Designation: D 6528 – 00

Standard Test Method for Consolidated Undrained Direct Simple Shear Testing of Cohesive Soils[1]

This standard is issued under the fixed designation D 6528; 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 This test method defines equipment specifications and testing procedures for the measurement of constant volume strength and stress-strain characteristics of cohesive soils after one-dimensional consolidation using a constant rate of simple shear deformation mode of loading. The constant volume condition is equivalent to the undrained condition for saturated specimens.

1.2 This test method is written specifically for devices that test rectangular parallelepiped or cylindrical specimens. Other more general devices, such as the torsional shear hollow cylinder, may be used to perform consolidated constant volume simple shear tests but are beyond the scope of this test method.

1.3 This test method is applicable to testing both undisturbed and compacted soils, however, it does not include specific guidance for compacting test specimens.

1.4 It shall be the responsibility of the agency requesting this test to specify the magnitude of the normal consolidation stress prior to constant volume shear and, when appropriate, the maximum normal consolidation stress, which will result in an overconsolidated specimen.

1.5 The values stated in SI units are to be regarded as the standard. Reporting test results in units other than SI shall be regarded as conformance with this test method.

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 standard.

1.6 *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:*

D 422 Test Method for Particle-Size Analysis of Soils[2]
D 653 Terminology Relating to Soil, Rock and Contained Fluids[2]
D 854 Test Method for Specific Gravity of Soils[2]
D 1587 Practice for Thin-Walled Tube Geotechnical Sampling of Soils[2]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]
D 2435 Test Method for One-Dimensional Consolidation Properties of Soils[2]
D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]
D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil an Rock as Used in Engineering Design and Construction[2]
D 4220 Practices for Preserving and Transporting Soil Samples[2]
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[2]
D 4452 Methods for X-Ray Radiography of Soil Samples[2]

3. Terminology

3.1 *Definitions*—The terms used in this test method are in accordance with Terminology D 653.

3.1.1 *shear modulus*, *n*—a measure of a material's resistance to shear stress, equal to the ratio of the increment in the shear stress to the resultant increment in angle of deformation expressed in radians. Also known as the modulus of rigidity.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *active height control*, *n*—a method of keeping the height of the specimen constant during the shearing process in

[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 Structural Properties of Soils.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

which the displacement control mechanism is physically adjusted in response to the axial displacement measurement.

3.2.2 *passive height control*, *n*—a method of keeping the height of the specimen constant during the shearing process in which the specimen and force measuring device are clamped by a mechanism that is much stiffer than the specimen.

4. Summary of Test Method

4.1 In this test method a specimen of cohesive soil is constrained axially between two parallel, rigid platens and laterally, such that the cross sectional area remains constant.

4.2 The specimen is loaded axially and allowed to consolidate one-dimensionally. Each normal load increment is maintained until excess pore water pressures are essentially dissipated as interpreted from the axial displacement rate. The maximum normal load is maintained until completion of one cycle of secondary compression or one day longer than the end of excess pore water pressure dissipation.

4.3 The specimen is sheared by displacing one platen tangentially relative to the other at a constant rate of displacement and measuring the resulting shear force. The platens are constrained against rotation and axial movement throughout shear.

4.4 The specimen volume is held constant during shear to simulate undrained conditions. Constant volume is achieved by changing the normal load applied to the specimen to maintain constant specimen height. Since the pore pressure is zero through shear, the change in normal stress is equal to the change in effective stress and assumed to be equal to the change in pore water pressure that would occur in a sealed specimen confined by a constant total stress.

NOTE 1—The quality of the result produced by this test method 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 D 3740 generally are considered capable of competent and objective testing/sampling/inspection/etc. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Significance and Use

5.1 The shear strength of a specimen depends on the soil type, normal consolidation stress, time of consolidation, rate of strain, and prior stress history of the soil.

5.2 In this test, the shear strength is measured under constant volume conditions that are equivalent to undrained conditions for a saturated specimen; hence, the test is applicable to field conditions wherein soils have fully consolidated under one set of stresses, and then are subjected to changes in stress without time for further drainage to take place.

5.3 The constant volume (undrained) strength is a function of stress conditions. In this test method, the strength is measured under plane strain conditions and the principle stresses continuously rotate due to the application of shear stress. This simple shear stress condition occurs in many field situations including zones below a long embankment and around axially loaded piles.

