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Standard Test Method for Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Fine-Grained Soils[1]

This standard is issued under the fixed designation D6467; 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—The standard was editorially updated in January 2022.

1. Scope*

1.1 Fine-grained soils in this Test Method are restricted to soils containing no more than 15 % fine sand (100 % passing the 425 µm (No. 40) sieve and no more than 15 % retained on the 75 µm (No. 200) sieve).

1.2 This test method provides a procedure for performing a torsional ring shear test under a drained condition to determine the residual shear strength of fine-grained soils. This test method is performed by shearing a reconstituted, overconsolidated, presheared specimen at a controlled displacement rate until the constant drained shear resistance is established on a single shear surface determined by the configuration of the apparatus.

1.3 In this test, the specimen rotates in one direction until the constant or residual shear resistance is established. The amount of rotation is converted to displacement using the average radius of the specimen and multiplying it by numbers of degrees traveled and 0.0174.

1.4 An intact specimen or a specimen with a natural shear surface can be used for testing. However, obtaining a natural slip surface specimen, determining the direction of field shearing, and trimming and aligning the usually non-horizontal shear surface in the ring shear apparatus is difficult. As a result, this test method focuses on the use of a reconstituted specimen to determine the residual strength. An unlimited amount of continuous shear displacement can be achieved to obtain a residual strength condition in a ring shear device.

1.5 A shear stress-displacement relationship may be obtained from this test method. However, a shear stress-strain relationship or any associated quantity, such as modulus, cannot be determined from this test method because the height of the shear zone unknown, so an accurate or representative shear strain cannot be determined.

1.6 The selection of effective normal stresses and determination of the shear strength parameters for design analyses are the responsibility of the professional or office requesting the test. Generally, three or more effective normal stresses are applied to a test specimen in a multi-stage test or a new specimen can be used for each effective normal stress to determine the drained residual failure envelope.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only and are not considered standard. The values given in parentheses are mathematical conversions to inch-pound units. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.8 All measured and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026 unless superseded by this standard.

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

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D2974 Test Methods for Determining the Water (Moisture) Content, Ash Content, and Organic Material of Peat and Other Organic Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
D7928 Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Terminology

3.1 *Definitions*—For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *consolidated, adj*—soil specimen condition after primary consolidation under a specific effective normal stress.

3.2.2 *presheared, adj*—soil specimen condition after shearing to at least one revolution of the ring in the direction of shear to create a failure surface prior to drained shearing.

3.2.3 *residual shear force, n*—the residual shear force is the average shear force being applied to the specimen when the shear resistance neither increases nor decreases with continued shear displacement.

3.2.4 *residual shear strength, n*—the minimum constant resistance of soil to shear along a fully developed failure surface and equals the residual shear force divided by the cross-sectional area of the specimen.

3.2.5 *drained residual strength state, n*—the state at which a soil exhibits residual shear strength and shear stress – shear displacement relationship becomes almost horizontal.

3.2.6 *indurated sediments, n*—sediments hardened by significant pressure and/or cementing agent to create a sedimentary rock such as shale.

4. Summary of Test Method

4.1 This test method consists of a consolidation and shear phase. The consolidation phase is accomplished by placing a specimen in the annular specimen container, applying a predetermined effective normal stress, usually in stages, through the top loading platen, providing for wetting and draining of the specimen; consolidating the specimen under each of the effective normal stresses; decreasing the effective normal stress to yield an overconsolidated specimen prior to preshearing for both single and multi-stage tests. The shear phase is accomplished by preshearing the specimen by rotating the specimen container at a slow and constant rate of shear deformation rotation against the top loading platen for at least one revolution; allowing the specimen to equilibrate before drained shearing, applying a slow and constant rate of shear deformation rotation during shearing; and measuring the torque/shearing force, vertical displacement, and rotation displacement until a constant value of shearing resistance is reached.

5. Significance and Use

5.1 The ring shear test is suited to the relatively rapid determination of drained residual shear strength because of the short drainage path through the thin specimen, the constant cross-sectional area of the shear surface during shear, unlimited rotational displacement in one direction, and the capability of testing one specimen under different effective normal stresses to obtain clay particles that are oriented parallel to the direction of shear to obtain residual shear strength envelope.

