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# Standard Test Method for Determining the Shear Strength of Soil-Geosynthetic and Geosynthetic-Geosynthetic Interfaces by Direct Shear[1]

This standard is issued under the fixed designation D5321/D5321M; 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 covers a procedure for determining the shear resistance of a geosynthetic against soil, or a geosynthetic against another geosynthetic, under a constant rate of deformation.

1.1.1 The test method is intended to indicate the performance of the selected specimen by attempting to model certain field conditions. Results obtained from this method may be limited in their applicability to the specific conditions considered in the testing.

1.2 The test method is applicable for all geosynthetics, with the exception of geosynthetic clay liners (GCLs), which are addressed in Test Method D6243/D6243M.

1.3 The test method is not suited for the development of exact stress-strain relationships for the test specimen due to the nonuniform distribution of shearing forces and displacement.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *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.*

1.6 *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.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft$^3$ (600 kN-m/m$^3$))

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft$^3$ (2,700 kN-m/m$^3$))

D2435/D2435M 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)

D3080/D3080M Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions (Withdrawn 2020)[3]

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4354 Practice for Sampling of Geosynthetics and Rolled Erosion Control Products (RECPs) for Testing

D4439 Terminology for Geosynthetics

D6243/D6243M Test Method for Determining the Internal and Interface Shear Strength of Geosynthetic Clay Liner by the Direct Shear Method

## 3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to soil and rock, refer to Terminology D653. For definitions of terms relating to geosynthetics, refer to Terminology D4439.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *adhesion, $c_a$, n*—the *y*-intercept of the Mohr-Coulomb strength envelope.



[1] This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.01 on Mechanical Properties.

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

[3] The last approved version of this historical standard is referenced on www.astm.org.

3.2.2 *atmosphere for testing geosynthetics, n*—air maintained at a relative humidity between 50 and 70 % and a temperature of 21 ± 2 °C [70 ± 4 °F].

3.2.3 *Mohr-Coulomb friction angle, δ, n*—(angle of friction of a material or between two materials, °) the angle defined by the least-squares, "best-fit" straight line through a defined section of the shear strength-normal stress failure envelope; the component of the shear strength indicated by the term δ, in Coulomb's equation, $\tau = c_a + \sigma_n * \tan(\delta)$ (see 12.6).

3.2.3.1 *Discussion*—The end user is cautioned that some organizations (for example, FHWA, AASHTO, along with state agencies who use these documents) are currently using the Greek letter, Delta (δ), to designate wall-backfill interface friction angle and the Greek letter, Rho (ρ), to designate the interface friction angle between geosynthetics and soil.[4,5]

3.2.4 *Mohr-Coulomb shear strength envelope, n*—the least squares, "best fit" straight line through a defined section of the shear strength-normal stress failure envelope described by the equation, $\tau = c_a + \sigma_n * \tan(\delta)$ (see 12.6). The envelope can be described for any chosen shear failure mode (example, peak or post-peak).

3.2.5 *secant friction angle, $\delta_{sec}$, n*—(angle of friction of a material or between two materials, °) the angle defined by a line drawn from the origin to a data point on the shear strength-normal stress failure envelope. Intended to be used only for the normal stress on the shearing plane for which it is defined.

3.2.6 *shear strength, τ, n*—the shear force on a given failure plane. In the direct shear test, it is always stated in relation to the normal stress acting on the failure plane. Two different types of shear strengths are often estimated and used in standard practice:

3.2.6.1 *peak shear strength*—the largest value of shear resistance experienced during the test under a given normal stress.

3.2.6.2 *post-peak shear strength*—the minimum, or steady-state value of shear resistance that occurs after the peak shear strength is experienced.

3.2.6.3 *Discussion*—The end user is cautioned that the reported value of post-peak shear strength (regardless how defined) is not necessarily the residual shear strength. In some instances, a post-peak shear strength may not be defined before the limit of horizontal displacement is reached.

3.2.7 *shear strength envelope, n*—curvi-linear line on the shear stress-normal stress plot representing the combination of shear and normal stresses that define a selected shear failure mode (for example, peak and post-peak).

