

## Physical Response of Geomembrane Wrinkles near Gcl Overlaps

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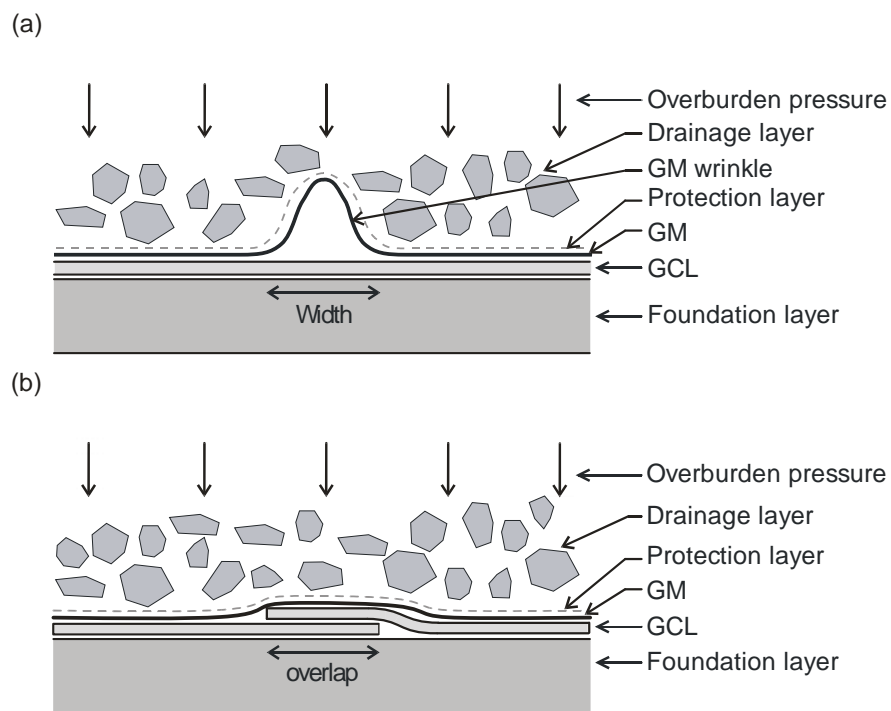
### ABSTRACT

Results from physical experiments are reported to quantify the deformations of geomembrane wrinkles near overlaps in an underlying geosynthetic clay liner (GCL) when subjected to vertical overburden pressure. The height and width of the wrinkle decreased, but a void remained between the geomembrane and GCL when subjected to a vertical pressure of 250 kPa. It was found that the deformation of the geomembrane wrinkle was not significantly altered by the presence of the overlap and that for the conditions tested there was no discernable opening of the GCL overlap when subjected to stress. It is anticipated that the proximity and orientation of the geomembrane wrinkle relative to the GCL overlap and the stress conditions arising from the deforming wrinkle can influence the hydraulic performance of the GCL overlap.

### INTRODUCTION

A composite geosynthetic liner consisting of a geomembrane (GM) on top of a geosynthetic clay liner (GCL) – see Figure 1 – can be very effective to limit leakage (i.e. flow under a hydraulic gradient) through landfill barrier systems. The geomembrane limits leakage to flow through holes (e.g., damage caused by puncture during construction or from the weight of overlying materials), while the presence of a low permeability GCL limits the amount of leakage through any holes. The rate of leakage will depend on (Rowe et al. 2004): the number and size of holes in the geomembrane; the thickness and hydraulic conductivity of the GCL; the thickness and hydraulic conductivity of any other soil materials beneath the GCL (e.g., a foundation/attenuation layer); the hydraulic gradient across the system; the interface transmissivity between the geomembrane and GCL; and any geometrical imperfections that may exist in the composite liner.

