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Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method¹

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1. Scope

1.1 This test method covers a procedure for determining the internal shear resistance of a Geosynthetic Clay Liner (GCL) or the interface shear resistance between the GCL and an adjacent material under a constant rate of displacement or constant stress.

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

1.3 This test method is applicable to all GCLs. Remolded or undisturbed soil samples can be used in the test device.

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

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

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards: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/ft³ (600 kN-m/m³))

¹ This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.04 on Geosynthetic Clay Liners.

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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.

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))

D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

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

D4439 Terminology for Geosynthetics

D6072 Practice for Obtaining Samples of Geosynthetic Clay Liners

3. Terminology

3.1 *Definitions*—For definitions of terms relating to soil and rock, refer to Terminology **D653**. For definitions of term relating to GCLs, refer to Terminology **D4439**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *adhesion, c_a , n* —the shearing resistance between two unlike materials under zero normal stress.

3.2.2 *angle of friction, n* —(angle of friction of a material or between two materials, $^\circ$), the angle whose tangent is the ratio between the limiting value of the shear stress that resists slippage internal to a body or between two solid bodies at rest with respect to each other and the normal stress across the contact surface.

3.2.3 *atmosphere for testing geosynthetics, n* —air maintained at a relative humidity of between 50 and 70 % and temperature of $21 \pm 2^\circ\text{C}$ ($70 \pm 4^\circ\text{F}$).

3.2.4 *coefficient of friction, n* —a constant proportionality factor relating shear to normal stress for a defined failure condition.

3.2.5 *cohesion c , n* —shear strength of material, or the interface between two materials, at zero normal stress; the component of the shear strength indicated by the term c , in Coulomb's equation $\tau = c + \sigma_n \tan(\phi)$.

3.2.6 *direct shear friction test, n* —for GCLs, a procedure in which the internal GCL or the interface between a GCL and

any other surface, under a constant normal stress specified by the user, is stressed to failure by the relative movement of one surface against the other for interface strength and by internal shear for internal strength.

3.2.7 *GCL, n*—a manufactured hydraulic barrier consisting of clay bonded to a layer, or layers, of geosynthetic materials.

3.2.8 *residual strength, n*—value of shear stress at sufficiently large displacement that shear stress remains constant with continued shearing.

3.2.9 *post-peak strength, n*—values of shear stress at some displacement beyond the peak shear strength where the shear stress approaches a constant value with continued displacement.

4. Summary of Test Method

4.1 The shear resistance internal to the GCL or between a GCL and adjacent material, or between any GCL combination selected by the user, is determined by placing the GCL and one or more contact surfaces, such as soil, within a direct shear box. A constant normal stress representative of field 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 horizontal displacement of the moving section of the shear box.

4.2 The test is performed for a minimum of three different normal stresses, selected by the user, to model appropriate field conditions. 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 whose slope is the coefficient of friction for peak strength between the two materials where the shearing occurred, or within the GCL. The y-intercept of the straight line is the cohesion intercept for internal shearing or adhesion intercept for interface shearing. 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, or the post-peak internal strength within the GCL. If the post-peak shear stresses have reached a constant value less than the peak strength, the post-peak strength is the interface residual strength or the internal residual strength.

5. Significance and Use

5.1 The procedure described in this test method for the shear resistance for the GCL or the GCL 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 GCLs, 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 1 and Note 2). The determined value may be a function of the applied normal stress, material

characteristics, size of sample, moisture content, drainage conditions, displacement rate, magnitude of displacement, 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—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 within a GCL or between a GCL and adjacent material. 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 GCL used, method of material placement and hydration, normal and shear stresses applied, means used to hold the GCL in place, 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. 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 results can be used in the design of GCL applications, including but not limited to, the design of liners and caps for landfills, cutoffs for dams, and other hydraulic barriers.

5.4 While the peak strengths and post-peak strengths measured by this test are generally reproducible by multiple laboratories, the displacement at which peak strength and post-peak strength occurs and the shape of the shear stress-horizontal 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 horizontal displacement measured in this test at peak strength may not match relative horizontal 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 3—The position of one of the containers should be adjustable in the normal direction to compensate for vertical deformation of the GCL, soil and adjacent materials.

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_{35} 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 at least 50 mm (2 in.) or six times the maximum particle size of the coarser soil tested, whichever is greater.

