Designation: D7499/D7499M − 09 (Reapproved 2014)

Standard Test Method for Measuring Geosynthetic-Soil Resilient Interface Shear Stiffness[1]

This standard is issued under the fixed designation D7499/D7499M; 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 details how cyclic loading is applied to geosynthetics embedded in soil to determine the apparent stiffness of the soil–geosynthetic interface.

1.2 Resilient interface shear stiffness describes the shear stiffness between a geosynthetic and its surrounding soil under conditions of small cyclic loads.

1.3 This test method is intended to provide properties for design. The test method was developed for mechanistic empirical pavement design methods requiring input of the resilient interface shear stiffness. The use of this parameter from this test method for other applications involving cyclic loading should be evaluated on a case-by-case basis. It can also be used to compare different geosynthetics, soil types, etc., and thereby be used as a research and development test procedure.

1.4 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.

1.5 *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. This standard may involve hazardous materials, and equipment.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3080/D3080M Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

D4439 Terminology for Geosynthetics

D4354 Practice for Sampling of Geosynthetics and Rolled Erosion Control Products(RECPs) for Testing

3. Terminology

3.1 For definitions of other terms used in this test method refer to Terminologies D123, D653, and D4439.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apertures, n*—the open spaces in geogrids which enable soil interlocking to occur.

3.2.2 *atmosphere for testing geosynthetics, n*—air maintained at a relative humidity of 60 ± 10 % and a temperature of 21 ± 2°C [70 ± 4°F].

3.2.3 *cross-machine direction, n*—the direction in the plane of the geosynthetic perpendicular to the direction of manufacture.

3.2.4 *failure, n*—an arbitrary point at which a material ceases to be functionally capable of its intended use.

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

3.2.6 *geosynthetic-soil resilient interface shear stiffness, n*—a parameter that describes the apparent stiffness of the interface between the soil and the geosynthetic determined by calculating the slope of the shear stress, shear displacement curve as the embedded geosynthetic is subjected to a cyclic load.

3.2.7 *junction, n*—the point where geogrid ribs are interconnected in order to provide structure and dimensional stability.

3.2.8 *machine direction, n*—the direction in the plane of the geosynthetic parallel to the direction of manufacture.

3.2.9 *pullout, n*—the movement of a geosynthetic over its entire embedded length, with initial pullout occurring when the back of the specimen moves, and ultimate pullout occurring when the movement is uniform over the entire embedded length.

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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.10 *pullout force, (kN), n*—force required to pull a geosynthetic out of the soil during a pullout test.

3.2.11 *pullout resistance, (kN/m), n*—the pullout force per width of geosynthetic measured at a specified condition of displacement.

3.2.12 *rib, n*—the continuous elements of a geogrid which are either in the machine or cross-machine direction as manufactured.

3.2.13 *wire gage, n*—a displacement gage consisting of a non extensible wire attached to the geosynthetic and monitored by connection to a dial extensometer, or electronic displacement transducer.

4. Summary of Test Method

4.1 In this test method, a horizontal layer of geosynthetic is embedded between two layers of soil. Six prescribed levels of horizontal cyclic force are applied to the geosynthetic at five specified levels of normal stress confinement. The maximum and minimum forces and corresponding displacements are recorded for the last ten cycles of each combination of normal stress and cyclic force (loading sequence).

4.2 The resilient interface shear stiffness (kPa/m or psi/in) of the test specimen can be calculated for any loading sequence by dividing the cyclic shear stress by the corresponding net recoverable horizontal displacement of the embedded geosynthetic

5. Significance and Use

5.1 This test method is intended as a performance test to provide the user with a set of design values for the test conditions examined.

5.1.1 The test method is applicable to all geosynthetics and all soils when loaded in a cyclic manner.

5.1.2 This test method produces test data, which can be used in the design of geosynthetic-reinforced pavement structures or in applications where geosynthetics are subjected to cyclic loads.

5.1.3 The test results may also provide information related to the in-soil stress-strain response of a geosynthetic under confined loading conditions.