Two sorts of imperfections are illustrated in Figure 1: geomembrane wrinkles (Fig. 1a) and GCL overlaps (Fig. 1b). Wrinkles are out-of-plane buckles that develop from thermal expansion when heated (e.g., while being exposed to the sun during construction) that, if not eliminated prior to burial, create features that permit essentially unobstructed lateral flow over an area equal to the length and width of the wrinkle. If a hole develops in the geomembrane at or near a wrinkle, the potential leakage rate can be substantially larger than if there was no wrinkle. Overlaps are the locations connecting adjacent panels of GCLs and consist of a physical overlap between 0.15 to 0.3 m, or more, depending on the manufacturer, product, engineering application and exposure conditions. Supplemental loose bentonite may be placed between the overlap to improve its hydraulic performance. The GCL overlap creates a small linear feature between GM and GCL and also introduces potential preferential lateral flow paths depending on the hydraulic performance of the overlap.



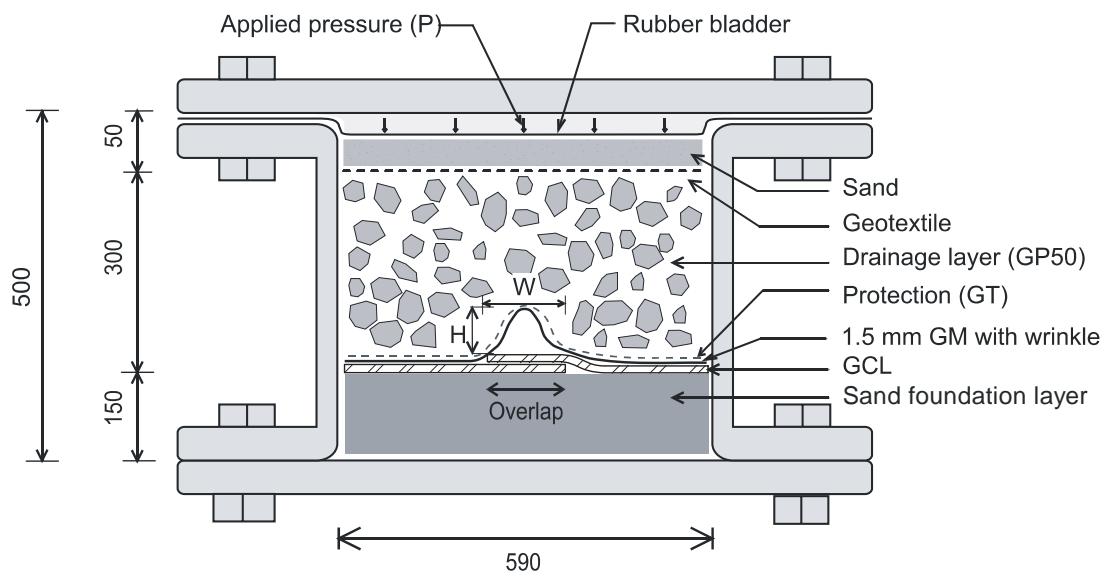
**Figure 1 Illustration of a GM/GCL composite liner showing: (a) a wrinkle in the geomembrane and (b) an overlap between GCL panels.**

The hydraulic performance of GCL overlaps has been studied under conditions of uniform vertical stress (e.g., Benson et al. 2004). However, Dickinson and Brachman (2006) have shown that wrinkles create potentially complex stress conditions for an underlying GCL when subject to vertical overburden pressure. Prior to conducting more elaborate tests that measure hydraulic performance of the overlap under actual physical conditions, the purpose of this paper is to report the results from a series of preliminary tests conducted to examine whether GCL overlaps impact geomembrane wrinkle deformations and also whether the deforming wrinkle causes movement at the GCL overlap that could impact its hydraulic performance.

