POINT STRAINS IN HDPE GEOMEMBRANES WITH AND WITHOUT GCL PROTECTION LAYERS

Geomembrane puncturing due to stones in the underlying surface (either a rocky subgrade or an inferior-quality compacted clay liner) is an important consideration for waste containment projects. In such cases, a nonwoven geotextile cushion may not be suitable because it would prevent intimate contact between the geomembrane and the underlying surface, thus impacting overall hydraulic performance. A geotextile-based GCL, on the other hand, could be quite appropriate for such an application because it not only provides puncture protection but also acts an additional hydraulic barrier. The attached paper from the 3rd International Symposium on Geosynthetic Clay Liners presents a laboratory test procedure for evaluating the effectiveness of a GCL as puncture protection for an overlying HDPE geomembrane.

The puncture test equipment is the pressure vessel specified in ASTM D5517, Standard Test Method for Large Scale Hydrostatic Puncture Testing of Geosynthetics. Truncated cones, with heights of 0.5 inch, 1 inch, and 1.5 inch were used as protrusions. The GCL protection layer was placed above the cones and a 60-mil HDPE geomembrane was placed on top of the GCL. A thin lead sheet was then placed over the geomembrane to record deformations. The entire assembly was loaded to a maximum pressure of 5,750 psf (275 kPa), which was maintained for 2 hours, or until the geomembrane punctured. At the end of the test, the lead sheet was retrieved and scanned with a laser profilometer. With the help of a CAD interface, the deformed shape of the lead sheet was used to calculate strain in the geomembrane test specimen.

Two methods were then used to calculate strain: the arch elongation method and the membrane method. The membrane method results showed that the strains on the geomembrane were about an order of magnitude lower when a GCL protection layer was in place. The arch elongation method was found to significantly under-predict the strain at high deformation levels close to a puncture. The test results presented in this paper show that it is possible to quantitatively determine the protection efficiency of a GCL during equivalency studies. Potential future tests would consider varying protrusion shapes and overburden pressures.

TR-272
Revised 01/11

3rd International Symposium on Geosynthetic Clay Liners
Würzburg, Germany 15 / 16 September 2010

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ABSTRACT
Deformation of a 1.5 mm thick high density polyethylene (HDPE) geomembrane was measured in the laboratory in a quasi-performance puncture test both with and without a geosynthetic clay liner (GCL) protection layer. The tests modelled a large angular stone on a firm subgrade such as may result from stones in bony subgrades and inferior quality compacted clay liners (CCLs). The measured deformation was then used to calculate uni-axial strain in the geomembrane. Under similar test conditions, the uni-axial point strain in the geomembrane was an order of magnitude lower when a GCL was used as a protection layer. Past publications on the same topic have reported the results in terms of the failure, i.e., puncture, pressure of the geomembrane. Although the effectiveness of GCLs as protection layers is well established, this paper presents a method that can be used to better quantify the protection performance of a given GCL for site-specific conditions. For example, whereas measuring puncture pressure can often be inconclusive as a result of the test reaching limit of the equipment without a failure, the strain measurement method always results in useful data. The method presented in this paper is quite valuable when establishing the equivalency of the GCL to a CCL as the puncture protection is often a part of the evaluation matrix.

1. INTRODUCTION

The liner system in most waste containment projects consist of geomembrane underlain by a GCL or a CCL. In some cases, the in-situ subgrade is accepted in lieu of a CCL if it meets certain permeability requirements. A very important concern with a GM-CCL or a GM-subgrade composite liner is the puncture of the geomembrane due to the stones in the underlying surface. The use of a nonwoven needlepunched geotextile as a protection layer is not suitable in this case because it prevents an intimate contact between the synthetic and the mineral liners. A geotextile-based GCL, on the other hand, is quite appropriate for this application as it not only provides a puncture protection but also acts as an additional liquid barrier. The use of a GCL as an additional waste barrier plus protection layer is quite common and this is certainly an old concept. However, the evaluation of a GCL as a protection layer, or a calculation of the protection efficiency of a GCL, is not simple. Tests performed with the aim of a puncture pressure are often inconclusive as there is no puncture of the geomembrane except at very large protrusion height. The use of strain measurement in a performance test is not well established in the US although the method is quite common in Europe.