5.2 Information derived from this test may be a function of soil gradation, plasticity, as-placed dry unit weight, moisture content, length and surface characteristics of the geosynthetic and other test parameters. Therefore, results are expressed in terms of the actual test conditions. The test measures the net effect of a combination of interface shear mechanisms, which may vary depending on type of geosynthetic specimen, embedment length, relative opening size, soil type, displacement rate, normal stress, and other factors.

5.3 Information between laboratories on precision is incomplete. In cases of dispute, comparative tests to determine if there is a statistical bias between laboratories may be advisable.

6. Apparatus

6.1 *Test Box*—An open rigid box consisting of two smooth parallel sides, a back wall, a horizontal split removable door, a bottom plate, and a load transfer sleeve. The door is at the front as defined by the direction of applied cyclic force. A typical box is shown in Fig. 1.

6.1.1 The box should be square or rectangular with minimum dimensions 457 mm [18 in.] long by 457 mm [18 in.] wide by 305 mm [12 in.] deep, if sidewall friction is minimized, otherwise the minimum width should be 760 mm [30 in.]. The dimensions should be increased, if necessary, so that minimum width is the greater of 20 times the D85 of the soil or 6 times the maximum soil particle size, and the minimum length greater than 5 times the maximum geosynthetic aperture size. The box shall allow for a minimum depth of 150 mm [6 in.] above and below the geosynthetic. The depth of the soil in the box above or below the geosynthetic shall be a minimum of 6 times the D85 of the soil or 3 times the maximum particle size of the soil, whichever is greater. The box must allow for at least 305 mm [12 in.] embedment length beyond the load transfer sleeve.

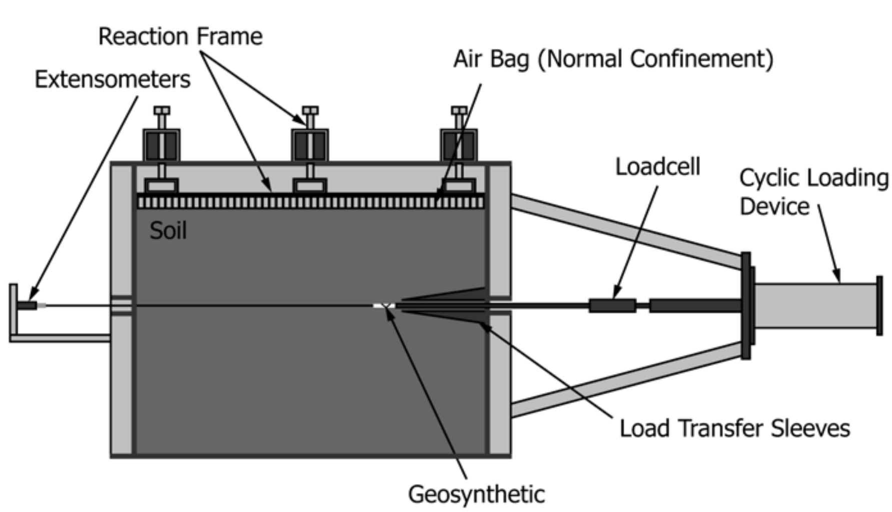

FIG. 1 Side View of Typical Test Device

NOTE 1—To remove side wall friction as much as possible a high density polyethylene (HDPE) geomembrane should be bonded to the inside surfaces of the pullout box. The sidewalls may also be covered with a layer of silk fabric, which has been shown to eliminate adhesion and has a very low friction value. Alternatively, a lubricant can be spread on the sidewalls of the box and thin sheets of polyethylene film used to minimize the side wall friction. It should be also noted that the effect of sidewall friction on the soil-geosynthetic interface can also be eliminated if a minimum distance is kept between the specimen and the side wall. This minimum distance is recommended to be 150 mm [6 in.].

6.1.2 The box shall be fitted with a pair of metal sleeves (load transfer sleeves) at the entrance of the box to transfer the force into the soil to a sufficient horizontal distance so as to significantly reduce the stress on the door of the box. The sleeves shall consist of two tapered (illustrated in Fig. 3) or non-tapered (no more than 13 mm [0.5 in.] thick) plates extending the full width of the pullout box and into the pullout box a minimum distance of 150 mm [6 in.], but it is recommended that this distance equal the total soil depth above or below the geosynthetic. Both design types must possess tapered edges at the point of load application in the soil that are no more then 3 mm [0.12 in.] thick. The plates shall be rigidly separated at the sides with spacers and be sufficiently stiff such that normal stress is not transferred to the geosynthetic between the plates.

