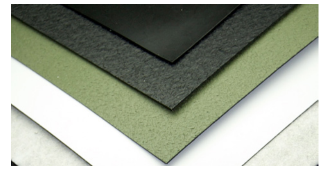
TECHNICAL NOTE

PRACTICAL GUIDANCE RELATED TO GEOSYNTHETIC INTERFACE SHEAR AND FRICTIONAL PERFORMANCE


[GSE Geomembranes]

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Geosynthetic materials are extremely useful and should be a common part of every geotechnical engineer's repertoire. How geosynthetics are utilized, particularly relative to their interface interaction with each other and to the soils that they are in contact with, is a critical issue in nearly every installation where they are used. Significant science has been undertaken and applied to this issue. Despite these efforts, however, there can be significant confusion on how the measurement and specification of interface friction and direct shear performance should be undertaken, what the construction requirements might be, and what specific variables are most critical. The goal of this paper is to present a simple plan for this situation, and, more importantly, to provide additional resources and references on how to address and execute in problematic areas.

While there is a great number of reference materials available, the recommended process can be described in a very straightforward manner:

1. Understand the goal: what is the design trying to achieve?

2. Compare with historical references: does this design seem reasonable, based on historical precedent?

3. Understand the variation: historical data is not always accurate; what variables affect testing and performance?

4. Conduct a test: it is always a good idea to conduct a laboratory test to validate design assumptions.

5. Create a specification: reduce the design requirements to a specification that can be used for project execution.

6. Validate the production materials with appropriate testing: both specification requirements and a duplicate test.

7. Assure construction occurs in agreement with the design assumptions: CQA and vendor selection matter.

The devil is, of course, in the details. The following sections discuss each of these steps in greater detail and provide useful references.

UNDERSTANDING THE GOAL(S)

It may sound overly simplistic, but the first step should be to understand the goal: what is one trying to accomplish? Commonly with geosynthetics, the designer is attempting to provide a barrier function: protection of groundwater, containment of solid or liquid wastes, or containment of valuable liquids (water or process liquids).

The engineer should make a choice as to the type of barrier or barrier system that he/she wishes to evaluate. Which material, or materials will be used: a single liner, a composite liner, a double composite liner with leak detection [(1)], or other construction? The basic design will dictate the interfaces that will need to be examined and potentially evaluated. Another basic but important point is design technique, specifically the selection of peak strength or residual (long-term displacement) strength as the controlling design criteria. Several authors have weighed in on this topic [(2)(3)], and designing for the residual strength of the interface with the lowest peak strength appears to be the most conservative methodology. Other items that require additional consideration at the initiation of a project are the overall application, the consequences of failure, and the different environments that the design will see over its life span. It is important to consider the performance of the design during the construction phase of the project; historically, the potential for failure is higher during this time period. Traffic and movement of construction equipment on the system [(4)] should be considered and controlled. If appropriate, calculations should be undertaken to determine what type of machinery and operation of the same are allowable during construction. Additional consideration should be given to the timing of operations. For example, how is the overburden and load to be placed on side slopes? Will the entire site be covered during the construction phase, or will some slopes and installed materials be exposed for a significant period of time? All of these issues should be generally understood prior to one investigating and calculating interface performance.

COMPARE WITH HISTORICAL REFERENCES:

Contrary to other recommendations, I believe it is important to consult historical literature [(5)] and databases during the initial evaluation of the interface performance. Once the variables described previously are generally understood, one can compare them to historical norms as a general reference. I strongly agree that this should not be a definitive evaluation. However, it is useful to the engineering practitioner to know if he is attempting something that is commonplace or if his design does not agree with the established standard of practice and performance. Clearly exceptional performance is possible, however additional planning, evaluation, testing and verification should be undertaken when usual performance is expected. The largest available database is published (to members only) by the Geosynthetic Institute.(http://www.geosynthetic-institute.org): GRI Report #30: Direct Shear Database of Geosynthetic-to-Geosynthetic and Geosynthetic-to-Soil Interfaces. Dr. Neil Dixon of Loughborough University (http://www.lboro.ac.uk/departments/cv/staff/profile/24.html) has also compiled a large number of interface test results. These two databases are currently being combined and a new version of the Geosynthetic Institute report #30 is anticipated in the future.

UNDERSTAND THE VARIATION:

When consulting the historical databases, it is imperative to have an understanding of what you're looking at. Specifically the level of variability that exists in the data even within specific test results should be understood. The variability for this test is quite high with estimates of up to nearly 30% [(6)(7)]. Furthermore, it has proven difficult to compare test results with variable conditions (i.e., high overburden pressures vs. low overburden pressures, high moisture levels vs. low moisture levels, etc). Also, when considering the geomembrane type, one might anticipate significant differences between the performance of different types of textured geomembranes[(8)], yet this data is commonly presented within one data set.

Professor Dixon does an excellent job of categorizing this variation in his paper[7] "Soil-geosynthetic interaction: Interface behavior." In section 2 of that paper, he lists sources of variation within the tests as follows:

"Interface shear behavior is a function of a large number of factors that can be summarized as (ASTM D 5321,2008):

- Applied normal stress
- Geosynthetic material characteristics
- Soil gradation
- Soil plasticity
- Density
- Moisture content
- Size of sample
- Drainage conditions
- Displacement rate
- Magnitude of displacement; and
- Other parameters"

I would offer an additional opinion on a specific item that fits under "Other parameters," but likely deserves its own heading and that is the methodology and techniques used to anchor geosynthetic layer(s) within the testing apparatus. The author's experience and discussions with others have lead to the opinion that this may be the single greatest cause of variation between laboratory to laboratory results. Seat time prior to testing and the timing, consistency, and amount of overburden pressures during the exposure to moisture, can also be very important parameters, particularly in the case of testing involving geosynthetic clay liners,.

There are two areas where this understanding comes into play. One is that the comparison of the design calculation results to "historical norms." In this area conservative engineering logic should be applied. The other area where understanding of variability is important is relative to the upcoming recommendations on testing evaluation, frequency, and sample repetition. While this paper is written from the perspective of multiple test events using multiple materials and combinations over a long period of time, most engineers have a very specific concern: the project that they are working on currently. A "one-of" interest is very practical from that perspective. The designer should have a clear estimate of variability in his mind prior to conducting testing and should set his design to accommodate that level of variability.

CONDUCT A TEST:

In nearly every case, even when historical norms show agreement with the expected design performance, it is advisable to conduct a laboratory test using one of the applicable standards. The goal of this test is to validate the design and identify any potential problem areas by verifying the estimations via a physical experiment. Another important benefit of running a test is the self-imposed requirement to identify all of the pertinent variables necessary to conduct an accurate and repeatable test. These include but are not limited to the variables listed above.

In the real world, economic and scheduling considerations usually drive the number and frequency of the testing. These tests are not inexpensive, usually running $2,000 to $3,000 for testing sufficient to calculate the friction angle at a specific condition. Further, a minimum of two weeks is commonplace for testing including the supply of materials, shipment, set-up time and so on. This schedule may be extended by a desire to obtain and use site-specific soils for testing or other special considerations [9]. While some authors have recommended multiple repeats and the use of multiple laboratories to assure accurate values, a single set of tests at three closely related overburden pressures is commonplace in practical experience. The above costs are schedule might vary in other parts of the world depending on availability of accredited testing facilities and the location of the project site.

The engineer should further understand that he should take a personal and project commitment to the laboratory of choice; it is not advisable to switch laboratories during a testing cycle or even over the life span of the entire project. Changing laboratories can contribute to variability and a less exact understanding of performance.

One final issue related to testing is the interpretation of the testing results. The question of internal cohesion should be settled early on in the design and all subsequent test result evaluated in a consistent fashion. While there are multiple opinions in literature on this topic, Rick Thiel has addressed this issue specifically and effectively [(10)].

CREATE A SPECIFICATION:

Having consulted historical data bases and conducted at least minimal testing, the engineer is now required to convert his performance understanding into specification requirements. The specification requirements will be distributed to the bidders and manufacturers of material and should be clear, concise and direct. It should be understood that no manufacturer will willingly agree to design specification criteria for material. In the case of geosynthetics, specifically geomembrane, it is common for an interface friction requirement to be specified via an asperity height [(11)] requirement. Admittedly, this feels like an intellectual compromise; however, it has proven to be effective in the real world. Some industry participants are researching this topic further and supplying additional characterization of the interface surfaces [(12)]. I believe that this type of surface characterization will become more commonplace over time, particularly in critical applications.

VALIDATE THE PRODUCTION MATERIALS:

It is the function of the engineer to bridge the gap of specification between the materials available and that are produced for the project and the function and performance of a completed installation. For example, the lumber supplier can't be held responsible for the construction of the house. That being said, it is a perfectly reasonable expectation of the engineer to require testing on production materials that are specifically supplied to the project.

Obviously this will occur after material production has been initiated and during a time-sensitive period. However, it is advisable to return to the same laboratory (and if possible, the same equipment and techniques) and duplicate the design validation testing with specific production materials whenever possible. This is in addition to the requirements for more common components of the specification and generally good manufacturing quality assurance processes.

ASSURE CONSTRUCTION OCCURS IN AGREEMENT WITH THE DESIGN ASSUMPTIONS:

There is an additional requirement that should be placed on the engineer. Assuming one is capable enough to have navigated this portion of the project with success, it is imperative to make two additional requirements which have been demonstrated[(13)(14)] to promote a project's success. These are proper selection of the geosynthetic installer and proper selection and authority for a construction quality assurance function.

It is recommended that the geosynthetic installer be selected based on historical performance, prior experience, insurability, training and certification of the installation crew, and a host of other variables besides being the lowest bidder on the project. There is an industry organization, the International Association of Geosynthetic Installers (www.iagi.org), which has done an excellent job of documenting the requirements for a successful installation, welding skills and experience and other variables that can have a strong contribution to project success. It is strongly recommended that IAGI certified welders and installers be utilized for all geosynthetic installations.

Further construction quality assurance has been proven time and again to be critical to project quality and the eventual successful performance of the installation. Again the criterion for construction quality assurance staff and performance has been established, in this case by the Geosynthetic Institute's certification program (http://www.geosynthetic-institute.org/icpintro.htm). Historical experience, knowledge and the authority to act when and where necessary is critical to successful CQA. Done properly, construction quality assurance staff acts as a product manager and facilitator and is beneficial to all involved. Is important to remember the construction quality assurance of the geosynthetics should continue until the geosynthetics are covered with sufficient soil or other materials to offer permanent protection for the environment that they will be in.

As discussed in the following section, the material that is designed for the project must be used, or choose one with MORE adhesion, not less. The long term stability and performance of the project is the primary objective.

INDUSTRY ORGANIZATIONS

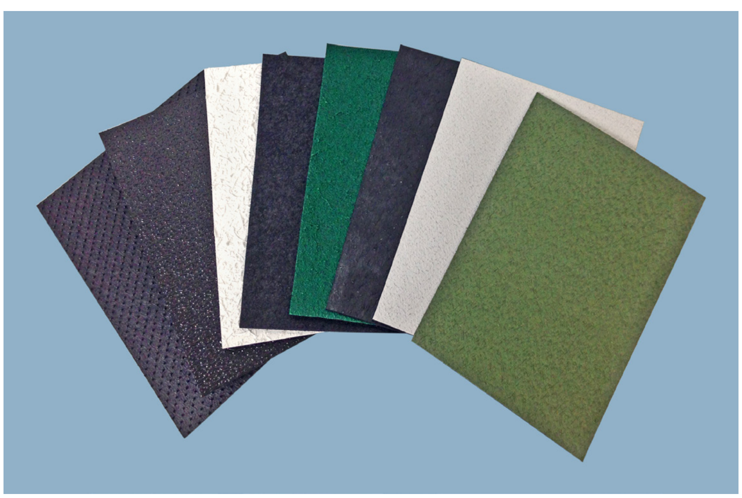
Association of Geosynthetic Installers
www.iagi.org

Geosynthetic Institute
www.geosynthetic-institute.org

CONCLUSIONS AND COMMENTARY:

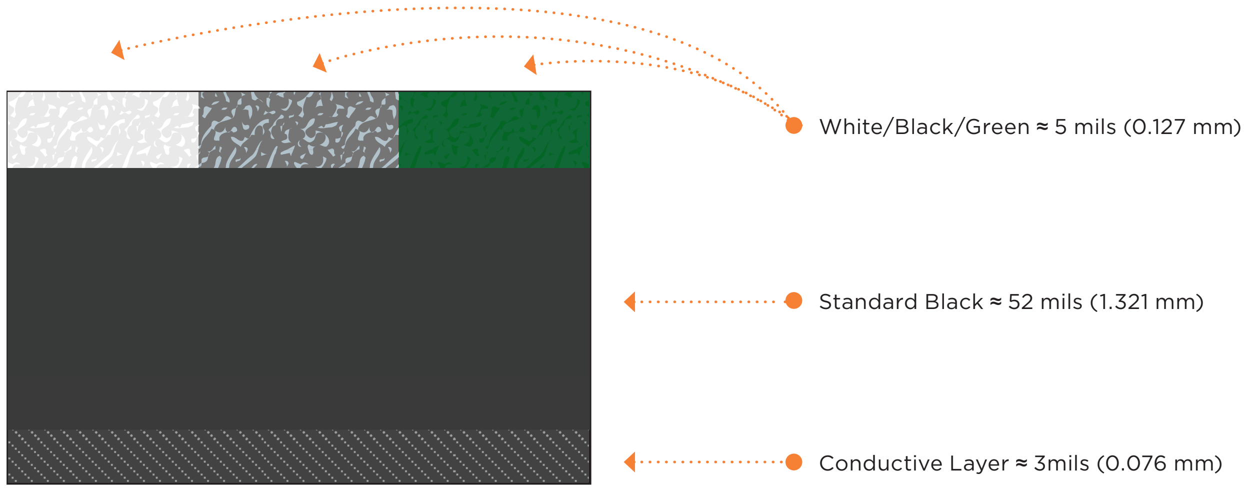
I occasionally receive questions regarding the various types of textured geomembrane and the benefits and advantages of each type. I would offer that some of the basis for these questions is that GSE has produced and sold every variety of textured geomembrane: structured, coextruded texture and "spray-on" texture. As the only producer to have this experience, GSE is uniquely positioned to comment and explain the advantages, disadvantages, and limitations of each type.

In general, the performance of textured geomembrane falls into two categories: structured geomembrane or a coextruded /sprayed-on texture which results in a more random distribution of texturing. Structured geomembrane is produced with a fixed pattern, usually a design of raised bumps or ridges. Structured geomembranes are nearly always produced on a flat cast extrusion line that utilizes contact rolls for cooling and impressing the texturing pattern into the geomembrane. The pattern, once established, cannot be easily altered, and attributes such as asperity heath and textured distribution are fixed.



A coextruded textured geomembrane is controlled, to a great extent, by the addition of either a gas or a chemical that decomposes to a gas within the outer layers of a 3 or more layer coextruded geomembrane (Fig 1).

Fig. 1



Coextruded textured geomembranes are commonly made on round die/ traditional blown film type extrusion equipment and uses chilled air to cool the geomembrane. The textured pattern made with this technology can be controlled and varied greatly; asperity height, texture density and other attributes can be changed and controlled. A common variation is differing asperity height and texture density on the two sides of the geomembrane to assure that, for example, in a seismic event the appropriate side of the interface will fail to allow for continued containment. This was demonstrated in the field during the 1994 Northridge earthquake [15]

Spray–on textured geomembrane shares many characteristics with coextruded textured geomembranes. The asperity height, texture density and other attributes can be changed and controlled. There are two basic differences with the spray-on product: 1) There is a limit to asperity height and texture density somewhat lower than that of coextruded textured geomembranes; 2) With spray-on texture it is possible to test and verify the physical properties of a smooth sheet prior to subjecting that sheet to the spray-on manufacturing process. Some perceive this as a great benefit. Additionally, the common decrease in break elongation with other textured sheet varieties does not occur with the spray-on textured variety. Some perceive this as a great benefit. The spray-on process consists of molten polymer, mixed with hot air sprayed onto the geomembrane at a given speed and concentration.

There are some general trends in the interface performance of these products by the type of manufacturing process used. A coextruded textured geomembrane and a spray-on textured geomembrane will generally offer a slightly increased frictional performance and better adhesion against a needle punched nonwoven geotextile than a structured geomembrane. In theory, a structured geomembrane will offer better performance with non-cohesive soils than a coextruded textured geomembrane. Both of these phenomena manifest as lower adhesion (the intrinsic "sticky-ness" of the two materials to each other). Again, this has been discussed in our industries literature [16 and 10]. I would specifically agree with commentary from Greg Richardson[17]: "As a simple rule, if you can take a piece of nonwoven fabric and essentially "polish" the surface of the textured geomembrane by hand, then it lacks the level of adhesion required for slope applications—pretty common sense among experienced designers!"

The issue of adhesion occasionally arises during the installation process. Some geosynthetic installers will express a preference for interfaces with lower adhesion. This allows another layer of geosynthetic to slide over a textured geomembrane will very little bonding/adhesion and without the use of what is described in the field as a "rub-sheet." For product interfaces with higher adhesion, the use of a rub sheet is common and slightly more time consuming for the geosynthetic installer. Any consideration to the installer's opinion in this matter is misdirected. I would suggest that proper slope stability and sufficient interface properties to resist slides and failures has far more importance to the designer and the owner than saving a few moments of the geosynthetic installer's time. The specific type of geomembrane that was selected should be used, or one with MORE adhesion, not less. The long term stability of the installation should be the major concern.

The primary concern at most construction sites is usually safety. On this subject, I quote Rick Thiel from an article in Geosynthetics Magazine(10): "…could have dire consequences on the safety of a design project. This problem may occur when designers consider only the operational or final build-out of a facility and they ignore the construction condition. Several failures have occurred during construction because of this. For example, an embossed geomembrane against a geotextile may perform well under high normal loads by providing a good friction angle and a modest y-intercept for operating and final build-out conditions. However, under the low normal loads experienced during construction of a thin soil veneer on a steep side slope, testing might reveal that the adhesion extrapolated from the high-normal load results do not exist at low normal loads. In this case, a more aggressive texturing that exhibits a 'Velcro®-effect' type of adhesion, or a very high friction angle, at low normal loads may be needed and should be verified at the proper normal loads."

Finally, I also take issue with some material suppliers who continue to propagate old, out-of date, and in my opinion, misleading information that suits their particular ends. Specifically, there was a study (18) published in November 1996 that compares the interface friction performance of PVC and HDPE geomembranes. While perhaps useful at the time, our industry has made so many advances since then, as to render that article obsolete. Clearly this topic has seen a great deal of effort and improved knowledge and performance over time; however, as an industry, we still have further to go towards the goal of a complete and reliable understanding of the materials performance across the broadest possible range of conditions.

FOOTNOTES:

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(2) Selected Papers on the Design Decision of Using Peak versus Residual Shear Strengths. GRI Report #29. Koerner, R.,The Geosynthetic Institute, Folsom, PA, USA http://www.geosynthetic-institute.org/

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(6) Geosynthetic Institute correspondence to GAI-LAP members, January 20, 2004

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(9) "Designer's Forum: Slope stability sensitivities on final covers" Thiel, R. Geosynthetics Magazine, Aug/Sept 2008 http://geosyntheticsmagazine.com/articles/0808_f1_slope.html

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(11) ASTM D7466-10 Standard Test Method for Measuring the Asperity Height of Textured Geomembrane, American Society for Testing and Materials, West Conshohocken, Pennsylvania, USA.

(12) "Characterization of textured geomembranes predictive of interface properties" Ramsey, B. and Youngblood, J. Geosynthetics Magazine June 2009 http://geosyntheticsmagazine.com/articles/0609_f1_characterization.html

(13) "Minimizing Geomembrane Liner Damage While Emplacing Protective Soil," Darilek, G.T., et.al., Geosynthetics '95 Conference Proceedings, Nashville, Tennessee, U.S.A., (1995).

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(16) "Commentary #1 Article on structured geomembranes", Thiel, R. Geosynthetics Magazine, April 2007, http://geosyntheticsmagazine.com/articles/0407_let1_comm1.html.

(17) "Commentary #2 Article on structured geomembranes", Richardson, G.R. Geosynthetics Magazine, April 2007, http://geosyntheticsmagazine.com/articles/0407_let2_comm2.html.

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