



Designation: D7702 – 11

Standard Guide for Considerations When Evaluating Direct Shear Results Involving Geosynthetics¹

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1. Scope

1.1 This guide presents a summary of available information related to the evaluation of direct shear test results involving geosynthetic materials.

1.2 This guide is intended to assist designers and users of geosynthetics. This guide is not intended to replace education or experience and should only be used in conjunction with professional judgment. This guide is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. Not all aspects of this practice may be applicable in all circumstances. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

1.3 This guide is applicable to soil-geosynthetic and geosynthetic-geosynthetic direct shear test results, obtained using either Test Method [D5321](#) or [D6243](#).

1.4 This guide does not address selection of peak or large-displacement shear strength values for design. References on this topic include Thiel ([33](#)), Gilbert ([12](#)), Koerner and Bowman ([16](#)), and Stark and Choi ([31](#)).

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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.*

¹ This guide 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. Referenced Documents

2.1 *ASTM Standards*:²

[D653](#) Terminology Relating to Soil, Rock, and Contained Fluids

[D5321](#) Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method

[D6243](#) Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method

[D4439](#) Terminology for Geosynthetics

3. Terminology

3.1 *Definitions*—For definitions of terms relating to soil and rock, refer to Terminology [D653](#). For definitions of term relating to geosynthetics and GCLs, refer to Terminology [D4439](#).

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *adhesion*, n — c_a , the component of shear strength indicated by the term c_a , in Coulomb's equation, $\tau = c_a + \sigma \tan \phi$

3.2.2 *Mohr-Coulomb friction angle* ϕ , 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 ϕ , in Coulomb's equation, $\tau = c + \sigma \tan \phi$

3.2.3 *coefficient of friction*, n —a constant proportionality factor relating shear to normal stress for a defined failure condition over a specific range of normal stresses.

3.2.4 *cohesion* c , n —the component of shear strength indicated by the term c , in Coulomb's equation, $\tau = c + \sigma \tan \phi$

3.2.5 *direct shear strength test*, n —for geosynthetics, a procedure in which the interface between a geosynthetic and

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.

any other surface, under a range of normal stresses specified by the user, is stressed to failure by the horizontal movement of one surface against the other.

3.2.6 *failure envelope, n* —Line on the shear stress-normal stress plot representing the combination of shear and normal stresses that would result in a shear failure.

3.2.7 *secant friction angle, ϕ_{sec} , n* —degrees) 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 at the shearing normal stress for which it is defined.

4. Significance and Use

4.1 The shear strength of soil-geosynthetic interfaces and geosynthetic-geosynthetic interfaces is a critical design parameter for waste containment systems, mining applications, dam designs involving geosynthetics, reinforced slopes, and liquid impoundments. Since geosynthetic interfaces often serve as a weak plane on which sliding may occur, shear strengths of these interfaces are needed to assess the stability of a waste mass or ore body over a lining system or the ability of a final cover to remain on a slope. Accordingly, project-specific shear testing using representative materials under conditions similar to those expected in the field is recommended for final design. Shear strengths of geosynthetic interfaces are obtained by either Test Methods D5321 (geosynthetics) or D6243 (geosynthetic clay liners). This guide touches upon some of the issues that should be considered when evaluating shear strength data. Because of the large number of potential conditions that could exist, there may be other conditions not identified in this guide that could affect interpretation of the results. The seemingly infinite combinations of soils, geosynthetics, hydration, and wetting conditions, normal load distributions, strain rates, creep, pore pressures, etc., will always require individual engineering evaluations by qualified practitioners. Along the same lines, the list of references provided in this standard is not exhaustive, nor are the findings and suggestions of any particular reference meant to be considered conclusive. The references and their related findings are presented herein only as examples available in the literature of the types of considerations that others have found useful when evaluating direct shear results.

4.2 The figures included in this guide are only examples intended to demonstrate selected concepts related to shear testing of geosynthetics. The values shown in the figures may not be representative and should not be used for design purposes. Site specific and material-specific tests should always be performed.

5. Shear Strength Fundamentals

5.1 Mohr (1776) first presented a theory for shear failure, showing that a material experiences failure at a critical combination of normal and shear stress, and not through some maximum normal or shear stress alone. In other words, the shear stress on a given failure plane was shown to be a function of the normal stress acting on that plane (5):

$$\tau = f(\sigma) \quad (1)$$

If a series of shear tests at different values of normal stress is performed, and the stress circle corresponding to failure is plotted for each test, at least one point on each circle must represent the normal and shear stress combination associated with failure (24). As the number of tests increases, a failure envelope (line tangent to the failure circles) for the material becomes apparent (Fig. 1).