## 4. Summary of Test Method

4.1 The shear resistance between a geosynthetic and a soil, or other material selected by the user, is determined by placing the geosynthetic and one or more contact surfaces, such as soil, within a direct shear box. A constant normal stress representative of design stresses is applied to the specimen, and a tangential (shear) force is applied to the apparatus so that one section of the box moves in relation to the other section. The shear force is recorded as a function of the shear displacement of the moving section of the shear box.

4.2 To define a Mohr-Coulomb shear strength envelope, it is recommended that a minimum of three test points be performed at different normal stresses, selected by the user, to model appropriate field conditions. However, there may be instances where fewer test points are desired (see Note 1). The peak shear stresses, or shear stresses at some post-peak displacement, or both, are plotted against the applied normal stresses used for testing. The test data are generally represented by a best-fit straight line through the peak strength values whose slope is the Mohr-Coulomb friction angle for peak strength between the two materials where the shearing occurred. The *y*-intercept of the straight line is the adhesion intercept. A straight line fit for shear stresses at some post-peak displacement is the post-peak interface strength between the two materials where the shearing occurred.

NOTE 1—There may be some investigative cases where only a single test point is desired. If the field design conditions will experience a range of normal stresses, it is standard industry practice to bracket the normal stress range with tests on both sides of the range, as it is unconservative to extrapolate results outside of the normal stress range tested. When defining a Mohr-Coulomb shear strength envelope over a range of normal stresses, standard industry practice is to use a minimum of three test points. Attempting to define a single linear Mohr-Coulomb shear strength envelope over too large of a normal stress range may prove to be problematic in many cases because most failure envelopes exhibit significant curvature over such a large range, particularly at low normal stresses on the shearing plane.



## 5. Significance and Use

5.1 The procedure described in this test method for determination of the shear resistance of the soil and geosynthetic or geosynthetic and geosynthetic interface is intended as a performance test to provide the user with a set of design values for the test conditions examined. The test specimens and conditions, including normal stresses, are generally selected by the user.

5.2 This test method may be used for acceptance testing of commercial shipments of geosynthetics, but caution is advised as outlined in 5.2.1.

5.2.1 The shear resistance can be expressed only in terms of actual test conditions (see Notes 2 and 3). The determined value may be a function of the applied normal stress, material characteristics (for example, of the geosynthetic), soil properties, size of sample, moisture content, drainage conditions, displacement rate, magnitude of displacement, and other parameters.

NOTE 2—In the case of acceptance testing requiring the use of soil, the user must furnish the soil sample, soil parameters, and direct shear test parameters. The method of test data interpretation for purposes of acceptance should be mutually agreed to by the users of this test method.

NOTE 3—Testing under this test method should be performed by laboratories qualified in the direct shear testing of soils and meeting the requirements of Practice D3740, especially since the test results may

[4] *LRFD Bridge Design Specifications*, 5th Edition, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 2010.

[5] "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines," *FHWA GEC 011*, FHWA NHI-10-024, Vol I, and FHWA NHI-10-025, Vol II, U.S. Department of Transportation, Federal Highway Administration (FHWA), Washington, DC, 2009.

depend on site-specific and test conditions.

5.2.2 This test method measures the total resistance to shear between a geosynthetic and a supporting material (substratum) or a geosynthetic and an overlying material (superstratum). The total shear resistance may be a combination of sliding, rolling, and interlocking of material components.

5.2.3 This test method does not distinguish between individual mechanisms, which may be a function of the soil and geosynthetic used, method of material placement and hydration, normal and shear stresses applied, means used to hold the geosynthetic in place, rate of shear displacement, and other factors. Every effort should be made to identify, as closely as practicable, the sheared area and failure mode of the specimen. Care should be taken, including close visual inspection of the specimen after testing, to ensure that the testing conditions are representative of those being investigated.

5.2.4 Information on precision among laboratories is incomplete. In cases of dispute, comparative tests to determine whether a statistical bias exists among laboratories may be advisable.

5.3 The test results can be used in the design of geosynthetic applications including, but not limited to: the design of liners and caps for landfills, mining heap leach pads, tailings impoundments, cutoffs for dams and other hydraulic barriers, geosynthetic-reinforced retaining walls, embankments, and base courses; in applications in which the geosynthetic is placed on a slope; for determination of geosynthetic overlap requirements; or in other applications in which sliding may occur between soil and a geosynthetic or between two geosynthetic materials.

5.4 The displacement at which peak strength and post-peak strength occurs and the shape of the shear stress versus shear displacement curve may differ considerably from one test device to another due to differences in specimen mounting, gripping surfaces, and material preparation. The user of results from this test method is cautioned that results at a specified displacement may not be reproducible across laboratories and that the relative shear displacement measured in this test at peak strength may not match relative shear displacement at peak strength in a field condition.

## 6. Apparatus

6.1 *Shear Device*—A rigid device to hold the specimen securely and in such a manner that a uniform shear force without torque can be applied to the tested interface. The device consists of both a stationary and moving container, each of which is capable of containing dry or wet soil and is rigid enough to not distort during shearing of the specimen. The traveling container must be placed on firm bearings and rack to ensure that the movement of the container is only in a direction parallel to that of the applied shear force.

NOTE 4—The position of one of the containers should be adjustable in the normal direction to compensate for vertical deformation of the substrate and geosynthetic.

6.1.1 Square or rectangular containers are recommended. They should have a minimum dimension that is the greatest of 300 mm [12 in.], 15× the $d_{85}$ of the coarser soil used in the test, or a minimum of 5× the maximum opening size (in plane) of the geosynthetic tested. The depth of each container that contains soil must be a minimum of 50 mm [2 in.] or 6× the maximum particle size of the coarser soil tested, whichever is greater.

NOTE 5—The minimum container dimensions given in 6.1.1 are guidelines based on requirements for testing most combinations of geosynthetics and soils. Containers smaller than those specified in 6.1.1 can be used if it can be shown that data generated by the smaller devices contain no bias from scale or edge effects when compared to the minimum-size devices specified in 6.1.1 for specific materials being tested. The user should conduct comparative testing prior to the acceptance of data produced on smaller devices. For direct shear testing involving soils, competent geotechnical review is recommended to evaluate the compatibility of the minimum and smaller direct shear devices.

6.2 *Normal Stress Loading Device,* capable of applying and maintaining a constant uniform normal stress on the specimen for the duration of the test. Careful control and accuracy (±2 %) of normal stress is important. Normal force loading devices include, but are not limited to: weights, pneumatic or hydraulic bellows, or piston-applied stresses. For jacking systems, the tilting of loading plates must be limited to 2° from the shear direction during shearing. The device must be calibrated to determine the normal stress delivered to the shear plane.

6.3 *Shear Force Loading Device,* capable of applying a shearing force to the specimen at a constant rate of shear displacement. The horizontal force measurement system must be calibrated, including provisions to measure and correct for the effects of friction and tilting of the loading system. The rate of displacement should be controlled to an accuracy of ±10 % over a range of at least 6.35 mm/min [0.25 in./min] to 0.025 mm/min [0.001 in./min]. The system must allow constant measurement and readout of the applied shear force. An electronic load cell or proving ring arrangement is generally used. The shear force loading device should be connected to the test apparatus in such a fashion that the point of the load application to the traveling container is in the plane of the shearing interface and remains the same for all tests. (See Note 6.)

NOTE 6—The operating range of normal and horizontal shear stresses for a device should be limited to between 10 % and 90 % of its calibrated range. If a device is used outside this range, the report shall so state and give a discussion of the potential effect of uncertainties in normal stress on the measured results.

6.4 *Displacement Indicators,* for providing continuous readout of the horizontal shear displacement, and if desired, vertical displacement of the specimen during the consolidation or shear phase, or both. Displacement indicators such as dial indicators, or linear variable differential transformers (LVDTs), capable of measuring a displacement of at least 75 mm [3 in.] for shear displacement and 25 mm [1 in.] for vertical displacement are recommended. The sensitivity of displacement indicators should be 0.02 mm [0.001 in.] for measuring shear displacement and 0.002 mm [0.0001 in.] for measuring vertical displacement.