5.4 The state of stress within the simple shear specimen is not sufficiently defined nor uniform enough to allow rigorous interpretation of the results. Expressing the data in terms of the shear stress and normal effective stress on the horizontal plane is useful for engineering purposes, but should not be confused with the effective stress parameters derived from other shear tests having better defined states of stress.

5.5 The values of the secant shear modulus can be used to estimate the initial settlements of embankments built on saturated cohesive soils due to undrained shear deformations.

5.6 The data from the consolidation portion of this test are comparable to results obtained using Test Method D 2435 provided that the more rigorous consolidation procedure of Test Method D 2435 is followed.

5.6.1 The axial displacements measured from Test Method D 2435 are somewhat smaller than for the simple shear test because the specimen's lateral confinement is less rigid and the top platen is unable to rotate.

5.6.2 The estimated preconsolidation pressure is comparable provided the specimen is loaded sufficiently into the normally consolidated range.

5.6.3 The rate of consolidation is comparable.

6. Apparatus

6.1 Fig. 1 presents a schematic diagram of the essential components for the apparatus. The following sections specify the component requirements.

6.2 *Normal Loading Device*—A suitable device for applying normal force to the specimen. The device must be capable of maintaining constant force for the entire test duration, permit quick application of force increments and allow continuous adjustment of force when using active height control.

6.3 *Shear Loading Device*—A device for applying shear force to the specimen with sufficient capacity and control to deform the specimen at the required displacement rate. Displacement should be smooth and continuous. As a minimum, the displacement rate should be within ± 15 % of the average calculated rate (12.3.7) from 50 % of the peak shear force to the end of the test. Vibration due to operation of this device should be sufficiently small so as not to cause visible ripples in a glass of water placed on the loading platform.

NOTE 2—Screw driven systems typically apply an increase in displacement rate with increasing shear load application.

6.4 *Force Measuring Devices*—Two devices are required: one for measuring normal force and one for measuring shear force. Each device shall have the necessary capacity and be accurate to ± 2 % of the applied maximum force for a given test. The devices shall be insensitive to eccentric loading or installed in a fashion to eliminate eccentric loading. The compressibility of the shear measuring device should not cause the deviation in shear displacement rate to exceed± 15 % of the average rate. When using passive height control the compressibility of the axial measuring device must satisfy the deflection requirement of 6.9.

6.5 *Axial Loading Ram*—The axial loading ram must hold one platen parallel to the other while allowing axial displacement of the specimen. If the piston resists the shear force, it must do so with negligible rotation of the platen.

6.6 *Shear Slide Table*—The shear slide table must hold the platens parallel to each other and allow shear displacement of

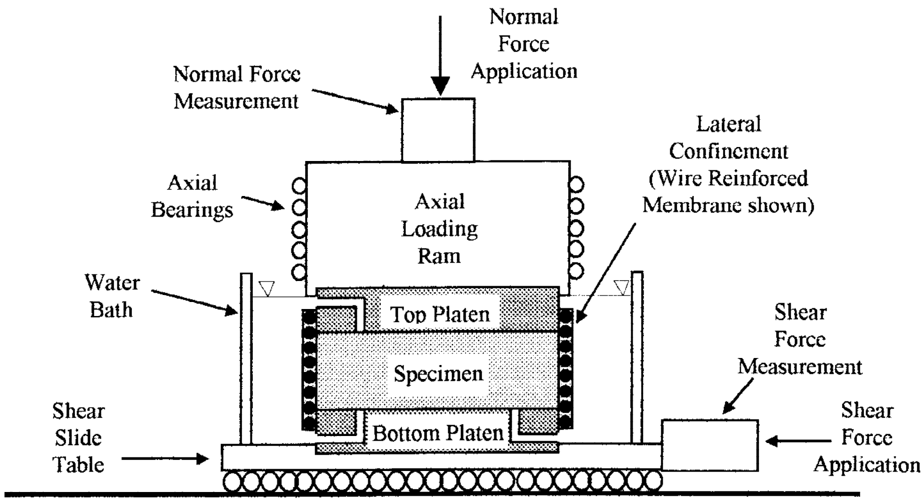

FIG. 1 Schematic Diagram of Essential Direct Simple Shear Components.

the specimen. When using passive height control and the slide table is within the height control boundaries, its compressibility must satisfy the deflection requirement of 6.9. The slide table shall allow a sufficient displacement to provide a minimum of 30 % shear strain.

