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GCL design series—Part 3: GCL installation and durability

This is the final part of a three-part *GFR* series summarizing key aspects of the industry's first comprehensive GCL design guidance document (the *GundSeal GCL Design Manual*, Thiel et al. 2001). Part I, published in the June/July issue of *GFR*, presented an overview of GCL hydraulic performance and leakage issues. Part II, published in the August issue of *GFR*, focused on slope stability of reinforced and unreinforced GCLs. Finally, Part III will expand on GCL installation, durability, and effective construction quality control (CQC) and construction quality assurance (CQA) to observe and verify the installation meets the design intent.

Material installation and construction monitoring guidelines

Proper material installation and covering procedures are essential to meet the design intent for effective environmental containment and long-term performance. Good standard industry guidance regarding material handling, subgrade preparation, panel deployment, alignment (**Photos 1**), overlapping and seaming can be found in ASTM D 5888, *Standard Practice for Storage and Handling of Geosynthetic Clay Liners*, and ASTM D 6102, *Standard Guide for Installation of Geosynthetic Clay Liners*. Additionally, guidelines are available from GCL manufacturers regarding GCL handling and installation. This article attempts to highlight some of the everyday construction issues that may not be explicitly covered in these standard industry references.

Engineering assumptions regarding GCL performance hinge on the geosynthetics' integrity being maintained through the construction process. Geosynthetics are manufactured with adequate durability to survive construction and service loadings, provided that contractors and installers follow recommended procedures. Designers, installers, contractors and operators must be aware that there are limits to the level of abuse that geosynthetics can tolerate.

A few of the very practical issues faced in the field are highlighted in this article, including:

- material handling (or, "Can we use forklifts?");
- subgrade preparation (or, "How big of a rock can we leave under the liner?");
- permissible vehicle size for traffic over the GCL (or, "Can we drive on it?");
- weather constraints (or, "Is it OK after it has been rained on?");
- seaming bentonite (or, "Do we have to use it?"); and
- soil covering (or, "Can we use scrapers and only 150 mm of cover?").

Caveat: the subject of this article is by its very nature non-definitive and subject to many site-specific conditions, and to the artful techniques of variously talented installers. The opinions in the article are those of the authors and are subject to healthy doses of criticism.

Photo 1: Installations of a GCL over a protective geotextile cushion.

Material handling ("Can we use forklifts?")

The basic guiding principle for loading, unloading, and moving material around the jobsite is to follow the manufacturer's recommendations. Generally, manufacturers will not condone moving and stacking rolls using the forks on a forklift. If an installer says "We do it all the time," then the designer's response should be something like "It's not in the specifications, and if you want to do it that way, you need to submit a change order and written approval from the manufacturer." That should put an end to the discussion.

Material unloading at the jobsite should be considered an important element of CQA. Oftentimes the geosynthetics will arrive well in advance of the trained installer, and either the owner or the general contractor will unload the materials. Neither of these two parties is necessarily trained, equipped or sensitive to the nuances of unloading geosynthetics, particularly GCLs. Usually they will resort to a forklift. The results are often that the outer five wraps of the GCL become speared with holes, and the inner cores of the rolls are broken in two places because their weight has been cantilevered over the ends of two forks, making subsequent use of stinger-bars and axle-bars more difficult. This does not happen just with neophyte contractors. The second author recently performed CQA with the most experienced landfill general contractor in his region, who has been constructing landfills in conjunction with

geosynthetics installations for over a dozen years. The owner of the landfill (a major national firm) asked this general contractor to unload the material in advance of the installer arriving on site, with the results exactly described above.

The key to success in this case is to be prepared with the proper equipment before the delivery trucks arrive on site.

Subgrade preparation ("How big of a rock can we leave under the liner?")