## METHOD

### Test setup

A rigid cylindrical test cell of internal diameter 590 mm and height 500 mm was used for all the experiments. A cross-section of the test cell showing test setup and materials tested is shown in Figure 2. Vertical overburden pressure is applied using air pressure to a rubber bladder placed on top of leveled sand along the top surface of simulated drainage layer. Rigidity of the test cell limited the outward deflection and produced horizontal stresses corresponding to zero lateral strain conditions. The inner wall of the test cell was lined with a friction treatment comprised of two 0.1 mm thick polyethylene sheets lubricated with high temperature grease. Direct contact of tested materials with friction treatment, in upper granular drainage layer, might cause physical damage to the friction treatment. The possible damage is prevented by the use of a protection layer. The protection layer consisted of six bands of 1.5-mm-thick geomembrane rings attached to a nonwoven geotextile (540 g/m<sup>2</sup>) using double sided tape. Each geomembrane ring is 45 mm wide and each ring is spaced 10 mm with the adjacent ring to permit vertical movement. This treatment has been shown to reduce the sidewall friction to less than 5° (Tognon et al. 1999). For the size of the test cell and the friction treatment employed, the pressure loss due to boundary friction at the location of the geomembrane is calculated to be less than 5% (Brachman and Gudina 2002). Since the effect of boundary friction is minimized, but not eliminated, the reported values of applied pressure should be reduced by 5% when considering an equivalent burial depth in a landfill.



**Figure 2 Cross-section through test cell for test 1 and 2. Dimensions in mm. Materials**

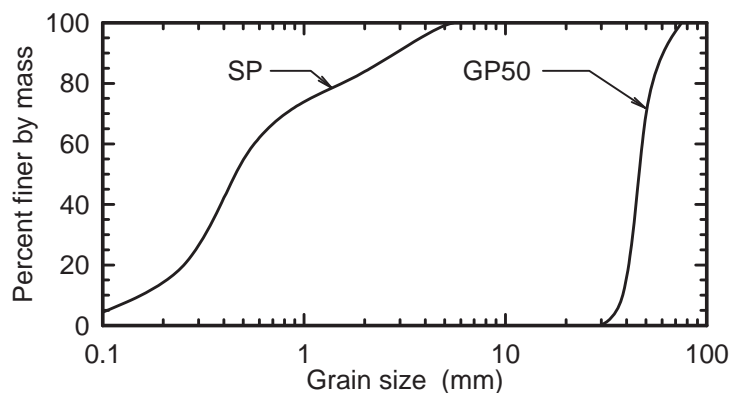
The case of a firm foundation layer beneath the GCL was examined in these tests by using a 150-mm-thick layer of poorly-graded dry sand (SP) as the subgrade. The sand used had dry density of  $1.75 \text{ g/cm}^3$  with a water content of less than 0.2%. The grain size distribution curve is shown in Figure 3.

The GCL tested had sodium bentonite ( $4500 \text{ g/m}^2$ ) sandwiched between a scrim-reinforced nonwoven carrier geotextile ( $200 \text{ g/m}^2$ ) and nonwoven cover geotextile ( $200 \text{ g/m}^2$ ) held together with needle-punching. The needle-punching fibers were thermally fused to the bottom of the carrier geotextile. The GCL was tested at two different initial water contents. For test 1, a dry GCL with an initial gravimetric water content of 4% and thickness of approximately 5.5 mm was used. For tests 2, 3 and 4, the GCL was hydrated with tap water for seven days under a confining stress of 20 kPa. The resulting initial water content of these samples was between 119 and 125% and had average initial thicknesses of 7.5 mm. In all tests, an overlap of 150 mm was examined, the centre of the GCL overlap was aligned with the centre of the test cell and no supplemental bentonite was added to the overlap.