6.7 *Lateral Confinement Device*—The specimen shall be constrained laterally such that the cross-sectional area at any location does not change by more than 0.1 % during shear. In addition, the confinement must allow uniform shear deformation. Circular specimens are generally confined by a wire reinforced membrane or stacked rigid rings. Square specimens generally are confined by stacked hollow plates or hinged solid plates. The thickness of the individual stacked rings or plates must be less than 1⁄10 of the specimen thickness in order to allow relatively uniform shear deformation. When the confining device is within a water bath, it shall be constructed of corrosion resistant material.

6.7.1 *Specimen Size Requirements*:

6.7.1.1 The minimum specimen diameter (or lateral dimension) shall be 45 mm.

6.7.1.2 The minimum specimen height shall be 12 mm.

6.7.1.3 The height to diameter, or minimum lateral dimension, ratio shall not exceed 0.4.

6.7.1.4 The specimen height shall not be less than ten times the maximum particle diameter (see 9.4).

6.7.2 *Platens*—The top and bottom platens of the apparatus shall be constructed of corrosion resistant material and have a circular, rectangular or square cross-section to match the specimen. The platens shall be designed to securely hold the porous disks and provide drainage from the specimen to the water bath and transfer shear to the specimen without horizontal slippage.

6.7.3 *Porous Disks*—The porous disks shall be brass, silicon carbide, aluminum oxide, or similar rigid corrosion resistant material. The disks shall be flat, fine enough to prevent intrusion of the soil into the pores, and rough enough to transfer the shear stress. The disks must be at least ten times more permeable than the soil. Disks must cover at least 90 % of the specimen surface and when smaller than the specimen, must be recessed into the platen such that the surface in contact with the soil is flush with the platen.

NOTE 3—It is sometimes necessary to increase the surface roughness of the porous disks in order to prevent interface slippage. Short metallic pins cemented into the disks have been used successfully but introduce large uncertainty in the shear strain calculations.

NOTE 4—Disks of ductile material, for example, brass, have been found to warp due to the shear stress and need to be flattened on a regular basis.

6.8 *Displacement Indicators*—To measure the change in specimen height and the shear deformation (axial and lateral movement of top platen relative to bottom platen) with a readability of 0.0025 mm.

6.9 *Volume Control Equipment*—One of the two following methods may be used to achieve constant volume during shear. With either method, the specimen is free to drain and the measured change in normal total stress during shear is assumed to be equal to the pore pressure which would develop in a sealed specimen confined by a constant total stress. In either case, the device shall not allow the specimen change in height to exceed 0.05 % including the equipment deformation determined in 10.1.

6.9.1 *Normal Force Adjustment Device*—Active height control requires a mechanism to continuously adjust the normal force to prevent changes in the specimen height during shear.

NOTE 5—A variety of devices are used including manual adjustment of a worm gear, computer control of a worm gear, and computer control of a pneumatic cylinder.

6.9.2 *Axial Displacement Clamp*—Passive height control requires a mechanism to lock the axial loading ram in place during shear. The normal force transducer must be moment insensitive and located between the specimen and the clamp or the specimen and the slide base.

6.10 *Specimen Trimming Device*—A trimming turntable or a cylindrical cutting ring may be used for cutting the cylindrical specimens to the proper diameter. A wire saw and miter box or cutting shoe may be used for rectangular specimens. The top and bottom 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 tolerance of ± 0.05 mm.

6.11 *Specimen Setup Frame*—A rigid frame to hold in alignment the bottom platen, the specimen in the trimming device, and expander containing the confinement device. The frame must allow the trimmed specimen to be transferred from the trimming device to the confinement device with a minimum of disturbance.

6.12 *Water Bath*—A method to provide the specimen with free access to water at atmospheric pressure and prevent specimen drying due to evaporation. The entire specimen and confinement device may be submerged in a water bath or the end platens may be connected to a standpipe by flexible tubing. In either case, water must be available to both ends of the specimen by means of the porous disks.

6.13 *Miscellaneous Equipment*—Including timing device with one second readability, caliper, dial comparator, distilled or demineralized water, spatulas, knives, trimming blade and wire saws.

6.14 *Balances*, in accordance with Test Method D 2216.

6.15 *Drying Oven*, in accordance with Test Method D 2216.

6.16 *Water Content Container*, in accordance with Test Method D 2216.

6.17 *Environment*—Tests shall be performed in an environment where temperature fluctuations are less than ± 2°C during shear, and there is no direct exposure to sunlight.