6.5 *Geosynthetic Clamping Devices,* required for fixing geosynthetic specimens to the stationary section or container, the traveling container, or both, during shearing of the specimen. Clamps and grips shall not interfere with the shearing surfaces within the shear box and must keep the geosynthetic specimens flat during testing. Gripping surfaces must develop sufficient shear resistance to prevent nonuniform displacement of the geosynthetic and adjacent geosynthetics. Gripping surfaces must develop sufficient shear resistance to prevent tensile failure within any geosynthetics material outside the specimen area subjected to normal stress. Flat, jaw-like clamping devices are normally sufficient. Textured surfaces or soil must be used to support the top or bottom, or both, of the geosynthetic. These surfaces must permit flow of water into and out of the test specimen. Work is still in progress to define the best type of textured surfaces. Selection of the type of textured surface should be based on the following criteria:

6.5.1 The gripping surface should be able to fully mobilize the friction between the gripping surface and the outside surfaces of the geosynthetic. The rough surfaces must be able to prevent slip between the geosynthetic and the gripping surface to prevent tensile failure in the geosynthetic.

6.5.2 The gripping surface must be able to completely transfer the applied shear force through the outside surfaces into the geosynthetic.

6.5.3 The gripping surface must not damage the geosynthetic and should not influence the shear strength behavior of the geosynthetic.

NOTE 7—The selection of specimen substrate may influence the test results. For instance, a test performed using a rigid substrate, such as a wood or metal plate, may not simulate field conditions as accurately as that using a soil substrate. However, use of compressible soils as a substrate is not recommended due to the possibility that these soils may compress under the applied normal load to the extent that the intended shear plane is no longer level with the gap between the two halves of the shear box. The user should be aware of the influence of substrate on direct shear resistance data. Accuracy, reproducibility, and relevance to field conditions should be considered when selecting a substrate for testing.

NOTE 8—Gripping and clamping systems vary widely and can be different based on the geosynthetic material being tested. Several authors have successfully used a multitude of systems.[6]

6.6 *Soil Preparation Equipment,* for preparing or compacting bulk soil samples, as outlined in Test Methods D698, D1557, or D3080/D3080M.

6.7 *Miscellaneous Equipment,* as required for preparing specimens. A timing device and equipment required for maintaining saturation of the geosynthetic or soil samples, if desired.

## 7. Geosynthetic Sampling

7.1 *Lot Sample*—Divide the product into lots, and for any lot to be tested, take the lot sample as directed in Practice D4354 (see Notes 9 and 10).

7.2 *Laboratory Sample*—Consider the units in the lot sample as the units in the laboratory sample for the lot to be tested. For a laboratory sample, take a sample extending the full width of the geosynthetic production unit and of sufficient length so that the requirements of 7.3 can be met. Take a sample that will exclude material from the outer edge.

7.3 *Test Specimens*—From each unit in the laboratory sample, remove three specimens (or fewer if specified by the user) as outlined in 7.3.1.

7.3.1 Remove specimens for shearing in a direction parallel to the machine, or roll, direction of the laboratory sample and specimens for shearing in a direction parallel to the cross-machine, or cross-roll, direction, if required (see Notes 9 and 10). All specimens should be sufficiently large to fit snugly in the container described in 6.1.1, and they should be of sufficient size to facilitate clamping. All specimens should be free of surface defects, etc., that are not typical of the laboratory sample. Space the specimens along a diagonal of the unit of the laboratory sample. Take no specimens nearer the edge of the geosynthetic production unit than one tenth the width of the unit.

NOTE 9—Lots for geosynthetics usually are designated by the producer during manufacturing. While the test method does not attempt to establish a frequency of testing for the determination of design-oriented data, the lot number of the laboratory sample should be identified. The lot number should be unique to the raw material and manufacturing process for a specific number of units, for example, rolls, panels, etc., designated by the producer.

NOTE 10—The shear strength characteristics of some geosynthetics may depend on the direction tested. In many applications, it is necessary to perform shear tests in only one direction that matches the direction of shear in the installation. In addition, it is often necessary to perform shear tests against a specific side of the geosynthetic that matches the installation. The direction of shear and the side of the geosynthetic specimen(s) tested must be noted clearly in the report for these cases.

NOTE 11—To help understand the shear strength characteristics of the geosynthetic interface, it may be useful to conduct pre-shear test nondestructive index testing (for example, thickness, asperity height, or mass per unit area) on the shear test specimen or destructive index testing (for example, ply adhesion) on material adjacent in shear direction to the location on the laboratory sample from which the shear test specimen was taken. These tests should be conducted in general accordance with the appropriate ASTM test method though the number of test specimens or measurements may differ.