6.2 *Normal Stress Loading Device*—Normal stress applied to the upper layer of soil above the geosynthetic must be constant and uniform for the duration of the load step. To maintain a uniform normal stress, a flexible pneumatic or hydraulic diaphragm-loading device which is continuous over the entire test box area should be used and capable of maintaining the applied normal stress within ±2 % of the required normal stress. Normal stresses utilized will depend on testing requirements; however, stresses up to 250 kPa [35 psi] should be anticipated. A recommended normal stress-loading device is an air bag.

6.3 *Cyclic Force Loading Device*—Horizontal cyclic force must be supplied by a device with the ability to apply cyclic load in the direction of the opening of the box. The force must be at the same level with the specimen.

6.3.1 The cyclic force system must be able to apply multiple load repetitions using a haversine-shaped load pulse consisting of a 0.2 s load followed by a 0.80 s rest period. The loading system must also be able to simultaneously maintain a minimum seating load on the material during cyclic loading.

6.3.2 Also, a device to measure the cyclic force (that is, a load cell) must be incorporated into the system and shall be accurate within ±0.5 % of its full-scale range.

6.4 *Displacement Indicators*—Horizontal displacement of the geosynthetic is measured at the entrance of the box and at several locations on the embedded portion of the specimen. Measurements outside the door at the box entrance are made by electronic displacement transducers (for example, linear variable differential transformers (LVDTs) can be used) mounted to the box frame to read against a plate attached to the specimen near the door.

6.4.1 Displacement measurements within the box may employ any of several methods, which place sensors or gauge connectors directly on the geosynthetic and monitor their change in location remotely. One such device utilizes wire gages, which are protected from normal stress by a surrounding tube, which runs from a location mounted on the specimen to the outside of the box where displacements are measured by displacement transducers.

6.4.2 All electronic measurement devices must be accurate to ±0.01 mm. Locations of the devices must be accurately determined and recorded. Minimum extension capabilities of 50 mm [2 in.] are recommended.

6.4.3 Determine the displacement of the geosynthetic at the front (leading end) and the rear (embedded end) of the geosynthetic at several locations along its width; suggested layout is shown in Fig. 2.

6.5 *Geosynthetic Clamping Devices*—Clamps which connect the specimen to the cyclic force system without slipping, causing clamp breaks or weakening the material may be used, see Note 2. The clamps shall be swiveled to allow the cyclic forces to be distributed evenly throughout the width of the sample. The clamps must allow the specimen to remain horizontal during loading and not interfere with the interface shear surface. Gluing, bonding, or otherwise molding of a geosynthetic within the clamp area is acceptable and recommended whenever slippage might occur. Thin metal rods or tubes may be used to reduce friction between the geosynthetic clamp/sample and the top edge of the lower load transfer sleeve (Fig. 3).

NOTE 2—A suggested method of clamping is shown in Fig. 4 and includes a simple clamp consisting of two pieces of 22 gauge sheet metal glued to both sides of the geosynthetic sample. The sheet metal plates should be at least the same width as the geosynthetic being tested. Special precautions should be taken to ensure that geotextile samples adhere to the sheet metal–such as making holes for the epoxy to flow through the fabric, however; all such modifications to the fabric to facilitate bonding should not interfere with the remainder of the geosynthetic protruding from the front edge of the sheet metal.