6.18 *Trimming Environment*—Trim the specimen in a glove box or room that has a high enough relative humidity to prevent changes in the water content of the soil.

7. Sampling

7.1 *Undisturbed Samples*:

7.1.1 Undisturbed samples having satisfactory quality for testing by this method may be obtained using procedures and apparatus described by Practices D 1587 and D 3550. Specimens also may be trimmed from large undisturbed block samples obtained and sealed in the field.

7.1.2 Undisturbed samples to be tested by this method shall be preserved, handled and transported in accordance with the practices for Groups C and D samples in Practice D 4220.

7.1.3 Undisturbed samples shall be sealed and stored such that no moisture is lost or gained between sampling and testing. Storage time and temperature fluctuations should be minimized.

7.1.4 The quality of simple shear test results diminish greatly with sample disturbance. No sampling procedure can assure completely undisturbed samples; therefore, careful examination of the sample and selection of the highest quality material for testing is essential for reliable testing.

NOTE 6—Examination for sample disturbance, stones or other inclusions, and selection of specimen location is greatly facilitated by x-ray radiography of the samples as described in Methods D 4452.

7.2 *Compacted Specimens*:

7.2.1 Compacted specimens may be prepared from bulk homogeneous material.

7.2.2 Bulk material should be handled and transported in accordance with the practices for Group B samples of Practices D 4220.

7.2.2.1 The material required for the specimen shall be batched by thoroughly mixing soil with sufficient water to produce the desired conditions. After batching, store the material in a covered container for at least 16 hours prior to specimen preparation.

8. Specimen Preparation

8.1 All reasonable precautions should be taken to minimize disturbance of the soil caused by vibration, distortion, and compression.

8.2 Test specimens and soil processing should be performed in an environment that prevents moisture change.

8.3 *Undisturbed Specimens*—Trim the specimen to the lateral dimension of the lateral confinement device.

8.3.1 Undisturbed soil collected using sample tubes shall be at least 2.5 mm larger in each dimension than the specimen dimension except as specified in 8.3.2 and 8.3.3. Trim away the additional material using one of the following methods.

NOTE 7—The degree of sample disturbance is known to increase towards the perimeter of the tube sample, and therefore, it is better to use larger diameter samples where possible.

8.3.1.1 When using a trimming turntable and cylindrical specimens, make a complete perimeter cut, the width of the blade, to reduce the soil diameter to that of the confinement ring. Gradually advance the specimen into the ring by the width of the blade. Repeat until the specimen protrudes from the bottom of the ring.

8.3.1.2 When using a cutting shoe, trim the soil to a gentle taper in front of the cutting surface with a knife or spatula. After the taper is formed, advance the cutter a small distance to shave off the remaining soil and form the final diameter. Repeat the process until the specimen protrudes from the top of the cutter.

8.3.1.3 When using a miter box and parallelepiped specimens, trim each side of soft to medium stiff soil with a wire saw. Finish each surface with a sharpened straight edge. Stiff soil is best trimmed with a sharpened straight edge. The specimen shall have orthogonal surfaces.

8.3.2 Fibrous soils, such as peats, and those soils that are damaged easily by trimming, may be transferred directly from the sampling tube to the confinement device, provided that the device has the same dimensions as the sampling tube.

8.3.3 Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of Practice D 3550 and this test method.

8.4 *Compacted Specimens*—The method of preparation and specifications, such as water content, density, and compactive effort shall be stipulated by the agency requesting the test; however, the specimen must be fabricated using the guidelines specified in 8.4.1-8.4.3.

8.4.1 Compact batched material in layers using a pressing or kneading action into a preparation mold or directly into the cutting shoe. The top of each layer shall be scarified prior to addition of material for the next layer.

8.4.2 When soil is to be compacted directly into the cutting shoe, the specimen must be fabricated in at least three layers and the compacted material should be thicker than the final trimmed specimen.

8.4.3 When soil is compacted into an oversize preparation mold, compact using more than three layers and then trim the specimen using the undisturbed preparation procedures.

8.5 Trim the top and bottom surfaces of the specimen to be flat and perpendicular to the specimen sides. This may be accomplished using the rims of the cutting shoe or an additional alignment device. For soft to medium soils, a wire saw should be used to rough cut the surface. For stiff soils, and all final surfaces, a straightedge with a sharpened cutting surface should be used to assure flatness.

8.6 If a small rock particle is encountered in any surface being trimmed, it should be removed and the resulting void filled with soil from the trimmings.