5.2 In general, the failure envelope described by Equation (1) is a curved line for many materials (5). For most geotechnical engineering problems, the shear stress on the failure plane is approximated as a linear function of the total or effective normal stress within a selected normal stress range, as shown in Fig. 1. This linear approximation is known as the Mohr-Coulomb failure envelope. In the case of total stresses, the Mohr-Coulomb failure envelope is expressed as:

$$\tau = c + \sigma \tan \phi \quad (2)$$

where:

- τ = shear stress,
- σ = normal stress,
- ϕ = friction angle (degrees), and
- c = cohesion (or adhesion between two materials)

In the case of effective stresses, the linear failure envelope is:

$$\tau = c' + (\sigma - u) \tan \phi' \quad (3)$$

or

$$\tau = c' + \sigma' \tan \phi'$$

where:

- u' = Pore pressure,
- σ' = effective stress,
- ϕ' = drained friction angle (degrees), and
- c' = effective stress cohesion or adhesion

5.3 Since most laboratory direct shear tests do not include pore pressure measurements, shear strength results reported by laboratories are normally expressed in terms of total normal stress. For direct shear tests involving geosynthetics, Test Methods D5321 and D6243 provide recommendations for shear displacement rates intended to allow excess pore water pressures generated during shearing to dissipate. Recommended shear rates are 0.2 in/min for geosynthetic (non-GCL) interface tests, 0.04 in/min for geosynthetic/soil (including GCLs) interface tests (37), and 0.004 in/min for GCL internal



FIG. 1 Curved Mohr failure envelope and equivalent Mohr-Coulomb linear representation (from Figure 20.16)

shear tests (7). However, as shown by Obermeyer et al (23), even slower displacement rates may be needed for GCLs and high-plasticity clay soils to ensure that positive pore pressures do not develop during shearing. If tests involving GCLs or clays are loaded or sheared too quickly, excess pore water pressures could develop, and results may not be representative of field conditions, which are often assumed to be drained. The assumption of drained conditions is reasonable because drainage layers are common in liner systems and because field loading rates are generally slow (11, 7). From Equation (3), positive pore pressures that are not allowed to dissipate will decrease the measured shear stress. Tests that are sheared undrained may yield erroneous results similar to those discussed in Section 9.

5.4 Combinations of shear stress and normal stress that fall on the Mohr-Coulomb failure envelope indicate that a shear failure will occur. Combinations below the failure envelope represent a non-failure state of stress (1). A state of stress above the envelope cannot exist, since shear failure would have already occurred.

6. Measurement and Reporting of Shear Strength by Test Methods D5321/D6243

6.1 The shear resistance between geosynthetics or between a geosynthetic and a soil is determined by placing the geosynthetic and one or more contact surfaces, such as soil, within a direct shear box. A constant normal stress representative of 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.

6.2 The test is run until the horizontal displacement exceeds 75 mm (3 in.) or other value specified by the user. 75 mm of displacement is the practical upper limit of most direct shear devices.

6.3 The testing laboratory plots the test data as a graph of applied shear force versus horizontal displacement. The peak shear force and the shear force at the end of the test are identified. The horizontal displacements associated with these shear forces are also determined. An example set of shear-displacement plots for a typical textured geomembrane/reinforced GCL interface is shown in Fig. 2a. Typical shear-displacement behavior of geosynthetic interfaces is discussed further in Section 9.

6.4 The shear stresses applied to the specimen for each recorded shear force are calculated by dividing the shear force by the specimen area. For tests in which the area of specimen contact decreases with increased displacement, a corrected area should be calculated, unless other technical interpretation arrangements are made ahead of time between the engineer and the testing laboratory.

6.5 The testing laboratory plots the peak shear stress and post-peak (also known as large displacement) shear stress versus applied normal stress for each test conducted. An example set of shear stress-normal stress plots for a typical textured geomembrane/reinforced GCL interface is shown in Fig. 2b.

