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

This standard is issued under the fixed designation D 6243; 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 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:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

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

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

D 2435 Test Method for One Dimensional Consolidation Properties of Soils[2]

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

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

D 4439 Terminology for Geosynthetics[3]

D 5321 Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method[3]

D 6072 Guide for Obtaining Samples of Geosynthetic Clay Liners[3]

3. Terminology

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

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 between solid bodies, °,) the angle whose tangent is the ratio between the limiting value of the shear stress that resists slippage between two solid bodies at rest with respect to each other and the normal stress across the contact surface.

3.2.2.1 *Discussion*—Limiting values may be at the peak shear stress or at some other failure condition defined by the user.

3.2.3 *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).

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

3.2.5 *cohesion, c, n*—the portion of the internal 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 range of normal stresses specified by the user, is stressed to failure by the relative movement of one surface against the other.

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

[1] This test method is under the jurisdiction of ASTM Committee D-35 on Geosynthetics and is the direct responsibility of Subcommittee D35.04 on Geosynthetic Clay Liners.

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

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

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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 generally are represented by a best fit straight line whose slope is the coefficient of friction 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.

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, generally are 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, especially since the test results may be dependent 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. Total shear resistance may be a combination of sliding, rolling, interlocking of soil particles, or adjacent surfaces, and shear strain, or a combination thereof, within the GCL specimen.

5.2.3 This test method does not distinguish between individual mechanisms, which may be a function of the soil used, method of soil placement, normal and shear stresses applied, rate of horizontal displacement, and other factors. Every effort should be made to identify, as closely as is practicable, the sheared area and failure mode of the specimen. 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.

6. Apparatus

6.1 *Shear Device*—A rigid device to hold the specimen securely and in such a manner that a uniform force without torque can be applied to the specimen. The device consists of both a stationary and moving container, 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 deformation of the GCL and adjacent materials.

6.1.1 Square or rectangular containers are recommended. They should have a minimum dimension that is 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 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 stress on the specimen for the duration of the test. Careful control and accuracy (±2 %) of normal stress is important. Normal stress loading devices include, but are not limited to, weights, pneumatic or hydraulic bellows, or piston-applied stresses. For jacking systems, the tilting of loading plates must be limited to less than 2° from horizontal during shearing.

NOTE 5—Due to the potential inaccuracies in the normal stress applied by some test devices, 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.

6.3 *Shear Force Loading Device*, capable of applying a shearing force to the specimen at a constant rate of horizontal displacement (strain controlled), or at a constant horizontal stress (stress controlled) in a direction parallel to the direction of travel of the soil container, or both. 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). In a constant stress test, the horizontal stress shall be maintained to an accuracy of ±2 % of the normal stress. 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.

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. 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.

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 shall not interfere with the shearing surfaces within the shear box and must keep the GCL specimens flat during testing. Flat jaw-like clamping devices normally are sufficient for interface testing. Where the internal shear resistance is to be measured, rough (textured) surfaces must be used on the top and bottom of the GCL to cause 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.

6.5.1 Selection of the type of rough (textured) surface should be based on the flowing criteria:

6.5.1.1 The gripping surface should be able to mobilize fully the friction between the gripping surface and the outside surfaces of the GCL:

6.5.1.2 The gripping surface should be able to transfer completely the shear stress through the outside surfaces into the inside of the GCL:

6.5.1.3 No slippage should occur between the gripping surfaces and the outside surfaces of the GCL, such that a tensile failure occurs within one or both of these surfaces of the GCL:

6.5.1.4 The gripping surface should not damage the outside surfaces of the GCL and should not influence the shear strength behavior of the GCL:

6.5.1.5 The resulting failure surface should be entirely within the GCL.

6.5.2 A textured steel gripping surface made of wood working rasps mounted on a rigid substrate has been found to work. Gluing of the GCL to a substrate may influence the strength behavior of the GCL and should not be used.

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 and reproducibility should be considered when selecting a substrate for testing.