8.7 Obtain two or three initial water content determinations of the soil in accordance with Test Method D 2216 from material trimmed adjacent to the test specimen if sufficient material is available or from the excess batched material.

8.8 Determine the initial moist mass of the specimen (M_{to}) by direct measurement or when in the cutting shoe by measuring the mass of the shoe with specimen and subtracting the tare mass of the shoe.

8.9 Determine the initial height (H_o) of the specimen to the nearest 0.025 mm by taking the average of at least four evenly spaced measurements using a dial comparator or other suitable measuring device.

8.10 Use the specimen setup frame to insert the fully trimmed specimen into the confinement device.

8.11 The cross-sectional area (A) of the specimen may be taken as that of the confinement device or the cutting shoe.

8.12 When index properties are specified by the requesting agency, store the remaining trimmings taken from around the specimen and judged to be similar material in a sealed container for determination as described in Section 9.

9. Soil Index Property Determination

9.1 Determination of index properties is an important adjunct to, but not a requirement of, this test method. These determinations when specified by the requesting agency should be made on the most representative material possible. When testing uniform materials, all index tests may be performed on adjacent trimmings collected in 8.12. When samples are heterogeneous or trimmings are in short supply, index tests should be performed on material from the test specimen as obtained in 11.4.6.2, plus representative trimmings collected in 8.12. There will not be sufficient soil, however, from the test specimen to meet the minimum sample requirements of all these index tests.

9.2 *Specific Gravity*—The specific gravity (G_s) shall be determined in accordance with Test Method D 854 on material as specified in 9.1. The specific gravity determined from another sample judged to be similar to that of the test specimen may be used for calculation in 12.1.5 whenever an approximate void ratio is acceptable.

9.3 *Atterberg Limits*—The liquid limit, plastic limit and plasticity index shall be determined in accordance with Test Method D 4318 using material from the sample as specified in 9.1. Determination of the Atterberg Limits are necessary for proper material classification and evaluation of test results. Atterberg Limits shall be determined on undried soil unless evidence exists to show that results are not affected by oven drying.

9.4 *Particle Size Distribution*—The particle size distribution shall be determined in accordance with the Test Method D 422 (except the minimum sample size requirement shall be waived) on a portion of the test specimen as obtained in 11.4.6.2. Particle size may be helpful when visual inspection indicates that the specimen contains a substantial fraction of coarse grained material.

10. Calibration

10.1 The measured axial displacements during consolidation and shear must be corrected for apparatus compressibility whenever the equipment deformation exceeds 0.05 % of specimen height.

10.1.1 Assemble the apparatus with a copper or steel disk of approximately the same size as the specimen.

10.1.2 Measure the axial displacement (D_c) as the normal force (N_c) is increased from the seating value to its maximum value and then returned to the seating value.

10.1.3 Graph or tabulate these displacements as a function of force.

10.2 The measured shear force must be corrected for the resistance of the lateral confinement whenever this value exceeds 1 % of the measured failure value. The resistance of the lateral confinement can be measured as described below.

10.2.1 Assemble the apparatus with the confinement device and a sealed water bag or frictionless bearing in place of the specimen, such that the separation between the platens is equal to the typical specimen height. Clamp the lateral confinement to the top and bottom platens to prevent it from rotating during the calibration.

10.2.2 Apply the shear displacement (δ_c) and measure the shear force (S_c) as the top platen is displaced relative to the bottom platen.

10.2.3 Graph or tabulate these forces as a function of shear displacement.

10.3 Depending on the apparatus configuration, it may be necessary to correct the measured normal and shear force for the friction in the loading ram and the slide table, respectively. These corrections are necessary whenever the friction exceeds 0.2 % of the maximum value for a given test. The friction can be measured as described in 10.3.1-10.3.6.

10.3.1 Assemble the apparatus without the confinement device.

10.3.2 Record the normal load while displacing the piston in the loading direction, and then, record the normal load while displacing the piston in the unloading direction.

10.3.3 Compute the normal force piston friction (N_{pf}) as one half the difference between these two values.

10.3.4 Record the shear force while displacing the shear piston in the loading direction, and then, record the shear load while displacing the piston in the unloading direction.

10.3.5 Compute the shear force piston friction (S_{pf}) as one half the difference between these two values.

NOTE 8—It is often convenient to include the shear piston friction in the calibration of the resistance of the lateral confinement device as measured in 10.2.

