Designer's Forum

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# Flexible geomembrane interface strengths

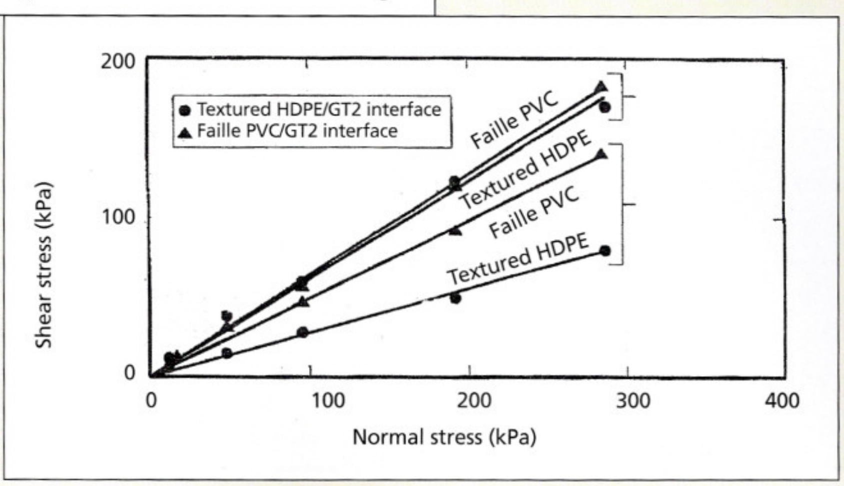
The usual design objective for impoundments and waste containment facilities is to maximize storage capacity. Thus, it is important to construct the side slopes as steeply as possible. To reduce leakage, usually a liner system that incorporates a geomembrane is installed. Domestic municipal and hazardous waste-containment facilities are required to have a liner and cover system that usually consists of a compacted clay liner and geosynthetic materials. The geosynthetic components routinely include layers of geonet or drainage composite, geotextile cushions and/or filters and a geomembrane. An important characteristic of slope stability is the shear resistance along the various component interfaces. A number of case histories suggest that the geomembrane can create a problematic interface due to low frictional resistance between it and another geosynthetic component or the compacted clay. This article describes the shear behavior of flexible geomembrane interfaces and presents a database of test results for comparison purposes. Since the shear resistance of geosynthetic interfaces is project-specific and and product-dependent, presentation and discussion of the test results are concentrated on the shear behavior rather than providing specific shear-strength values for use in design applications.

Torsional ring shear (Stark and Poeppel, 1994; Stark et al. 1996; and Eid and Stark, 1997) and large-scale direct shear (ASTM D 5321) tests were conducted to investigate the shear behavior of flexible geomembrane/nonwoven geotextile interfaces. Specifically, a 0.75-mm-thick polyvinyl chloride (PVC) geomembrane was sheared against five different nonwoven geotextiles and compared to 1.5-mm-thick smooth and textured high-density polyethylene (HDPE) and very flexible polyethylene (VFPE) geomembranes. Many PVC geomembranes are manufactured with a smooth side and an embossed side. The embossed side surface usually resembles a file and is called a "faille-finished" surface. Accordingly, a faille PVC geomembrane interface is one in which the faille-finished surface of a PVC geomembrane is sheared against another geosynthetic component. Test results indicate that the smooth side of the PVC geomembrane yields a larger interface shear resistance than the faille-finished side due to the higher flexibility and larger contact area of the smooth side. Since the faille side of a PVC geomembrane renders a lower interface shear resistance than the smooth side, it was deemed appropriate/conservative to compare the shear strength of the faille PVC geomembrane interfaces to the HDPE and VFPE geomembrane interfaces.

Another study objective was to provide a comparison between geosynthetic interface shear-strength data obtained from torsional ring shear and large-scale direct shear tests. To accomplish this, large-scale direct shear tests were conducted on the same geomembrane interfaces that were tested in the torsional ring. The large-scale direct shear apparatus used in this study allows a 300-mm by 300-mm metric specimen to be sheared over a lower geosynthetic specimen that is 300 mm by 350 mm. The normal stress is applied pneumatically and the same shear displacement rate was used for the ring shear and direct shear tests to avoid displacement rate-related discrepancies in the test results. The direct shear tests were also conducted at the same normal stresses used in the ring shear tests to provide a direct comparison of the shear stress-displacement relationships and peak and residual shear strengths.

The ring shear and direct shear tests yielded similar stress-displacement relationships and peak interface friction angles. However, the direct shear apparatus yielded higher residual interface strengths because the device could not exceed a shear displacement of 100 mm. Therefore, it was assumed that the ring shear device yields similar results as the large-scale direct shear apparatus for the interfaces considered herein and could be used as a substitute for the direct shear apparatus as suggested in ASTM D 5321 (1998). As a result, the majority of the testing was conducted using the more cost-effective ring shear device, but at least one direct shear test was conducted on each interface to verify the agreement between the apparatuses.

***Figure 1:*** Interface shear testing.




## *Geosynthetics and equipment used in shear testing*

Geosynthetics used in the interface shear testing are listed below. An identifier (in parentheses) is given after each geosynthetic to facilitate comparison of the test results in **Table 1** throughout this article. A forthcoming technical paper, Hillman and Stark, (1999) describes the test procedures and results in greater detail and can be obtained from PVC Geomembrane Institute (PGI).

- Polyvinyl Chloride geomembrane (PVC): a 0.75-mm-thick geomembrane with a faille-finished side and a smooth side. This geomembrane is manufactured

**TABLE 1. SUMMARY OF GEOMEMBRANE/NONWOVEN GEOTEXTILE INTERFACE FRICTION ANGLES (FOR COMPARISON PURPOSES ONLY*)**

| Geomembrane/nonwoven geotextile interface | Peak friction angle (deg) | Shear displacement at peak (mm) | Residual friction angle (deg) | Shear displacement at residual (mm) |
|---|---|---|---|---|
| Faille PVC/GT1 | 28-25 | 500-50 | 28-24 | 500-650 |
| Faille PVC/GT2** | 37-33 | 700-10 | 37-26 | 700-150 |
| Faille PVC/GT3 | 25-27 | 400-13 | 25-24 | 400-900 |
| Faille PVC/GT4 | 20-22 | 200-21 | 20-30 | 200-300 |
| Smooth PVC/GT4 | 29-30 | 900-400 | 29-30 | 900-400 |
| Faille PVC/GT5 | 30-27 | 400-70 | 30-26 | 400-550 |
| Smooth HDPE/GT2** | 11-9 | 4-2 | 7-5 | 55-35 |
| Textured HDPE/GT2** | 44-30 | 11-6 | 25-15 | 100-150 |
| Smooth VFPE/GT2** | 11-7 | 3-1 | 6-5 | 50-30 |
| Textured VFPE/GT2** | 38-27 | 7-5 | 25-19 | 150-200 |

Note: Each entry corresponds to values at normal stresses of 17 and 400 kPa, respectively. For example, the faille PVC/GT1 interface has a secant peak friction angle of 28 degrees at a normal stress of 17 kPa and 25 degrees at a normal stress of 400 kPa.

* Site-specific interface testing should be conducted for design purposes.

** Highest normal stress was 285 kPa instead of 400 kPa.

by Canadian General-Tower Ltd., Cambridge, Ontario, Canada.

- Textured High-Density Polyethylene Geomembrane (T-HDPE): A 1.50-mm-thick co-extruded textured geomembrane manufactured by GSE Lining Technology Inc., Houston, Texas.
- Smooth High-Density Polyethylene geomembrane (S-HDPE): A 1.50-mm-thick smooth geomembrane that is manufactured by GSE Lining Technology Inc., Houston, Texas.
- Textured Very Flexible Polyethylene geomembrane(T-VFPE): A 1.00-mm-thick co-extruded textured geomembrane that is manufactured by GSE Lining Technology Inc., Houston, Texas.
- Smooth Very Flexible Polyethylene Geomembrane (S-VFPE): A 1.00-mm-thick smooth geomembrane that is manufactured by GSE-Lining Technology Inc., Houston, Texas.
- Nonwoven Geotextile (GTI): A nonwoven polypropylene geotextile with a mass per unit area of 540 $g/m^2$. This geotextile is manufactured by Amoco, Atlanta, Ga.
- A nonwoven polyester geotextile with a mass per unit area of 540 $g/m^2$. This geotextile is manufactured by Johns Manville, Spartanburg, S.C.
- A nonwoven geotextile (GT3): A nonwoven polypropylene geotextile with a mass per unit area of 205 $g/m^2$. This geotextile was manufactured by Polyfelt America, Atlanta, Ga.
- Nonwoven geotextile (GT4): A nonwoven polypropylene geotextile with a mass per unit area of 540$g/m^2$. This geotextile was manufactured by Polyfelt America, Atlanta, Ga.
- Nonwoven geotextile (GT5): A nonwoven calendered polypropylene geotextile with a mass per unit area of 540 $g/m^2$. This geotextile was manufactured by Amoco, Atlanta, Ga.

## *Flexible geomembrane database*

The shear testing resulted in a database (**Table 1**) of the interface shear resistance of PVC, HDPE, and VFPE geomembranes with typical nonwoven geotextiles. Each entry contains peak and residual shear strength and shear displacement values obtained for

***Figure 2:*** Comparison of failure envelopes for faille PVC and textured HDPE geomembrane/GT2 geotextile interfaces

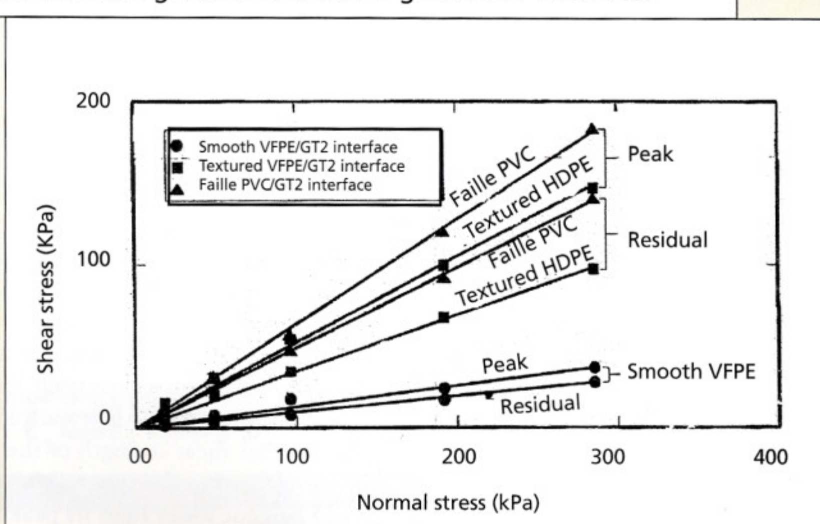
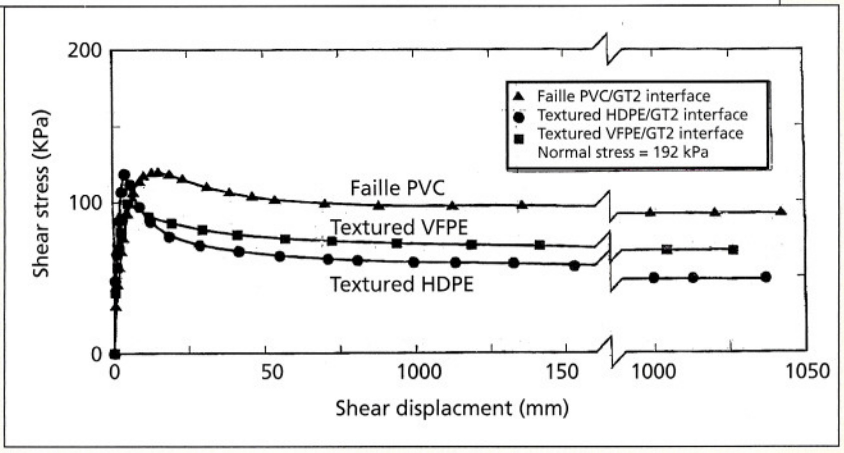


*Figure 3:* Comparison of failure envelopes for faille PVC, smooth VFPE and textured HDPE geomembrane/GT2 geotextile interfaces




the lowest (17kPa) and highest (285 or 400 kPa) testing normal stresses. The database provides designers and agencies with information for understanding the frictional performance of certain geosynthetic interfaces, as well as information for selecting the appropriate nonwoven geotextile for composite liner or cover systems that utilize a geomembrane to maximize interface shear resistance. This database is for comparison purposes, so site-specific interface testing should be conducted for design purposes.

## Comparison of PVC and HDPE geomembrane/ nonwoven geotextile interface strengths

The peak and residual shear strengths of the textured and smooth HDPE geomembrane interfaces can be compared to those interfaces in Table 1.

Additionally, peak and residual failure envelopes for faille PVC and textured HDPE geomembrane/GT2 nonwoven geotextile interfaces are show in **Figure 1**. These two interfaces have similar peak failure envelopes. However, there is a significant difference in the post-peak strength loss experienced by the interfaces, as reflected in the residual failure envelopes. Specifically, the textured HDPE geomembrane Interface underwent a larger post-peak strength loss compared to the faille PVC geomembrane interface. A textured HDPE geomembrane interface usually experiences a 50-60 percent post-peak strength loss (Stark et al. 1996). The possible reasons for this large strength loss are that the asperites of the textured HDPE geomembrane tear or pull out the filaments of the geotextile and orient them parallel to the direction of shear and the geomembrane texturing is smoothed or polished due to the shear displacement along the interface. On the other hand, the faille PVC geomembrane tore or pulled out a smaller quantity of filaments from the geotextile and the geomembrane did not become polished; both of which resulted in the geotextile staying relatively intact and the interface exhibiting only a small post-peak strength loss. At normal stresses of 48 kPa and below, the PVC geomembrane extracted few if any filaments because the geotextile was unable to sufficiently embed in the PVC geomembrane. As a result, little, if any, post-peak strength loss was observed at normal stresses less than or equal to 48 kPa for all of the PVC geomembrane/nonwoven geotextile interfaces tested. This behavior has important design implications. For example, these characteristics suggest that PVC geomembranes are well suited for applications in which low normal stresses are expected,such as landfill cover systems, or where seismically induced permanent deformations may result. For normal stresses between 48 kPa and 285 kPa, the residual shear strength of the PVC geomembrane interface was only about 15 to 25 percent lower than its peak shear strength versus 50-60 percent post-peak strength loss for textured HDPE.

## Comparison of PVC and VFPE geomembrane/ nonwoven geotextile interface strengths

It was anticipated that VFPE geomembranes, because of their flexibility, would yield interface shear strengths similar to those of PVC geomembranes. **Figure 2** presents a comparison of the peak and residual failure envelopes for faille PVC, textured VFPE, and smooth VFPE geomembrane/GT2 geotextile interfaces. The failure envelopes indicate that the peak shear strength of the textured VFPE geomembrane interface was less than the faille PVC geomembrane interface. Additionally, the textured VFPE interface experienced a larger post-peak strength loss than the faille PVC interface because the texturing damaged the nonwoven geotextile during shear and the geomembrane texturing was smooth or polished. **Figure 2** also indicates that the smooth VFPE geomembrane interface exhibited lower peak and residual shear strengths than the faille PVC and textured VFPE geomembrane interfaces.

As a final comparison, **Figure 3** presents the shear stress-displacement relations for faille PVC, textured HDPE, and textured VFPE geomembrane/GT2 geotextile interfaces at a normal stress of 192 kPa. The VFPE and RDPE geomembrane interfaces reached a peak strength condition after approximately 8 mm of shear displacement and then experienced a substantial post-peak strength loss (40 to 60 percent). On the other hand, the faille PVC interface peaked at a shear displacement of about 30 mm and lost only 20 to 25 percent of the peak shear strength. Additionally, a comparison of **Figures 1 and 2** shows that textured HDPE geomembrane interfaces produced higher peak and lower residual failure envelopes than the corresponding textured VFPE geomembrane interfaces. In conclusion, faille PVC geomembrane/nonwoven geotextile interfaces appear to yield similar peak interface shear strengths and considerably higher residual shear strengths than similar textured HDPE and textured VFPE geomembrane/nonwoven geotextile interfaces. Again this has important design implications for slopes where a residual interface shear resistance may be appropriate or where seismically induced permanent deformations may accumulate or where a residual interface shear resistance may be appropriate or where seismically induced permanent deformations may accumulate.

## Summary

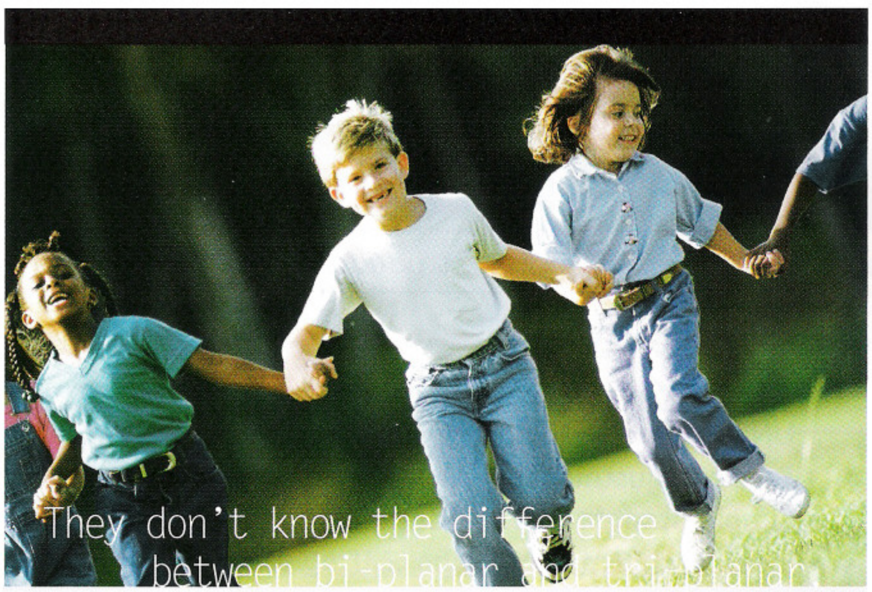
This article briefly describes the shear behavior of flexible geomembrane/nonwoven geotextile interfaces. In addition, a database of PVC, HDPE and VFPE geomembrane/nonwoven geotextile interface strengths is presented that can be used for comparison purposes. Since the shear resistance of geosynthetic interfaces is project specific and product dependent, the test results shown in **Table 1** should be used to illustrate the shear behavior, rather than providing specific strength values for use in design applications of the tested geosynthetic interfaces. The following conclusions are based on the shear testing data and described in more detail in a forthcoming paper by Hillman and Stark, (1999):

1. The interface shear strengths obtained from torsional ring shear tests are in agreement with those obtained from large-scale direct shear tests for the interfaces studied herein. Therefore, it was assumed that the ring shear device could be used as a substitute for the large-scale direct shear apparatus is permitted by ASTM D5321 (1998).

2. The smooth side of a PVC geomembrane provides higher peak and residual interface shear resistances than the faille side. Additionally, there was no noticeable post-peak strength loss for the smooth PVC geomembrane interfaces. The greater frictional resistance of the smooth side of a PVC geomembrane is attributed to its higher flexibility and larger contact area than the faille side. The high flexibility of the smooth side also accounts for the negligible post-peak strength loss in smooth PVC geomembrane/nonwoven geotextile interfaces. Since the faille side yielded lower interface shear resistances than the smooth side, the database in **Table 1** focuses on faille PVC geomembrane interfaces to provide lower bound values of peak and residual interface strengths.

3. Faille PVC geomembrane/nonwoven geotextile interfaces exhibit smaller post-peak strength losses than similar smooth and textured HDPE and VFPE geomembrane interfaces. Textured HDPE geomembrane/ nonwoven geotextile interfaces exhibit post-peak strength losses of 50 to 60% and textured VFPE geomembrane interfaces 35 to 45% as compared to less than 25% for the faille PVC geomembrane interfaces tested herein. The textured geomembranes exhibit a larger post-peak strength loss because the texturing tears or pulls out more geotextile filaments and orients them parallel to the direction of shear, and the geomembrane texturing may be smoothed or polished during this process. Additionally, faille PVC geomembrane/nonwoven geotextile interfaces do not exhibit a post-peak strength loss at normal stresses less than 48 kPa. The post-peak strength loss at normal stresses greater than 48 kPa is primarily caused by the tearing or pulling out of some of the geotextile fil-





aments that are embedded in the faille PVC geomembrane. At low normal stresses, the geotextile is unable to embed into the faille PVC geomembrane, which reduces the post-peak strength loss. A smaller post-peak strength loss may be beneficial in applications where a post-peak strength is applicable to design; e.g., steep side slopes or seismically active regions

4. A polyester-based nonwoven geotextile yields higher peak and residual interface shear strengths when sheared against the faille PVC geomembrane surface than a polypropylene-based nonwoven geotextile. This trend has also been observed for textured HDPE geomembrane/nonwoven geotextile interfaces (Stark et al. 1996). Thus, the polymer composition of a non-woven geotextile influences geomembrane interface shear resistance.

5. Nonwoven geotextile fiber type appears to have an impact on PVC geomembrane/nonwoven geotextile interface shear strength. Staple fiber nonwoven geotextiles appear to yield higher, interface strengths than continuous single-filament nonwoven geotextiles for faille PVC geomembrane interfaces. The opposite trend, i.e., continuous single-filament nonwoven geotextiles yielding a higher interface shear resistance than staple fiber nonwoven geotextiles was observed for textured HDPE geomembrane/nonwoven geotextile interfaces (Stark et al. 1996).

6. A nonwoven geotextile mass per unit area 205 g/m$^2$ appears to result in higher peak interface strengths than a 540 g/m$^2$ geotextile for the faille PVC geomembrane surface tested herein. This trend was also observed for textured HDPE geomembrane/ nonwoven geotextile interfaces Stark et al. (1996).

7. Calendering a nonwoven geotextile produces greater interface shear strength with the faille PVC geomembrane than a non-calendared geotextile. This trend was also observed for textured HDPE geomembrane/nonwoven geotextile interfaces Stark et al. (1996). GFR

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