5.2 The apparatus allows a reconstituted specimen to be overconsolidated and presheared prior to drained shearing. Overconsolidation and preshearing of the reconstituted specimen significantly reduces the horizontal displacement required to reach a residual condition, and therefore, reduces soil extrusion, wall friction, and other problems (Stark and Eid, 1993)[3]. This simulates a preexisting shear surface along which the drained residual strength can be mobilized.

5.3 The ring shear test specimen is annular so the angular displacement differs from the inner edge to the outer edge. At the residual condition, the shear strength is constant across the specimen so the difference in shear stress between the inner and outer edges of the specimen is negligible.

NOTE 1—Notwithstanding the statements on precision and bias contained in this test method: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent testing. Users of this test method are cautioned that compliance with Practice D3740 does not ensure reliable testing. Reliable testing depends on several factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Shear Device,* to hold the specimen securely between two porous discs. The shear device provides a mean for

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

[3] Stark, T.D. and Eid, H.T. (1993). "Modified Bromhead Ring Shear Apparatus," *Geotechnical Testing Journal*, ASTM, Vol. 16, No. 1, March, 1993, pp. 100-107.

applying an effective normal stress to the faces of the specimen, for measuring changes in thickness of the specimen, for permitting drainage of water through the porous discs at the top and bottom boundaries of the specimen, and for submerging the specimen in water. The device is capable of applying a torque to the specimen along a shear surface parallel to the faces of the specimen. A number of different ring shear devices are commercially available, in practice, or are being developed so a general description of a ring shear device is presented without schematic diagrams. The location of the shear surface depends on the configuration of the specimen container and/or apparatus. As a result, the shear surface may be located near a soil/porous disc interface or at the mid-height of the specimen if an upper ring can be separated from a bottom ring as is done in a direct shear box. The device shall have low friction along the inner and outer walls of the specimen container developed during shearing. Friction may be reduced by having the shear surface occur at the top of the specimen container and modifying the specimen container walls with low-friction material. The frames that hold the specimen shall be sufficiently rigid to prevent their distortion during consolidation and shearing. The various parts of the shear device shall be made of a material such as stainless steel, bronze, or coated aluminum that is not subject to corrosion by moisture or substances within the soil. Dissimilar metals, which may cause galvanic action, are not permitted.

6.2 *Specimen Container,* a device containing an annular cavity for the soil specimen with an inside diameter not less than 50 mm (2 in.) and an inside to outside diameter ratio not less than 0.6. The container has provisions for drainage through the top and bottom. The initial specimen thickness, before consolidation and preshearing, is not less than 5 mm (0.2 in.). The maximum particle size for non-indurated soils is limited to 10 % of the initial specimen height as stated in the test specimen description.

6.3 *Torque Arm/Loading Platen Assembly,* may have different bearing stops for the proving rings, load cells, or force or torque transducers to provide different options for the torque measurement.

6.4 *Porous Discs,* two porous metal discs such as, bronze, stainless steel, carborundum, or corundum, mounted on the top loading platen and the bottom of the specimen container cavity to allow drainage from the soil specimen along the top and bottom boundaries. The outer and inner diameters of the discs shall be 0.1 mm (0.004 in.) less, and greater than those of the specimen annular cavity, respectively.

6.4.1 The porous discs must have good contact between the disc and the soil and a surface or pattern that develops a strong interlock with the soil specimen to aid in transfer of shear stress to the top and bottom boundaries of the specimen. The discs must be sufficiently serrated to develop a strong interlock with the soil specimen so shearing occurs in the soil and not at the soil-disc interface. If failure occurs at the soil-disc interface, the resulting resistance will be extremely low. This interlock can be accomplished by minimizing the disc surface area in contact with the soil and having part of the disc penetrate into the specimen. The serration must have a depth of between 10 and 15 % of the specimen height before shearing.