10.3.6 Measure the mass of the top platen (M_{tp}).

11. Procedure

11.1 *Assembling the Equipment*:

11.1.1 The apparatus must be assembled in such a manner as to prevent a change in water content of the specimen. Dry porous disks must be used with dry, expansive soils, and may be used for all soils. Damp disks may be used with soils having low swell potential. Saturated disks may only be used with saturated soils that have a low affinity for water.

11.1.2 Arrange the loading devices, such that no force is being applied and record the normal force (N_o) and shear force (S_o) zero readings.

11.1.3 Place the specimen assembly in the loading device, clamp it in place and apply a small normal seating stress of approximately 5 kPa.

NOTE 9—The most appropriate normal seating stress depends on the stiffness of the soil. It should be as large as possible to eliminate seating displacement errors yet not so large as to cause consolidation.

11.1.4 Immediately adjust the axial displacement indicator and record the zero reading (D_o). If necessary, add additional normal stress to prevent swelling of the specimen. Conversely, if the specimen begins to compress, reduce the seating stress.

11.1.5 Adjust the shear displacement indicator and record the zero reading (δ_o).

11.1.6 Inundate the specimen with water. When using non-saturated stones, it may be necessary to flush water through the bottom, and top stones separately to provide the specimen with adequate access to water. As inundation and specimen wetting occur, increase the normal stress as required to prevent swelling. Record the normal load required to prevent swelling and the resulting displacement reading.

11.2 *Consolidating the Specimen*:

11.2.1 Apply increments of constant total normal force to consolidate the specimen to the stress level specified by the requesting agency. The loading schedule shall comply with the guidelines specified in 11.2.1.1-11.2.2.4.

11.2.1.1 If detailed compression characteristics, including the preconsolidation pressure, are to be measured then the load schedule shall conform to Test Method D 2435.

11.2.1.2 The standard loading shall consist of a load increment ratio (LIR) of unity that is obtained by doubling the stress on the soil for each increment. A LIR as large as two may be used for stresses below the preconsolidation pressure.

11.2.1.3 The standard unloading may be selected such that each successive stress is one-fourth as large as the preceding stress.

11.2.2 The time sequence of displacement readings and the minimum load duration shall conform to the following.

11.2.2.1 Record the axial displacement (D) of the specimen and the time before each stress increment application.

11.2.2.2 If detailed compression characteristics are required then follow Test Method D 2435.

11.2.2.3 For stress increments where time displacement data are not recorded, leave the load on the specimen for at least the time required to reach 90 % consolidation for the maximum stress increment as determined in 12.2.3.3.

NOTE 10—The time required to satisfy this criteria will not be known until the consolidation phase of the test is complete. Therefore, a conservative estimate of the consolidation time should be used to ensure the test comforms to this requirement

11.2.2.4 For the maximum stress increment, obtain sufficient time displacement readings to determine the end of primary consolidation. Keep this stress on the specimen the lesser of ten times longer or one day longer than the time required for 95 % consolidation as determined in 12.2.3.4.

11.3 *Shearing the Specimen under Constant Volume Conditions*:

11.3.1 Record the preshear readings of axial displacement (D_{ps}), shear displacement (δ_{ps}), normal force (N_{ps}), and shear force (S_{ps}).

11.3.2 Activate the height control system to maintain the current preshear specimen height (H_{ps}). Either method must maintain the specimen height after accounting for apparatus compressibility to within 0.05% of its pre-shear value.

11.3.2.1 Active height control must be performed by adjusting the normal force applied to the specimen to counteract movements of the axial displacement of the specimen after accounting for apparatus compressibility due to changes in the normal force.

11.3.2.2 Passive height control must be performed by clamping the normal force application system in such a way that the force can be measured and change in the specimen height after accounting for apparatus compressibility is less than 0.05 % during shear.

11.3.3 The specimen must be sheared at a rate that is slow enough to allow dissipation of excess pore pressures generated during shear. These excess pore pressures, while theoretically zero, result from approximations to the ideal state of simple shear strain. The maximum strain rate shall result in specimen failure in a time that exceeds twice the time for 90 % consolidation as determined in 12.2.3.3.

NOTE 11—Much of the existing data and practical experience have been developed using a shear strain rate of 5 % per hour.

11.3.4 Shear the specimen by displacing the platens relative to each other using a constant rate of displacement as estimated in 11.3.3.

11.3.5 Take sufficient readings of axial displacement (when using active height control), shear displacement, shear force and normal force to define the stress versus strain behavior. More readings will be required at the early stages of shear deformation.