The relative thinness of GCLs requires that more attention be given to subgrade preparation than would be given during the construction of a compacted clay liner. In general, the subgrade preparation specifications that are used for geomembrane installations are adequate for GCLs. Owners switching from traditional compacted-clay-based liners to GCLs should be aware that more attention must be given to subgrade preparation than previous construction projects. Typical construction techniques for the final preparation of the subgrade surface include watering plus vibratory or smooth-drum rolling of the subgrade soil surface; final grade control is typically obtained with a smooth blade, rubber-tired grader, or its equivalent.

Loose rocks can also be a problem. Even though it may appear that loose rocks are embedded in a soil matrix in the subgrade, these rocks will tend to roll over and displace during final panel adjustments. Even though some of these may not technically be a problem for the GCL (because of its self-sealing ability), they can be a problem for the overlying geomembrane which will end up with undesirable, conspicuous "bumps" in the finished product. A good technique for difficult subgrade conditions is to water the subgrade approximately one hour in advance of GCL deployment, and then smooth-drum roll the area just before GCL deployment. The exact timing of watering, rolling and deployment depends on the site-specific soils and weather conditions.

Proper CQA procedures, in accordance with ASTM D 6102, should include a final visual inspection of the subgrade surface to identify unacceptable surface protrusions (typically larger than 12 mm), excessive rutting (typically greater than 25 mm), abrupt vertical displacement differences, or other areas that may damage the GCL during or after installation. These areas should be eliminated by removing protruding objects, smooth-drum compaction, or the placement of a protective soil/geotextile cushion layer prior to installation of the GCL (**Photo 1**).

All of that being said, the bentonite layer of GCLs generally has the swelling capacity to seal small punctures (generally less than 25 mm) induced from above or below the liner and perform in accordance with the Giroud empirical leakage equation (Giroud et al. 1997; and Giroud and Badu-Tweneboah 1992) as described in Part I of this GCL design series. Even so, walking around and feeling lumpy rocks covered by GCLs and geomembranes never inspires confidence, and the ASTM recommendations should be pursued as a general goal.

Photo 2: Deployment of a geomembrane over a GCL with an all-terrain vehicle.

Permissible vehicle size for traffic over the GCL ("Can we drive on it?")

Installers and contractors invariably ask if they can drive on various geosynthetics. In response to this issue, there are no absolute answers, but general guidelines should be followed with the aim of preserving the integrity of the geosynthetics. For example, geosynthetics are not manufactured and designed to be driven over, and yet under carefully controlled circumstances they could be driven over by fully loaded scrapers without causing any damage. Would we say that is ever allowed in the specifications? Certainly not! And yet some leeway could be given.

The authors have found that the best compromise is to specify that the only equipment allowed on geosynthetics are those pieces of equipment specifically approved in writing by the manufacturers, such as all-terrain vehicles (ATVs) (**Photo 2**) unless field demonstrations convince the engineer that other types of equipment will work. This requires that the installer submit a written proposal and then execute a field demonstration. If any conditions change from the initial demonstration, additional demonstrations may be needed. The situation to avoid is an installer coming to the field with an out-of-spec method saying, "This is the way we always do it…"

The largest variables that affect the use of equipment directly on GCLs are the moisture content of the bentonite and the type of GCL. The drier the GCL, the less it will be influenced by equipment wheel loads. Reinforced GCLs will fare much better with equipment traffic than unreinforced GCLs. It is common that ATV's and six-wheel gators are allowed directly on dry fabric-encased GCLs. Although this equipment is sometimes allowed on geomembrane-supported GCLs, it is better to have a 0.5- to 0.75-mm slip sheet between the vehicle and the bentonite with these materials if the bentonite side is facing up. Larger equipment, such as a loader, is also allowed on fabric-encased GCLs, but only if the GCL is dry, there is

Photo 3: Final manual alignment of a deployed GCL.

a good subgrade, and turns are very gentle. Some types of rubber-cleated track equipment have also been used.

Even with reinforced GCLs, if the bentonite becomes moist to the extent that it behaves like a plastic putty, virtually no equipment should be driven on it. The bentonite will become displaced, and the reinforcement may be damaged in the wheel paths.

Weather constraints ("Is it OK after it has been rained on?")

Upon approval of the GCL material through the manufacturer's certifications, conformance testing, and on-site inspection, its installation is very quick and straightforward. One of the most critical CQC/QA items during installation is to ensure that the bentonite does not become overly hydrated (mainly from precipitation). There are two reasons for this: (1) increased potential for damage to the GCL product during installation if the bentonite is moist and soft (described above), and (2) slope stability issues for encapsulated bentonite designs.

One partial fallacy is that the GCL is ruined if it becomes hydrated from rain before being covered. Another partial fallacy is that a GCL is just fine if it becomes hydrated from rain. The real answer is: it depends…

Sodium bentonite is typically considered hydrated when the moisture content exceeds 50%. At a moisture content greater than 50%, localized bentonite thinning may occur due to transient construction pressures where there is inadequate soil cover above the GCL. Therefore, if the hydrated bentonite can be allowed to dry to a point that allows careful covering of the GCL with soil materials without creating uneven bearing stresses that cause it to shear, then it should be fine. If construction must proceed in a way that hydrated bentonite will experience small bearing capacity failures evidenced by bentonite thinning (e.g., such as a footprint in the mud), then it probably should be removed and replaced.

A typical installation specification may include a maximum installed bentonite moisture content of 30% to ensure minimal bentonite prehydration. A localized hydrated area of the GCL bentonite layer may be rectified by allowing that area to sun/air dry prior to covering, increasing the overlap distance for a hydrated area adjacent to roll edges, or supplementing the hydrated area with additional granular bentonite.

In general it is in everyone's interest to get the GCL covered with no hydration from rain. This is accomplished by:

- covering the rolls of GCL with protective tarps as soon as they arrive on site;
- requiring the GCL that is deployed be covered the same day with geomembrane or soil; and
- constructing a project from the high end to the low end.

Photo 4: Soil cover placement over a GCL.

Seaming bentonite ("Do we have to use it?")

This issue is still not resolved even today (although who knows, maybe it will be by the time this article is printed). Here are the authors' opinions:

- Geomembrane-supported GCLs: no

seaming bentonite is required because the bentonite is virtually exposed. Even the very light spunbonded geotextile ("spider web") sometimes adhered to the surface of the bentonite does not inhibit the sealing ability at seams.

• Geotextile supported GCLs:

(1) Woven-to-woven geotextile interface: no seaming bentonite is required.

(2) Woven-to-nonwoven geotextile interface: more research required. At this point, when in doubt, leave it in! The cost and extra work is truly minimal, so it should be required in this case.

(3) Nonwoven-to-nonwoven geotextile interface: seaming bentonite required.

Soil covering ("Can we use scrapers and only 150 mm of cover?")

All GCL installations must include a soil cover to eliminate bentonite free swelling and maintain the hydraulic performance of the bentonite. If the cover soil is granular drainage material, it should be free of sharp or angular objects greater than 12 mm that may cause damage to the liner. The cover should include a minimum 300-mm-thick soil layer placed "in a timely manner" after deployment of the GCL. **Photo 4** illustrates typical soil cover placement over a GCL.

In addition to physical protection of the installed GCL liner, the objective of soil cover placement is to prevent the bentonite from hydrating with no confining normal load. The three crucial durability issues related to covering a GCL with soil are:

• covering in a timely manner;

• covering in a careful manner; and

• covering with an adequate soil thickness. These factors, discussed below, should be considered, and installation procedures should be closely followed so that the fundamental design performance of the GCL is not affected.

Soil covering in a timely manner

The objective of covering a GCL in a "timely manner" is to prevent the bentonite from hydrating with no confining pressure. With an encapsulated bentonite between geomembranes, however, the issue is significantly reduced, if not eliminated altogether, as long as the bentonite is covered with the overlying geomembrane by the end of each working day.

How one defines "timely manner" depends upon the moisture conditions of the subgrade and the type of GCL. Construction quality assurance (CQA) specifications should set maximum allowable exposure times before soil covering, and every instance of exceeding these exposure times should be verified by field inspection.

For example, for nonreinforced GCLs (worst-case situation) the following general recommendations address the three basic moisture characteristics of agronomic soils, the intent being to cover the GCL before bentonite hydration and migration due to construction loads would cause concern:

• If the subgrade is relatively dry (approaching the "wilting point" moisture content that makes vegetation growth difficult), the GCL should be covered within five days.

• If the subgrade is damp to moist (approaching the "field capacity" moisture content that allows lush vegetation), the GCL should be covered within three days.

• If the subgrade is moist to wet (approaching saturation), it is advisable to cover the GCL by the following morning.

For reinforced GCLs, all of these time frames can be exceeded. Installers, engineers, and CQA personnel are advised to observe the condition of the bentonite and determine at what point it becomes malleable (greater than about 40–50% moisture content) and have it covered before that point.

Soil covering in a careful manner

The high level of performance demonstrated by composite liners with GCLs assumes that certain size defects in the geomembrane would be rendered benign by the underlying bentonite from the GCL. Very large defects through a GCL, however, might be beyond a GCL's sealing ability. Spinning wheels or tracks on construction equipment, for example, could rip a large gap in a geosynthetics-only lining system. Therefore, industry-accepted construction installation and monitoring practices should be followed (such as those established by ASTM D 6102, or the manufacturer's recommendations) to prevent these types of defects from occurring.

After a minimum 300 mm of soil is in place over the liner system, the potential for further construction- or operations-induced damage becomes remote. To ensure the liner system's integrity, therefore, it is crucial that the placement and spreading of the cover soil layer over the GCL composite-liner geomembrane be properly executed. To eliminate the possibility of large through-liner defects for the project, two installation and monitoring practices should be followed:

• Develop appropriate construction specifications that alert the installer, general contractor, and owner to the specific actions and activities that should be taken and avoided.

• Provide for a high level of CQC and CQA during liner deployment and soil cover operations. Typically, this involves having a ground person directly monitor the cover soil placement operations.

Thicker soil covering for high traffic areas and roads

As discussed, hydrated bentonite may migrate and thin in response to differential stresses, depending on the magnitude of confinement and the degree of differential stress. With the encapsulated-bentonite design (geomembrane-bentonite-geomembrane) and isolation of the bentonite from potential prehydration, this is of minimal concern.

Areas above the liner system that experience heavy construction loads should be required to have adequate soil cover to protect the liner system beneath the wheel paths. At least 300 mm of cover soil is generally adequate for track equipment. For heavier traffic areas and haul routes, a minimum soil cover of 600 mm to 900 mm should be required, depending on the intensity of usage and the size of the equipment. The extra material on the haul routes can subsequently be spread out with a dozer at the end of the construction project.

CQC and CQA

General CQA Considerations for GCLs

As stated by Koerner and Daniel (1993), "Far fewer things can go wrong with the installation of a GCL compared to placement and compaction of a compacted clay liner." GCLs are not only much easier to monitor during construction, but also provide a higher level of visible and quantifiable quality assurance in verifying the installed manufactured product meets the

design intent.

Insuring quality in the constructed project is often divided into two categories: material verification and construction monitoring.

Material verification

Projects commonly require that a manufactured material be verified to meet the project specifications before it is accepted. There are three levels of verification that can be applied, depending on the level of confidence that the owner requires to confirm a product meets a given specification.

- Certification letter: A letter from the supplier stating that the material meets specific performance standards is often accepted by the owner or purchaser.
- Review of the manufacturer's test results: An owner or purchaser may wish to require that the supplier submit the results of the manufacturer's quality control (MQC) testing conducted for the rolls supplied for the project.
- Independent conformance testing: Samples of the material may be taken by the owner or purchaser and subjected to various quality assurance (QA) tests. These tests are referred to as conformance tests, used to verify that the material conforms to project and material specifications.

Typical index tests performed as part of MQC for GCLs are found in ASTM D 5889. When quality assurance conformance testing is performed, it often includes some of these index tests, usually less frequent than the manufacturer's quality assurance testing for the GCL. In addition to the typical QC/QA index tests and testing frequency performed by manufacturers, designers should consider conducting performance tests to verify that project-specific requirements are met for critical projects. For example, direct shear tests are sometimes performed with materials produced for a particular project to verify that the actual materials meet minimum design expectations.

Monitoring during installation

The following monitoring activities are typically performed to achieve a quality GCL installation:

- proper material storage and handling
- bentonite moisture content
- proper subgrade preparation
- specified overlapped seam distance
- adequate seaming bentonite, if required
- absence of bentonite prehydration
- proper repairs and patches
- absence of dislodged bentonite
- absence of debris in the overlapped seams
- minimal material wrinkles and fishmouths
- proper attachment to structures
- proper material anchorage at slopes
- adequate bentonite protection and timely covering
- only permitted equipment directly on geosynthetics

CQA observation of soil cover operations

Given that most lining system damage occurs during soil cover activities, the CQA party is often required to provide a ground person to observe soil cover operations. The primary function of CQA monitoring is to verify that the soil spreading operations are performed in accordance with the specifications and do not cause damage to the lining system.

Contractor observation of soil cover operations

In the absence of CQA monitoring during soil cover operations, the contractor performing soil covering should provide a ground person in front of the spreading activities at all times. The primary responsibilities of the ground person are:

- to establish and maintain adequate grade control of the cover soil layer;
- to manually reduce or flatten wrinkles in the installed liner in advance of soil spreading;
- to identify and caution against any potential damage to the lining system.

Post-installation electrical defect detection survey

For GCL-geomembrane composite liner installations with welded geomembrane seams, a simple but highly effective electric defect-detection survey can be performed. Electric defect detection is performed after the soil cover is placed above the lining system to locate potential installation and/or soil cover damage. This technology is not applicable to single-composite overlapped GM-GCL applications because the overlaps interrupt the required continuous electrical insulator provided by the geomembrane. For designers interested in pursuing this technology for sensitive projects that include a geomembrane with welded seams, additional information on electric defect detection surveys is provided by Thiel et al. (2001).

Summary

The authors hope that this final segment of the three-part series on GCL design guidance alerts potential users of GCLs to the critical need not to ignore manufacturers and ASTM guidelines for handling and installation of GCLs. It is also hoped that we have brought to light some other subtle points from our experience that may not be as explicitly covered by standard industry literature for the benefits of GCL installations. All engineers designing with and specifying GCLs are encouraged to spend time in the field and visit GCL manufacturing facilities to develop an appropriate appreciation of the benefits and limitations of these very useful materials.

References

ASTM D 5888. Storage and Handling of Geosynthetic Clay Liners.

ASTM D 5889. Quality Control of Geosynthetic Clay Liners.

ASTM D 6102. Guide for Installation of Geosynthetic Clay Liners.

Giroud, J.P., and K. Badu-Tweneboah. 1992. Rate of leakage through a composite liner due to geomembrane defects. Geotextiles and Geomembranes, vol. 11, no. 1:1–28.

Giroud, J.P., K. Badu-Tweneboah, and K.L. Soderman. 1997. Comparison of leachate flow through compacted clay liners and geosynthetic clay liners in landfill liner systems. Geosynthetics International, vol. 4, nos. 3 and 4: 391–431.

Koerner, R.M., and D.E. Daniel. 1993. Technical equivalency assessment of GCLs to CCLs. Proceedings of the 7th GRI Seminar: Geosynthetic Liner Systems: Innovations, Concerns, and Designs. Geosynthetic Research Institute, Drexel University, Folsom, Pa. 255–275.

Thiel, R., D.E. Daniel, R.B. Erickson, E. Kavazanjian, Jr., and J.P. Giroud. 2001. The GSE GundSeal GCL Design Manual. GSE Lining Technology Inc., Houston, Texas.

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