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

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 D 6072 (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). The specimens should be slightly larger than the inside dimensions in all directions of the soil container described in 6.1.1, and they should be of sufficient size to facilitate clamping. All specimens should be free of surface defects, etc., that are not typical of the laboratory sample. Space the specimens along a diagonal of the unit of the laboratory sample. Take no specimens nearer the edge of the GCL production unit than 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. 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. Do not apply a normal stress. 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 any large variation in applied shear force after movement of the traveling container has been initiated. Any such variations may be indications of damaged or misaligned bearings, or an eccentric application of the shear force.

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

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. 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, that is supporting substrates, soil, geosynthetics, GCLs, and gripping surfaces.

9.4.2 Type of clamping, or 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.

9.4.5 Normal stresses during the shear phase.

9.4.6 Method of shearing, that is constant rate of horizontal displacement or constant horizontal stress. For constant rate of horizontal displacement tests, the shear rate must be defined or the procedure for the lab to follow to establish the shear rate must be given (see 10.7 and 11.6). For constant stress tests, the applied shear load, method of application, and test duration must be defined (see Note 10).

10. Procedure A—GCL Internal Shear Resistance

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. The specimen must cover the entire substrate. Half the thickness of the GCL should extend above the top of the lower box. The GCL should be sufficiently long to be clamped.

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. Fix the loading plate and apply the normal stress to the specimen.

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 9)

NOTE 9—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 D 2435 to determine when primary consolidation is complete. Use a degree of primary consolidation of 90 % or more as the equilibrium condition.

10.5 If the seating load does not equal the normal load for testing, apply the normal load for the test and monitor vertical displacements until the sample comes to equilibrium. Verify equilibrium (see Note 9) 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.

10.6 Place and zero the horizontal 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.

10.7 Apply the shear force using a constant rate of displacement or constant stress condition. The rate of loading should be specified by the user. The displacement rate should normally be relatively slow so that insignificant excess pore pressures exist at failure. Some applications may require rapid loading to simulate field conditions.

NOTE 10—Some people use a horizontal displacement of 1 mm/min (0.04 in./min). This value comes from the default value given in Test Method D 5321 for testing the interface strength between geosynthetics and soils. 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. For drained shearing, the following equation can be used as a guide to determine the maximum rate of horizontal displacement:

$$R = \frac{d_f}{50 \cdot t_{50} \cdot \eta} \quad (1)$$

where:

R = rate of horizontal displacement, mm/min,

d_f = estimated horizontal displacement at peak shear stress or at the residual shear strength as requested by the user, mm,

t_{50} = time required for specimen to reach 50 % consolidation under the current normal stress increment determined from methods described in Test Method D 2435 with double drainage, min, and

η = factor to account for drainage conditions on the shear plane:

use 1 for internal shear of GCL with drainage at both boundaries;

use 4 for shear of the interface between GCL and an impermeable material;

use 0.002 for shear of the interface between GCL and a pervious material.

10.7.1 At some values of normal stress, the specimen will not exhibit well defined time-displacement curves from which to determine t_{50} in those instances, at t_{50} estimated for the material with sufficient normal stress to cause compression (not swelling) should be used. If an alternate value of t_f, is selected, the rationale for the selection shall be explained with the test results.

NOTE 11—Direct shear tests also may be conducted using a constant shear stress approach. This approach can be achieved by any of the following three methods:

(a) *Controlled Stress Rate Method*, where the shear force is applied to the test specimen under a uniform rate of horizontal load increase until slipping or failure of the test specimen occurs;
(b) *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;
(c) *Constant Stress Creep Method* where the shear force is applied using method (a) or (b) until the specified constant shear stress is reached. The constant shear stress then is maintained and the test monitored for the duration specified.

The user shall specify the desired loading conditions for the constant shear stress approach.