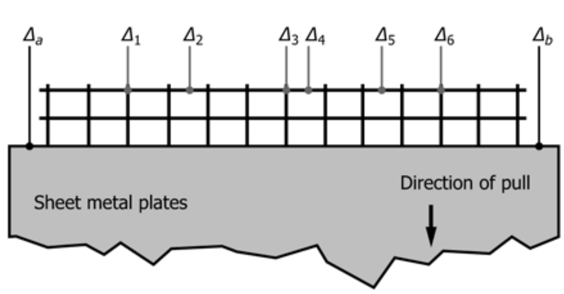

FIG. 2 Example Instrumentation Layout

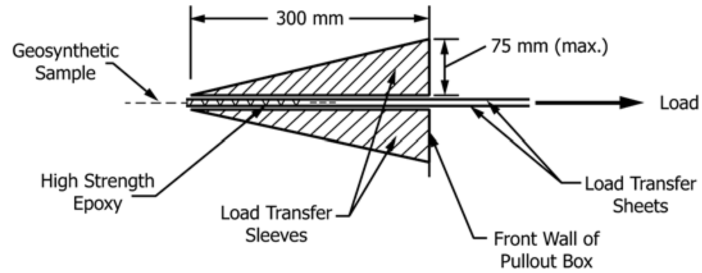

FIG. 3 Side View of Load Transfer Sleeve Arrangement

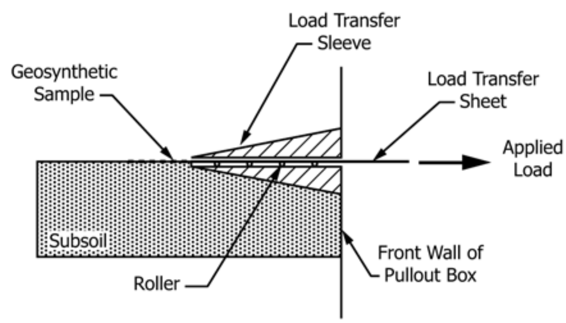

FIG. 4 Geosynthetic Clamping Detail

6.6 *Soil Preparation Equipment*—Use equipment as necessary for the placement of soils at desired conditions. This may include compaction devices such as vibratory or "jumping-jack" type compaction, or hand compaction hammers. Soil container or hopper, leveling tools and soil placement/removal tools may be required.

6.7 *Miscellaneous Equipment*—Measurement and trimming equipment as necessary for geosynthetic preparation, a timing device and soil property testing equipment if desired.

7. Geosynthetic Sampling

7.1 *Lot Sample*—Divide the product into lots and for any lot to be tested, take the lot samples as directed in Practice D4354, see Note 3.

NOTE 3—Lots of geosynthetics are usually designated by the producer during manufacture. While this test method does not attempt to establish a frequency of testing for 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, panel, etc.) designated by the producer.

7.2 *Laboratory Sample*—Consider the units in the lot sample as the units in the laboratory sample for the lot to be tested. Take for a laboratory sample, a sample extending the full width of the geosynthetic production unit, of sufficient length along the selvage or edge from each sample roll so that the requirement of 7.3 can be met. Take a sample that will exclude material from the outer wrap unless the sample is taken at the production site, at which point inner and outer wrap material may be used.

7.3 *Test Specimens*—For each unit in the laboratory sample, remove the required number of specimens.

7.3.1 Remove the minimum of specimens for testing in a required direction, see Note 4. The length of the embedded geosynthetic should be between 51 mm [2 in.] and 102 mm [4 in.] and contain two full grid apertures. Samples that do not meet these criteria should follow the guidelines outlined in Note 5. The width of the specimen shall be at least 305 mm [12 in.] and must allow for a minimum of 75 mm [3 in.] clearance on each side of the test specimen from the side walls of the test box if the side wall friction is minimized (see Note 1), otherwise the minimum clearance should be 150 mm [6 in.] on each side. The length of the test specimen shall be of sufficient size to facilitate clamping and maintain the required length and width specifications. The minimum width of the test specimen shall be 305 mm [12 in.] and should include a minimum of five tensile elements (that is, ribs/strands). All specimens should be free of surface defects, etc., not typical of the laboratory sample. Take no specimens nearer the selvage edge of the geosynthetic production unit than 1⁄10 the width of the unit.

NOTE 4—The interface interaction characteristics of some geosynthetics may depend on the direction tested. In some applications, it may be necessary to perform tests in both the machine and the cross-machine directions. In all cases, the direction of cyclic load of the geosynthetic specimen(s) should be clearly noted.

