The enhancement of interface shear strength between two nonwoven geotextiles

By Gregory N. Richardson and Pieter K. Scheer

Introduction and problem statement

Interfaces involving nonwoven to nonwoven geotextile surfaces are sometimes part of the design of landfill liner systems. This is most likely the case in a double-liner system where a geosynthetic clay liner (GCL) is often designed below the upper (primary) geomembrane and is in contact with an underlying drainage geocomposite used in the leak detection system (Figure 1) or when multiple nonwoven geotextiles are overlain to create a heavier cushion layer. Unfortunately, the interface between two nonwoven geotextiles has the potential to have the lowest interface shear strength when compared to other liner-system interfaces. This problem is particularly true at low normal loads (< 1,000 psf) and if a hydrated GCL is involved.

Enhancing this interface requires either finding the preferred orientation of the selected geosynthetics or the addition of a small amount of coarse sand to the interface. Such means of enhancement of the shear strength of this interface have been found by the authors to be relatively quick, simple, and inexpensive. This article reviews these concepts.

Background: Interface shear strength—design and specification

Interface shear strength is approximated in terms of Mohr-Coulomb shear strength parameters based on the following equation:

\[ \tau = \sigma \tan \phi + c \]

Equation 1, where:
\( \tau \) = shear strength (psf)
\( \sigma \) = applied normal load (or stress) (psf)
\( \phi \) = friction angle (degrees)
\( c \) = cohesion/adhesion (psf).

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Figure 1 | Typical double-liner system cross-section

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Normally, the required shear strength values are specified by the design engineer corresponding to the values required to achieve the minimum allowable factor(s) of safety in the slope stability evaluation. For low normal loads (< 1,000 psf), the required shear strength values are typically determined using a veneer stability analysis. The simplest and most conservative way to evaluate veneer stability is to use the infinite slope equation:

\[ FS = \left(\frac{\tan \phi}{\tan \delta}\right) \]

**Equation 2, where:**
- \( FS \) = factor of safety
- \( \phi \) = minimum interface friction angle (degrees)
- \( \delta \) = maximum slope angle (degrees).

Other more general stability equations can also be used in the evaluation of veneer stability (Ohio EPA 2004). Of these, the Matasovic (1991) equation is particularly useful and widely used. For higher normal loads, the required shear strength values are typically determined by computer methods using “block” failure surfaces where the liner system forms much of the failure surface in each analysis.

The actual project-specific normal load range may include one low normal load for short-term veneer conditions (for example, 200 psf to consider 2 ft. of overlying soil protective cover) and two to three loads covering a range of higher service normal loads that will eventually be acting on the interface due to future waste placement. Although, typically, only peak shear strength values are specified, sometimes, depending on the design and/or permitting requirements, residual (large-displacement) shear strength values are of interest and are specified in addition to, or in lieu of, peak shear strength values. If, as the authors have seen to be the case for many older landfill designs, there are no design shear strength values or if any of the shear strength values or the prior evaluation(s) look problematic, then additional slope stability analyses should be performed to verify or determine the required minimum values.

It should be noted that most often the slope stability evaluation identifies only the friction angle (\( \phi \)) component of shear strength (i.e., the cohesion (c) is assumed to be zero) for the worst-case interface (see Equation 2). To model all possible combinations of friction angle (\( \phi \)) and cohesion (c) would be too time consuming and not necessary. The required interface shear strength value at a particular normal load should be determined from the friction value only. As an example, for \( \phi = 20^\circ \), \( c = 0 \) psf, and a normal load of 2,000 psf, the required shear strength (see Equation 1) is 728 psf.
Conformance testing

Prior to construction, interface shear strength must always be confirmed using the direct shear method—ASTM D 5321 or ASTM D 6243 (for interfaces involving GCLs)—using representative materials proposed for construction. Testing must be performed over the range of specified normal loads to verify that the materials proposed for construction meet the design shear strength parameters. The design engineer must also specify the rate of displacement and any special sample preparation requirements (i.e., how to hydrate GCL test specimens). Unless non-standard materials are specified for use, representative materials (i.e., same model) are typically used in the testing in that waiting for actual materials to be produced for the project is often not practical due to scheduling concerns.

The direct shear test measures the total resistance to shear along the tested interface for a given normal load and rate of displacement. The reported test results should give both peak and residual shear strength values and best-fit lines are generated for both peak and residual values over the range of normal loads evaluated to give overall peak and residual friction angles and cohesion/adhesion values for the interface (Figure 2).

Enhancement of interface shear strength—preferred orientation

The first potential solution to the enhancement of interface shear strength for any interface involving a geosynthetic is to determine the preferred orientation of the selected product(s). A perfect example of this relating to nonwoven-to-nonwoven interfaces involves certain reinforced GCLs which have one side where the reinforcing has been heat burnished against the nonwoven geotextile. This side has been found to perform quite well in contact with the nonwoven surface of a drainage geocomposite due to the “Velcro” action of the small nubs on the heat-burnished side. (It acts in a fashion similar to a textured geomembrane that is manufactured using coextrusion or
The direct shear test measures the total resistance to shear along the tested interface for a given normal load and rate of displacement.

Sand addition—mechanism, sand type

If material orientation does not improve interface shear strength results for nonwoven to nonwoven interfaces, the addition of a small amount of coarse sand to the interface can provide a dramatic improvement. If one were to take a piece of a typical nonwoven geotextile and sprinkle some sand on top, much of the sand would stick (embed in reality) readily to the surface even if the geotextile was held vertically. Once another piece of geotextile is added on top, the sand grains are forced into the matrix of the geotextiles. The sand has a significant mechanical bond to the fibers of the geotextiles, particularly for coarser sand. Thus, a substantial interlocking mechanism is created, which would logically be maintained between the materials indefinitely. As the amount of sand used increases, the interface friction angle approaches the internal friction angle of the sand.

As far as the type of coarse sand to use, the authors recommend angular or subangular manufactured concrete sand (majority of grain size range between No. 8 and No. 100 sieve). The angularity is important such that the sand grains do not act as ball bearings. Additionally, the grain size of concrete sand is large enough for the sand particles to establish the desired mechanical bond with the fibers of the geotextiles. Concrete sand is also readily available in most locations.

Sand addition—laboratory test results

The following is a discussion of the results of laboratory testing on two projects where sand was used as an enhancement of the interface shear strength between two nonwoven geotextiles. For both of these projects, the interface evaluated was a GCL (hydrated) against a drainage geocomposite.
Project 1:
For Project 1 (a site in North Carolina), the materials met project requirements except for interface shear strength at a normal load of 200 psf. The 77 psf shear strength measured at 200 psf normal load corresponds to an interface friction angle of 21.1° (tan⁻¹ 77/200). This was of concern due to a portion of the site having 3H:1V (18.4°) slopes. The resulting factor of safety by Equation 2 would only be 1.16 (tan 21.1°/tan 18.4°). With the addition of approximately 1 lb/sy (1 lb. per yd²) of sand, the interface shear strength im-
proved 38% to 106 psf. This produced an interface friction angle of 27.9° (tan⁻¹ 106/200) and a factor of safety of 1.59 (tan 27.9°/tan 18.4°). Note that 1 lb/sy of sand is a very minor amount as it is not nearly enough to cover (obscure) the surface of the underlying geotextile surface (Photo 1).

Project 2:
Although 1 lb/sy is more than adequate to improve the interface shear strength values under low normal loads, regulators for this project in Pennsylvania were concerned about performance under higher service loads. Under a low normal load of 200 psf, the interface shear strength improved from 77 lbs. (21°) with no sand to 127 (32.4°) with 1 lb/sy of concrete sand (a 65% improvement). Under a higher service load of 3,750 psf, the interface shear strength improved from 1,986 lbs. (27.9°) with no sand to 2,533 lbs. (34°) with 1 lb/sy of concrete sand (a 28% improvement).

Sand addition—recommended specs and CQA parameters
Based on the authors’ experience on two projects (as noted above), where sand was used as an enhancement of the interface shear strength between nonwoven geotextiles, the following information is offered for use in project specifications and construction quality assurance (CQA) plans.

Specifications:
For designs including a nonwoven to nonwoven interface, the design engineer should specify the preferred orientation and/or addition of coarse sand at a nominal rate of 1 lb/sy (actual rate to be verified by laboratory testing). There are several options to placing the sand: 1) spreading with a small agricultural spreader tossed on the back of an ATV (if ATVs are allowed); 2) placing at the top and/or along the slope and brooming into place; 3) hand broadcasting; 4) placing at the top of the slope and pulling the material down the slope with the installation of the overlying material; or 5) any combination of the above. Note that Option 4 is a bit crude and is not practical to verify over the whole slope, but was thought to do an adequate job on Project 1.

CQA:
The addition of sand should be monitored visually in the field by applying 1 lb. of sand evenly over a 1-sy test area in the field and noting the general appearance. If over a larger area the sand is a bit heavier in one area and a bit lighter in one area that would be acceptable. However, the general appearance of the sand should mimic the test area. In addition, the sand application could be monitored quantitatively by tracking the approximate weight of sand applied over a
particular area. For example, truck weight tickets could be used. Being that there is a large tolerance for the amount of sand creating the desired improvement, the authors feel the visual methods are more than sufficient to ensure proper performance. And remember, more sand is OK!

Sand addition -- cost

Based on a nominal application rate of 1 lb/sq yd of sand, approximately 2.4 tons/acre will be required (1 lb/ sq yd x 4,800 sq yd/acre x 1 ton/2,000 lb). That’s only about $72/acre for the sand assuming a delivered cost of $30/ton. The time and cost required to spread the sand depends greatly on the method that is used. However, the authors think the overall added cost for the sand addition would be well less than $0.01 per ft.²

Summary and conclusions

The interface between certain nonwoven geotextiles has the potential to have the lowest interface shear strength when compared to other liner system interfaces. Often finding the preferred orientation of the geosynthetics can provide acceptable shear strength values. However, for some nonwoven to nonwoven interfaces the addition of a small amount of coarse sand can significantly improve interface shear strength.

Should the design include a nonwoven to nonwoven interface, the design engineer should anticipate that, depending on the actual materials selected for use, there could be a problem in meeting the required interface shear strength values for this interface especially at low normal loads. By specifying the preferred orientation or the optional addition of coarse sand (the need/amount to be determined through actual testing), a relatively quick, simple, and inexpensive means can be provided for improving interface shear strength and gaining material acceptance.

References


Interface Friction / Direct Shear Testing & Slope Stability Issues

Friday, May 19, 2006, 8 am - 5 pm
Embassy Suites @ Airport, Philadelphia
Guest Speaker: Tony Eith
Waste Management, Inc.

- Why slope failures occur
- How to determine and use shear strength
- Understanding ASTM D 5321 and ASTM D 6243 - friction test methods
- How to avoid meaningless test data
- How to specify a relevant direct shear testing
- How to evaluate friction test results
- Failures; lessons learned

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