## 8. Shear Device Calibration

8.1 The direct shear device must be calibrated to measure the internal resistance to shear inherent to the device. The inherent shear resistance is a function of the geometry and mass of the traveling container, type and condition of the bearings, type of shear loading system, and the applied normal stress. The calibration procedure described in this section is applicable to certain devices. Other procedures may be required for specific devices. Refer to the manufacturer's literature for recommended calibration procedures. (See Note 12.)

8.2 Assemble the shear device completely without placing a specimen inside it. If the design permits, apply a normal stress equal to that for which friction is being measured. If applying a normal stress, some low-friction mechanism such as rollers must be used to resist the normal stress without creating a shear resistance. Some boxes do not permit calibration with a normal stress. Adjust the gap between the upper and lower box to the value used in shear testing. Apply the shear force to the traveling container at a rate of 6.35 mm/min [0.25 in./min]. Record the shear force required to sustain movement of the traveling container for at least 75 mm [3 in.] total shear displacement. Record the applied shear force at 1-mm [0.05-in.] intervals. Determine the average shear force over the

[6] Fox et al., 1997; Pavlik, 1997; Trauger, et al., 1997; Fox, et al., 1998; Zanzinger and Alexiew, 2000; Olsta and Swan, 2001; Triplett and Fox, 2001; Marr, 2002; Koerner and Lacy, 2005; Fox, et al., 2006; and Allen and Fox, 2007.

75 mm [3 in.] of displacement. Variations in shear force of more than 25 % of the average value may indicate damaged or misaligned bearings, an eccentric application of the shear force, or a misaligned box. The equipment must be repaired if the measured shear force varies by more than 25 % of the average value.

8.3 The maximum shear force recorded is the internal shear correction to be applied to shear force data after the testing of the specimens. The internal shear correction for device friction should not exceed 10 % of the measured peak strength.

NOTE 12—Calibration of electronic equipment used in this method and calibration for device friction should be performed at least once per year using traceable reference materials.

## 9. Conditioning

9.1 For tests on geosynthetics without soil, test specimens at the temperature specified in the standard atmosphere for testing geosynthetics. Humidity control is normally not required for direct shear testing.

9.2 When soil is included in the test specimen, the method of conditioning is selected by the user or mutually agreed upon by the user and the testing agency. Material required for the specimen shall be batched by thoroughly mixing soil with sufficient water to produce the desired water content. Allow the soil to stand prior to compaction in accordance with the following guide:

| Classification (by Practice D2487) | Minimum Standing Time, h |
|---|---|
| SW, SP | No Requirement |
| SM | 3 |
| SC, ML, CL | 18 |
| MH, CH | 36 |

9.2.1 In the absence of specified conditioning criteria, as described in 9.3, the test should be performed at the temperature specified in the standard atmosphere for testing geosynthetics. Relative humidity control should be performed when specified by the user.

9.3 The minimum user-specified test conditioning criteria include the following:

9.3.1 The test configuration, including all components from the top to the bottom (supporting substrates, soil, geosynthetics, and gripping surfaces).

9.3.2 Type of clamping, gripping surfaces, or both.

9.3.3 Compaction criteria for soil(s), including dry unit weight, moisture content, and conditions for compacting the soil adjacent to the geosynthetic material.

9.3.4 Sample conditioning, such as wetting and soaking/hydration of the geosynthetic separately or with the entire test section. Wetting should be defined by either pouring water onto the sample or by spraying geosynthetics with water. Conditions must be defined during soaking/hydration for the type of fluid, duration of soaking, criteria to define completion of soaking, normal stress to be applied during soaking, and whether the geosynthetic is to be hydrated by itself or with other interface components assembled.

9.3.5 Normal stresses during the shear phase.

9.3.6 Rate of shearing or the procedure for the lab to follow to establish the rate of shearing (see 10.7 and 11.6).

## 10. Procedure A – Geosynthetic on Geosynthetic Interface Friction

10.1 Place the lower geosynthetic specimen flat over a rigid substrate in the lower container of the direct shear apparatus. The substrate may consist of soil, wood, roughened steel plates, or other rigid media (see Note 7 cautioning against using compressible soils as a substrate). The specimen must cover the entire substrate, and the upper surface of the specimen must extend above the edges of the lower container.

10.1.1 If the test is to be performed using wet specimens, remove the wetted specimen from the conditioning chamber and blot the upper surface of the specimen free of excess surface moisture. Begin the test as soon as possible after removing the specimen from the conditioning chamber.