NOTE 5—The sample length is relatively short when compared to traditional pullout tests to ensure that strain and shear stress along the length of the geosynthetic are generally uniform when loaded. The length of the geosynthetic should be reduced if the strain in the first 1.0 cm of embedded length is greater than 5 %. However, the length of geogrids should not be less than one aperture or contain partial apertures. Specimen sizes that are longer than specified or contain more than two grid apertures are permissible provided shear stress and strain remain relatively uniform along the entire embedded specimen length throughout the test.

8. Conditioning

8.1 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 testing agency. In the absence of specified conditioning criteria, the test should be performed in the atmosphere for testing geotextiles defined in 3.2.2.

8.2 When the geosynthetic is to be tested in the wet condition, saturate the specimen in water for a minimum of 24 h prior to testing, see Note 6.

NOTE 6— Geosynthetics which do not absorb measurable quantities of water, such as some geomembranes, geogrids, and geonets, may not require a full 24 h saturation period for the purpose of this test.

9. Procedure

9.1 *Prepare Pullout Box*—Assemble pullout box with only the bottom half of the door in place. Determine the amount of soil necessary to achieve the desired dry unit weight of the soil when placed in the lower half of the box. The bottom layer of soil should be slightly above the bottom half of the door (approximately 5 mm [0.2 in.] – Fig. 4) to avoid dragging of the geosynthetic on the door. The calculated amount of soil is placed in the bottom section of the box and compacted as required. The required number of lifts and amount of compactive effort to be used is a function of the soil type and moisture content, and should be noted. The soil placement procedure that is used should allow for a uniform soil dry unit weight along the box. Level the soil surface. The front section of soil should be excavated such that the bottom part of the metal sleeve can be placed with the upper surface horizontal and level with the soil.

NOTE 7—The effects of pore water pressure have not been evaluated for this test method. This test should be run dry, using only sufficient moisture to attain the specified compacted density.

9.2 *Place Geosynthetic*—Obtain a test specimen as described in Section 7. Trim the specimen to fit loosely inside the box using the width specifications outlined in 6.1.1 and 7.3. Clamp the sample outside the entrance of the box, gluing or preparing the area within the clamp, as necessary, without damaging the sample. Connect sample and clamp to the cyclic force device. Place the geosynthetic within the metal sleeve at the box entrance. Attach the electronic displacement transducers to the clamp outside of the box.

9.2.1 Next, the in-soil displacement devices are installed. Connect the gauges to the specimen and measure locations of gauges relative to the door. Multiple gauges should be evenly spaced along the width of the sample at the front (loaded end) and rear (embedded end). Gauges can be attached by hooking wire to a glued-on tab or in the case of geogrids, attaching directly on to the specimen. Care must be taken to assure any slack in the wire is eliminated.

9.2.2 The front (or leading) edge of the embedded geosynthetic should be lined up with the embedded edge of the load transfer sleeves (Fig. 4).

9.3 *Embed the Geosynthetic*—Install top metal sleeve and top half of door positioned above the test specimen at the entrance of the box. Place the desired amount of soil on top of geosynthetic to the required level (see 6.1). Use the same placement method as used for the bottom soil layer, see 9.1.

9.4 *Apply Normal Compressive Stress*—Normal stress can be provided by way of a hydraulic or pneumatic diaphragm method as previously described in 6.2. Hydraulic and/or pneumatic devices must be calibrated and any change in pressure during testing noted. Normal stresses must be applied before test is started. If consolidation of the soil in the box is required to eliminate excess soil pore pressure or to model field conditions, the required time for consolidation should be calculated as outlined in Test Method D3080/D3080M.

9.5 *Testing*—Testing consists of a conditioning phase followed by several (30) sequential loading steps.

9.5.1 To begin the test, condition the geosynthetic-soil interface by applying a minimum of 1000 repetitions of a load equivalent to a total maximum shear stress (Eq 1) on the geosynthetic of 30 kPa [4.4 psi] at a normal stress of 77.6 kPa [11.25 psi] and at a minimum shear stress (seating stress) of 2.7 kPa [0.4 psi].

$$F_{max} = \tau_{max}(2 \times W_g \times L_g) \quad (1)$$

where:

F_{max} = maximum cyclic force, kN,
τ_{max} = maximum total cyclic shear stress, kPa,
W_g = width of the geosynthetic, m, and
L_g = length of the geosynthetic, m.

