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Interpretation(s) of Laboratory Generated Interface Shear Strength Data for Geosynthetic Materials With Emphasis on the Adhesion Value

by

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Interpretation(s) of Laboratory Generated Interface Shear Strength Data for Geosynthetic Materials With Emphasis on the Adhesion Value

The beginning point of this White Paper is based on the assumption that a designer has a credible set of laboratory generated shear stress versus shear displacement curves on the desired geosynthetic-to-geosynthetic or geosynthetic-to-soil interface tested per ISO 12957 or ASTM D5321, or ASTM D6243 if geosynthetic clay liners are involved. In this regard we are considering having such data as shown in Figure 1. It is clearly seen that many behavioral trends are possible.

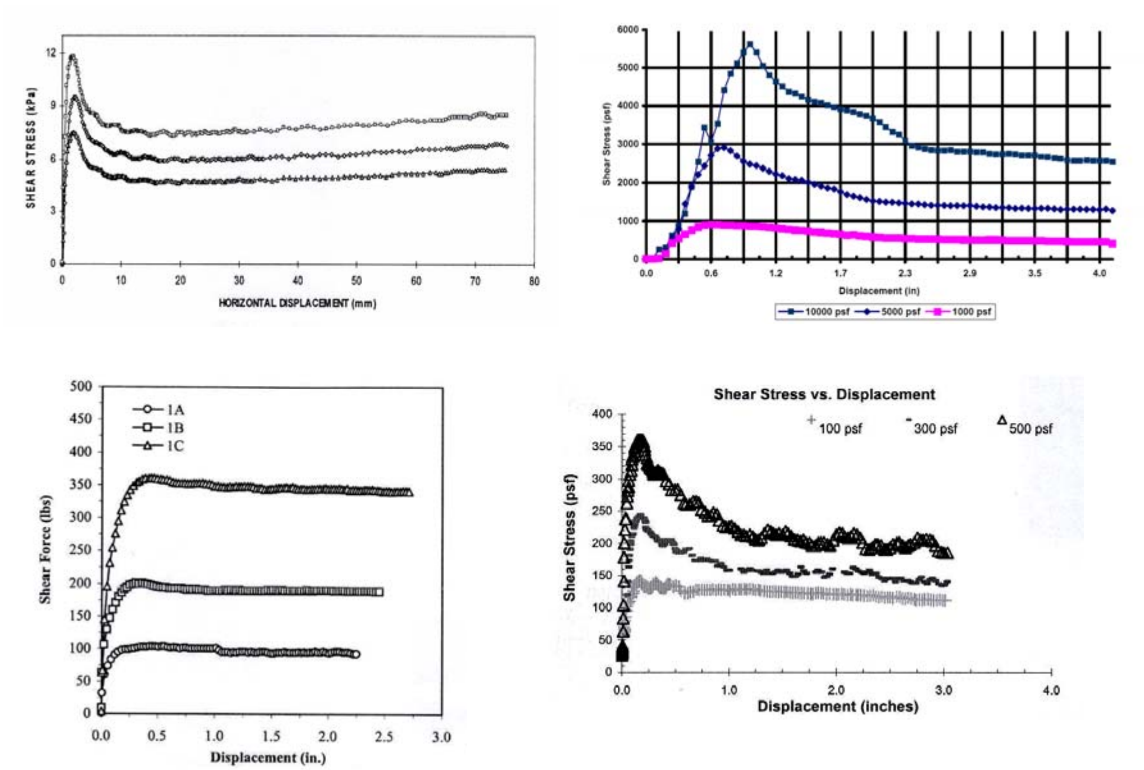

Figure 1 – Various stress versus displacement curves for different geosynthetic materials. (Data compliments of TRI, Golder, Precision and SGI Laboratories)

Either the designer or the testing laboratory will have to generate the Mohr-Coulomb failure envelope from these curves by selecting one point on each normal stress curve and plotting the results on a normal stress versus shear stress curve as shown in Figure 2a. A least squares fit of the data point produces the failure envelope. Even further, one might have more than one such failure envelopes; peak, large displacement and/or residual. Please note, however, that this White Paper is <u>not</u> about the selection of peak, large displacement or residual values and the technical literature is abundant on that subject.