6.4.2 The hydraulic conductivity of the discs shall be substantially greater than that of the soil, but shall be textured fine enough to prevent excessive intrusion of the soil into the pores of the disc. The porous discs shall be clean and free from cracks, chips, and nonuniformities. New porous discs should be boiled for at least 10 minutes and left in the water to cool to ambient temperature before use. Immediately after each use, clean the porous discs with a nonabrasive brush and boil to remove clay particles that may reduce their permeability. Alternatively, ultrasonic cleaning could be used to clean the porous disc.

NOTE 2—Exact criteria for porous disc texture and hydraulic conductivity have not been established. For normal soil testing, medium-grade discs with a hydraulic conductivity of about 5.0×10^{-4} to 1.0×10^{-3} cm/s (0.5 to 1.0×10^{3} ft/year) are appropriate for testing fine-grained soils.

6.5 *Loading Devices:*

6.5.1 *Device for Applying and Measuring the Normal Force*—The device shall be capable of rapidly applying and maintaining the normal force to within ±1 % of the specified force.

6.5.2 *Device for Shearing the Specimen*—This device shall be capable of shearing the specimen at a uniform rate of rotation, without difference in shear displacement rate due to friction. The rate to be applied depends upon the consolidation characteristics of the soil (see 9.6.1). The rate is usually maintained with an electric motor and gear box arrangement.

6.6 *Shear Force Measurement Device,* two proving rings, load cells, in combination with a lever arm or a torque transducer accurate to measure a force of 0.1 N (0.03 lbf).

6.7 *Water Bath,* container for the specimen container and water needed to inundate the specimen.

6.8 *Controlled High-Humidity Environment*—For preparing the specimen, such that the water (moisture) content gain or loss during specimen rehydration is minimized.

6.9 *Vertical Deformation Indicators*—Dial gauge, or other suitable device, capable of measuring the change in thickness of the specimen, with a sensitivity of 0.0025 mm (0.0001 in.).

6.10 *Rotational Horizontal Deformation Indicator*—Ring shear device having gauge or etched scale on circumference of the ring base to measure the degrees traveled, and thus the shear displacement, or other methods capable of obtaining a sensitivity of at least 1.0 mm or 1.5°.

6.11 *Equipment for Determination of Water Content,* in accordance with Test Method D2216.

6.12 *Sieves*—425 µm (No. 40) and 75 µm (No. 200) sieves conforming with Specification E11.

6.13 *Miscellaneous Equipment,* including timing device that can be read to seconds, site-specific, distilled or demineralized water, mortar, pestle, spatulas, razor blades, straightedge, data sheet or acquisition system to monitor the test, and so forth.

6.14 *Wall Friction Reduction*—Wall friction may be significant during the shearing process causing an overestimate of the residual strength, therefore, minimization of wall friction is necessary. For example, if the specimen container consists of a single piece of metal, the amount of wall friction depends on the magnitude of top platen settlement into the specimen container, type of soil, and material lining of the specimen container walls. In this type of specimen container, the thickness of soil trapped between the inner and outer walls of the specimen container and the upper porous disc should be minimized. If the specimen container can be separated into two pieces, the opening between the upper and lower halves must be wide enough to prevent particles from becoming trapped in the opening and that shearing occurs at this opening. Other techniques also can be used to reduce wall friction.

7. Sampling and Test Specimens

7.1 The sample used for specimen preparation is to be sufficiently large so that a ring shear specimen and specimens for index property tests, for example, Atterberg Limits (Test Method D4318), particle size distribution (Test Method D6913), and clay-size fraction (Test Method D7928), can be prepared. The specimen being tested should be at or near full saturation.

7.2 The liquid limit, plastic limit, plasticity index (Test Method D4318), and clay-size fraction (Test Method D7928) of the specimens are measured using the same processed soil as used for shear testing.

7.3 If an intact specimen is desired, the sample obtained from the field shear surface could be trimmed to produce an annular specimen. This must be done in such a way that moisture loss or gain is minimized. A preexisting field shear surface may consist of small seams of clayey material surrounded by material with a coarser gradation. If so, to simulate field preexisting shearing conditions only the clayey shear zone material is to be tested and not the coarser surrounding material.