10.2 Slide the two container halves of the shear box together and fix them in the start position. Place the upper geosynthetic specimen over the previously placed lower specimen so that both specimens are flat, free of folds, wrinkles, etc., and in complete contact within the test area. The specimen must protrude below the lower surface of the upper container. Only the two specimens are to be in contact within the test area.

10.3 Place the superstratum (soil or textured surface) over the upper specimen so that a uniform stress may be applied over the entire specimen within the test area. Fix the loading plate and apply the normal compressive stress to the specimen.

10.4 Clamp the specimen to constrain failure to the interface between the upper and lower geosynthetic specimens.

10.5 Apply the normal seating load. If the test is for a wet condition, inundate the specimen and monitor vertical displacements until the sample comes to equilibrium.

10.5.1 If the seating load does not equal the normal load for testing, apply the normal load and monitor vertical displacements until the sample comes to equilibrium. Verify equilibrium before proceeding.

10.6 Place and zero the shear displacement indicators onto the traveling container. Assemble the shear force loading device such that the loading ram is in contact with the traveling container, but no shear force is applied. If necessary, adjust the location of the horizontal loading ram to minimize the induced moment. Create a gap between the upper box and the lower box. The gap should be large enough to prevent friction between the boxes during shear.

10.7 Apply the shear force using a constant rate of displacement. The rate of displacement should be specified by the user. The displacement rate should normally be relatively slow so that insignificant excess pore pressures exist at failure, unless the application requires rapid loading to simulate field conditions. In the absence of any material specifications, use a maximum displacement rate of 5 mm/min [0.2 in./min].

10.8 Record the shear force as a function of shear displacement. A minimum of 50 data points should be obtained per test.

10.9 Run the test until the shear displacement exceeds 75 mm [3 in.] or other value specified by the user (see Note 13). The test may be stopped sooner if the shear force has reached steady state (see Note 14.)

NOTE 13—Some interfaces may require displacement larger than 3 in. to reach a steady-state strength value. Other methods such as reset tests, reversal tests, and drum shear apparatus may be required in these instances.

NOTE 14—Shear force may be considered to have reached steady state once it has peaked and exhibits no significant increase or decrease for 12.7 mm [0.5 in.] of shear displacement after reaching peak.

10.10 At the end of the test, remove the normal stress from the specimen and disassemble the device carefully. Inspect the failure surface and clamp area carefully in order to identify the failure mechanisms involved. Obtain a digital image of the failure surface. Note evidence of shear strains within the specimen or at the clamps.

10.10.1 Evidence of shear strains from testing of a specimen that is not typical of other specimens tested may result in discarding of the specimen and retesting. If excessive strains in the specimen or slipping occurs, the test may have to be rerun at a lower normal compressive stress.

10.11 Repeat the test at a new normal stress with new geosynthetic specimens. Test a minimum of three specimens (or fewer if specified by the user), each at a different normal stress selected by the user.

10.12 Plot the test data as a graph of applied shear force versus shear displacement. For this plot, identify the peak shear force and the post-peak shear force, if reached. Determine the shear displacements for these shear forces. Subtract the internal shear correction determined in 8.3 from these forces to obtain the corrected shear forces for peak and post-peak conditions.

10.13 Calculate the peak shear stress, and the post-peak shear stress, if reached, as directed in 12.2.

## 11. Procedure B – Soil on Geosynthetic Friction

11.1 Place the geosynthetic specimen flat over a substrate in the lower container of the direct shear apparatus. The substrate may consist of soil, wood, roughened steel plates, or other media (see Note 7 cautioning against using compressible soils as a substrate). The specimen must cover the entire substrate, and the upper surface of the specimen must extend above the edges of the lower container. Remove all folds and wrinkles in the geosynthetic. The geosynthetic must extend in the direction of relative movement of the upper box a sufficient distance to permit clamping of the geosynthetic to the lower box. Clamp the geosynthetic to the lower box.

11.2 Bring the upper half of the box into position. Place soil within the upper box and in direct contact with the geosynthetic. Compact the soil to the specified moisture and density. Use care not to damage the geosynthetic during compaction. Assemble the normal loading apparatus as given by the manufacturer's instructions. Use a rigid normal loading plate between the top of the soil and the normal loading apparatus.

