Designer's Forum

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Interface shear strength: Part 1–geomembrane considerations

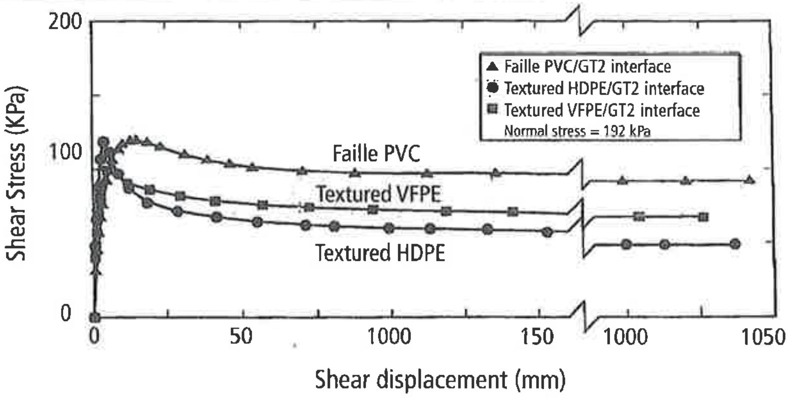
In 1984, as part of the design of hazardous waste landfill cells in Ohio, a sample of hand-textured HDPE geomembrane was flown from Germany to the USA for evaluation. The sample was taken to the airport in Frankfurt and a passenger was paid to carry it to Houston—this is probably why you are asked, "Has a stranger given you a package?" every time you now board a commercial airline. In any case, the sample never arrived in Houston, for it turned out the flight was actually bound for Atlanta! Days later, the sample was finally found in the Atlanta airport. For many designers, a clear understanding of geomembrane-related interface shear strength concerns has been as elusive as this early textured HDPE geomembrane sample.

This two-part series will review much of what we currently know regarding interface shear strength. The first article focuses on geomembrane interface shear strength basics. The second article presents broader design considerations, including seismic stability considerations and additional geotextile and GCL considerations.

Interface testing

The shear strength of interfaces is most commonly measured in the laboratory using the 0.3-m x 0.3-m (1-ft. x 1-ft.) direct shear device standardized by ASTM Standard D-5321. Such shear boxes allow testing of normal load ranges between nearly zero and 1200 KPa (25,000 psf) and relative displacements of up to 7.6 cm (3 in.). More recent research (Stark and Poeppel 1994; Moss 1999) has focused on the use of a cylindrical direct shear test that provides for larger relative displacements. This followed the observation that many geosynthetics experience a significant loss of shear strength at large displacements. Such large displacements are generally associated with large displacements induced by seismic events or potential waste subsidence. Today, interface shear strengths are commonly reported in terms of "peak" strength and large displacement "post-peak" strength. **Figure 1** shows the shear stress vs. displacement for several common interfaces.

Figure 1: Shear stress vs. displacement for several common interfaces.



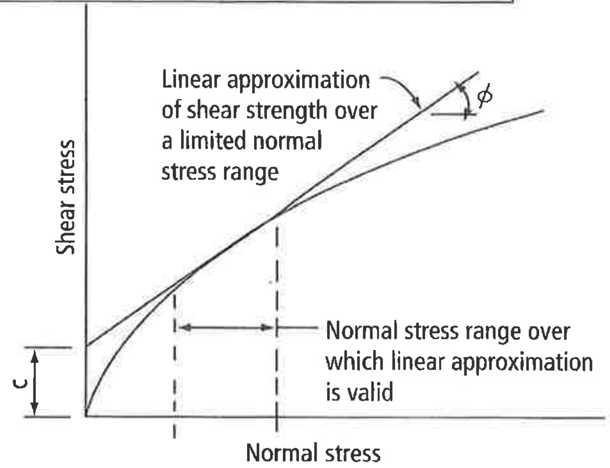
It is important that the test equipment and sensitivity are appropriate for the normal and shear loads being experienced in the test, and that the test be performed for normal loads representative of design normal loads. The most common strength-related errors in stability analyses stem from using strength parameters that do not correspond to the stress level at the surface being analyzed.

Interface shear strength is often referred to as "interface friction," as the frictional component is often the most common expression for the shear strength. If the shear strength is not linear with normal load (common with geosynthetic interfaces), it is often appropriate to express the shear strength in terms of both "friction" and "cohesion" parameters. It is important to note that these are only mathematical parameters describing the shear strength over a defined normal load range, and it is generally unconservative to extrapolate either below or above that normal load range (**Figure 2**).

Smooth geomembranes

The interface strength between smooth geomembranes, soils, geotextiles or geonets is the obvious starting point for understanding interface strengths. Significant testing of smooth geomembranes was first reported in 1984 at the Denver geomembranes conference. Saxena and Wong (1984) clearly showed the decrease from peak strength with increasing displacement and avoided expressing Mohr-Coluomb failure strength parameters. Martin, Koerner

Figure 2: Curve shear strength envelope.



and Whitty (1984) set the stage for ensuing years by expressing the peak strength in terms of an equivalent friction angle. This was shortly followed by an exhaustive study by Williams and Houlihan (1987) that continued the trend of reporting only the peak strength. These early studies focused on the shear strength of smooth geomembranes with sands and geotextiles. "Rough" geomembranes tested during this period were scrim-reinforced geomembranes that included Hypalon and some PVC. The roughness was simply the pattern of the woven scrim reflected in the surface.

These important initial studies clearly established that project-specific shear tests had to be performed with the actual soil, geomembrane, geonets and geotextile to be used. This testing did establish the following "peak" strength trends for smooth geomembranes that remain true today:

- The interface strength increases with decreasing hardness of the surface of the geomembrane. Thus, flexible geomembranes such as PVC will have a larger interface shear strength and, therefore, friction angle than hard geomembranes such as HDPE. This is true for sand, geotextile and geonet interfaces.
- The interface strength with a geotextile is dependent on the polymer, strength and modulus of the geotextile. Thus, shear strength generalizations for geotextile-geomembrane interfaces should be done with great caution—i.e., all nonwovens are not created equal.

Concern regarding post-peak interface shear strengths became strong in 1993 when Section 258.14 of RCRA Subtitle D regulations (40 CFR Part 258) required a seismic evaluation of all landfills in seismic impact zones. The nationwide introduction of landfill liners concurrently with the implementation of rigorous seismic design guidelines led to concerns regarding large displacement performance of critical interfaces. EPA's own seismic guidance (Richardson and Kavazanjian 1995) provided a clear basis for the technical need for large displacement interface strengths.

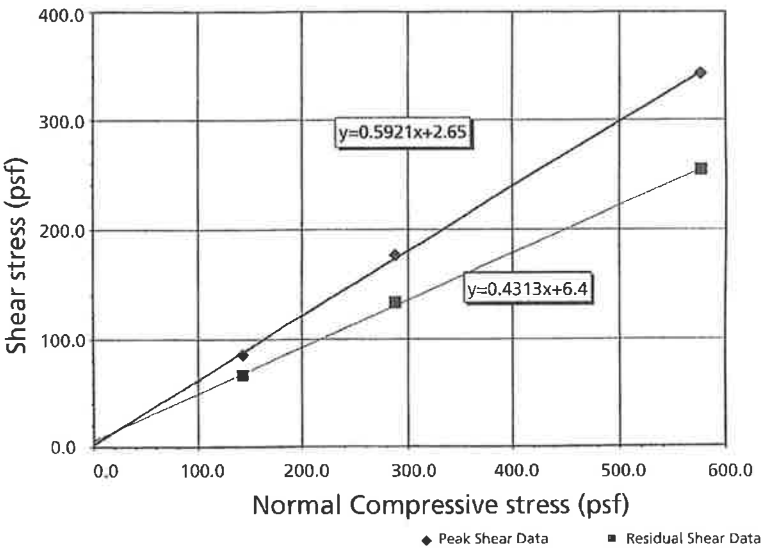
Pioneering work was performed by Stark and Poeppel (1994) using a cylindrical direct shear surface that allows very large displacements of the interface. This work showed that displacements much larger than the 7.6-cm (3-in.) limit of common shear boxes is required to determine a true residual shear strength. For this reason, the lower shear strength at the end of a conventional shear test is referred to as the "post-peak" strength and not the true residual strength. A more recent summary of this testing program by Stark and Richardson (2000) presented the following observations:

- At small displacements, the results of the cylindrical direct shear testing agreed with that from conventional shear boxes.
- Smooth PVC-geotextiles interfaces had the same peak and residual shear strengths.
- Smooth HDPE experienced a significant reduction from peak to residual shear strength.
- Smooth PVC consistently had a significantly higher interface shear strength than smooth HDPE.

Interestingly, the loss of interface strength at peak conditions by HDPE has been used beneficially in designs proposing a "weak" sand or geotextile interface

above a smooth liner system (Luellen, Dove and Swan 1999). The weak interface is intended to define the failure block and limit shear displacement through the liner system.

Figure 3: Failure envelope for embossed HDPE geomembrane.



Textured HDPE geomembrane

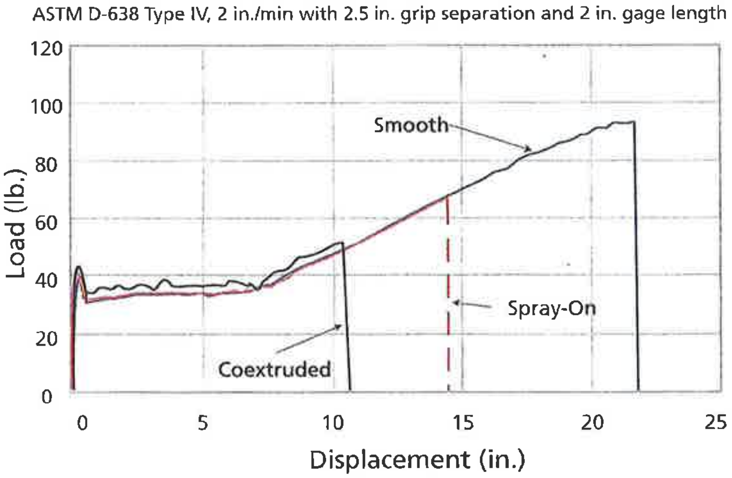
Three techniques are used to commercially texture geomembranes: embossing, coextrusion and spray-on. The following section discusses the actual process and technical concerns for the designer.

Embossing: The geomembrane passes between steel rollers having texture patterns engraved on them. Texture patterns range from the very light fabric like faille surface applied to one face of PVC geomembranes to what appear to be football cleats applied to HDPE geomembranes. Embossed geomembranes can develop significant interface shear strength at service loads but have one very critical oddity: the majority of embossed geomembranes lack the hook-and-loop-like tack with geotextiles that most designers take for granted. The impact of no apparent adhesion must be understood by the designer.

Figure 3 shows the failure envelop for an embossed HDPE geomembrane. Note that the apparent adhesion, e.g., low normal load shear strength, is essentially zero. This can have a significant impact on construction using these geomembranes. "Hook-and-loop" adhesion has a typical strength of 2.4 to 4.8 KPa (50 to 100 psf). This adhesion is essential if the geomembrane is being placed on a slope or to minimize the potential for slippage of dozer tracks during placement of cover soils (Paruvakat and Richardson 1999). The value of a double-bonded geonet is eliminated when used with embossed geomembranes. If the designer wants the "hook-and-loop" effect between the geomembrane and the drainage composite, a minimum apparent zero normal load adhesion of 2.4 Kpa (50 psf) should be specified.

Coextruded: The surface layers of HDPE or VFPE geomembranes can be coextruded with nitrogen gas in the molten polymer. The escaping nitrogen produces the roughened surface. The coextruded texturing is very consistent and cannot separate from the geomembrane core. This texturing process does result in a decrease in the strain at both yield and failure in comparison to smooth sheet of the same polymer. **Figure 4** shows the load-elongation curves for 1.5 mm (60 mil) HDPE smooth, coextruded and spray-on textured geomembrane. Note that the coextruded texturing offers a strain at failure that is less than that of either the smooth or spray-on texturing.

Figure 4: Load-elongation curves for 1.5 mm (60 mil) HDPE geomembrane with three types of texture.



Spray-on: Molten HDPE polymer is sprayed on the surface of a smooth HDPE geomembrane. The advantages of the sprayed-on texturing include no loss of strain at failure or yield and the ability to have smooth edges to simplify seaming. The key to the proper performance of the sprayed-on texturing is proper bonding of the texture to the smooth sheet. **Photo 1** shows a spray-on textured geomembrane that was rejected at the job site because the texturing could be wiped off by hand using a credit card! Ob-

Photo 1: Geomembrane with inadequate spray-on texture bond.

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viously, CQA direct shear testing is required to confirm the adequacy of the texture bond. The designer should prudently direct shear testing to be performed to at least 50% higher normal loads than anticipated to provide adequate reserve bond strength.

Measuring geomembrane roughness

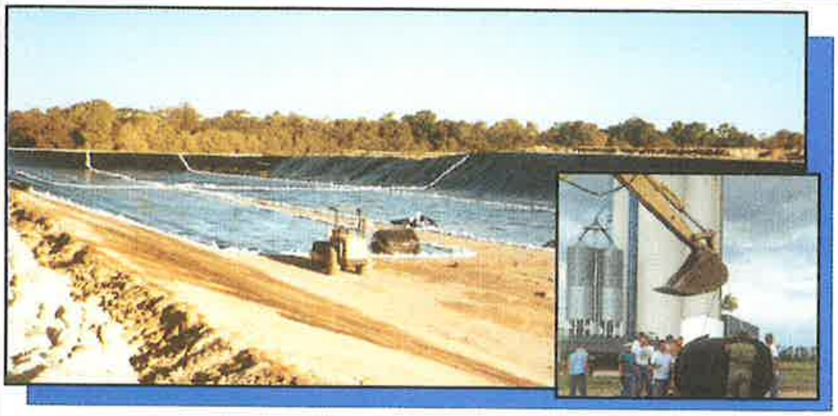
Since the first field application of textured geomembrane, the industry has searched for a simple index test to verify the level of texturing during manufacturing and during installation. Interface testing using ASTM D-5321 cannot be performed in the field and would be cumbersome at best for a manufacturer's QC test. One of the first attempts at a roughness index test was the use of a "standard" carpet interface. The first instance of this test used carpet attached to a brick that was hand-drawn over the texturing using a fish-weighing scale. Lovingly referred to as the "Crumley" sled in honor of a BFI engineer working on the project, the device did not gather a following. The next "carpet" block was part of a tilt-table test proposed by the Geosynthetics Research Institute (GRI). This test was eventually retired because of wide scatter in the test results.

The next generation of surface roughness index tests focused on dimensionally quantifying the textured surface. The first attempt was the use of Asperity Measurement (GRI Method GM-12) that measured the asperity height (distance from peak to valley). GM-12 uses a depth gage extending from a plate resting on the texturing to measure the depth of the valleys at 10 locations over a roll width. More recent index methods have sought to provide a more continuous evaluation of roughness by measuring surface profiles or area contours.

Dove and Harpring (1999) presented an excellent summary of surface profiling techniques at Geosynthetics Conference 1999. By drawing a stylus over the surface of a textured geomembrane, it is possible to establish the continuous two-dimensional profile of the texturing. These surface data are then used to generate several index constants: R_a is the average height of the texturing, R_t is the maximum peak-to-valley height, Δ_a is the average slope, and S is the average spacing between peaks. Dove and Harpring showed that the interface shear strength between textured sheet and sand was influenced by these index parameters. Dove, Adams and Johnson (2001) further showed that these parameters could be used as part of a manufacture QC program and in the development of a more effective texturing. However, as a field CQA process, surface profiling has a questionable future due to the complexity of the profiling equipment.

Summary

Given that the presence of a geomembrane is the root cause of a majority of landfill stability problems, this article has presented a review of some of the basic parameters that affect geomembrane interface shear strength. Part 2 of this article will present specific stability analysis recommendations and interface shear strength considerations for other geosynthetics. GFR



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