The junior author of this paper has published several articles on the topic of the use GCLs as protection layers including Allen & Narejo (2010), Narejo et al. (2007), and Narejo et al. (2002). A problem encountered in these studies was the lack of the geomembrane puncture at the limit of the equipment. Therefore, many tests in these publications were noted as being inconclusive. A similar problem in North and South America arises quite often with performance puncture tests when site soil is used as the underlying or overlying material against which a protection layer is to be tested. The results of these expensive tests are often based on visual description of gouges, depressions and scratches.

The strain measurement of HDPE geomembranes in puncture mode has been reported by several authors including Tognon et al. (2000) and Brachman & Gudina (2008). Concern in most published works in the past has been with the overlying gravel drainage layer and protection materials of interest have rightfully been nonwoven needlepunched geotextiles. The EN 13719 method for site specific puncture testing also targets the overlying gravel layers. This paper makes use of the procedure of strain measurement and improves it with a computer-aided drafting (CAD) interface. The goal of the preliminary results presented in this paper are to work out the details of the procedure and use the current ASTM hydrostatic puncture test method (ASTM D5514) to quantify the effectiveness of GCLs as protection layers. The procedure is to be extended further with more tests as well as calibration using strain measurement with strain gauges. The current paper is also of interest in comparing the results of the ASTM method D 5514 (Standard Test Method for Large Scale Hydrostatic Puncture Testing of Geosynthetics) that is based on puncture pressure measurement and EN 13719 that is based on strain measurement.

2. EQUIPMENT AND PROCEDURE

The test equipment utilized in this paper is according to ASTM method D5514 and has also been reported in the past in Narejo et al. (1996), and Narejo et al. (2007). Figure 1 presents photos of this test equipment. Essentially a section of a large – 0.9 m – steel pipe forms the body of the pressure vessel used in the test. To the body are added legs and a flange. A circular cap of the matching size with a flange completes the pressure vessel. Within the body of the pressure vessel is prepared the subgrade with the desired shape, size and orientation of the protrusions. In this paper, three truncated cones with the desired cone height exposed above a sand layer were utilized as protrusions. These protrusions are best suited for comparative or conformance type of tests which is the goal of this paper. Cone heights of 13 mm, 25 mm and 38 mm were used in the test program. Such an arrangement represents isolated gravel particles on a subgrade on which a GCL and a geomembrane is to be installed.

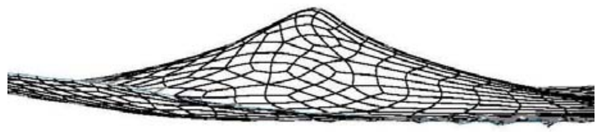
Figure 1. Pressure vessel and truncated cones utilized for performing the test.

Once the desired cone height was achieved by adjusting sand around the cones, the GCL protection layer was placed on top of the cones. The GCL layer was not fixed within the flanges of the vessel. On top of the GCL layer, a 1.5 mm HDPE geomembrane was placed such that it extended to the outside edges of the flange of the vessel. Lead sheet was placed on the top of the geomembrane but not within the flanges, i.e., the lead sheet was not fixed within the flanges. A linear low density geomembrane of 1 mm thickness was placed on top of the lead sheet and over the flanges. The entire assembly was then loaded to a maximum pressure of 275 kPa at a rate of 6.9 kPa/minute. The pressure was applied with air pressure. A constant pressure of 275 kPa was maintained for 2 hours unless the geomembrane punctured prior to the target time or maximum pressure. At the end of the test, the lead sheet was retrieved and scanned with a laser profilometer. The deformed shape of the lead sheet was utilized to calculate strain in the geomembrane test specimen.