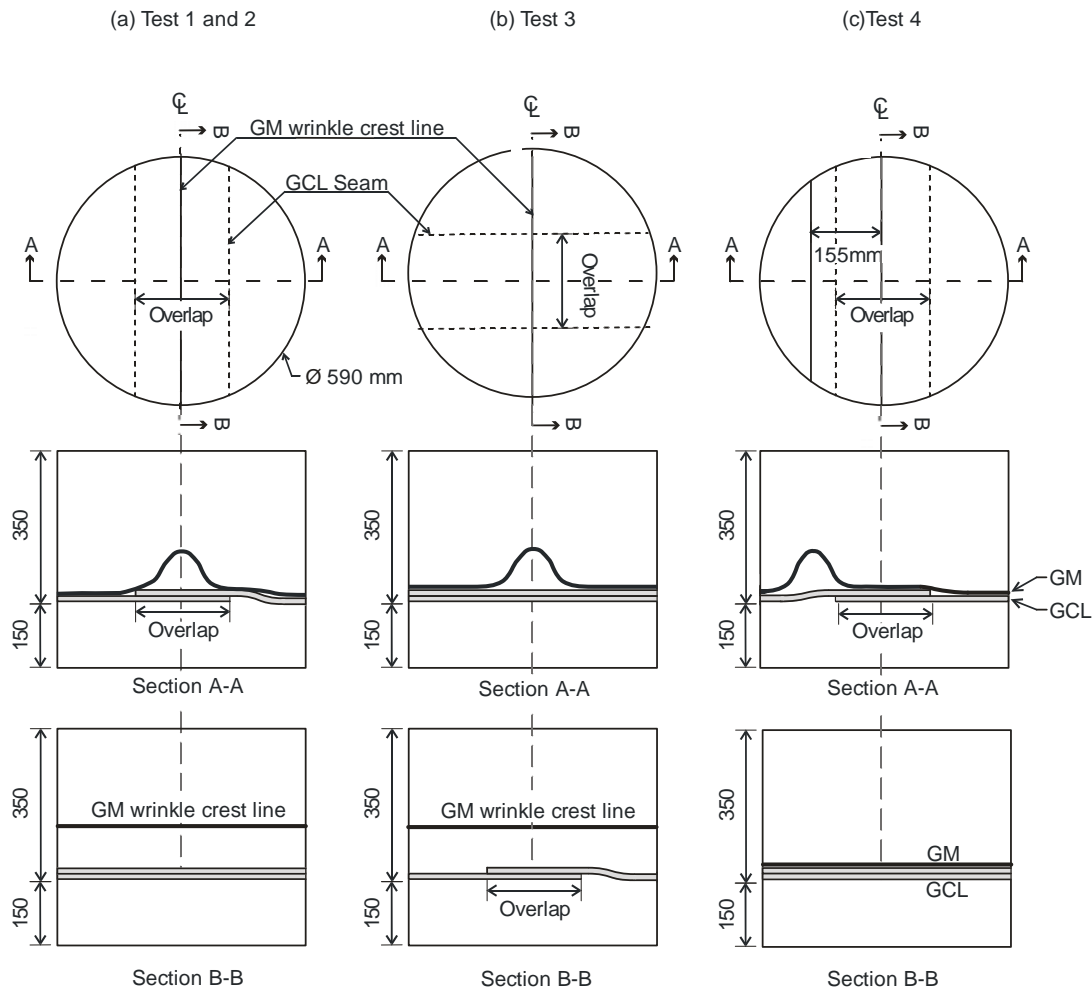
In all tests, a 1.5-mm-thick smooth high-density polyethylene geomembrane with an artificially formed wrinkle was placed above the GCL. The wrinkles had an initial height of approximately 60 mm and width of 200 mm. Figure 4 details the three different scenarios of the wrinkle location relative to the GCL overlap were tested. In tests 1 and 2, the crest line of the wrinkle coincided with the centre-line of GCL seam (Fig. 4a). In test 3, the wrinkle was positioned at  $90^\circ$  to the GCL seam (Fig. 4b), while in test 4, the wrinkle crest line was offset 155 mm from the centre of GCL seam (Fig. 4c).

A nonwoven needle-punched geotextile (GT) was placed between the geomembrane and the overlying coarse gravel drainage layer. This geotextile had mass per unit area of  $540 \text{ g/m}^2$ .

