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Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method[1]

This standard is issued under the fixed designation D 5321; 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, another geosynthetic, or a soil and geosynthetic in any combination.

1.1.1 The test method is intended to indicate the performance of the selected specimen by attempting to model certain field conditions.

1.2 The test method is applicable for all geosynthetics. Remolded or undisturbed soil samples can be used in the test device.

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

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all 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 653 Terminology Relating to Soil, Rock and Contained Fluids[2]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft/lbf/ft^3(600 kN/m/m^3))[2]

D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56 000 ft-lbf/ft^3(2700 kN/m/m^3)[2]

D 3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions[2]

D 4354 Practice for Sampling of Geotextiles for Testing[3]

D 4439 Terminology for Geosynthetics[3]

3. Terminology

3.1 Definitions—For definitions of terms relating to soil and rock, refer to Terminology D 653. For definitions of terms relating to geosynthetics, refer to Terminology D 4439.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *adhesion*, c_a(FL^{-2}), *n*—the shearing resistance between soil and another material under zero externally applied pressure. **(D 653, D-18)**

3.2.2 *angle of friction*, *n*—(angle of friction between solid bodies) (degrees) the angle whose tangent is the ratio between the maximum value of the shear stress that resists slippage between two solid bodies at rest with respect to each other and the normal stress across the contact surface. **(D 653, D-18)**

3.2.3 *atmosphere for testing geosynthetics*, *n*—air maintained at a relative humidity of 65 ± 5 % and temperature of 21 ± 2°C (70 ± 4°F). **(D 4439)**

3.2.4 *coefficient of friction*, *n*—a constant proportionality factor, relating normal stress and the corresponding critical shear stress, at which sliding starts between two surfaces. **(D 653, D-18)**

3.2.5 *direct shear friction test*, *n*—for geosynthetics, a procedure in which the interface between a geosynthetic and any other surface, under a range of normal stresses specified by the user, is stressed to failure by the horizontal movement of one surface against the other.

3.2.6 *geosynthetic*, *n*—a planar synthetic product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a man-made project, structure, or system. **(D 4439)**

4. Summary of Test Method

4.1 The coefficient of friction between a geosynthetic and soil, or between any geosynthetic combination 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 compressive stress 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 horizontal displacement of the moving section of the shear box.

[1] This test method is under the jurisdiction of ASTM Committee D-35 on Geosynthetics and is the direct responsibility of Subcommittee D35.01 on Mechanical Properties.

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

[3] *Annual Book of ASTM Standards*, Vol 04.09.

The test is performed for a minimum of three different normal stresses, selected by the user, to model appropriate field conditions. The peak (or alternatively, the residual) shear stresses recorded are plotted against the applied normal compressive stresses used for testing. The test data are generally represented by a best fit straight line whose slope is the coefficient of friction between the two materials where the shearing occurred. The y-intercept of the straight line is the adhesion.

5. Significance and Use

5.1 The procedure described in this test method for determination of the coefficient of soil and geosynthetic or geosynthetic and geosynthetic friction by the direct shear method 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 parameters 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 below.

5.2.1 The coefficient of soil and geosynthetic friction can be expressed only in terms of the soil used in testing (see Notes 1 and 2). The coefficient of friction is a function of the applied normal compressive stress, soil gradation, plasticity, in-place density, moisture content, and other parameters.

NOTE 1—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.

NOTE 2—Soil and geosynthetic friction tests should be performed by laboratories experienced in the friction testing of soils, especially since the test results may be dependent on site-specific soil conditions.

5.2.2 This test method measures the total resistance to sliding of a geosynthetic with a supporting material (substratum) or an overlying material (superstratum). Total sliding resistance may be a combination of sliding, rolling, interlocking of soil particles and geosynthetic surfaces, and shear strain within the geosynthetic specimen.

5.2.3 The test method does not distinguish between individual mechanisms, which may be a function of the soil used, method of soil placement, normal and shear stresses applied, rate of horizontal displacement, and other factors. Every effort should be made to identify, as closely as is practicable, the sheared area and failure mode of the specimen so that comparison tests can be performed. 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 between laboratories is incomplete. In cases of dispute, comparative tests to determine whether a statistical bias exists between laboratories may be advisable.

