Concern for GCL Shrinkage when Installed on Slopes

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Scope of This Paper

This paper suggests that the dimensional stability of geosynthetic clay liners (GCLs) should be a significant design consideration worthy of special attention in specifications and testing. This issue, which has been all but ignored in the design profession to date, is being raised as a result of reported field observations.

Recognition of the Issue

In the past two years, five cases have come to the authors attention where separation of reinforced fabric-support GCL seams on slopes has been observed. All of the cases involved a slope that had been covered with a GCL overlain by an HDPE geomembrane for some period of time with no overlying soil cover. The second author was personally involved with one of the projects. The other four projects have only been described verbally to the authors. In every case there was a unique reason why the overlying geomembrane had to be cut open or removed, and upon exposure the parties were surprised that the GCL overlaps had been lost and gaps now existed where there had previously been overlaps. In all cases the GCL had purportedly been installed in accordance with standard industry and manufacturer's guidelines, and in most (if not all) cases under the observation of third-party construction quality assurance.

It is significant to mention that the exposure duration of the geomembrane-exposed slopes may have ranged from months to years for the different projects that had problems. One response to the problem would be to insist that the slopes be covered "immediately" with soil to constrain the geosynthetics from moving. While this could be a potential outcome of a scientific study into this problem, for the time being it is state of the practice to allow geomembrane-covered slopes to be exposed for extended periods of time. Even if the intent is to cover the slopes with drainage and/or operations soil materials within the scope of the construction contract, the time lag between deployment of the geomembrane on the slopes and the actual covering with soil could easily be measured in months. Furthermore, it is a very common occurrence in designs, at least on the West Coast (and the author suspects elsewhere in the world, as well), that the client wishes the slopes to remain uncovered for several months after the construction is over for operational reasons.

These anecdotal stories are quite compelling in their demand for our attention. If the overlap of the GCL is lost, then the fundamental design premise of a complete composite liner loses its integrity. The stories are also compelling in that there are related industry experiences suggesting corroboration of this situation (described below), and there are also mechanisms that can be deduced that would lead to large-scale shrinkage of GCL panels (described below). Given the recent stories, the corroborating experiences, and some engineering deductions, the author has prepared this paper to suggest the need for immediate research and design considerations of this issue.

Limited Information Regarding Second Author's Case History

A composite liner system composed of a double nonwoven needlepunched GCL placed under a textured HDPE geomembrane was constructed in Roanoke, Virginia. Approximately 140,000 square feet of GCL and geomembrane was placed in May 2000. During soil covering on a 3:1 side slope, the embossed textured HDPE geomembrane slid on the GCL interface. For four months work was halted while the slide situation was being addressed. Most of the area was left uncovered with soil during this time, and thus the geomembrane was left exposed with the underlying GCL. When work resumed in October, it was decided that the geomembrane had to be removed and replaced with a more aggressively textured material. Upon removal of the geomembrane there were gaps noted in about 30,000 square feet of the installed GCL, repeated in 15 to 20 seams. While the overlying geomembrane may have moved, no movement of the GCL relative to the subgrade was observed over the entire time period. The GCL panel edges had initially been overlapped by at least 6 inches, and now many had gaps of 2 to 3 inches. Figure 1 shows a photograph of a typical gap. All of the seams were cap-stripped with a 2-foot wide strip of GCL before continuing with the project.

Figure 1. Photograph showing gap in GCL panels after removal of geomembrane.

Background of Corroborating Experiences and Related Industry Literature

It has been known for many years in the industry that unreinforced fabric-supported GCLs that are deployed with a high initial moisture content could shrink substantially if they are not covered with a soil layer soon after deployment. The author's experience, networking with other designers in the industry, and discussions with manufacturers, has substantiated that shrinkage of unreinforced GCLs is a known issue. For example, when an unreinforced GCL is left exposed for less than 24 hours, shrinkage can be severe enough to completely lose the overlaps along the edges and create gaps a few inches wide between the panels. Experienced CQA monitors and installers have learned to work with this primarily by having the soil cover installed very quickly. Although not explicitly stated as such, perhaps this is the reason that one manufacturer's installation guidelines (CETCO, 2001) for a non-reinforced product suggest that in hot weather conditions the product must be covered with soil within 8 hours of deployment. Other than that statement, the author is not aware of any manufacturer or literary citation that suggests caution related to GCL shrinkage and potential loss of overlaps. Furthermore, as far as the author knows, any level of practical or implied recognition of GCL panel shrinkage has been limited exclusively to unreinforced GCLs.

Other than a minimum 6-inch overlap distance on seams, there is no mention in ASTM D6102, "Standard Guide for Installation of GCLs" of the potential concern for GCL shrinkage and loss of overlap.

An interesting allusion to the potential for GCL shrinkage was noted in the early beginnings of GCL usage, before these materials were even called GCLs (they were called ‘prefabricated bentonite clay liners’). Eith et al. (1990) noted: “If, for some reason, the liquid is then removed from the system [meaning the GCL], the volume will reduce leading to shrinkage.” They noted cracking in a sample that was air-dried for 10 days. They suggested desiccation cracking could be totally eliminated with the application of pressure from overburden soil, although the evidence described in the next paragraph suggests that even cover soil may not eliminate desiccation cracking. Nonetheless, the benefit of normal pressure from soil cover to inhibit volume change is certainly a good principle.

There has been some recent industry acknowledgement of GCL desiccation and associated cracking. Several papers discussing this issue were presented in the 2002 symposium on Clay Geosynthetic Barriers that was held in Nuremberg (e.g. Babu et al. (2002) and Melchior (2002)). The concerns regarding GCL shrinkage presented in those papers was primarily related to shrinkage cracks and the relationship of this observation to the ion exchange that occurs in the bentonite over time in the field. The interesting aspect of those papers is the extent to which they recognize how substantial shrinkage forces are as the bentonite dries. In the experience reported in those papers, the shrinkage forces that occur as the bentonite dries results in cracks even when the GCL is below a confining soil cover layer. One of the important mechanisms contributing to irreversible shrinkage that is recognized in those studies is the shrinkage that results from ion exchange (namely calcium ions exchanging for sodium ions in the bentonite). While shrinkage will occur from both desiccation and ion exchange, that from the ion exchange is irreversible. None of those studies suggested a problem with shrinkage of the overall GCL panel dimensions.

The only place that the authors are aware of mention of the potential for a large-scale shrinkage issue that could result in loss of overlap is from a very recent publication that was not even available during the preparation of this paper. The author was asked to review a draft of Daniel and Koerner (2004) and obtained the following quotes from Chapter 5 of that reference (***emphasis added by author):***

> “The minimum specified overlap distance should be verified. This is typically 150 to 300 mm (6 to 12 in.) ***depending upon the particular product, site temperature, and humidity conditions***.”
>
> “The overlap distance is typically 150 to 300 mm (6 to 12 in.). For temporarily exposed GCLs, or GM covered GCLs, ***warm temperatures can reduce the moisture content of the bentonite and cause reduction or even complete loss of overlap distance. This is obviously unacceptable***.”
>
> ***“If reduction in overlap distance from elevated temperatures is anticipated, the overlap should be increased or the system should be covered and/or backfilled to minimize bentonite drying***.”

The authors do not claim to have performed a complete literature survey to determine if the issue of GCL panel dimensional stability has been previously identified. It is quite possible it has been previously mentioned, even if only as a side-thought. In any case, the authors are confident that it has not been raised as a *significant* issue that should be considered in the preparation of design specifications. The authors are hereby raising the question to the industry that perhaps this is a significant question for which design standards and testing should be developed, both for reinforced as well as unreinforced GCLs.

Potential Shrinkage Mechanisms

The reason for shrinkage of GCL panels has not been studied in detail to date. The author surmises four potential mechanisms for loss of GCL seam overlap at this time:

1. A likely mechanism is that shrinkage of the bentonite layer occurs as it loses moisture, as implied in the Daniel and Koerner (2004) reference mentioned above. Bentonite is well known to be a very expansive clay, and will shrink and swell significantly with changes in moisture. The immense potential for swelling of the bentonite in GCLs has been recognized since the beginning of its use in liners (e.g. Clem (1992) reports the ability to swell over 10 times its dry volume). If it has such a great potential to swell with the addition of water, would it not have an equal propensity to shrink upon moisture loss?