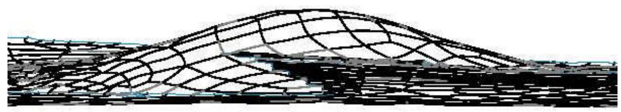
3. MATERIALS, MEASUREMENTS AND CALCULATIONS

The test results and the interpretation are of a preliminary nature as the test program has been just initiated and is currently ongoing. All tests included in this paper were performed on a 1.5 mm thick smooth HDPE geomembrane available commercially in the US. Tests were performed at three cone heights of 13 mm, 25 mm and 38 mm both with and without a GCL protection layer. The GCL used in the test program had a mass per unit area of 4775 grams/m^2 and was of nonwoven needlepunched – bentonite – woven structure with the entire sandwich needlepunched. The nonwoven needlepunched side of the GCL faced the protrusions.

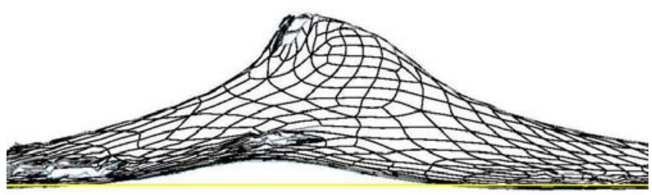
The deformation of the geomembrane at the end of the test was recorded with the lead sheet. This lead sheet had a thickness of 1.3 mm and compliant to the requirements of EN 12588. A record of the strain with pressure or time is not available from this type of test. However, a digital image of the lead sheet was obtained with a laser profilometer. This digital image was then converted to a CAD file for the purpose of measurement of the deformation. Figure 2 shows the scans for the six tests reported in this paper. Note that the scanner treats the lead sheet as a three-dimensional solid giving various views such as top, back, side, etc. This image has to be dissected to obtain a two-dimensional geomembrane shape for calculating strain.



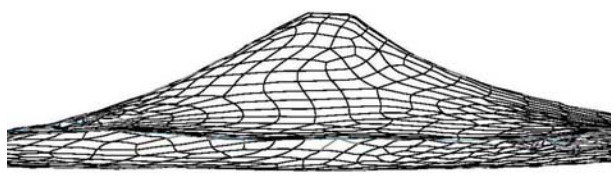
(a) At 13 mm cone height, no protection



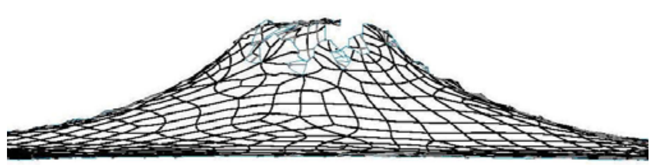
(b) At 13 mm cone height, with GCL protection