NOTE 4—The minimum container dimensions given in 6.1.1 are guidelines based on requirements for testing most combinations of GCLs and adjacent materials. 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. 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 force on the specimen for the duration of the test. Careful control and accuracy ($\pm 2\%$) of normal force 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 less than 2° from the shear direction during shearing. The device must be calibrated to determine the normal force 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 horizontal 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 $\pm 10\%$ 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 5).

NOTE 5—The operating range of normal 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 horizontal displacement and 25 mm (1 in.) for vertical displacement are recommended. The sensitivity of displacement indicators should be at least 0.02 mm (0.001 in.) for measuring horizontal displacement and 0.002 mm (0.0001 in.) for measuring vertical displacement.

6.5 *GCL Clamping Devices*, required for fixing GCL 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 GCL specimens flat during testing. Gripping surfaces must develop sufficient shear resistance to prevent non-uniform displacement of the GCL 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. Where the internal shear resistance of the GCL is to be measured, rough (textured) surfaces must be used on the top and bottom of the GCL to force internal shearing within the GCL. 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 rough surfaces. Selection of the type of rough 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 GCL: The rough surfaces must be able to prevent slip between the GCL and the gripping surface to prevent tensile failure in the geotextile. This requirement also applies to any geosynthetics used to determine interface shear strength of the GCL.

6.5.2 The gripping surface must be able to completely transfer the applied shear force through the outside surfaces into the inside of the GCL: A textured steel gripping surface made of rasps, truss plates, nail boards or machined angled spikes 1-2 mm tall mounted on a rigid substrate have been found to work. Truss plates with teeth ground down so they extend 1-2 mm into the GCL with at least 1 point per cm^2 are the preferred gripping surface for this standard, and should be used unless specific factors dictate a different gripping surface. Indicate the gripping surface type, spacing and height on the test report. Gluing of the GCL to a substrate may influence the strength behavior of the GCL and may not be used.

6.5.3 The gripping surface must not extend into the failure plane for internal shear of the GCL. The resulting failure surface for internal shear of GCL should be entirely within the GCL.

NOTE 6—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 resistance data. Accuracy, reproducibility, and relevance to field conditions 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 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. GCL Sampling

7.1 *Lot Sample*—Divide the product into lots, and for any lot to be tested, take the lot sample as directed in Guide D6072 (see Note 5 and Note 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 GCL 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 the required number of specimens as outlined in 7.3.1.

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 (see Note 7 and Note 8). 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 GCL production unit than $\frac{1}{10}$ the width of the unit.

NOTE 7—Lots for GCLs usually are designated by the producer during manufacturing. While this 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 8—The strength characteristics of some GCLs 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. The direction of shear in the GCL 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, 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.

8.2 Assemble the shear device completely without placing a specimen inside it. If the device 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 boxes 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 50 mm (2 in.) total horizontal displacement. Record the applied shear force at 1 mm (0.05 in.) intervals. Determine the average shear force over 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.

8.4 *Calibrations*—Calibration of electronic equipment used in this method and calibration for device friction should be performed at least once per year using methods traceable to NIST reference standards. Check calibrations using documented internal reference methods should be performed at least every 3 months, or any time the equipment has been moved, modified, damaged, rusted or unused for more than 1 month.

9. Conditioning

9.1 Maintain samples at the as-received moisture content until ready to cut specimens for testing.

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

9.3 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 D2487	Minimum Standing Time, h
SW, SP	No Requirement
SC, SM, ML, CL, MH, CH	16

9.3.1 In the absence of specified conditioning criteria as described in 9.4, the test should be performed at the temperature specified in the standard atmosphere for testing GCLs. Relative humidity should be controlled when specified by the user.

9.4 The minimum user specified conditioning criteria include the following:

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

9.4.2 Type of clamping, and gripping surfaces, or both.

9.4.3 Compaction criteria for soil(s), including dry unit weight, moisture content and conditions for compacting the soil adjacent to the GCL or other geosynthetics.

9.4.4 Sample conditioning, such as, wetting, soaking/hydration, and consolidation of GCL separately or with entire test section. Wetting should be defined by either pouring water onto the sample or by spraying GCL or other geosynthetic with water. Conditions must be defined during soaking/hydration for the type of fluid, duration of soaking, criteria to define completion of consolidation during soaking, normal stress to be applied during soaking, and whether GCL is to be hydrated by itself or with other interface components assembled. The GCL should be hydrated sufficiently long to come to full hydration unless otherwise specified. Hydration may be performed outside of the shear box under the required conditions and the hydrated specimen than transferred to the shear box, provided (1) the GCL is not damaged by the transfer, (2) the hydrating conditions have not caused bentonite to extrude to