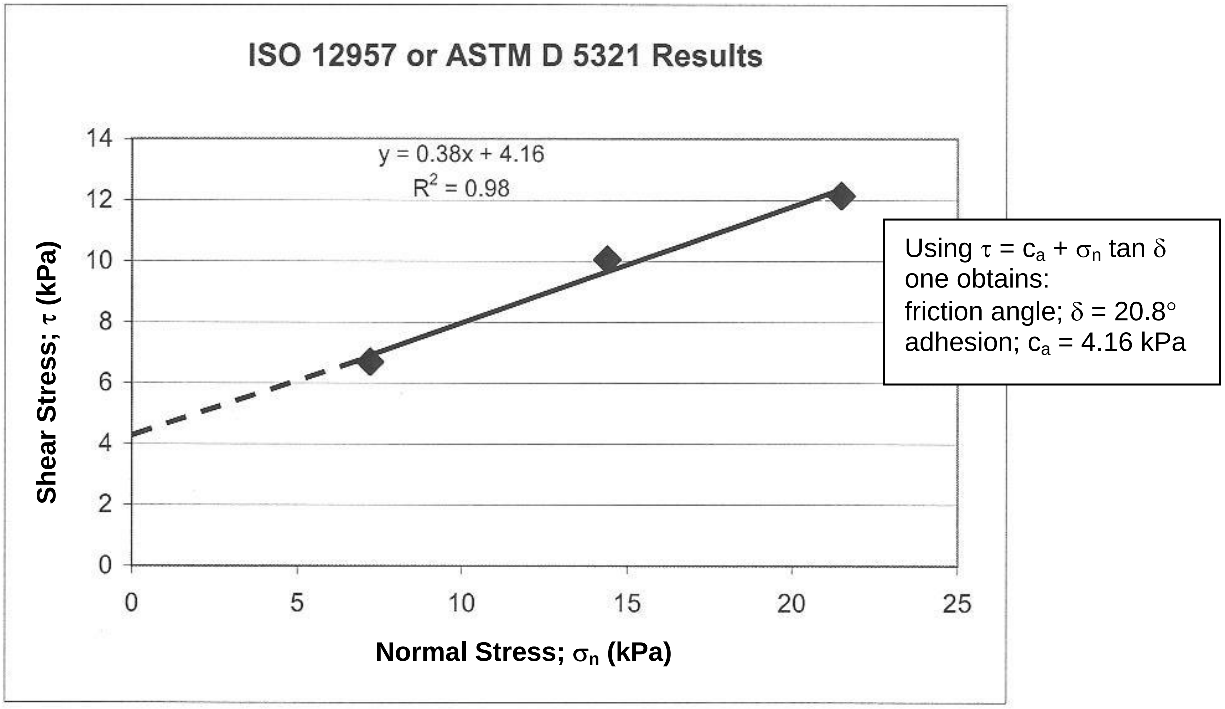

Figure 2a – Three point laboratory data leading to the drawing of a failure envelope and subsequent measurement of friction angle and shear strength intercept (or adhesion) values.

At any rate, to begin the present discussion on the interpretation of the selected failure envelope, the designer is confronted with something like that shown Figure 2a. Here the data points are clearly identified and the failure envelope is usually generated by a least squares fitting procedure. The dashed extension to the y-axis is often the general assumption particularly for low normal stresses as indicated. Note that there are indeed exceptions to this situation such as curved failure envelopes within the normal stress range tested, or zero normal stress tests. They are special cases and will be discussed later.

Interpretation #1 – Use of full "c_a" and full "δ" values

Assuming that the previous failure envelope is based on credible laboratory procedures, properly simulated insofar as representative samples, normal stress selection, moisture conditions, strain rate, etc., our recommended approach is to use the shear strength parameters directly in your slope stability analysis and, if found to be adequate, for your materials specification criteria as well. For landfill cover veneer stability problems all GSI Members and Associate Members should have our spread sheet calculation program which is extremely easy to use. For others, there are many computer codes available. For a hypothetical veneer slope stability example using the two shear strength parameters (c_a and δ) from Figure 2a, the input information is as follows:

- cover soil thickness h = 0.3 m
- slope angle β = 18.4° (3-to-1)
- length of slope L = 30.0 m
- unit weight of cover soil γ = 18.0 kN/m^3
- friction angle of cover soil ϕ = 30.0 deg
- cohesion of cover soil c = 0.0 kN/m^2
- friction angle of interface δ = 20.8 deg
- adhesion of interface c_a = 4.16 kPa (= 87 psf)

By using the program just mentioned or similar procedure, the resulting slope factor-of-safety value is; FS = 3.62. This is a relatively high value and would generally be considered quite conservative. One point worth mentioning, however, is the strong influence of the adhesion value on factor-of-safety. To illustrate this, we now vary the c_a-value between zero and ten while holding everything else the same. This procedure results in the following table; clearly illustrating the sensitivity of the FS-value to this particular parameter.