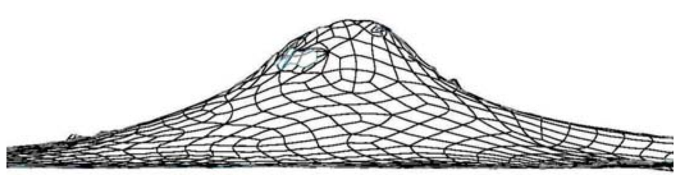
(c) At 25 mm cone height, no protection



(d) At 25 mm cone height, with GCL protection



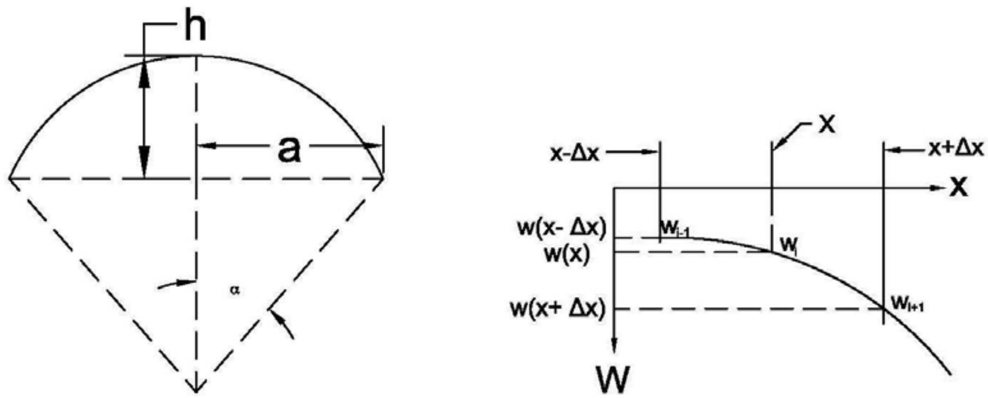
(e) At 38 mm cone height, no protection



(f) At 38 mm cone height, with GCL protection

Figure 2. The deformed shape of the lead sheet for three cone heights and two cases (protected and unprotected) as captured by the profilometer.

Two types of strains were calculated from the profiles in Figure 2: average longitudinal strain, and membrane strain along the profile of the geomembrane. The procedure for the calculation is illustrated in Figure 3. The average longitudinal strain is calculated with the same method as used by the DIN standard for performance puncture test (DIN 13719).



$$\varepsilon_a = \frac{\left(h^2+a^2\right)\cdot \sin^{-1}\left(\frac{2ah}{h^2+a^2}\right)}{2ah} - 1,\ h<a$$

$$\varepsilon_m = \sqrt{\left(1+\left(\frac{1}{2\Delta x}\left[w_{i+1}-w_{i-1}\right]\right)^2\right)} - 1$$

(a) Arch elongation method

(b) Membrane method

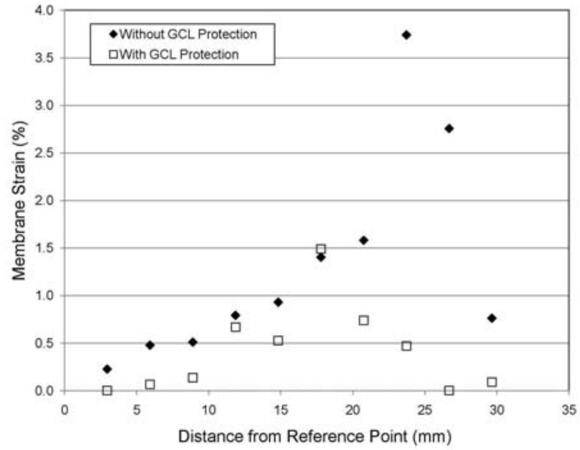
Figure 3. Illustration of the strain calculation procedure.

In the arch elongation method (Figure 3a), h = maximum depth of deformation (mm), and a = shortest cord length. Note that only one value results at the end of each test as the entire dent or bulge caused by a truncated cone is treated as one depression. The membrane strain is calculated from the deformed shape of the geomembrane using a first order central finite difference approximation (Figure 3b). The procedure has been described in more detail by Brummermann et al. (1994) and Tognon et al. (2000). In the membrane strain method w_{i-1} and w_{i+1} are deformations at points i-1 and i+1, respectively and Δx is the grid spacing.

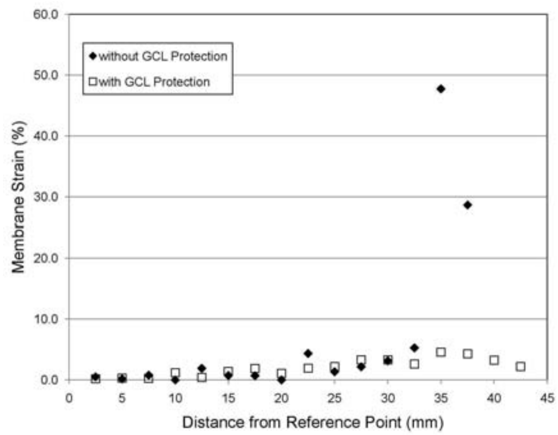
4. RESULTS, ANALYSIS AND DISCUSSION

The test results for membrane strain are presented in Figure 4. The membrane strain is calculated starting from a reference point at which there is little or no noticeable deformation of the geomembrane. As is seen in Figure 2, the curvature of the profile of the geomembrane increases as one moves closer to the peak corresponding to the tip of the truncated cone. Just before the tip of the cone, the strain becomes the highest after which it becomes zero at the top of the cone where the geomembrane profile is flat. At a cone height of 13 mm, the maximum strain in the geomembrane without the GCL protection is around 3.8 mm for the specific test conditions applicable here. For the same conditions, the strain in the geomembrane with a GCL protection layer is 1.5 mm. Therefore, the GCL reduces the strain by around 50%.