5.3 The test method produces test data that can be used as follows: in the design of 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 soil/geosynthetic or geosynthetic/geosynthetic friction is critical to design.

6. Apparatus

6.1 *Shear Device*—A rigid device to hold the specimen securely and in such a manner that a uniform force without torque can be applied to the specimen. The device consists of both a stationary and moving container, both of which are capable of containing dry or wet soil and are rigid enough to prevent distortion 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 3—One container should be adjustable to compensate for deformation of the soil.

6.1.1 Square or rectangular containers are recommended; they should have a minimum dimension that is the greater of 300 mm (12 in.), 15 times the d_{85} of the coarser soil used in the test, or a minimum of five times the maximum opening size (in plan) of the geosynthetic tested. The depth of each container should be 50 mm (2 in.) or six times the maximum particle size of the coarser soil tested, whichever is greater. The minimum specimen to width to thickness ratio is 2:1.

NOTE 4—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 scale or edge effects bias when compared to the minimum size devices specified in 6.1.1. 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 the normal stress is important. Normal stress 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 10 mm (0.4 in.) from the center to the edge of the plate during operation of the test device.

6.3 *Shear Force Loading Device*, capable of applying a shearing force to the specimen at a constant rate of displacement (strain controlled) in a direction parallel to the direction of travel of the soil container. The rate of displacement should be controlled to an accuracy of ±10 % over a wide range of displacements. The system must allow constant measurement and readout of the shear force applied. 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.

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. Dial indicators, or linear variable differential transformers (LVDT), capable of measuring a displacement of at least 75 mm (3 in.) for horizontal 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 horizontal 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 shall not interfere with the shearing surfaces within the shear box and must keep the geosynthetic specimens flat during testing. Flat jaw-like clamping devices are normally sufficient. Gluing of the geosynthetic specimen to a substrate (such as wood), which is placed in either or both of the soil containers, is an acceptable clamping technique, provided that soil is not used along with the wooden substrate and it does not interfere with the test operation or that the glue does not change the shearing properties of the geosynthetic specimen. If gluing is used, the specimen should be checked carefully to ensure that shearing of the glued surface does not occur. A trial test is recommended to establish the proper type of glue and setting time.

NOTE 5—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. The user should be aware of the influence of substrate on direct shear friction data. Accuracy and reproducibility should be considered when selecting a substrate for testing.

6.6 *Soil Preparation Equipment*, for preparing or compacting bulk soil samples, as outlined in Test Methods D 698 or D 1557 or Method D 3080.

6.7 *Miscellaneous Equipment*, as required for preparing geosynthetic 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 D 4354 (Notes 5 and 6).

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 along the selvage or edge from each sample roll so that the requirements of 7.3 can be met. Take a sample that will exclude material from the outer wrap unless the sample is taken at the production site, in which case inner and outer wrap material may be used.

7.3 *Test Specimens*—From each unit in the laboratory sample, remove the required number of specimens as outlined below.

7.3.1 Remove a minimum of three specimens for shearing in a direction parallel to the machine (or roll) direction of the laboratory sample and three specimens for shearing in a direction parallel to the cross-machine (cross-roll) direction, if required (Note 6). The specimens should be slightly larger than the inside dimensions in all directions of the soil 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 selvage or edge of the geosynthetic production unit than 1⁄10 the width of the unit.

NOTE 6—Lots for geosynthetics are usually designated by the producer during manufacturer. 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 7—The frictional characteristics of some geosynthetics may depend on the direction tested. In many applications, it is necessary to perform shear test in only one direction. The direction of shear in the geosynthetic specimen(s) must be noted clearly in these cases.

8. Shear Device Calibration

8.1 The direct shear device is 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, and type of shear loading system.

8.2 Assemble the shear device completely without placing a specimen inside it. Do not apply a normal stress. Apply the shear force to the traveling container at a rate of 10 mm/min (0.5 in./min). Record the shear force required to sustain movement of the traveling container for at least 50 mm (2 in.) total horizontal displacement. Record any large variation in applied shear force after movement of the traveling container has been initiated. Any such variations may be indications of damaged or misaligned bearings, or an eccentric application of the shear force.