Adhesion; "c_a"		Resulting FS-value
kPa	lb/ft^2	
0	0	1.18
2	42	2.35
4	84	3.53
6	125	4.70
8	167	5.80
10	209	7.05

Presented now is the heart of this White Paper concerning the *issue of how reliable is this laboratory generated c_a-value?* The ultimate decision is yours as the designer, but our opinions on different geosynthetic materials and related interfaces are as follows:

(a) For textured geomembranes against geotextiles or soil, the asperities (be they manufactured as structured, blown film, or impinged) are on the material giving rise to the high adhesion values, so we recommend using the adhesion value accordingly. Only by continuously rubbing the surfaces against one another can asperity reorientation occur and we feel this is an artifact of aggressive laboratory testing as has been done (and reported) using the ring shear testing device in particular. Alternatively, concern has been expressed when testing at very high normal stresses. The thought in both instances is that if you eliminate adhesion from textured geomembranes you are essentially assuming smooth geomembrane sheet. This is a designer's prerogative, but be prepared to have very gentle slopes in so doing.

(b) For smooth geomembranes against other geosynthetics or soil, a small adhesion is often observed. This is particularly the case for LLDPE, fPP, EPDM, and PVC. Each of these geomembranes are less hard than HDPE, and thus an indentation can be visualized (particularly dealing with soil) which is clearly a function of the applied normal stress. Assuming that the appropriate normal stresses were used in the direct shear test, we feel that one is generally justified in its use.

(c) For geotextiles thermally bonded to geonets or other types of drainage cores, we feel that the full value of adhesion should be used. Most of these geocomposites can barely be "delaminated" in the conducting of the test and we have never heard of a field delamination problem from a properly manufactured geocomposite interface in this regard.

(d) For the internal shear strength of reinforced GCLs, the fibers would have to pull-out or break (or both) for a loss of adhesion. While you can force this to happen in the lab, we have no evidence of this occurring in the field. Test results invariably show high adhesion values. Furthermore, longevity (durability) of the fibers in a hydrated bentonite atmosphere promises 100-year lifetime, or longer. We have a creep-related paper in this regard. Thus, we see no reason not to use the laboratory generated value of adhesion for reinforced GCLs manufactured by either needlepunching or stitching. Of course, the upper and lower interfaces of the GCLs must be independently evaluated.

(e) For certain geosynthetic-to-soil interfaces, the interface shear behavior may force the failure plane into the soil. This results in the identification of the soil's shear strength and if there is a shear strength intercept it is a cohesion value and can be used accordingly.

Thus, if adhesion from short-term testing is indicated by the failure envelope and the long-term permanence of the physical or mechanical mechanism giving rise to this adhesion is logical to anticipate, its use in a stability analysis and subsequent material's specification is felt to be generally justified.

Interpretation #2 – Use of zero "c_a" and full "δ" value

For the situation where an adhesion is indicated by the failure envelope and you as the designer feel that its long-term existence is not justified, the most conservative approach you can take is to simply translate the entire failure envelope in a parallel manner down by the amount of adhesion indicated on the original data-generated graph; see Figure 2b.

The effect of this very conservative approach on the FS-value of the slope is substantial. The shear strength is now represented by a friction angle alone and the site-specific result will be very flat slopes. For example, the 3-to-1 slope in the hypothetical example given previously with an adhesion of zero, now has a FS = 1.18 using this approach. For the interfaces mentioned previously, we do not recommend this approach.

Alternatively, one could also decrease the adhesion slightly, but not entirely. That said, we really don't know how to comment on this type of "compromise" situation?