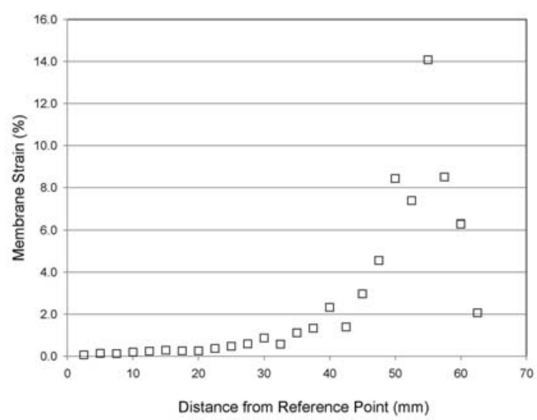
For 25 mm cone height, the geomembrane is just approaching the failure as can be seen in the steep profile at the left side in Figure 2(c). This point is at about 35 mm from the reference point and the strain in the geomembrane at this point is around 48% as is plotted in Figure 4(b). For this same condition, the membrane strain in the geomembrane when a GCL is used at a protection layer is around 4%. Therefore, the geomembrane strain is an order of magnitude lower when a GCL protection layer is used. The strain then decreases to zero at exactly the top of the cone where the profile is flat.



(a) 13 mm cone height



(b) 25 mm cone height



(c) 38 mm cone height with GCL protection

Figure 4. Membrane strain for various cone heights for 1.5 mm HDPE geomembrane with and without GCL protection except at 38 mm cone height where the geomembrane failed.

The last set of data is presented in Figure 4(c) corresponding to the 38 mm cone height tests represented by Figure 2(e) and 2(f). Note in Figure 2(e) a large hole in the geomembrane resulting from the puncture. As a result of the significant gap in the profile, it is not possible to calculate membrane strain for the case of 38 mm cone height without a protection layer. While there is actual rupture of the geomembrane without the GCL, the test with GCL results in a maximum membrane strain of 8% as is shown in Figure 4(c). Figure 4(c) again shows that there is possibly an order of magnitude lower strain when a GCL is used as a protection layer.

Arch elongation is an average value of the strain calculated across the entire depression. The arch strain values for each of the test – except at 38 mm cone height without protection – are presented in Table 1 below. The arch strain ranges from 3% for the case of the geomembrane with GCL at 13 mm cone height to 15% at 25 mm cone height without protection layer. The arch strain value approaches membrane strain at low cone deformations corresponding to lower cone heights. In most cases, especially in case of significant localized deformation, the arch strain method significantly under-predicts the strain in the geomembrane.

Table 1. Arch elongation strain in the geomembrane.

Cone Height (mm)	Arch Elongation Strain (%)	
	Without GCL Protection	With GCL Protection
13	6	3
25	15	11
38	NA*	11

* = geomembrane punctured during the test

5. CONCLUSIONS

The deformed profile of a 1.5 mm thick HDPE geomembrane in a quasi-performance puncture test was transformed into a CAD matrix through a profilometer. The profile was then used to calculate uni-axial point strains according to arch elongation and membrane strain methods. The arch elongation method was found to significantly under-predict the strain at high deformation levels close to a puncture. The membrane method shows that the point strain in the HDPE geomembrane is an order of magnitude lower when a GCL protection layer is used. Additional parameters such as the type of GCL, the shape of the protrusion, the pressure and the nature of the overburden pressure must be further studied on the basis of this procedure. The test results presented in this paper show that it is possible to quantitatively determine the protection efficiency of a GCL during equivalency studies. Currently, many investigators use a visual description of the condition of the geomembrane when loaded against the underlying surface.

6. REFERENCES

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