9.5.2 Next, conduct the cyclic interaction test following the load sequence shown in Table 1. Begin by setting the normal confinement to 15.5 kPa [2.25 psi] and applying a cyclic shear stress ranging between the total maximum shear stress of 2.2 kPa [0.3 psi] and the seating stress of 0.5 kPa [0.1 psi] (Sequence No. 1, Table 1).

9.5.3 Apply 100 to 300 repetitions (refer to Table 1) of the cyclic shear stress using a haversine-shaped load pulse consisting of a 0.2 s load followed by a 0.8 s rest period. Record the maximum and minimum shear stress, as well as maximum and minimum displacements of the rear and front of the sample, for the last 10 cycles.

9.5.4 Increase the normal confinement to 31.0 kPa [4.5 psi] and apply a cyclic shear stress between the total maximum shear stress of 4.3 kPa [0.6 psi] and the seating stress of 1.1 kPa [0.2 psi] (Sequence No. 2, Table 1) and repeat the previous step at this new stress level.

9.5.5 Continue the test for the remaining load sequences in Table 1 (Nos. 3 to 30) and record the maximum and minimum shear stress and displacements for the last 10 cycles for each step. Stop the test if, at any time, failure occurs (that is, the known tensile capacity of the geosynthetic is surpassed or gross pullout occurs). Gross pullout is defined as the point when the rear (embedded end) of the sample has displaced one-tenth of the original length of the sample. The information collected up to the point of failure is still valid and, depending on the design conditions, may be sufficient to describe the interaction characteristics for a given level of anticipated shear stress.

TABLE 1 Test Sequence for Cyclic Pullout Test

Sequence	Normal Pressure		Seating Stress		Cyclic Shear Stress		Total Shear Stress		No. of Reps
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
Cond.	77.6	11.25	2.7	0.4	27.1	3.9	29.8	4.3	1000
1	15.5	2.25	0.5	0.1	1.6	0.2	2.2	0.3	300
2	31.0	4.5	1.1	0.2	3.3	0.5	4.3	0.6	300
3	51.7	7.5	1.8	0.3	5.4	0.8	7.2	1.0	100
4	77.6	11.25	2.7	0.4	8.1	1.2	10.8	1.6	100
5	103.4	15	3.6	0.5	10.8	1.6	14.4	2.1	100
6	15.5	2.25	0.5	0.1	3.3	.5	3.8	0.6	300
7	31.0	4.5	1.1	0.2	6.5	0.9	7.6	1.1	300
8	51.7	7.5	1.8	0.3	10.8	1.6	12.6	1.8	100
9	77.6	11.25	2.7	0.4	16.3	2.4	19.0	2.8	100
10	103.4	15	3.6	0.5	21.7	3.1	25.3	3.7	100
11	15.5	2.25	0.5	0.1	5.4	0.8	6.0	0.9	300
12	31.0	4.5	1.1	0.2	10.8	1.6	11.9	1.7	300
13	51.7	7.5	1.8	0.3	18.1	2.6	19.9	2.9	100
14	77.6	11.25	2.7	0.4	27.1	3.9	29.8	4.3	100
15	103.4	15	3.6	0.5	36.1	5.2	39.7	5.8	100
16	15.5	2.25	0.5	0.1	7.6	1.1	8.1	1.2	300
17	31.0	4.5	1.1	0.2	15.2	2.2	16.3	2.4	300
18	51.7	7.5	1.8	0.3	25.3	3.7	27.1	3.9	100
19	77.6	11.25	2.7	0.4	37.9	5.5	40.6	5.9	100
20	103.4	15	3.6	0.5	50.6	7.3	54.2	7.9	100
21	15.5	2.25	0.5	0.1	13.5	2.0	14.1	2.0	300
22	31.0	4.5	1.1	0.2	27.1	3.9	28.2	4.1	300
23	51.7	7.5	1.8	0.3	45.1	6.5	47.0	6.8	100
24	77.6	11.25	2.7	0.4	67.7	9.8	70.4	10.2	100
25	103.4	15	3.6	0.5	90.3	13.1	93.9	13.6	100
26	15.5	2.25	0.5	0.1	19.0	2.8	19.5	2.8	300
27	31.0	4.5	1.1	0.2	37.9	5.5	39.0	5.7	300
28	51.7	7.5	1.8	0.3	63.2	9.2	65.0	9.4	100
29	77.6	11.25	2.7	0.4	94.8	13.8	97.5	14.1	100
30	103.4	15	3.6	0.5	126.4	18.3	130.0	18.9	100