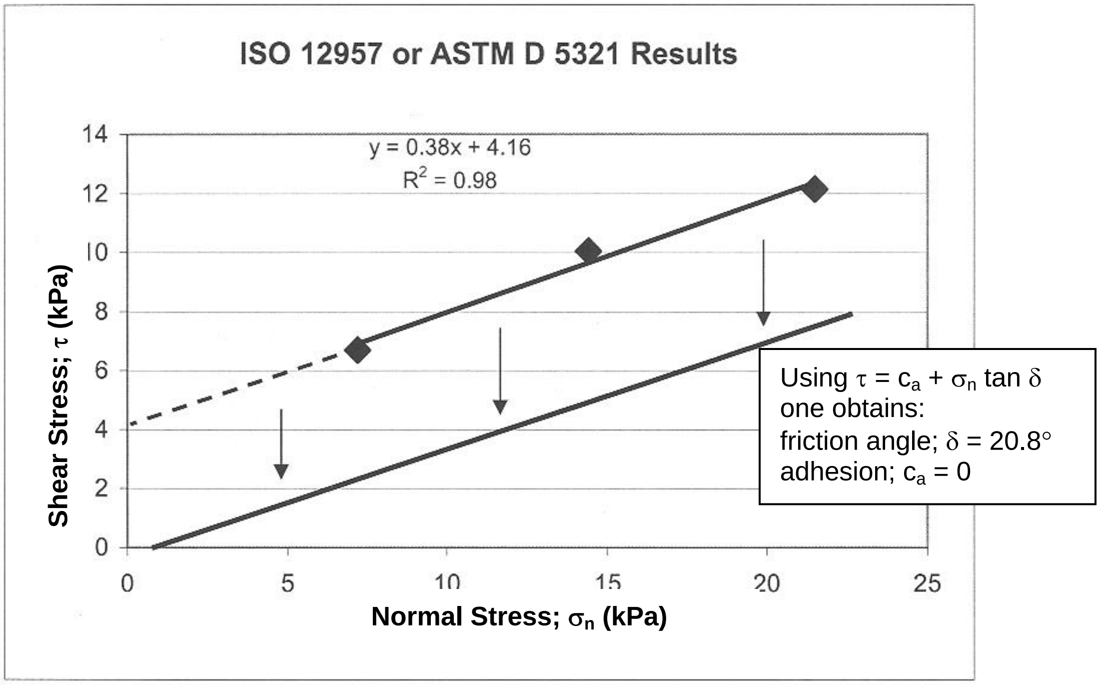

Figure 2b – Parallel translation downward of the entire laboratory generated failure envelope by an amount equal to the y-axis intercept, i.e., the adhesion.

Interpretation #3 – Use of zero "c_a" at zero normal stress only

A hybrid interpretation somewhere between the interpretations just presented is sometimes suggested, but its logic is somewhat difficult to fathom. In essence, the adhesion is lost only at zero normal stress but not at higher normal stresses. Thus, the failure envelope is forced through the origin but thereafter it is based on a least squares fit of the laboratory tested points as they were generated. Figure 3 illustrates the situation where the resulting friction angle is seen to be 32.2°. For our hypothetical example, this results in FS = 1.93. Alternatively, and equally difficult to fathom, is when only one laboratory point is generated and the failure envelope is forced through it and the origin. Both approaches are the least conservative of those mentioned in this White Paper giving rise to a rotation of the failure envelope and the highest friction angle possible. The angle resulting from this practice has been variously called "secant friction angle", "secant angle", or "modulus angle". Of the group, secant angle is probably the best description for this interpretation since it shouldn't be confused with the Mohr-Coulomb friction angle, and modulus brings with it completely other test procedures like tension testing.

We generally do not recommend such approaches for the reason that adhesion should be an intrinsic property of the interface involved and not be arbitrarily eliminated or used on the basis of a particular normal stress, or stresses. (That stated, if the interface is tested at zero normal stress and found to have zero adhesion, the origin is a valid point and should then be used accordingly).

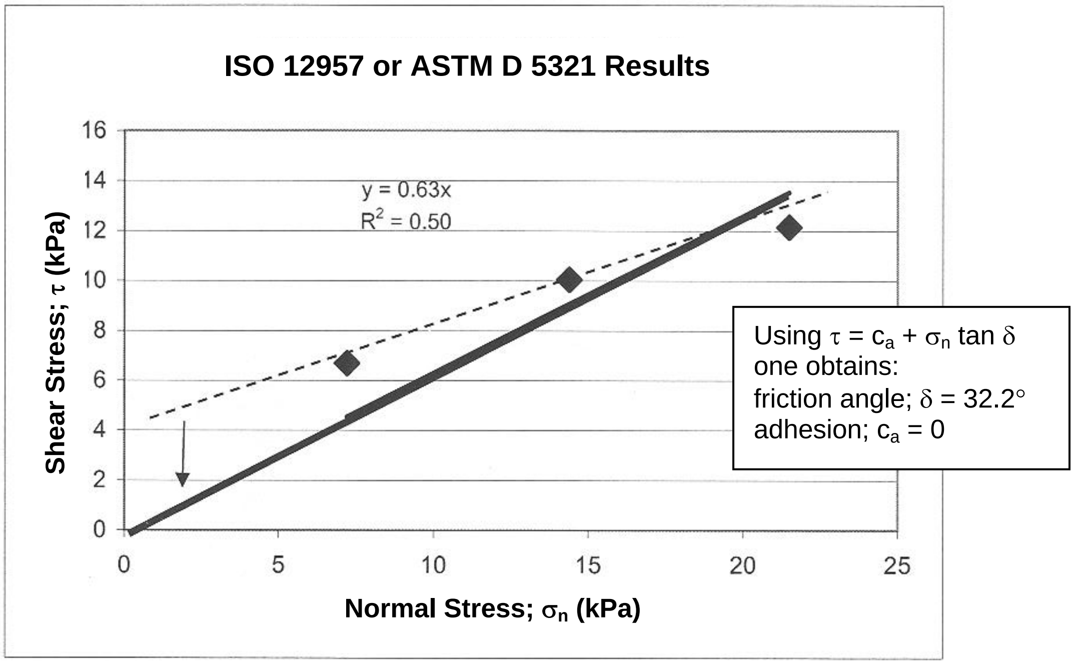

Figure 3 – Elimination of adhesion at zero normal stress but not at any of the three laboratory measured data points.

Interpretation #4 – Use of the total shear strength at a particular normal stress

A very straightforward approach to a specification value is to require a certain shear strength value at a particular normal stress. This is particularly the case if the failure envelope is curved as mentioned previously. In so doing, a specifier is requiring a single point to be taken from the failure envelope which is targeted at the expected field normal stress. Figure 4 suggests that if the field normal stress is 17.2 kPa it results in a required shear strength of 10.7 kPa, or greater. The shear strength value is thereby reflective of both a frictional component and adhesion, neither of which are specifically identified.

In so doing one avoids specifying individual "c_a" and "δ" values and much of the previous discussion is altogether avoided. The method can be extended to give two, or more, values of shear strength (or even the equation of the failure envelope) at different normal stresses in the form of a "required" table.

This approach has been used by a select few designers but is far from common practice. There is nothing of a fundamental nature which says it cannot be done and it would avoid some of the other complications inherent with different approaches.

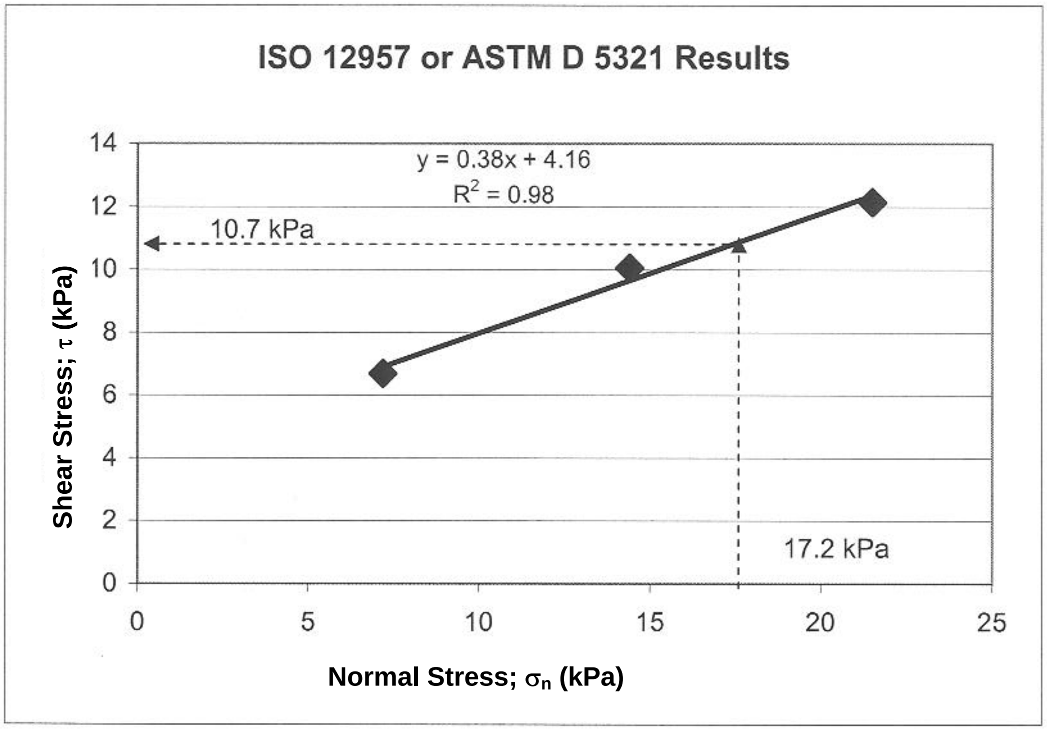

Figure 4 – Use of a laboratory generated failure envelope by specifying a site-specific normal stress and requiring a minimum value of shear strength taken directly off of the y-axis.

In summary, there are probably other or intermediate interpretations of an interface shear strength failure envelope for use in design and then a subsequent specification, but those presented here are felt to be the most common.