6.6 The testing laboratory then draws a least-squares “best-fit” straight line through the peak shear stress data points, Equation (2). The y-intercept of the straight line with $x = 0$ axis is the adhesion intercept, c_a for interface strength or cohesion intercept c , for internal strength. The slope of the straight line is the peak coefficient of friction. Taking the inverse tangent of

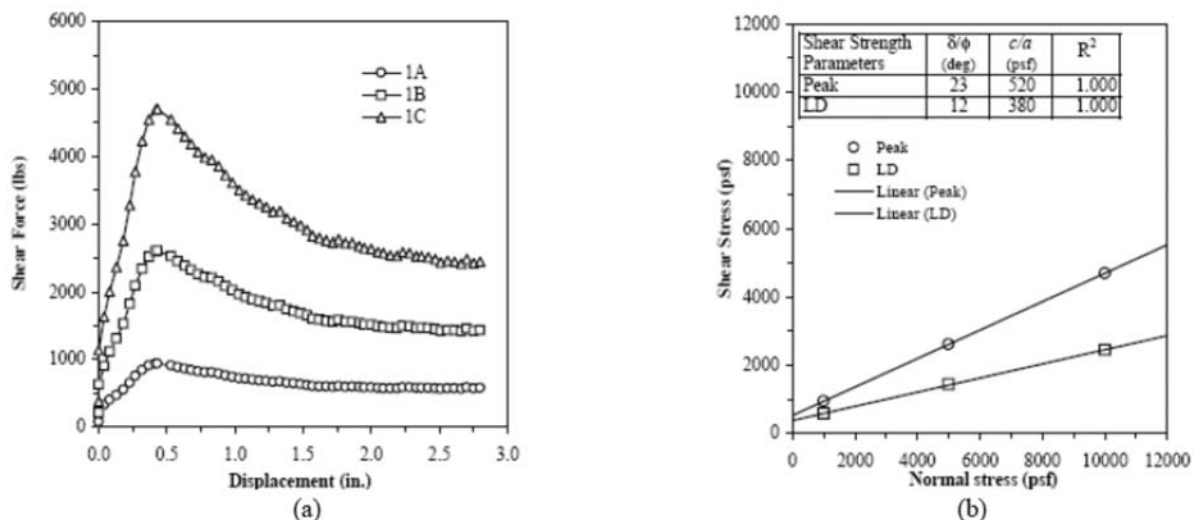


FIG. 2 Typical Shear-Displacement Curves (a) and Peak and Large Displacement Failure Envelopes (b) for a Textured Geomembrane/Needlepunch Reinforced GCL Interface

the peak coefficient of friction yields the peak angle of friction, ϕ_{peak} . This exercise is then repeated to determine the large displacement cohesion and the large displacement angle of friction, ϕ_{LD} .

7. Evaluation of the Mohr-Coulomb Failure Envelope

7.1 Traditionally, the laboratory-reported Mohr-Coulomb strength parameters c and ϕ have been used to assess the stability of slopes containing geosynthetics using limit equilibrium methods. Although Test Methods D5321 and D6243 call for the testing laboratory to draw a best-fit line through the shear stress-normal stress data and determine c and ϕ , it is strongly recommended that the design engineer also evaluate the data to determine the appropriate strength parameters to be used in a slope stability analysis.

7.2 It is important to note that the reported Mohr-Coulomb parameters only define the failure envelope for the range of normal stresses tested. Extrapolation of both friction angle and cohesion intercept outside the range of normal stresses tested may not be representative. Extrapolating the failure envelope below the lowest normal stress tested can overestimate shear strength, since the failure envelopes for many geosynthetic interfaces can curve sharply to the origin. Similarly, extrapolating the failure envelope above the highest normal stress tested can overestimate shear strength, since the failure envelope for many geosynthetic interfaces flatten at high loads (27). If some extrapolation is required, a conservative and safe method would be as follows (34):

Extrapolation of the shear strength envelope to lower normal loads would go from the result tested at the lowest normal load back through the (0,0) origin.

Extrapolation of the shear strength envelope to high normal loads would go from the result tested at the highest normal load with a horizontal line of constant shear strength.

Any extrapolation of shear strengths with resulting strengths greater than these suggestions cannot be defended by the test results.