9.6 *After Test*—Remove normal stress and disassemble the device. Identify and inspect the soil-geosynthetic interface. Check for uniform geosynthetic deformation.

10. Calculations

10.1 Determine unit weight of soil above and below the geosynthetic and water content of soil if appropriate.

10.2 The total normal stress applied to the test specimen is determined by adding the applied normal stress to the normal stress due to soil above the geosynthetic according to Eq 2 as follows:

$$\sigma_N = \sigma_s + \sigma_a \tag{2}$$

where:

σ_N = total normal stress applied to test specimen, kPa,
σ_s = normal stress due to soil above geosynthetic, kPa, and
σ_a = normal stress due to the applied normal stress, kPa.

10.3 Calculate the average maximum and minimum displacement of the geosynthetic using Eq 3 and Eq 4 for the last ten cycles in each loading sequence to account for any strain in the material.

$$\Delta_{max} = \frac{\Delta_{avg \cdot max \cdot rear} + \Delta_{avg \cdot max \cdot front}}{2} \tag{3}$$

$$\Delta_{min} = \frac{\Delta_{avg \cdot min \cdot rear} + \Delta_{avg \cdot min \cdot front}}{2} \tag{4}$$

where:

Δ_{max} = average maximum displacement of the geosynthetic for a given load cycle, m,
Δ_{min} = average minimum displacement of the geosynthetic for a given load cycle, m,
$\Delta_{avg \cdot max \cdot rear}$ and $\Delta_{avg \cdot min \cdot rear}$ = average maximum and minimum displacement of the rear (embedded end) of the geosynthetic for a given load cycle, respectively; determined from multiple sensors across the rear of the sample; m, and
$\Delta_{avg \cdot max \cdot front}$ and $\Delta_{avg \cdot min \cdot front}$ = average maximum and minimum displacement of the front (leading end) of the geosynthetic for a given load cycle, respectively; determined from multiple sensors across the front of the sample, m.

10.4 Calculate the resilient interface shear stiffness for each cycle, G_i, using the maximum and minimum shear stresses and average maximum and minimum displacements recorded from the last ten load cycles for all of the loading sequences using Eq 5 (as illustrated in Fig. 5). The equations for the maximum and minimum shear stress, τ_{max} and τ_{min} are given in Eq 6 and Eq 7, respectively. The loss of area due to the geosynthetic being pulled out is accounted for by adjusting the original length by $\Delta_{avg \cdot acc \cdot perm}$, the amount the rear (embedded end) of the sample permanently displaced during the course of the test.

$$G_i = \frac{\tau_{max} - \tau_{min}}{\Delta_{max} - \Delta_{min}} \tag{5}$$

$$\tau_{max} = \frac{F_{max}}{2 \times W_g \times \left(L_o - \left(\Delta_{avg \cdot acc \cdot perm} + \Delta_{avg \cdot max \cdot rear}\right)\right)} \tag{6}$$

