the cylindrical samples to the proper specimen diameter. The cutting ring may be part of the confinement ring or a separate piece that fits on the confinement 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. In either case, the cutting tool must be properly aligned to form a specimen of the same diameter as that of the ring. The top and bottom surface of the specimen may be rough trimmed with a wire saw. All flat surfaces must be finish trimmed with a sharpened straight edge and shall have a flatness tolerance of ± 0.05 mm (0.002 in.).

6.14 *Recess Spacer*—A disc (usually made of acrylic) used to create a gap between the top of the specimen and the top edge of the confinement ring. The disc should be thick enough to be rigid and larger in diameter than the outside diameter of the confinement ring. One surface of the disc should have a protrusion that is 0.1 mm (0.005 in.) less than the inside diameter of the confinement ring, a thickness of at least 1.2 mm (0.050 in.) and a flatness tolerance of ± 0.03 mm (0.001 in.).

6.15 *Specimen Measuring Device*—The specimen height may be computed from the height of the confinement ring and the recess spacer or measured directly. If applicable, the device to measure the thickness of the specimen shall be capable of measuring to the nearest 0.01 mm (0.001 in.) or better and shall be constructed such that its use will not penetrate the surface of the specimen. The specimen diameter may be assumed equal to the inside diameter of the confinement ring.

6.16 *Temperature Maintaining Device*—The temperature of the consolidometer, test specimen, and reservoir of pore fluid shall not vary more than ± 3°C (± 6°F). 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 a temperature within the tolerance specified above.

6.17 *Water Content Containers*—In accordance with Test Method D2216.

5.8.2*Minimum Specimen Thickness* shall be 20 mm (0.75 in.) but shall be not less than 10 times the maximum grain diameter as determined in accordance with Method D 422D 422.

5.8.3*Minimum-Specimen-Diameter-to-Thickness Ratio*shall be 2.5.

5.8.4*Thickness of the Ring*shall be such that, under assumed hydrostatic stress conditions in the specimen, the change in diameter of the ring will not exceed 0.03% under the greatest load applied.

5.8.5*Ring*shall be made of a material that is noncorrosive in relation to the soil and pore fluid being tested. The inner surface shall be highly polished or shall be coated with a low-friction material.

5.9*Porous Disk*:

5.9.1The porous stones shall be of silicon carbide, aluminum oxide, metal, or other suitable material that is not attacked by the soil or soil moisture and shall be of medium grade. For soft fine-grain soils, a fine-grade porous stone shall be used. The stone shall be fine enough that the soil will not extrude into the pores, but have sufficient permeability so as not to impede the flow of water from the specimen. (Exact criteria have not been established.)

5.9.2The diameter of the top stone shall be 0.2 to 0.5 mm (0.01 to 0.02 in.) less than that of the ring.

5.9.3The stone shall be thick enough to prevent breaking. The top stone shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the stone.

5.10*Moist Room*—In climates where moisture loss during preparation exceeds 0.1%, the specimen shall be prepared in a moist room.

5.11*Trimmer or Cylindrical Cutter* , for trimming the specimen down to the inside diameter of the consolidometer ring with a minimum of disturbance.

5.12*Specimen-Measuring Device*, capable of measuring specimen height and diameter to the nearest 0.02 mm (0.001 in.).

5.13

6.18 *Drying Oven*, that can be maintained at 230 ± 9°F (110 ± 5°C).

5.14*—In accordance with Test Method D2216.*

6.19 *Miscellaneous Equipment*—Specimen trimming and carving tools, including spatulas, knives, and wire saws, moisture content cans, and data sheets as required.

6.Sampling

6.1Sampling and field investigation shall be conducted in accordance with Practice D 1587D 1587. Specimens cut from block samples may also be used.

6.2If suitable specimens can be obtained using Practice D 3550D 3550, then they may be used.

6.3Transport and handling of samples shall be conducted in accordance with Practice D 4220D 4220—Specimen trimming and carving tools such as spatulas, knives, and wire saws, data sheets, and wax paper or teflon sheet as required.

7. Calibration

7.1 Measure diameter (D_r) and height (H_r) of the confinement ring to the nearest 0.01 mm (0.001 in.).

7.2 The cross sectional area (A) of the specimen may be computed from the inside diameter of the consolidometer ring to four significant digits in mm^2 (in.^{2}).

