Designation: D5321 – 12

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; 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.

1.3 The test method is not suited for the development of exact stress-strain relationships for 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:*[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 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

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 Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method

3. Terminology

3.1 *Definitions:* 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 *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).

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

3.2.3 *Mohr-Coulomb shear strength envelope, n*—(angle of friction between two materials) (degrees) the angle whose tangent is the slope of the line relating limiting value of the shear stress that resists slippage between two solid bodies and the normal stress across the contact surface of the two bodies. Limiting value may be at the peak shear stress or at some other failure condition defined by the user of the test results. This is commonly referred to as interface friction angle. **(D653)**

3.2.4 *Mohr-Coulomb friction angle, δ, n*—(angle of friction of a material or between two materials, degrees) 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).

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[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.

NOTE 1—The end user is cautioned that some organizations (for example, FHWA, AASHTO along with state agencies who using 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 (Reference: AASHTO, 2010. LRFD Bridge Design Specifications, 5th Edition, American Association of State Highway and Transportation Officials, Washington, D.C. and FHWA, 2009. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines, U.S. Department of Transportation, Federal Highway Administration, Washington DC, FHWA NHI-10-024 Vol I, NHI-10-025 Vol II, and as FHWA GEC011).

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

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:

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

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

NOTE 2—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 *secant friction angle,* δ_{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 2shear strength-normal stress failure envelope. Intended to be used only for the normal stress on the shearing plane for which it is defined.

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 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 3). 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 3—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 Note 4 and Note 5). The determined value may be a function of the applied normal stress, material characteristics (for example, of the geosynthetic), soil properties, size of sample, drainage conditions, displacement rate, magnitude of displacement, and other parameters.

NOTE 4—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 standard.

NOTE 5—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 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 vs. 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 standard 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 are 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 6—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 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 that contains soil must be a minimum of 50 mm (2 in.) or six times the maximum particle size of the coarser soil tested, whichever is greater.

NOTE 7—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 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 6.35mm/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 8)

NOTE 8—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 indicatorus such as dial indicators, or linear variable differential transformers (LVDT), 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 non-uniform 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 and/or bottom 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 or textured surfaces. Selection of the type of texture surface should be based on the following criteria:

6.5.1 The gripping surface should be able to mobilize fully 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 9—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 10—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: 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.

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

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 (Note 11 and Note 12).

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 Note 11 and Note 12). All the 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 1⁄10 the width of the unit.

NOTE 11—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 12—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

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 13)

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 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 13—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: