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Standard Test Method for Determining the Internal and Interface Shear Strength of Geosynthetic Clay Liner by the Direct Shear Method[1]

This standard is issued under the fixed designation D6243/D6243M; 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 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 deformation.

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. See Test Method D5321/D5321M for interface shear testing of non-GCL geosynthetics.

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 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 non-conformance with the standard.

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/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

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

D5321/D5321M Test Method for Determining the Shear Strength of Soil-Geosynthetic and Geosynthetic-Geosynthetic Interfaces by Direct Shear

D6072/D6072M 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 terms relating to GCLs, 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.

3.2.2 *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].

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

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 13.6).

3.2.4.1 *Discussion*—The end user is cautioned that some

[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.

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.[3,4]

3.2.5 *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**

3.2.6 *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 shear strength-normal stress failure envelope. Intended to be used only for the normal stress on the shearing plane for which it is defined.

3.2.7 *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:

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

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

3.2.7.3 *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.

3.2.8 *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 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 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 horizontal 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 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 whose slope is the Mohr-Coulomb friction angle 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.

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 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 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 standard.

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 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

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

[4] "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines," *FHWA GEC 011*, FHWA-NHI-10–024, Vol 1 and FHWA-NHI-10–025, Vol II, U.S. Department of Transportation, Federal Highway Administration (FHWA), Washington, DC, 2009.

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 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 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 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 4—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 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 should be at least 50 mm [2 in.] or six times 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 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 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 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 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 at least 0.02 mm [0.001 in.] for measuring shear 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. 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. 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 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 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 to 2 mm tall mounted on a rigid substrate have been found to work. Truss plates with teeth ground down so they extend 1 to 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 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.[5]

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. 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 Practice D6072/D6072M (see Notes 6 and 7).

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 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 three specimens for shearing in a direction parallel to the cross-machine, or cross-roll, direction, if required (see Notes 9 and 10). 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 GCL production unit than 1⁄10 the width of the unit.

NOTE 9—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 10—The shear 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. 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 GCL specimen(s) must be noted clearly in 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, 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. (See Note 11).

NOTE 11—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.

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 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 75 mm [3 in.]

[5] 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.

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.

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

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 control should be performed when specified by the user.

9.4 The minimum user specified test conditioning criteria include the following:

9.4.1 The test configuration, including all components from the top to bottom (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 then 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 the outer faces of the geotextile, and (*3*) transfer time is kept to a minimum and the specimen is not allowed to dry.

9.4.5 Normal stresses during the shear phase.

9.4.6 Rate of shearing or the procedure for the lab to follow to establish the shear rate must be given (see 10.7 and 11.6).

10. Procedure A—GCL Internal Shear Strength

10.1 Adjust the lower roughened surface so that it is one-half the thickness of the GCL below the top of the lower box. Place the GCL over the lower roughened surface in the shear box. The lower roughened surface must be sufficiently rough to prevent slippage between the surface and the bottom of the GCL. The specimen must cover the entire substrate. Half the thickness of the GCL should extend above the top of the lower box. If clamps are used, the GCL should be sufficiently long to permit the bottom geotextile to be clamped to one side of the bottom shear box and the top geotextile to be clamped to the opposite side of the top shear box. The GCL must be flat, free of folds and wrinkles, and in complete contact with the roughened substrate.

10.2 Slide the two halves of the shear box together and fix them in the start position.

10.3 Place a top roughened surface over the GCL specimen. The top plate must be sufficiently rough to prevent slippage between the top of the GCL and the plate. Fix the loading plate and apply the normal stress to the specimen. Gripping and clamping systems currently available may not shear GCL specimens internally under some test conditions, such as tests under low normal loads.

10.4 Apply a 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 12.)

NOTE 12—The acceptance sequence for the seating load, normal load, and wetting will depend on the application, as described in 9.4. Insufficient information exists at this time to provide a single application sequence. Tailor the test sequence to application conditions. Use methods described in Test Method D2435/D2435M to determine when primary consolidation is complete. Use a degree of primary consolidation of 90 % or more as the equilibrium condition. Avoid applying a single load increment sufficiently large to cause bentonite to squeeze through the geotextile, unless that load increment simulates an actual field condition as requested by the user.

10.5 If the seating load does not equal the normal load for shearing, increase the normal load in steps to avoid squeeze out of bentonite from the GCL. When the normal load for the shear test is reached, monitor vertical displacements until the sample comes to equilibrium. Verify equilibrium (see Note 12) before proceeding. If the GCL has been hydrated in a separate apparatus and transferred to the shear box, apply the same load used in hydration in the shear box and verify equilibrium, or wait for a time period not less than twice the time taken to removal of the seating load in the hydrating box until its reapplication in the shear box. The normal load may have to be applied in increments with time for consolidation allowed in each increment to avoid extrusion of bentonite outside the GCL geotextiles. The GCL should be allowed to fully consolidate under the final increment so that excess pore pressures are essentially zero prior to the start of shear.

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 loading ram to minimize the induced moment. 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.

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.

NOTE 13—The appropriate rate of horizontal loading for GCLs depends on several factors, including the GCL, the materials on both sides of the GCL, the normal stress level, the hydrating conditions and the field drainage conditions. Research has shown that rates of 1 mm/min for interface shear and 0.1 mm/min for internal shear provide appropriate shear strengths for design purposes provided the test specimens are fully hydrated under a normal stress of at least 1 psi and consolidated under a normal stress of 10 psi. Other conditions may require determination of the appropriate hydrating conditions, consolidation conditions, and strain rates to simulate actual field conditions. Some of the older shear boxes for this test cannot displace slower than 0.125 mm/min. This rate is an acceptable substitute for 0.1 mm/min.

NOTE 14—Direct shear tests also may 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.

10.8 Record the shear force as a function of 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 15). The test may be stopped sooner if the shear force has reached steady-state (see Note 16).

NOTE 15—Some interfaces may require displacement larger than 3 in. to reach a steady-stage strength value. Other methods such as reset tests, reversal tests and drum shear apparatus may be required in these instances.

NOTE 16—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. Note evidence of tensile shear strains within the specimen or at the clamps.

10.11 Evidence of shear strains from testing 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 stress, or the substrate-GCL interface made rougher to prevent slippage.

10.12 At the end of the test, take a sample from the center of the GCL and determine its moisture content.

10.13 Repeat the test at a new normal stress with a new GCL specimen. Test a minimum of three specimens (or less if specified by the user), each at a different normal stress selected by the user.

10.14 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.

10.15 Calculate the peak shear stress, and the post-peak shear stress if reached, as directed in 13.2.

11. Procedure B—GCL to Geosynthetic Interface Shear Strength

11.1 Place the lower specimen (GCL or geosynthetic) 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.

11.2 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.

11.3 Slide the two container halves of the shear box together and fix them in the start position. Place the upper 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.

11.4 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 12). If the GCL has been hydrated in a separate apparatus and transferred to the shear box, apply the same load used in hydration in the shear box and verify equilibrium, or wait for a time period not less than twice the time taken to removal of the seating load in the hydrating box until its reapplication in the shear box. The test normal load may have to be applied in increments with time for consolidation allowed in each increment to avoid extrusion of bentonite outside the GCL geotextiles. The GCL should be allowed to fully consolidate under the final increment so that excess pore pressures are essentially zero prior to the start of shear. This may require several days for the final increment.

11.5 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. 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.

11.6 Apply the shear force using a constant rate of displacement that is slow enough to dissipate excess pore pressures, as described in 10.7. 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].

11.7 Record the shear force and horizontal displacement as described in 10.8. Continue the test until the horizontal displacement exceeds 75 mm [3 in.] or other value specified the user. The test may be stopped sooner if the shear force has reached steady-state (see Note 16).

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. Note evidence of tensile strains within the GCL, geosynthetic, 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-GCL 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, take a sample from the GCL and determine its moisture content.

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

11.11 Plot the test data as directed in 10.14.

11.12 Calculate the peak shear stress, and the post-peak shear stress, if reached, as directed in 13.2.

12. Procedure C—Soil on GCL Shear Strength

12.1 Soil can be placed in either the upper or lower container of the direct shear apparatus.

12.2 If soil is to be placed in the upper container, place the GCL 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 GCL. The GCL must extend in the direction of relative movement of the upper box a sufficient distance to permit clamping of the GCL to the lower box. Clamp the GCL to the lower box.

12.2.1 Bring the upper half of the box into position. Place soil within the upper box and in direct contact with the GCL. Compact the soil (see Note 17) to the specified moisture and density. Use care not to damage the GCL 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 17—Compaction of the soil directly on the GCL may cause damage to the GCL specimen. Additionally if the GCL is prehydrated, the soil-GCL interface may become distorted with the possible extrusion of bentonite into the interface. Alternatively, the soil can be compacted in the upper container away from the GCL. If compacted away from GCL, care should be taken to make sure that there is no sidewall friction between the upper container and the soil such that the normal load is fully applied to the soil-GCL interface.

12.2.2 Although this is not preferred, some devices permit the soil to be placed below the GCL in the lower container. 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 GCL 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 18—Sections 12.1 through 12.2 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.

12.3 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 12). If the GCL has been hydrated in a separate apparatus and transferred to the shear box, apply the same load used in hydration in the shear box and verify equilibrium, or wait for a time period not less than twice the time taken to removal of the seating load in the hydrating box until its reapplication in the shear box. The test normal load may have to be applied in increments with time for consolidation allowed in each increment to avoid extrusion of bentonite outside the GCL geotextiles. The GCL should be allowed to fully consolidate under the final increment so that excess pore pressures are essentially zero prior to the start of shear. This may require several days for the final increment.

12.4 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.

12.5 Apply the shear force using a constant rate of displacement that is slow enough to dissipate excess pore pressures, as described in 10.7. 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].

12.6 Record the shear force and horizontal displacement as described in 10.8. Continue the test until the horizontal 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 16).

12.7 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. Note evidence of tensile strains within the GCL 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 GCL 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-GCL 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.

12.8 At the end of the test, remove the soil specimen to determine the moisture content. Take a sample from the GCL and determine its moisture content.

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

12.10 Plot the test data as directed in 10.14.

12.11 Calculate the peak shear stress, and the post-peak shear stress if reached, as directed in 13.2.

13. Calculation

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

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

$$\tau = F_s / A_c \quad (1)$$

where:

τ = shear stress (kPa),
F_s = shear force (kN), (See 10.14 or 11.11)
A_c = corrected area (m^2). (See 13.4 for calculating area correction.)

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

$$\sigma_N = F_N / A_C \quad (2)$$

where:

σ_N = normal stress (kPa),
F_N = normal load (kN), (See 10.5 or per 11.4), and
A_C = corrected area (m^2). (See 13.4 for calculating area correction.)

13.4 For tests in which the area of specimen contact decreases with increased displacement, a corrected area may 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:

$$A_C = A_O - A_i \quad (3)$$

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.

13.4.1 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.

13.5 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.

13.6 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:

$$\tau = C_a + \sigma_n * \tan(\delta) \quad (4)$$

where:

τ = peak shear stress,
σ = normal stress,
δ = 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, intercept C_a for interface strength, or cohesion intercept for internal strength.

13.6.1 Additionally, the Mohr-Coulomb friction angle may be calculated based on shear stresses at some post-peak condition. The procedures in 13.5 and 13.6 can be used to determine a post-peak failure envelope and post-peak adhesion or cohesion intercept, using the shear stress and normal stress for this other condition. Parameters obtained for a condition other than peak should be clearly identified with what condition they relate.

13.7 A secant friction angle may be calculated for each test conducted using the following equation:

$$\delta_{sec} = \tan^{-1}(\tau / \sigma_n) \quad (5)$$

where:

σ_{sec} = secant friction angle (degrees),
τ = measured peak shear stress during test, and
δ_n = measured normal stress during test.

14. Report

14.1 In the report of test results by the direct shear method, include the following information:

14.1.1 Project, type(s), and description of GCL specimens tested and direction tested.

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

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

14.1.4 All test conditions, including normal pressures used, rate of shear displacement, specimen (including soil) construction, and clamping/gripping methods used. A sketch of the test specimen and test setup is recommended.

14.1.5 Statement of any departures from the suggested test procedure, including use of the test device outside of its calibrated operating range, as required for special studies, so that the results can be evaluated and used.

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

14.2.1 Tabulated value-pairs of shear stress (peak and/or user-defined post-peak) and applied normal stresses.

14.2.2 Plots of shear force versus shear displacement.

14.2.3 Plots of shear stress (peak and/or user-defined post-peak) versus normal stress.

14.2.4 If a minimum of three test points were conducted at three different normal loads, the Mohr-Coulomb shear strength envelope for peak and/or user defined post-peak conditions can be plotted and the corresponding value of Mohr-Coulomb friction angle and adhesion can be provided. Indicate over what normal stress range the value of friction angle and adhesion apply.

NOTE 19—If reporting Mohr-Coulomb strength parameters (friction angle and adhesion), it is recommended to add a cautionary note stating that the interpretation of shear strength results should be performed by an experienced practitioner; some materials may have significantly non-linear shear strength envelopes; and it may not be acceptable to extrapolate shear strength envelopes outside of the range of normal stresses that were tested.

14.2.5 If calculated, the secant friction angle value can be reported for each test point.

14.3 Clearly indicate whether area correction is required and applied or not.

14.4 Clearly define the mode of failure and where shearing occurred. It is sometimes useful to include pictures of the failure surface with the description.

15. Precision and Bias

15.1 *Precision*—The precision of this test method is being established.

15.2 *Bias*—The value of the internal and interface shear resistance of GCL can be defined only in terms of the materials 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.

15.2.1 The value of the internal and interface shear resistance of GCL can be defined only in terms of a test method. When this test method is the determining test method, measurements of the internal or interface shear resistance of GCL have no bias.

16. Keywords

16.1 coefficient of friction; direct shear; GCL; interface shear resistance; performance test; shear resistance

APPENDIX

X1. CHECKLIST FOR SPECIFYING TESTS PERFORMED USING ASTM TEST METHOD D6243/D6243M

X1.1 Per 5.1, the direct shear test conditions are generally selected by the user. This appendix is intended to aid the user in specifying the direct shear test parameters required to obtain an intended shear result. It is recommended that the user consult with the test laboratory performing the test.

Type of test: ☐ **Interface shear** ☐ **Internal shear**

Sample Materials to be Tested

Material(s) for which shear will be tested: 1) ______________________
2) ______________________

For geosynthetic materials, one side of the material may differ from the other side of the material. If applicable, note the specific side or characteristics for the side of the material which should be tested at the interface:

1) ______________________

2) ______________________

Orientation of material(s): 1) ☐ Machine Direction ☐ Cross Direction ☐ NA
2) ☐ Machine Direction ☐ Cross Direction ☐ NA

Sample Conditioning

If interface is with soil, specify compaction density and moisture content (MC) for soil placement:

☐ Lightly Compacted ☐ Specified density = _________ ☐ kN/m³ ☐ 1bf/ft³

☐ As-received MC ☐ Specified MC = _________ %

☐ Based on ASTM D698 test results:

Maximum Dry Density = _________ ☐ kN/m³ ☐ 1bf/ft³ Optimum MC = ________ %

☐ Based on ASTM D1557 test results:

Maximum Dry Density = _________ ☐ kN/m³ ☐ 1bf/ft³ Optimum MC = ________ %

Note – Over-sized corrected test values from ASTM D698 and D1557 are typically not applied in calculating compaction density and moisture content as gradations minus 19.5 mm

[0.75 in.] sieve of soil sample are used due to dimensions of most shear boxes. If requesting use of rock correction values to be applied, check box ☐

If compaction unit weight and moisture content for soil placement is based on ASTM D698 or D1557 test results:

Compaction criteria = ________________ % of maximum dry unit weight

Moisture Content = ☐ optimum water content

☐ plus (+) _________ % points(s) relative to optimum

☐ minus (–) _________ % points(s) relative to optimum

Conditioning of GCL: = ☐ Hydrated

☐ Partially hydrated to specific WC = ____________ % WC

☐ Wetted by pouring water over entire specimen

☐ Wetted by spraying water over entire specimen

☐ As-received

If GCL shall be hydrated under applied normal load other than test normal load prior to application of test normal load:

Normal load = ________________ ☐ kPa ☐ lbf/ft^2 ☐ psi

Minimum duration = __________ hours

Conditioning of Other Geosynthetic materials:

☐ Wetted by pouring water over entire specimen

☐ Wetted by spraying water over entire specimen

☐ As-received

Shear Testing Parameters

Shear test normal load: ☐ kPa ☐ lbf/ft^2 ☐ psi

1) __________ 2)__________ 3) __________ 4) __________ 5) __________

Note – The normal loads selected should bracket the design normal loads being evaluated.

List if there is a specified Normal Load Application Sequence to be applied:

____

____

____

Interface saturation condition

- ☐ Inundated with Water—Interface is submerged in water prior to consolidation and through duration of shear.
- ☐ Spray Wetted—The interface surface is wetted using a spray bottle during placement of specimens, but not submerged in water.
- ☐ Dry—No addition of water during placement of specimens or shear.

Seating/Consolidation time under test normal load prior to shearing: __________ hours

Shear displacement rate: (circle appropriate units)

- ☐ 1 mm/min; 0.04 in./min
- ☐ _______ mm/min; in./min

Other test instructions:

____

____

____