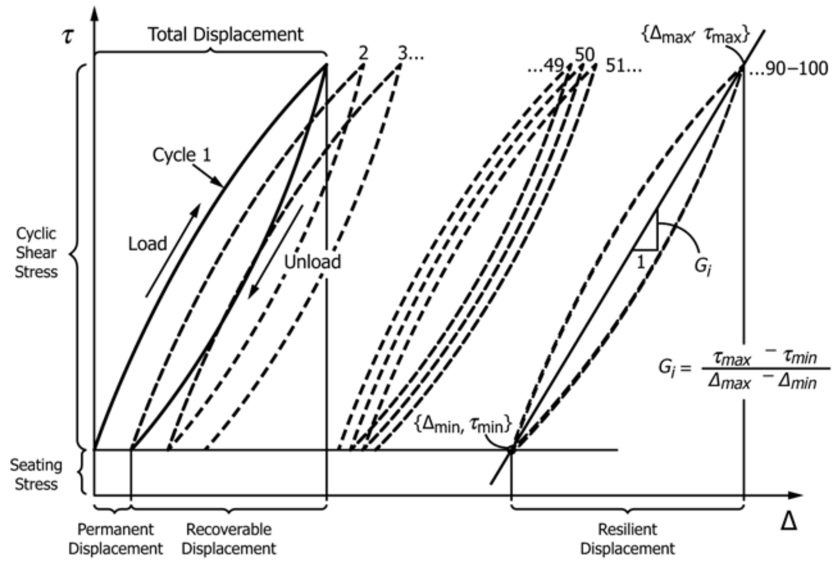

FIG. 5 Illustrated Test Progression and Calculation of Resilient Interface Shear Stiffness

$$\tau_{min} = \frac{F_{min}}{2 \times W_g \times \left(L_o - \Delta_{avg \cdot acc \cdot perm}\right)} \tag{7}$$

where:

G_i = resilient interface shear stiffness, kPa/m,
τ_{max} = maximum total cyclic shear stress, kPa,
τ_{min} = minimum total cyclic shear stress, kPa,
L_o = initial embedded length of the geosynthetic, m,
$\Delta_{avg \cdot acc \cdot perm}$ = average accumulated permanent displacement induced in the sample from pullout, m.

10.5 Calculate the average interface shear stiffness for each load sequence, G_n, using Eq 8.

$$G_n = \frac{\sum_{1}^{10} G_i}{i} \tag{8}$$

where:

G_n = average resilient interface shear stiffness for a specific load sequence n, kPa/m.

10.6 Plot the test data as a graph of maximum interface shear stress versus the resilient interface shear stiffness for each load sequence as illustrated in Fig. 6.

11. Report

11.1 The report shall include the following:

11.1.1 Description of test apparatus.

11.1.2 Test conditions.

11.1.3 Any departures from standard procedure.

11.1.4 Identification and description of geosynthetic sample(s).

11.1.5 Dimensions of geosynthetic specimen within the pullout box.

11.1.6 Identification of and descriptions of soil including soil classification, water content, unit weight, grain size, and other appropriate identifying information.

11.1.7 All basic data including normal stresses, displacement measurements, and corresponding resistance values.

11.1.8 Plot(s) of interface shear stiffness versus interface shear stress.

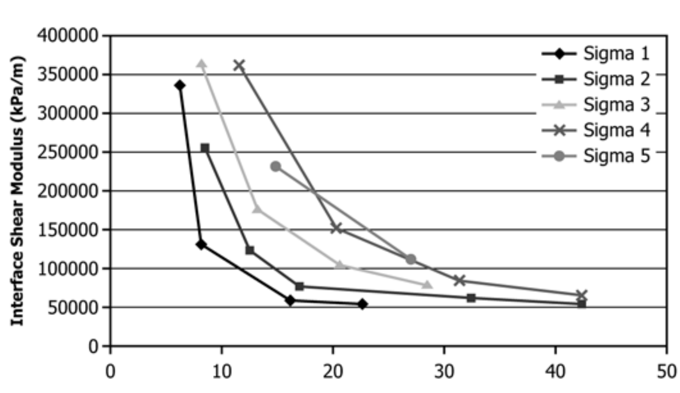

FIG. 6 Typical Interface Shear Stiffness versus Interface Shear Stress Plot

11.1.9 Description of the geosynthetic specimen conditions before and after testing.

12. Precision and Bias

12.1 *Precision*—The precision of the procedure in this test method is being established.

12.2 *Bias*—No justifiable statement can be made on the bias of the procedure in this test method since the true value cannot be established by accepted referee methods.

13. Keywords

13.1 geosynthetic; performance test; pullout resistance; soil; soil-geosynthetic interface shear stiffness