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

10.9 Run the test until the horizontal displacement exceeds 50 mm (2 in.) or other value specified by the user.

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

10.11 Repeat the test at a new normal stress with a new GCL specimen. Test a minimum of three specimens, each at a different normal stress specified by the user.

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

10.13 Calculate the peak shear stress, and alternatively, the shear stress at the end of the test, if required, as directed in Section12. Subtract the internal shear correction (determined in 8.3) from the shear stress. The difference between the recorded shear stress and the internal shear correction is the actual shear stress applied to the specimen.

11. Procedure B—Interface Shear Resistance

11.1 Place the soil (if used), clamping substrate (if used), and geosynthetic within the lower shear box. If soil is to be used in the lower box, compact it into the lower box to the specified moisture and density. Fill the lower container with soil so that the surface of the soil specimen protrudes a distance equal to one-half of the d_{85} of the soil, as described in Method D 3080. A protrusion of 1 mm is sufficient for fine-grained soils. Carefully level the soil surface.

11.2 Place the GCL loosely onto the roughened surface. 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 the GCL to the upper box.

11.3 Bring the upper half of the box into position and assemble the normal loading apparatus as given by the manufacturer's instructions. Use a roughened plate between the top of the GCL and the normal loading plate. Clamp the GCL to the upper box.

NOTE 12—Sections 11.1-11.3 apply to commonly occurring test conditions. Other interface conditions, test conditions, and material combinations may be desired to model specific test conditions. The test report should describe specific variations made from this test method to model specific conditions.

11.4 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 9). 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.

11.5 Place the 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. If necessary, adjust the location of the loading ram to minimize the induced moment.

11.6 Apply the shear force using a constant rate of displacement that is slow enough to dissipate soil 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 as described in 10.8. Continue the test until the horizontal displacement exceeds 50 mm (2 in.) or other value specified the user.

11.8 Remove the normal stress and disassemble the device at the end of the test. Carefully inspect and identify the failure surface of the specimen and the area of the specimen clamp. Specimen failures should be consistent for all tests in order for the test data to be comparable.

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

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

11.11 Plot the test data as directed in 10.12 and 10.13.

12. Calculation

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

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

$$\tau = F_s/A_c \tag{2}$$

where:
τ = shear stress (kPa),
F_s = shear force (kN), and
A_c = corrected area (m^2).

12.2.1 For tests in which the area of specimen contact decreases with increased displacement, a corrected area 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 horizontal displacement of the traveling container. For square or rectangular containers, the corrected area is calculated for each displacement reading using the following equation:

$$A_c = A_o - (d \times W) \tag{3}$$

where:

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

12.2.2 No area correction may be required for tests in which the stationary container is larger than the traveling container, provided that the horizontal displacement of the traveling container does not result a decrease in specimen contact area (see Note 13).

NOTE 13—For devices which apply the normal stress as a constant force, for example by dead weights, any area correction applied to the shear force also should be applied to the normal force.

12.3 Plot the limiting values of shear stress versus applied normal stress for each test conducted. Limiting values typically are at peak shear stress and at the end of the test. Other limiting values may be specified by the user. The shear stress and normal stress axes must be drawn to the same scale.

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

$$\tau = c + \sigma_n \times \tan(\phi) \tag{4}$$

where:

τ = peak shear stress,
σ_n = normal stress,
ϕ = angle of friction (degrees), and
c = cohesion intercept.

The y-intercept of the straight line with $x = 0$ axis is the adhesion intercept, intercept c_a, or cohesion intercept.

12.5 Additionally, the coefficient of friction may be calculated based on shear stresses at some displacement or at the end of the test. The procedures in 12.4 can be used to determine a friction angle and 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. Report

13.1 In the report of the internal or interface shear resistance by the direct shear method, include the following information:

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

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

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

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

13.1.5 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.

13.2 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 friction angle values. Indicate over what normal stress range the values of adhesion or cohesion and friction angle apply.

14. Precision and Bias

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

14.2 *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.

14.2.1 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.

15. Keywords

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