7.3 Apply a thin coat of grease to the inside perimeter and measure the mass of the confinement ring plus the filter screen and the recess spacer (M_r) to the nearest 0.01 g.

7.4 Measure the thickness of the recess spacer plus the filter screen (T_{rs}).

7.5 The consolidometer deflects due to both changes in cell pressure and axial load, referred to as apparatus compressibility. The apparatus compressibility must be subtracted from the measured deformations in order to correctly compute the specimen axial strain.

7.6 During consolidation, the measured axial displacements shall be corrected for apparatus compressibility whenever the equipment deformation exceeds 0.05 % of the specimen height.

7.6.1 Assemble the apparatus with a copper or steel disk of approximately the same size as the specimen, the filter screen and the porous disks.

7.6.2 Record readings of the axial displacement (AD_n) and axial force (AF_n) as the axial force is increased from the seating value to its maximum value and then returned to the seating value.

7.6.3 Use these data to establish the relationship between apparatus deformation (δ_{af}) as a function of net force (F_a).

7.7 During back pressure saturation, the measured axial displacement shall be corrected for apparatus compressibility whenever the equipment deformation exceeds 0.05 % of the specimen height.

7.7.1 Assemble the apparatus with a copper or steel disk of approximately the same size as the specimen, the filter screen and the porous disks.

7.7.2 Apply a seating net force to the calibration disk ($F_{a,o}$) prior to applying any chamber pressure and record the axial displacement (AD_o).

7.7.3 Increase the chamber pressure and manually adjust the force back to the seating value ($F_{a,o}$).

7.7.4 Record readings of the axial displacement (AD_n) and the chamber pressure (CP_n) at this point.

7.7.5 Repeat steps 7.7.2 through 7.7.4 until a maximum selected chamber pressure has been reached.

7.7.6 Use these data to establish the relationship between apparatus displacements (δ_{ap}) as a function of chamber pressure (σ_c).

7.8 If the design of the consolidometer is such that chamber pressure affects the axial load measuring device (due to the chamber pressure pushing the piston from the consolidometer), the change in readings with changes in chamber pressure shall be determined by calibration.

7.8.1 Assemble the apparatus without a specimen.

7.8.2 Record readings of the axial force (AF_n) and the chamber pressure (CP_n) as the chamber pressure is increased from zero to its maximum value and then returned to zero.

7.8.3 Create a plot of axial force (f) versus chamber pressure (σ_c).

7.8.4 Compute the effective area of the piston (A_p) as the slope of this line and the effective piston weight (W_p) as the intercept with the force axis .

8. Sampling

8.1 Intact samples having satisfactory quality for testing by this test method may be obtained using sampling procedures and apparatus described by Practices D6519, D1587 and D3550. Specimens may also be trimmed from large intact block samples as obtained using Practice D7015.

~~7.Specimens~~

~~7.1Prepare the specimen so moisture loss is less than 0.1%; if necessary, prepare the specimen in a moist room. Trim the specimen to the inside diameter of the consolidometer ring. Fill with remolded soil any minor indentations in the specimen that would leave voids between the specimen and the ring. Place the specimen in the ring and trim it flush with the plane surface of the ring. The surface must be smooth. A specimen ring with the cutting edge attached provides the most accurate fit in most soils.~~

~~7.2Organic soils, such as peat, and those soils that are easily damaged, may be transferred directly from the sampling tube to the ring where the ring and tube sizes have been selected for this purpose, provided that the cutting edge of the ring has the same diameter as the sample.~~

~~7.3Determine the mass and height of the specimen. Record the specimen mass, height, and diameter.~~

8.2 Intact samples shall be preserved, handled, and transported in accordance with the Groups C and D samples described in Practice D4220.

8.3 Intact samples shall be sealed and stored such that no moisture is lost or gained between sampling and testing. Storage time should be minimized and excessively high (> 32°C) or low (< 4°C) temperatures should be avoided.

8.4 The quality of one-dimensional consolidation test results will diminish greatly with sample disturbance. No intact sampling procedure can assure perfect sample quality. Therefore, careful examination of the intact sample and selection of the highest quality soil for testing is essential for reliable testing.