11.3.6 Continue to shear the specimen until at least 20 % shear strain or the shear force has dropped 20 % below the maximum value.

11.4 Disassemble Equipment

11.4.1 Minimize access of water to the specimen by draining the water bath and stones.

11.4.2 Remove the shear force from the specimen.

11.4.3 Reduce the normal force to the seating value.

11.4.4 If the requesting agency requires the water content during shear.

11.4.4.1 Allow the specimen to swell for the lesser of the time required for 95 % consolidation or one hour.

11.4.4.2 Record the final reading of axial displacement (D_f).

11.4.5 Remove the specimen from the equipment and determine the final moist mass (M_{tf}).

11.4.6 Determine the final water content (ω_f) and dry mass of solids according to Test Method D 2216.

11.4.6.1 If material is not needed for index tests then use the entire specimen.

11.4.6.2 If the index tests must be performed on the test specimen, use a representative (pie slice) portion of the specimen for water content (ω_{fp}) determination and the remaining undried soil for index tests.

12. Calculation

12.1 *Specimen Properties*:

12.1.1 Obtain the dry mass of the total specimen, in Mg, by direct measurement or when part of the specimen is used for index testing, calculate the dry mass as follows:

$$M_d = \frac{M_{tf}}{1 + \omega_{fp}} \tag{1}$$

where:

M_{tf} = final moist mass of total specimen after swelling, Mg, and

ω_{fp} = final water content from wedge of specimen after swelling, decimal form.

12.1.2 Compute the volume of solids, in m^3, as follows:

$$V_s = \frac{M_d}{G_s \rho_w} \tag{2}$$

where:

G_s = specific gravity of solids, and

ρ_w = density of water, Mg/m^3.

12.1.3 Calculate the specimen height at any time during the test, in m, as follows:

$$H = H_o - (D - D_o - D_c) \tag{3}$$

where:

H_o = initial specimen height, m,

D = axial displacement, m,

D_o = initial setup displacement measurement, m, and

D_c = apparatus compressibility from calibration curve which depends on the axial load, m.

12.1.4 Calculate the water contents, in percent, as follows:

$$\text{Initial water content: } \omega_o = \frac{M_{to} - M_d}{M_d} \times 100 \tag{4}$$

$$\text{Preshear water content: } \omega_{ps} = \frac{M_{tf} - A\rho_w\ (H_f - H_{ps}) - M_d}{M_d} \times 100$$

$$\text{Final water content: } \omega_f = \frac{M_{tf} - M_d}{M_d} \times 100$$

where:

M_{to} = initial moist mass of specimen, Mg,

A = cross sectional area of specimen, m^2,

H_f = final specimen height after swelling, m, and

H_{ps} = specimen height at start of test, m.

12.1.5 Calculate the void ratio as follows:

$$\text{Initial void ratio: } e_o = \frac{H_o A - V_s}{V_s} \tag{5}$$

$$\text{Preshear void ratio: } e_{ps} = \frac{H_{ps} A - V_s}{V_s}$$

12.1.6 Calculate the initial degree of saturation, in percent, as follows:

$$S_o = \frac{G_s \omega_o}{e_0} \tag{6}$$

12.2 *Consolidation Characteristics*:

12.2.1 Compute the axial strain, in percent, as follows:

$$\epsilon_a = \frac{D - D_o - D_c}{H_o} \times 100 \tag{7}$$

12.2.2 Compute the normal effective stress, in MN/m^2 as follows:

$$\sigma'_n = \frac{N - N_{pf} + M_{tp} \times 9806.6}{A} \tag{8}$$

where:

N = applied normal force, MN,

N_{pf} = correction to normal force, due to friction, MN, and

M_{tp} = mass of top platen, Mg.

12.2.3 Determine the time corresponding to 95 % consolidation during the maximum stress increment using the following procedure (see Test Method D 2435 for more details).

12.2.3.1 Plot axial displacement (or strain) versus the square root of time for the increment.

12.2.3.2 Draw a straight line through the points representing the initial readings which exhibit a straight line trend. Extrapolate this line back to t = 0 and obtain the ordinate (or strain) representing 0 % primary consolidation.

12.2.3.3 Draw a second straight line through the 0 % primary consolidation ordinate such that the abscissa of this line is 1.15 times the abscissa of the line drawn through the data. The intersection of this second line with the curve defined by the data gives the displacement (or strain) at 90 % consolidation.