NOTE 15—Although this is not preferred, some devices permit the soil to be placed below the geosynthetic. Similar procedures for placing the soil should be used as described herein with the necessary modifications to place the soil in the lower container. If soil is used in the lower container, fill the container so that the surface of the soil specimen protrudes a distance equal to one half of the $d_{85}$ of the soil as described in Test Method D3080/D3080M. A protrusion of 1 mm is typically sufficient for fine-grained soils. Level the soil surface carefully before placing the geosynthetic upon it. The user must be cautioned that this method is not advised if a compressible soil is being tested, as compressible soils may consolidate after applying the normal load resulting in a situation where the intended shear plane is no longer level with the gap between the two halves of the shear box.

NOTE 16—Subsections 11.1 and 11.2 apply to commonly occurring test conditions. Other interface conditions, test conditions, and material combinations may be desired to model specific test conditions. The test report should describe specific variations made from this test method to model specific conditions.

11.3 Apply the normal seating load. If the test is for a wet condition, inundate the specimen and monitor vertical displacements until the sample comes to equilibrium. (See Note 17.)

NOTE 17—The acceptance sequence for the seating load, normal load, and wetting will depend on the application, as described in 9.3. Insufficient information exists at this time to provide a single application sequence. Adjust the test sequence to application conditions. Use methods described in Test Methods D2435/D2435M to determine when primary consolidation is complete. Use a degree of primary consolidation of 90 % or more as the equilibrium condition.

11.4 If the seating load does not equal the normal load for testing, apply the normal load for testing and monitor the vertical displacements until the sample comes to equilibrium. Verify that equilibrium is reached before proceeding. (See Note 17.)

11.5 Position the shear displacement indicators. Assemble the shear force loading device such that the loading ram is in contact with the traveling container, but no shear force is applied. Create a gap between the upper box and the lower box. The gap should be just large enough to prevent friction between the boxes during shear and small enough to minimize loss of soil from the specimen into the gap. If necessary, adjust the location of the loading ram to minimize the induced moment.

NOTE 18—The gap between the upper and lower halves of the interface shear box should be increased for some geosynthetic materials such as geogrids and geotextiles. This will help prevent particles from hanging up between the gap and the geosynthetic, which could result in an artificially high friction angle. See Test Method D3080/D3080M, subsection 9.9.

11.6 Apply the shear force using a constant rate of displacement that is slow enough to dissipate excess pore pressures in the soil, as described in 10.7 (see Note 19). If excess pore pressures are not anticipated on the interface, apply the shear force at a rate of 1 mm/min [0.04 in./min].

NOTE 19—The appropriate rate of shearing depends on several factors, including the geosynthetic, the materials on both sides of the geosynthetic, the soil, the normal stress level, the hydrating conditions, and the drainage conditions. For drained shearing, the following equation can be used as a guide to determine the maximum rate of shear displacement:

$$R = d_f / (50 * t_{50} * f) \quad (1)$$

where:

$R$ = rate of shear displacement, mm/min,
$d_f$ = estimated shear displacement at peak shear stress,
$t_{50}$ = time required for specimen to reach 50 % consolidation under the current normal stress increment. This time is determined from methods described in Test Methods D2435/D2435M assuming double drainage, min, and
$f$ = factor to account for drainage conditions on the shear plane.

Use a value of 4 for factor $f$ on shear where the geosynthetic has low permittivity or the soil has low permeability. Use a value of 0.002 for factor $f$ on shear between a geosynthetic with high permittivity and a pervious soil. At some values of normal stress, the specimen will not exhibit well-defined time displacement curves from which to determine $t_{50}$. In those instances, use a $t_{50}$ determined for a higher normal stress that is sufficient to cause measurable consolidation of the soil. If an alternate value of $t_{50}$ is selected, the rationale for the selection shall be explained with the test results.

NOTE 20—Direct shear test may also be conducted using a constant shear stress approach. This approach can be achieved by three different methods:

*(I) Controlled Stress Rate Method,* where the shear force is applied to the test specimen under a uniform rate of horizontal force increase until slipping or failure of the test specimen occurs,

*(II) Incremental Stress Method,* where the shear force is applied in uniform or doubling increments and held for a specific time before proceeding to the next increment, until slipping or failure of the test specimen occurs,

*(III) Constant Stress (Creep) Method,* where the shear force is applied using Method (I) or (II) until the specified constant shear stress is reached. The constant shear stress is then maintained and the test monitored for the specified duration.

The user shall specify the desired loading conditions for the constant shear stress approach. The laboratory shall clearly indicate the type of test and rates of load application for test run with the constant shear stress approach.

11.7 Record the shear force and shear displacement as described in 10.8. Continue the test until the shear displacement exceeds 75 mm [3 in.] or other value specified by the user. The test may be stopped sooner if the shear force has reached steady state. (See Note 14.)

11.8 Remove the normal stress and disassemble the device at the end of the test. Carefully inspect and identify the failure surface of the specimen and the area of the specimen clamp. Obtain a digital image of the failure surface. Specimen failures should be consistent for all tests in order for the test data to be comparable. Note evidence of tensile strains within the geosynthetics or at the clamps. Evidence of shear strain patterns that are not typical of other specimens tested may indicate that the result should be discarded and the test repeated. If the geosynthetic specimen is damaged at a location other than the intended shear surface, the test may have to be rerun at a lower normal stress, or the substrate-geosynthetic interface made rougher to prevent slippage. When testing involves soil, materials in one half of the shear box may plow into those in the other half. During disassembly, inspect the soil surface for signs of plowing and include observations in the report.

11.9 At the end of the test, remove the soil specimen to determine the moisture content.

11.10 Repeat the procedure for a minimum of two additional normal stresses (or fewer if specified by the user).

11.11 Plot the test data as directed in 10.12.

11.12 Calculate the peak shear stress and the post-peak shear stress, if reached, as directed in 12.2.

## 12. Calculation

12.1 For tests using soil, calculate the initial and final water content, unit weight, and degree of saturation, if required.

12.2 Calculate the shear stress applied to the specimen for each recorded shear force as follows:

$$\tau = F_S/A_C \tag{2}$$

where:

$\tau$ = shear stress (kPa),
$F_S$ = shear force (kN), (see 10.12 or 11.11), and
$A_C$ = corrected area ($m^2$). (See 12.4 for calculating area correction.)

12.3 Calculate the corrected normal stress applied to the specimen for each recorded shear force as follows:

$$\sigma_N = F_N/A_C \tag{3}$$

where:

$\sigma_N$ = normal stress (kPa),
$F_N$ = normal load (kN), (see 10.5 or per 11.4), and
$A_C$ = corrected area ($m^2$). (See 12.4 for calculating area correction.)

12.4 For tests in which the area of specimen contact decreases with increased displacement, a corrected area must be calculated. This will occur in test devices in which the stationary and traveling containers have the same overall plan dimensions. In this case, the actual contact area will decrease as a function of shear displacement of the traveling container. The corrected area is calculated for each displacement reading using the following equation:

$$A_C = A_O - A_i \tag{4}$$

where:

$A_C$ = corrected area ($m^2$),
$A_O$ = initial specimen contact area ($m^2$), and
$A_i$ = contact area ($m^2$) between specimens at each increment of shear displacement corresponding to the shear force measured at that same increment.

12.4.1 No area correction may be required for tests in which the stationary container is larger than the traveling container, provided that the shear displacement of the traveling container does not result in a decrease in specimen contact area.

12.5 Plot the peak shear stress and post-peak shear stress, if obtained, versus applied normal stress for each test conducted. The shear stress and normal stress axes must be drawn to the same scale.

12.6 If there are a minimum of three test points conducted at three different normal loads, a Mohr-Coulomb shear strength envelope can be developed by connecting the data points through the peak shear stress with a best-fit straight line. Some judgment and experience may be required to construct this line, which is referred to as the "peak failure envelope." A single straight-line fit may be inappropriate for highly curved shear strength envelopes. The Mohr-Coulomb friction angle is determined using the following equation:

$$\tau = c_a + \sigma_n * \tan(\delta) \tag{5}$$

where:

$\tau$ = peak shear stress,
$\sigma_n$ = normal stress,
$\delta$ = Mohr-Coulomb friction angle (degrees), and
$c_a$ = adhesion intercept.

The $y$-intercept of the straight line with $x = 0$ axis is the adhesion intercept for interface strength.