8.3 The maximum shear force recorded is the internal shear correction to be applied to shear force data after the testing of geosynthetics or soil specimens.

9. Conditioning

9.1 For geosynthetic friction tests without soil, test specimens at the temperature specified in the 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. In the absence of specified conditioning criteria, 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 When the geosynthetic is to be tested in the wet condition, soak the specimen in water for a minimum of 24 h prior to testing (Note 8).

NOTE 8—Geosynthetics that do not absorb measurable quantities of water may not require a 24-h soaking period for this test.

10. Procedure A—Geosynthetic and Geosynthetic 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, or steel plates or other rigid media. 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 containers 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 a rigid superstratum 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 As required, clamp the specimen to constrain failure to the interface between the upper and lower geosynthetic specimens.

10.4.1 One or both of the specimens may be glued or epoxied to the rigid superstrate or substrate, subject to the limitations described in 6.5. This may be a substitute for clamping.

10.5 Place and zero the 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.

10.6 Apply the shear force using a constant rate of displacement. In the absence of any material specifications, use a maximum displacement rate of 5 mm/min (0.2 in./min).

10.7 Record the shear force as a function of displacement. If the data are not recorded continuously, a minimum of 20 data points should be obtained per test.

10.8 Run the test until the applied shear force remains constant with increasing displacement. Displacements ranging from 25 to 75 mm (1 to 3 in.) are generally required to generate this residual shear force.

10.9 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. Note evidence of shear strains within the specimen or at the clamps.

10.9.1 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 occur, the test may have to be rerun at a lower normal compressive stress.

10.10 Repeat the test at a new normal compressive stress under new geosynthetic specimens. Test a minimum of three specimens, each at a different normal stress selected by the user.

10.11 Plot the test data as directed in 11.11 and 11.12.

11. Procedure B—Soil and Geosynthetic Friction

11.1 Place soil or rigid substrate in the lower container, as required. Compact the soil at the specific moisture content to the density desired. Fill the lower container with soil 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 Method D 3080. A protrusion of 1 mm is sufficient for fine-grained soils. Level the soil surface carefully.

11.2 Place the lower geosynthetic specimen loosely over the substrate. Clamp or otherwise fix the end of the specimen temporarily, and reset it to ensure that the geosynthetic specimen is in complete contact with the soil. Remove all folds or wrinkles and verify that the protrusion of the soil substrate is suitable as outlined in 11.1.

11.2.1 For specimens tested in the saturated state, blot the upper surface of the specimen to remove excess moisture.

11.3 Fix the two soil containers in the start position, and place the upper geosynthetic specimen, if used, as directed in 10.2.

11.3.1 Clamp or fix the upper geosynthetic specimen temporarily before placing the upper soil, if used, and adjust the distance between the soil containers so that the distance between the upper surface of the geosynthetic specimen and the lower surface of the upper soil container is at least equal to the d_{85} of the upper soil. Alternatively, the upper container can be raised after placement and compaction of the upper soil layer.

11.4 Place the upper soil at the desired density and moisture content in a manner that minimizes damage to the geosynthetic specimen. Unclamp the geosynthetic specimen and apply the normal compressive stress.

11.4.1 If required, consolidate the soil specimens to eliminate excess soil pore pressures or to model field conditions. Required consolidation times are calculated as outlined in Method D 3080 (Note 9).

11.4.2 After the consolidation period, reclamp the geosynthetic specimen to the upper or lower container, as required. If the failure surface is not to be constrained to any particular surface, the specimen may remain unclamped.

11.5 Place the displacement indicators and assemble the shear loading device as described in 10.5.

11.6 Apply the shear force using a constant rate of displacement that is slow enough to dissipate soil pore pressures, as described in Method D 3080 (Note 9). If excess pore pressures are not anticipated, and in the absence of a material specification, apply the shear force at a rate of 1 mm/min (0.04 in./min).