7.3 In the sample laboratory report shown in Fig. 2b, the peak Mohr-Coulomb failure envelope, in kPa, is described by: $\tau_{\text{peak}} = 24.9 + \sigma \cdot \tan 23^\circ$ ($\tau_{\text{peak}} = 520 + \sigma \cdot \tan 23^\circ$, in psf). The large-displacement Mohr-Coulomb failure envelope, in kPa, is described by: $\tau_{\text{LD}} = 18.2 + \sigma \cdot \tan 12^\circ$ ($\tau_{\text{LD}} = 380 + \sigma \cdot \tan 12^\circ$, in psf). These expressions are only valid for the range of normal stresses tested; in this example, from 47.9 to 479 kPa (1,000 to 10,000 psf).

7.4 As shown in Fig. 3 (based on Blond and Elie[2]), the term ϕ in the “best-fit” Mohr-Coulomb failure envelope, $\tau = c + \sigma \tan \phi$, is known as the Mohr-Coulomb friction angle.

7.5 Some testing laboratories also report secant friction angles, ϕ_{sec} . As shown in Fig. 3, the secant friction angle is defined by a line drawn from the origin to a data point on the shear strength-normal stress failure envelope. The secant friction angle is only intended for use with the normal stress for which it was defined and should not be confused with the Mohr-Coulomb friction angle (7). Except for cases where $c = 0$ and the failure envelope is linear, the secant and Mohr-Coulomb friction angles will be different. (Section 8 discusses

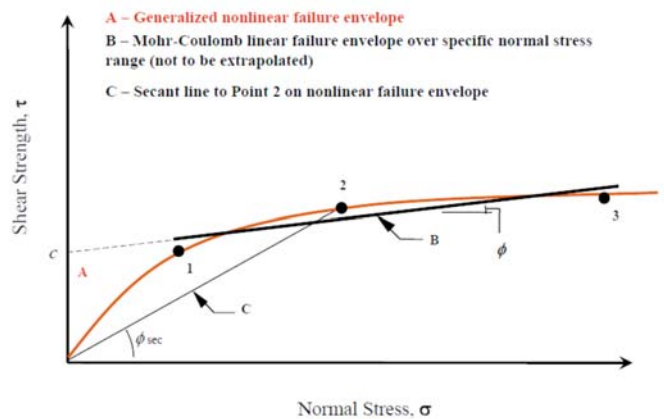


FIG. 3 Friction Angles (based on Fox and Stark, 2004, and Blond and Elie, 2006).

how the secant angle can be useful when interpreting shear strength results for a slope stability analysis).

NOTE 1—Contrary to standard practice, the ISO standard on shear strength properties defines the “angle of friction” as the secant angle, not the Mohr-Coulomb angle.

7.6 In simple cases where the shear strength data is actually linear, the linear failure envelope constructed by the testing laboratory should be an accurate representation of the available shear strength. However, Fox and Stark (7) and Giroud et al (13) show that interpretation of the failure envelope may not be as straightforward if the data indicate curved or multilinear failure envelopes. Fox and Stark presented several common models used to characterize GCL shear strength envelopes (Fig. 4), which can also generally apply to many geosynthetic interfaces. Additionally, several studies have shown that many geosynthetic interfaces exhibit non-linear failure envelopes over a large range of normal stresses, including textured geomembranes/nonwoven geotextiles (30; 19), smooth geomembranes/clays (29), reinforced GCLs (8, 4, 41), and textured geomembranes/GCLs (37, 4). In such cases, the linear shear strength parameters (c and ϕ) reported by the laboratory may not be appropriate, or may only be appropriate for a portion of the data. For example, Fig. 5 from Giroud et al (13)

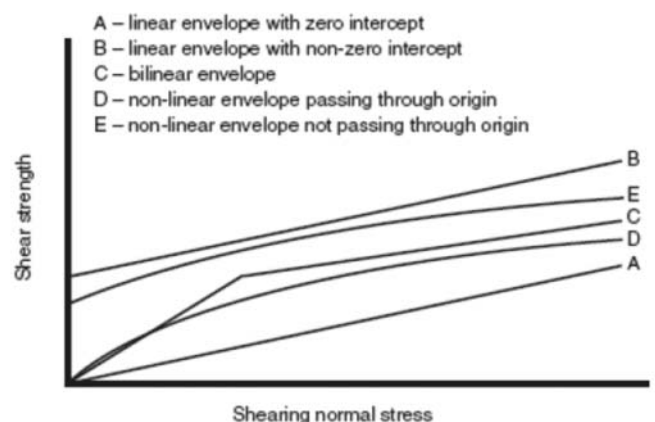


FIG. 4 Typical failure envelope shapes for GCL and geosynthetic interfaces (Fox and Stark, 2004).