7.4 A reconstituted non-indurated fine-grained specimen may be prepared by disaggregating an air-dried representative sample and passing it through the 425 µm (No. 40) sieve or an appropriate sieve, for example, opening size less than or equal to 10 % (0.5 mm) of the initial specimen height. Air dried method must not be used for highly plastic soils, tropical soils, and organic soils based on Test Methods D2974. Soil with more than 25.0 % organic content based on Test Methods D2974 is to be reconstituted without drying.

7.5 After processing, the reconstituted sample could be mixed with site specific water/fluid or distilled water until a water (moisture) content near or above the liquid limit is obtained. Using this water (moisture) content reduces/minimizes the amount of air trapped during placement of the soil paste into the annular cavity of specimen container. A water (moisture) content between the liquid and plastic limits can be used if air is not likely to be trapped in the annular cavity. The soil paste must then be allowed to rehydrate for 24 h preferably in a humidity control environment before transferring it to a specimen container.

7.6 Because of the high initial water (moisture) content of the reconstituted specimen, the consolidation may be significant. For this reason, adding and consolidating additional material for proper shear testing as discussed in Section 9 might be required.

7.7 Reconstituted specimens of highly indurated fine-grained specimen (that is, overconsolidated clays, mudstones, claystones, and shales) may be prepared by ball-milling an air-dried representative sample and passing it through the U.S. Standard 75 µm (No. 200) sieve. Ball-milling facilitates disaggregation of the clay particles and reduces the shear displacement required to achieve a residual strength condition (LaGatta, 1970[4]). If ball-milling is not used and other disaggregation methods are used, that is, soaking (Test Method D4318), blenderizing, disc milling, and mortar and pestle (Test Method D4318), greater shear displacement will be required to disaggregate the mudstone, claystone, and shale particles and achieve a residual strength condition in the apparatus because they are not as effective as ball-milling in disaggregating highly indurated materials. The additional shear displacement can be large and create testing problems such as soil extrusion and wall friction that can result in unconservative residual strength. Non-indurated soils must not be ball-milled because it will change the gradation of the soil. Non-indurated soils must be passed through the 425 µm (No. 40) sieve as required for Atterberg Limits (Test Method D4318).

7.8 Care is to be taken during disaggregation and mixing operations to avoid introducing impurities into the sample.

8. Calibration

8.1 The calibration is to determine the deformation of the apparatus, exclusive from the specimen, when subjected to the consolidation load. Because only deformation caused by specimen consolidation will be reported for complete tests the apparatus deformation at each consolidation load must be subtracted from the observed deformations during a test.

8.2 The lever arm used to apply the consolidation load must be horizontal at all times so as to maintain the loading ratio of 10:1 for each load added to the hanger system.

8.3 The lever arm shall also be adjusted such that it does not apply any significant load to the specimen when resting and only the load applied to the hanger system is applied to the specimen.

8.4 Assemble the ring-shear device with the porous discs and a metal calibration disc or plate of a thickness approximately equal to the desired test specimen and slightly smaller in width. The metal calibration disc shall have parallel end surfaces finished to a high degree of precision, and be clean without any grit. Similarly, the sample holder shall be clean without any grit. Record the zero or "no load" reading.

8.5 Apply increments of normal force up to the equipment limitations, and record the normal displacement indicator reading and normal force. Remove the applied normal force in reverse sequence of the applied force, and record the normal displacement indicator readings and normal force. Plot the load-deformation relationship of the apparatus as a function of

[4] La Gatta, D.P. (1970). "Residual Strength of Clay and Clay-Shales by Rotation Shear Tests," *Harvard Soil Mechanics Series* No. 86, Harvard University, and U.S. Army Corps of Engineers Contract Report S-70-5, June, pp. 47-48, 224

normal load. Retain the results for future reference in determining the thickness of the test specimen and compression within the test apparatus itself.

8.6 Remove the calibration disc or plate.

8.7 Calibration for the equipment load-deformation characteristics needs to be performed on the apparatus when first placed in service, or when apparatus parts are changed.

NOTE 3—Other methods of proven accuracy for calibrating the apparatus are acceptable.

