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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~~ intact, laboratory reconstituted, and compacted soils, however, it does not include specific guidance for reconstituting or 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.

~~1.5The 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.~~

~~1.5.1In 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~~

1.5 All recorded and calculated values shall conform to the guide for significant digits and rounding established in Practice D 6026.

1.5.1 The procedures used to specify how data are collected/recorded and calculated in this test method 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; 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 test method to consider significant digits used in analysis methods for engineering design.

1.5.2 Measurements made to more significant digits or better sensitivity than specified in this standard shall not be regarded a nonconformance with this standard.

1.6 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.

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~~[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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[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Strength and Compressibility of Soils.

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

~~1.6~~1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety 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

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 854~~Test Method for Specific Gravity of Soils[2]~~ Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D 1587 Practice for Thin-Walled Tube ~~Geotechnical~~ Sampling of Soils for Geotechnical Purposes

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 2435~~Test Method for One-Dimensional Consolidation Properties of Soils[2]~~ Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D 3550~~Practice for Ring-Lined Barrel Sampling of Soils[2]~~ Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4220 Practices for Preserving and Transporting Soil Samples

D 4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D 4452~~Methods for X-Ray Radiography of Soil Samples[2]~~ Practice for X-Ray Radiography of Soil Samples

D 6026 Practice for Using Significant Digits in Geotechnical Data

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 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 method of shearing, 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.~~ —A suitable device for applying normal force to the specimen. The device must be capable of maintaining constant force during the consolidation phase of a test, permit quick application of force for consolidation increments, and allow continuous adjustment of force when using active height control or be rigidly locked in place when using passive 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~~ capacity, be accurate to ~~± 2%~~ ±1 % of the applied maximum force for a given test and have a readability of at least 4 significant digits 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 the specimen. When using passive height control and the slide table is within the height control boundaries, its compressibility must

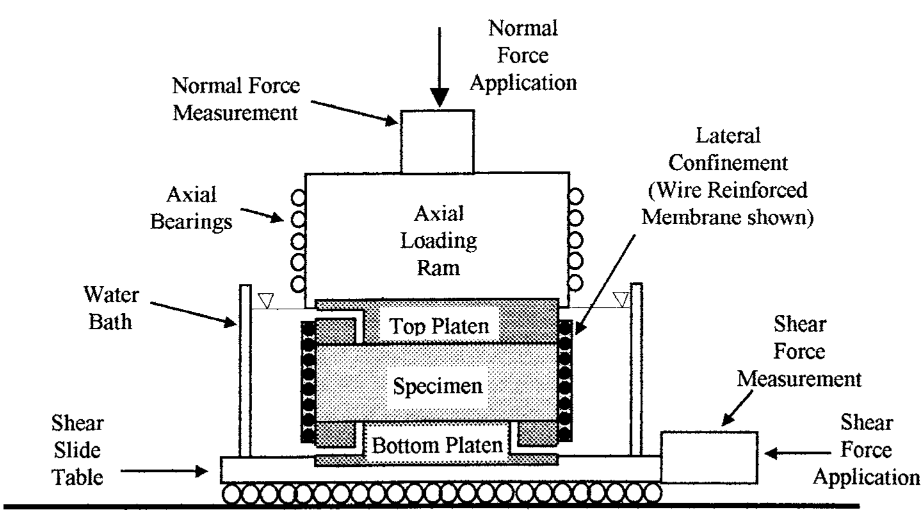

FIG. 1 Schematic Diagram of Essential Direct Simple Shear Components.

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.~~ —Two devices are required: one to measure the change in specimen height and one for the shear deformation (axial and lateral movement of top platen relative to bottom platen). These devices shall have a range of at least 50 % of the initial height of the specimen and shall have an accuracy of at least 0.25 % of full range and a readability of at least 4 significant digits of the initial specimen height.

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*~~Intact Samples:

~~7.1.1Undisturbed~~7.1.1 Intact 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~~intact block samples obtained and sealed in the field.

~~7.1.2Undisturbed~~7.1.2 Intact 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.

~~7.1.3Undisturbed~~7.1.3 Intact 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 *Laboratory Reconstituted and Compacted Specimens*:

~~7.2.1Compacted specimens may be prepared from bulk homogeneous material.~~

7.2.1 Laboratory reconstituted and 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*~~*Intact Specimens*— Trim the specimen to the lateral dimension of the lateral confinement device.

~~8.3.1Undisturbed~~8.3.1 Intact 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*~~Laboratory Reconstituted and 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~~intact 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.