12.2.3.4 The displacement (or strain) at 95 % consolidation is 1⁄18 more than the difference between 0 % and 90 % values. The time for 95 % consolidation, t_{95}, is the intersection of the curve defined by the data and this ordinate.

12.2.4 If detailed compression characteristics are required follow the calculation section of Test Method D 2435.

12.3 *Shear Characteristics*:

12.3.1 Calculate the shear strain, in %, as follows:

$$\gamma = \frac{\delta - \delta_{ps}}{H_{ps}} \times 100 \tag{9}$$

where:

δ = shear displacement, m, and

δ_{ps} = shear displacement at start of shear, m.

12.3.2 Calculate the shear stress, in MN/m^2, as follows:

$$\tau = \frac{S - S_c - S_{pf}}{A} \tag{10}$$

where:

S = measured shear force, MN,

S_c = shear resistance of lateral confinement device as a function of shear displacement, MN, and
S_{pf} = correction to shear force due to slide table friction, MN.

12.3.3 Calculate the axial strain, in %, as follows:

$$\epsilon_a = \frac{D - D_{ps} + D'_c - D_c}{H_{ps}} \times 100 \quad (11)$$

where:
D_{ps} = axial displacement at the start of shear, m, and
D'_c = apparatus compressibility at the start of shear, m.

12.3.4 Calculate the normal effective stress using the equation of 12.2.2.

12.3.5 Calculate the shear induced pore pressure, in MN/m^2, as follows:

$$\Delta u_s = \sigma'_{nc} - \sigma'_n \quad (12)$$

where:
σ'_{nc} = normal consolidation stress at the start of shear, MN/m^2.

12.3.6 Calculate the secant shear modulus, in MN/m^2, as:

$$G = \frac{\tau - \tau_{ps}}{\gamma} \times 100 \quad (13)$$

where:
τ_{ps} = shear stress at the start of shear, percent.

12.3.7 Calculate the average strain rate, in %/s, as:

$$\dot{\gamma} = \frac{\gamma_{100} - \gamma_{50}}{t_{100} - t_{50}} \quad (14)$$

where:
γ_{50} = shear strain at 50 % of the peak shear stress, %,
γ_{100} = shear strain at the peak shear stress, %,
t_{50} = time at 50 % of the peak shear stress, s, and
t_{100} = time at the peak shear stress, s.

NOTE 12—Since the strain rate typically increases throughout shear when using screw driven load frames, this calculation provides a nominal value for comparative purposes.

13. Report

13.1 The report shall include the following:

13.1.1 Project name and location, boring number, sample number and depth, specimen location in sample.

13.1.2 Soil description and classification in accordance with Practice D 2488 or Test Method D 2487 when Atterberg Limits and percent passing #200 sieve are available. Specific gravity of solids, Atterberg Limits and grain size distribution when available plus source of such data when not measured on test specimen.

13.1.3 Soil Conditions

13.1.3.1 Average water content of trimmings

13.1.3.2 Initial specimen water content, void ratio density, and degree of saturation

13.1.3.3 Preshear void ratio (and water content when requested)

13.1.4 Test Procedure

13.1.4.1 Undisturbed or compacted specimen

13.1.4.2 Trimming procedure

13.1.4.3 Shear strain rate (nominal value)

13.1.4.4 Specimen height and diameter

13.1.5 Consolidation results

13.1.5.1 Tabulate the axial strain, normal stress and load duration for each consolidation increment

13.1.5.2 When applicable provide consolidation results as required by Test Method D 2435.

13.1.5.3 Maximum and preshear consolidation stress and strain

13.1.5.4 Load duration of the maximum and preshear consolidation stress

13.1.5.5 t_{95} for maximum stress increment

13.1.6 *Shear Results*:

13.1.6.1 Tabulate the shear strain, shear stress, normal stress, pore pressure, axial strain and shear modulus.

13.1.6.2 Graph the shear stress versus shear strain

13.1.6.3 Graph the shear stress versus normal effective stress

13.1.6.4 Graph the shear induced pore pressure versus shear strain

13.1.6.5 Graph the axial strain versus shear strain when using active height control

13.1.6.6 Graph the log shear modulus versus log shear strain

14. Precision and Bias

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

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

15. Keywords

15.1 clays; cohesive soils; consolidated undrained test; consolidation test; constant volume test; recompression; samples; shear apparatus; shear strain; shear strength; shear test; simple shear; soils; stress-strain curve; undisturbed samples; undrained shear tests