NOTE 9—For the large-soil specimens typically used for this test, excess pore pressures may not be dissipated using the guidelines in Method D 3080. True drained conditions may not exist if this is the case, and the test should not be considered drained. Thinner soil specimens or very slow deformation rates, or both, should be considered if drained conditions are desired.

11.7 Record the shear force as described in 10.7, and run the test until a residual shear force is attained as determined in 10.8.

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. Specimen failures should be consistent for all tests in order for the test data to be comparable.

11.9 At the end of the test, remove the soil specimen to determine the density and moisture content, if required.

11.10 Repeat the procedure for a minimum of two additional normal compressive stresses.

11.11 Plot the test data as a graph of applied shear force versus container displacement. For this plot, identify the peak shear force or residual shear force, if required. Determine the horizontal displacements for these shear forces.

11.12 Calculate the peak shear stress (or, alternatively, the residual stress, if required), as directed in Section 12. Subtract the internal shear correction (determined in 9.3) from the shear stress. The difference between the recorded shear stress and the internal shear correction is the actual shear stress applied to the specimen.

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

$$T = F_S / A_C$$

where:
T = shear stress (kPa),
F_S = shear force (kN), and
A_C = corrected area (m^2).

12.2.1 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 horizontal displacement of the traveling container. For square or rectangular containers, the corrected area is calculated for each displacement reading using the following equation:

$$A_C = A_O - (d\,W)$$

where:
A_C = corrected area (m^2),
A_O = initial specimen contact area (m^2),
d = horizontal displacement of the traveling container (m), and
W = specimen contact width in a direction perpendicular to that of shear force application (m).

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

12.3 Plot each shear stress, as determined in 11.11 and 11.12, versus applied normal compressive stress for each test conducted. The shear stress and normal stress axes must be drawn to the same scale.

12.4 Connect the data points with a best fit straight line. Some judgment and experience may be required to construct this line, which is referred to as the failure envelope. The slope of the failure envelope is the coefficient of friction. The angle of friction is determined using the following equations:

$$\delta_p = \tan^{-1}(\omega_p)$$

where:
δ_p = angle of friction corresponding to the peak shear stress (degrees), and
ω_p = the coefficient of friction corresponding to the peak shear stress.

12.4.1 Alternatively, the coefficient of friction may be calculated based on residual shear stresses recorded during testing using the following equation:

$$\delta_r = \tan^{-1}(\omega_r)$$

where:
δ_r = angle of friction corresponding to the residual shear stress (degrees), and
ω_r = the coefficient of friction corresponding to the residual shear stress.

12.5 The y-intercept of the shear stress versus normal stress plot is the adhesion.

13. Report

13.1 In the report of the coefficient of geosynthetic/geosynthetic or soil/geosynthetic friction by the direct shear method, include the following information:

13.1.1 Project, type(s), and description of geosynthetic specimens tested and direction tested.

13.1.2 Complete information on any soils used in testing, including soil preparation, compaction, moisture, gradation, classification, etc., and the methods used.

13.1.3 Description of the test apparatus, including container dimensions, loading apparatus, and recording devices used.

13.1.4 All test conditions, including normal compressive pressures selected, rate of horizontal displacement, specimen (including soil) construction, and clamping methods used. A sketch of the test specimen used is recommended.

13.1.5 Statement of any departures from the suggested test procedure, as required for special studies, so that the results can be evaluated and used.

13.2 Complete test data, including plots of shear force versus horizontal displacement and a plot of shear stress versus normal compressive stress for the tests conducted. Clearly mark all data points, the failure envelope, and the adhesion and coefficient of friction values.

14. Precision and Bias

14.1 The precision of this test method is being established.

14.2 *Bias*—The value of the coefficient of soil and geosynthetic friction can be defined only in terms of the soil and conditions used during testing. Because of the many variables involved and the lack of a superior standard or referee method, there are no direct data to determine bias.

14.2.1 The value of the coefficient of geosynthetic and geosynthetic friction can be defined only in terms of a test method. When this test method is the determining test method, measurements of the coefficient of geosynthetic/soil and geosynthetic/geosynthetic friction have no bias.

15. Keywords

15.1 coefficient of friction; direct shear; geosynthetics; interface shearing resistance; performance test