9. Procedure

9.1 Assemble the specimen container.

9.2 Place and secure the bottom moist porous disc to the bottom of the specimen container.

9.3 A spatula is used to place the reconstituted soil paste into the annular specimen cavity. The top of the specimen is planed flush with the top of the specimen container.

9.4 *Preconsolidation:*

9.4.1 Place and secure the specimen container containing the specimen into the empty water bath that is attached to the apparatus. Place the top platen with the moist and clean porous disc over the top of the specimen.

9.4.2 Place a small seating load so that the effective normal stress applied to the specimen including the seating load and the top platen is approximately 3.0 kPa (0.4 psi).

9.4.3 Attach and adjust the vertical displacement measurement device and obtain the initial time and vertical displacement reading.

9.4.4 Fill the water bath with test water, and keep it full for the duration of the consolidation and shear phases.

NOTE 4—If an intact specimen is used, water should be added after applying a normal stress that equals or exceeds the in-situ vertical stress to reflect field conditions, and the vertical stress should be adjusted to prevent volume change of the specimen until equilibrium is reached.

9.4.5 Consolidate the specimen to the highest desired effective normal stress for the shear strength envelope using a load increment ratio (LIR) of unity. For each load increment, verify completion of primary consolidation using Test Method D2435 before proceeding. Because of the high initial water (moisture) content of the specimen, ensure there is sufficient specimen in the container after consolidation for proper shear testing, which may require adding and consolidating additional material before reaching the highest normal stress. For the Bromhead Ring Shear Device a sufficient specimen thickness is 3 mm or 60 % of its initial thickness.

9.4.6 When data for the maximum consolidation increment yields a well-defined normal deformation versus log time relationship which extends into secondary compression, the relationship could be interpreted as in Test Method D2435 and the time to mobilize the peak shear resistance or failure should be computed using the following equation:

$$t_f = 50 \quad t_{50} \tag{1}$$

where:

t_f = total estimated elapsed time to failure, min, and
t_{50} = time required for the specimen to achieve 50 % consolidation under the specified effective normal stress (or increment) based on 12.5.1.3 in Test Method D2435 using the end-of-primary consolidation reading, min.

9.4.7 When data for the maximum consolidation increment do not satisfy the requirements of 9.4.5 but yield a well defined normal deformation versus root time relationship, the relationship should be interpreted as in Test Method D2435 and the time to failure should be computed using the following equation:

$$t_f = 11.6 \quad t_{90} \tag{2}$$

where:

t_{90} = time required for the specimen to achieve 90.0 % consolidation under the specified effective normal stress (or increment), min.

9.5 *Preshearing*—Create a shear surface using the following steps:

9.5.1 After consolidating to the highest desired effective normal stress, unload the specimen to the lowest desired effective normal stress on which the shear strength will be measured.

NOTE 5—Another possible procedure is that the specimen can be presheared at the highest normal stress over the course of 10 hours or longer to minimize soil extrusion. A slow shearing rate will minimize extrusion. After preshearing, the specimen should be left to reach equilibrium, which is indicated by no further volume change before the residual strength is measured at the highest normal stress. After completing this test, the specimen can be unloaded to other normal stresses to obtain a residual strength envelope. After unloading, the specimen is unloaded and allowed to fully rebound before shearing at that normal stress.

9.5.2 Swing the two proving rings or load cell assemblies toward the torque arm so that the two bearing adjustment rods create a right angle with the bearing stops on the torque arm. Secure the proving ring or load cell assemblies into place. This step can be skipped if a torque transducer assembly is used instead of two proving rings or load cell assemblies.

9.5.3 Shear the specimen slowly by selecting a shear displacement rate less than 25 degrees/min. Specimen must be sheared by rotating the ring shear base to at least one complete revolution. A slow rate of shear displacement is selected to minimize soil extrusion during preshearing.

9.5.4 Swing the proving ring or load cell rods away from the torque arm. This step can be skipped if a torque transducer assembly is used instead of two proving rings or load cell assemblies.

9.5.5 Ensure dissipation of any excess pore water pressure induced during preshearing by allowing sufficient time so the specimen vertical displacement after preshearing becomes almost negligible.

9.6 *Shearing*—Shear specimen under drained conditions using the following steps: