August 1999
Volume 17, Number 6

Developing a standard of practice for GCLs

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A standard of practice presents guidelines for the actual design, specification, shipment, and installation of a material. Standards of practice for geosynthetic materials can be valuable to engineers, due to the current lack of national design standards for such products.

Since its inception in 1984, ASTM Committee D-35 on Geosynthetics has focused on the development of index and performance specifications for geosynthetic applications. The index tests are intended for manufacturer quality control and for limited conformance tests performed by the user. Performance tests produce actual numerical values that can be used to design for specific applications. These index and performance tests have emerged after varying degrees of debate over their detail, but not their form.

ASTM Committee D-35 is beginning to develop standards of practice that may play a more significant role in how designers implement the actual design process for geosynthetics. Thus, a standard of practice will define how ASTM index and performance standards should be integrated into design.

While the general concept of a standard of practice requires discussion, this column will focus on specific design considerations for geosynthetic clay liners (GCLs), for potential inclusion in the forthcoming document.

Standard of practice: GCLs

ASTM Subcommittee D35.04 on Geosynthetic Clay Liners formed a task group to produce an initial draft standard of practice for GCL applications. At the January D-35 meeting in Memphis, the group developed a working standard of practice document, and a summary of the design considerations is presented herein. **Table 1** identifies task-group members and their specific responsibilities. ASTM D-35 members are encouraged to provide input to the task group.

Table 1 ASTM D35.04 GCL STANDARD OF PRACTICE TASK GROUP

Subject	D35.04 member	E-Mail address
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Design Considerations	Dr. Greg Richardson, P.E.	greg@gnra.com
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It is important to note that Committee D-35 has yet to submit the working standard-of-practice document to the ASTM balloting process. Consequently, it is not an approved ASTM standard and should not be construed as such. Those interested in becoming involved in the ASTM process should contact D-35 staff manager Pat Picariello at 610/832-9720, e-mail ppicarie@astm.org.

Standard of practice: design considerations

A standard of practice must present specific recommendations on key design considerations. Such recommendations must include currently accepted design equations and a clear discussion as to the limitations of current knowledge. Design considerations currently planned for inclusion in the D35.04 standard of practice examine GCL physical stability and the chemical stability of the bentonite that forms the composite barrier component. A summary of these design considerations follows:

Leakage Rate

The rate that liquids pass through a GCL or GCL/geomembrane (GM) composite must be quantified in order to evaluate the effectiveness of a GCL barrier system. The leakage rate, Q, through a hydrated GCL can be calculated from Darcy's Law as follows:

$$Q = K\,([h + t_{GCL}]/t_{GCL})\,A$$

where K is the bentonite permeability, t_{GCL} is the effective thickness of the GCL, h is the height of the liquid above the GCL, and A is area.

Leakage through a GCL/GM composite is calculated by the following equations (Giroud 1997):

Circular defect:

$$Q = C_{qo} i_{avgo} a^{0.1} h^{0.9} K^{0.74}$$

Square defect:

$$Q = C_{qo} i_{avgo} a^{0.2} h^{0.9} K^{0.74}$$

Infinitely long defect

$$Q^* = C_{q}\infty b^{0.1} h^{0.45} K^{0.87}$$

Rectangular defect:

$$Q = C_{qo} i_{avgo} b^{0.2} h^{0.9} K^{0.74} + C_{q\infty}(B - b) b^{0.1} h^{0..45} K_g^{0.87}$$

where C_{qo} is the quality of GCL/GM contact ($C_{qogood} = 0.21$, $C_{qopoor} = 1.15$), i_{avgo} is the average hydraulic gradient obtained from **Figure 1**, a is the area of the defect (m^2), h is the head acting on the liner (m), K is the GCL permeability, b is the side length of a square defect (m) and $C_{qo\infty}$ is the quality of GCL/GM contact for the infinitely long case ($C_{qo\infty good} = 0.52$, $C_{qo\infty poor} = 1.22$).

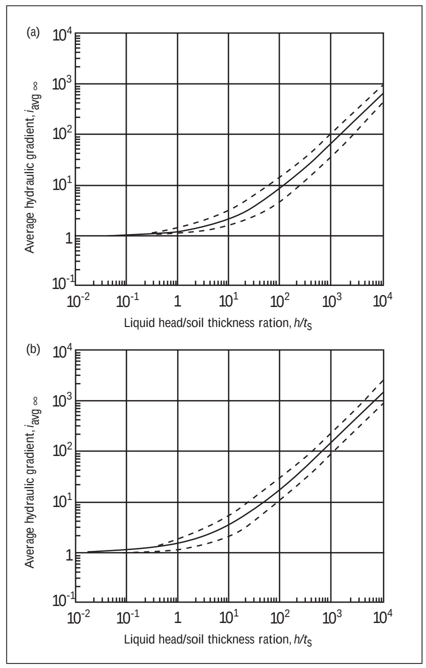

***Figure 1**. Values of the average hydraulic gradient to be used in equations for liquid migration-rate calculations: (a) with a circular or square defect, (b) with an infinitely long defect.*

Most commercial GCLs use bentonite that develops a permeability of approximately 3 x 10^{-9} cm/sec. The flow through a 1-cm^2 hole with 30 cm of water standing on it can be calculated as approximately 0.1 gal/day assuming a 6-mm thick GCL.

Application of the above equations currently is limited by our ability to accurately define the actual GCL thickness, t_S, under service loads for use in **Figure 1**.

Internal shear strength

GCLs commonly are divided according to structure—either reinforced or unreinforced (Koerner 1996). Reinforced GCLs have cross fibers that connect the two geotextiles that form the composite exterior. The GCL's internal-shear strength will be influenced by the bentonite clay and, if present, needled or stitched fibers that penetrate through the thickness of the GCL. The strength provided by each of these components also is affected by the degree of clay hydration, the normal load that acts on the GCL, and the shear strain that occurs across the composite. Unfortunately, precise details on each of these components for a given product are not made available to the designer. Laboratory tests performed on GCLs measure the simultaneous contribution of all internal shear-strength components and do not provide a clear understanding of internal mechanisms.

The bentonite component of the GCL has a hydrated shear strength that is influenced by the degree of hydration and the normal loading. The shear strength of hydrated clays was evaluated by Olson (1974), who produced typical effective stress-failure envelopes. According to his work, the lowest bentonite shear strength can reach and still remain effective is approximately 5 psi (720 psf) at a normal load of approximately 40 psi (5760 psf). This strength can be increased by reducing the percentage of bentonite in the clay, but at a cost of increased permeability. At lower normal loads, the degree of hydration increases, and the shear strength decreases to zero at no normal load. At higher normal loads, Daniel showed that the drained friction angle of the bentonite clay decreases and approaches 7 degrees. The lower limit for the shear strength (cohesion + frictional) can be assumed to be approximately 5 psi (720 psf). Swelling pressures of bentonite can easily reach 2000–4000 psf (Gromoko 1974). This may control the equilibrium water content, and therefore the shear strength at low normal loads, if a ready supply of moisture is available.

Stitched or needled fibers that penetrate through the thickness of a reinforced GCL contribute to shear strength as the geotextile surfaces move differentially apart. The amount of shear strength added by the fibers at low strains also may be influenced by the anchorage or tensioning of the fibers to the geotextiles. At present, there is no data that clearly shows the relationship between needling and stitching variables on the internal shear strength.

In the past, the contribution of needled reinforcement fibers to the peak shear strength has been demonstrated by comparing internal total-stress peak shear strength data to the effective shear strength of bentonite as determined by Olsen (1974). In this case, the higher peak shear strength must be due to the contribution of the needled fibers, which is significant across the full range of normal loads.

Continued shear of a reinforced GCL beyond the peak-stress point lowers the residual strength. Data presented by Scranton (1996) indicates that the residual strength of an unreinforced GCL is approximately 1.0–0.6 times the peak strength. My previous article with Thiel and Mackey clearly showed that the shear strength of a reinforced GCL approaches that of an unreinforced GCL at large internal shear displacements (1998). This also was observed by Gilbert et al. (1996).

The needled-fiber polymers and the bentonite may creep, i.e., deform, when subjected to long-term loadings. Recent published reports by Koerner (1996) and Trauger et al. (1996) have shown that the majority of internal-shear displacements occur during the first 100 hours of loading. Essentially, if field conditions do not change, and the installation survives the initial week of loading, the GCL is stable. This certainly has been observed during the U.S. Environmental Protection Agency's (EPA) recent GCL slope tests in Cincinnati (Scranton 1996). At the test site, reinforced GCLs have remained stable with little or no ongoing deformation on slopes as steep as 2H:1V. This implies a minimum static slope-stability factor of 1.5 when extrapolated to 3H:1V slopes.

Evaluation of allowable in-service stresses

The effective normal load and shear that act on the GCL in service determine the geosynthetic's minimum required shear strength. In conventional landfill design, two common conditions illustrate the extremes of this consideration: low normal loads and low shears typical of GCLs in final-cover systems, and high normal loads and high shears typical of landfill-liner applications.

Two service conditions related to GCL stability are of concern to a designer: *slope-stability* applications resulting in shear being applied through a GCL, and *bearing-capacity* problems related to varying normal loads being applied to the GCL. The analysis for both service conditions is straightforward but worth reviewing.

Veneer slope stability

The infinite slope model is the simplest and most conservative method of evaluating GCL stability in veneer-type systems, which are common to landfill liners and final-cover systems. You may assess The pseudo-static factor of safety and yield acceleration for the cover with the following general equations for the stability of an infinite slope:

$$FS = \frac{\tan\phi[(1 - u)/(\gamma \bullet z)] - k_S \bullet \tan\beta \bullet \tan\phi}{k_S + \tan\beta}$$

where FS = factor of safety, k_S = seismic coefficient, γ = unit weight of slope material(s), u = excess water or gas pressure on the slip surface and ϕ = angle of internal friction of the assumed failure interface or surface.

The above equation yields the factor of safety for both cohesionless interfaces (cohesion = 0). The infinite slope equation can be used to predict static side-slope shear stresses generated on and within a GCL barrier as part of a typical final cover. For a 4H:1V side slope, design shear stresses typically range from 50 to 80 psf. Typical normal loads that act on a GCL barrier in a final cover system range from 200 to 300 psf. These normal loads are less than the swelling pressure generated by the bentonite. Therefore, the GCL's long-term strength is heavily dependent on the strength of the reinforcement fibers, if present. At these low normal loads, the internal shear strength of an unreinforced GCL is less than 100 psf and results in too low a factor of safety to protect against long-term creep of the side-slope cover.

General slope stability

Liner systems beneath thick waste layers experience high normal loads that limit bentonite hydration, but may also experience high shear stresses due to waste instability. Figure 2 shows a slope-stability analysis performed to determine the minimum GCL internal-shear strength in a liner system. The normal load that acts on the failure surface can be taken as the approximate average weight of waste over the surface. The actual shear strength of a potential GCL must then be determined using the ASTM D-6243 "Direct Shear Test for GCLs." Daniel et al. published test data resulting from such an analysis for both peak and large displacement conditions (1993). The large displacement data are appropriate for seismic conditions evaluated using the displacement method.

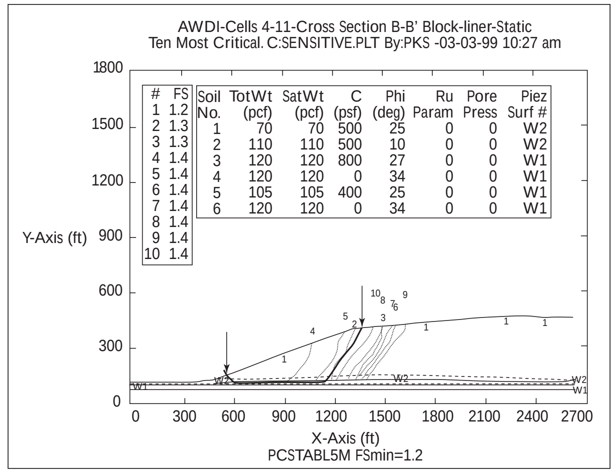

***Figure 2**. Slope-stability analysis.*

Bearing capacity

Differential normal loads can lead to lateral shearing of the bentonite, which may produce hydraulic failure and potential stability problems. Such differential normal loads can result from vehicle traffic over a final cover.

Traffic-related bearing-capacity stresses on a GCL can be quickly and conservatively evaluated using a simple 60-degree "cone" of load distribution below a wheel load. For example, with a 2-ft cover over the GCL, the contact pressure generated by a typical rubber-tired off-road truck, e.g., Cat D25D (40,000 lb wheel load, contact stress =1870 psf and contact area radius = 2.6 ft), can be calculated by increasing the loaded area based on the depth of the GCL.

For a 2-ft depth, the radius of the loaded area equals 2.6 ft + 2 ft/Tan 60º or 3.75 ft. This produces a contact stress at the GCL equal to $40,000/(\pi \times 3.75^2) = 905$ psf. This normal stress will exceed the bearing capacity of hydrated bentonite ($q_{allow} = Nc \times c$. 5.5×150 psf = 825 psf—see discussion of bentonite shear strength below) and cause lateral displacement of the bentonite and damage to the GCL hydraulic integrity.

Research by Fox et al. (1996) also has shown that the localized bearing capacity of a GCL can be influenced by the particle size of adjacent soils. Coarse drainage layers may increase the contact normal stresses and lead to localized bearing-capacity failures and lateral movement of the bentonite. For this reason, and because lateral drainage systems are used often with barrier systems, stone drainage systems must be evaluated carefully.

Evaluation of key physical properties

Designing for GCLs requires knowledge of the material's internal shear strength and interface frictional properties under extreme service conditions.

Internal shear strength field evaluation

The internal shear strength of a hydrated GCL depends on the strength of the geotextiles and the cross fibers. To ensure both components are adequate, GCL tensile strength and peel strength must be tested. Richardson (1996) and Heerteen et al. (1995) have shown that peel strength correlates to the internal shear strength of the hydrated GCL. Given the simplicity of the peel test, a designer may wish to specify an increased frequency of peel testing with a minimum of one direct-shear test confirmation per project. This allows the degree of reinforcement to be confirmed on a roll-by-roll basis, without the delays and costs associated with direct-shear testing. A minimum peel strength of 15 lb for a 1-in. wide sample is recommended.

No formal test method has been developed to specifically determine GCL peel strength. ASTM D 4632 is used to compare peel strengths and to develop relationships between peel and internal shear strength. Sometimes the test is performed on samples of varying width, so it is important that the designer either specify the sample width (4 in. is recommended) or that the resulting strength be specified in lb/in.

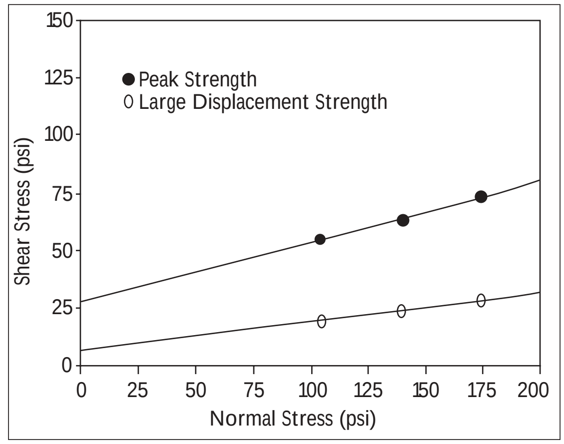

***Figure 3**. ASTM D-6243, Direct Shear Test data for GCL.*

GCL frictional properties

The external frictional properties of a GCL's surface are influenced by the type of geotextile that forms the surface and the possible presence of hydrated bentonite that has moved through the GCL. Available GCLs use both nonwoven geotextiles and woven geotextiles made of slit-film filaments. The latter provide both a lower interface friction and a greater potential for migration of hydrated bentonite to the surface of the GCL. Years of direct-shear tests have demonstrated that a nonwoven geotextile provides exceptional interface friction with textured geomembranes (a "Velcro" effect) and most soils. Nonwoven-covered GCLs can be used with smooth geomembranes only on slopes of less than 10 degrees.

To maximize the stability of GCL/GM composites on slope applications, reinforced GCLs constructed with a nonwoven geotextile on one face and a woven geotextile on the other should be placed with the nonwoven side against a textured geomembrane. The woven geotextile has a significant number of cross-fiber tufts that roughen the surface and typically provide a satisfactory interface with soils.

Chemical compatibility

Certain fluids that reduce the bentonite's effectiveness must be avoided, unless the clay is modified to deal with them. Research has demonstrated that *after hydration with water*, immersion in the following organic compounds does not increase GCL permeability: unleaded gasoline, gasohol, diesel fuel, jet fuel, and typical municipal solid-waste (MSW) leachate. Other researchers have indicated that GCLs are generally resistant to many organic and inorganic liquids.

Ruhl and Daniel (1997) identified the following types of solutions that, when used for *initial hydration*, cause an increase in GCL permeability: calcium-rich solutions, strongly acidic solutions, and strongly basic solutions. This finding is confirmed by Egloffstein (1997), who reports that high ion concentrations in the permeant during initial GCL swelling result in reduced swelling overall. Manufacturers report that sufficient concentrations of the following parameters (listed in order of importance) can increase GCL permeability:

1. potassium ions
2. magnesium ions
3. calcium ions
4. chloride ions (if this indicates disassociated salts and, therefore, the presence of positive ions)
5. pH less than 4
6. sulfate.

Calcium ions can leach from such calcium-rich materials as limestone, which should not be used as a cover over a GCL. Dobras and Elzea (1993) reported on the use of soda ash (sodium carbonate) to restore the performance of GCLs that had become contaminated by the intrusion of positively charged, soluble ions from a cover rich in dolomitic limestone. The composites were first exposed, then covered with an even layer of soda ash. The bentonite was reactivated with fresh water, and the limestone cover was replaced with a soil free of adverse exchangeable cations.

Gas diffusion

The ability of a GCL to limit gas migration may be important if the GCL will comprise the barrier in a final-cover system. To be effective, the clay liner must be fully hydrated such that gas cannot readily flow through the bentonite granules in the manufactured product.

Trauger and Lucas (1993) measured the diffusion of benzene and methane through hydrated GCLs as a function of moisture content. This study measured a permeance relative to methane of less than 1.0E-9 m/s when the moisture content of the GCL exceeds 100%. At moisture contents less than 90%, the methane flow rate increased significantly. No benzene flows were measured through the hydrated GCL, and researchers surmised that benzene had sorbed into the bentonite.

Summary

ASTM standards of practice provide one means of establishing consistent use of geosynthetic materials. A successful GCL standard of practice will no doubt be followed quickly by development of similar documents for geonets, geotextiles, geomembranes, and erosion-control products. As such, the authors feel that it is important to solicit input from both users (designers) and manufacturers for this initial effort. GFR

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