2. Another potential mechanism is tension and associated necking of the GCL panels. The problems brought to the author's attention in the past two years seem to have occurred on slopes, where it is conceivable that some downslope tension may have existed.

3. A third potential mechanism that has been identified is "caterpillar" forces caused by expansion and contraction of the overlying geomembrane. If the geomembrane is textured, then perhaps its expansion and contraction, as well as shifting due to wind forces, might cause tugging and pulling on the underlying GCL panels that could cause them to go into tension and/or to shift. Note that this mechanism would primarily cause shifting to occur, rather than shrinkage, unless tension were induced that led to necking.

4. Ion exchange, as mentioned above, has been noted to cause a volume reduction in bentonite.

5. Shrinkage of the geotextiles. While dimensional changes of geotextiles has not been particularly noted in the literature in the past, it is possible that the internal stresses imparted to particular types of GCLs may result in shrinkage of the product when it is allowed to relax in an unrolled

configuration. This would require research on the part of the manufacturers.

It is possible that other mechanisms for shrinkage could exist that have not been identified by the author. Of the four mechanism surmised, the first mechanism having to do with moisture loss would, in the authors' opinion, pose a consistent concern for GCLs installed on a slope and covered with a geomembrane but with no soil cover. The other mechanisms could all be contributing factors to a greater or lesser extent depending on project-specific conditions. The loss of moisture from compacted clay liners covered with a geomembrane on slopes has been commonly acknowledged and often cited in the literature (e.g. Bowders et al. 1997). It is the authors' hypothesis that the same phenomenon, i.e., moisture loss, can be presumed to occur with GCLs installed on slopes and covered with geomembranes. The authors presume the following sequence of events, which is the same sequence that occurs with clay liners:

- After the GCL and geomembrane are installed on a slope, the geomembrane absorbs heat from the sun during the daytime. Temperatures up to 50° C have been measured on the geomembrane surfaces due to solar heat absorption.
- The hot geomembrane will tend to vaporize moisture in the soil immediately beneath the geomembrane. In this case, it will be moisture from the GCL and also the subgrade if the GCL is on a soil subgrade.
- During the night time, the temperature cools substantially, and the vaporized moisture beneath the geomembrane will condense and form droplets, many of which condense on the lower side of the geomembrane.
- On slopes, gravity will cause the droplets to flow downhill and gather at the toe.
- The process recurs the next day, and every day is like a pump cycle extracting moisture from the slope and causing it to pond under the geomembrane at the toe of the slope. On clay liner projects the effect can be very dramatic with large water pillows needing to be 'bled' out. The volume of water may be less with GCLs, but has also been noted to create water pillows, probably because of the contribution of subgrade soil moisture.

This presumed shrinkage mechanism would not occur on flat areas because the factor of gravity removing the droplets every night would not occur. That is, the droplets would tend to remain in place and when the sun came out to vaporize the moisture the next day, it would be the same moisture. What is the critical slope at which condensed moisture will tend to drain away? That is not known at this point.

A corollary problem that would exist with this presumed mechanism of moisture loss on the slope is the problem of moisture gain at the toe of slope. As previously mentioned, this issue can be especially evident and large with clay liners because of the volume of water. There will be less water with GCLs, but moist subgrade soils and long slopes could experience saturation of the toe. For encapsulated GCL designs, which seem to be more popular on the West Coast of the United States than elsewhere, excess saturation at the toe could be undesirable.

Research Need

The impetus for preparing this paper was to call attention to a potential industry need to address GCL overlaps on slopes.

Regarding current industry recommendations for overlaps to address the issue of shrinkage there are no definitive guidelines at this point. The authors understand that, in recognition of this issue, some designers are now recommending 12-18" overlaps on slopes in areas where they previously would have specified 6 inches. Note, however, that these recommendations could change depending on the sensitivity of a particular manufacturer's product. This, in turn, could be different when different types of geotextiles are used, different levels of needle punching, and different initial moisture contents in the bentonite.

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