Overlying the geomembrane wrinkle and geotextile protection layer was a 300 mm-thick layer of nominal 50-mm poorly-graded gravel (GP50) to simulate a granular leachate collection system and meet the requirement of Ontario, Canada landfill regulations (MOE, 1998). The gravel layer was placed, without any compaction, at a dry density of  $1.52 \text{ g/cm}^3$ .



**Figure 3 Grain size distributions of foundation (SP) and drainage layer (GP50).**



**Figure 4 Plan and cross-section views showing location of GM wrinkle relative to the GCL overlap. Dimensions in mm.**

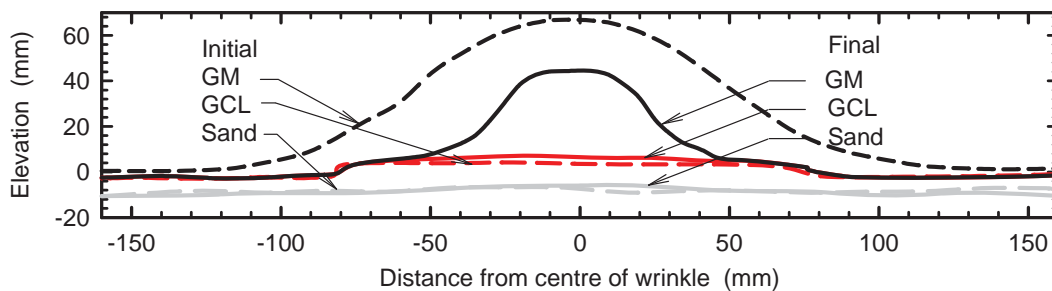
### Procedure

Materials were carefully placed in the test cell and the initial geometry of foundation layer, GCL and the geomembrane was measured to an accuracy of  $\pm 0.1$  mm using a profiler. The rubber bladder was placed on top of leveled sand along the top surface of gravel layer and was clamped between the flange and lid of the test cell (Figure 3). The pressure was applied at the rate of 50 kPa increment in every 10 minutes and then held constant at a maximum applied pressure of 250 kPa for 100 hours. Temperature was maintained at  $22 \pm 1^\circ\text{C}$  throughout the test.

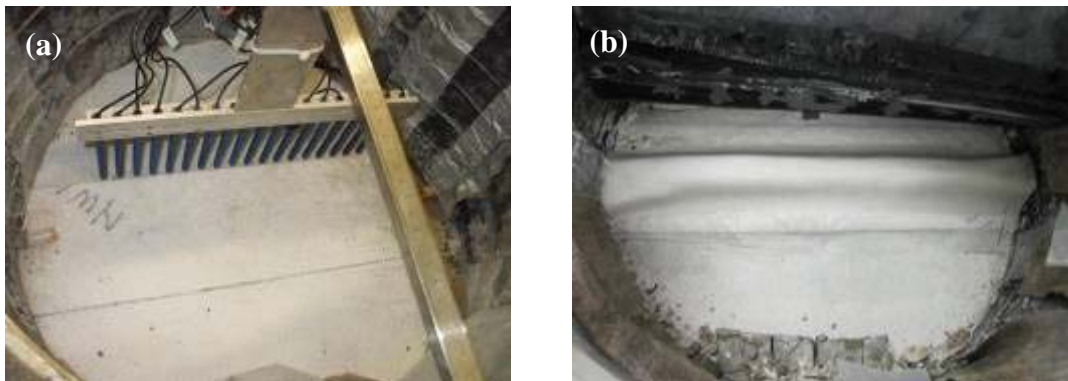
After of 100 hours, but while the pressure was still applied, a low shrinkage grout of plaster of Paris was injected into the remaining void space beneath the geomembrane to record the deformed shape of wrinkle. After the grout was allowed to set for approximately 30 minutes, the pressure was released and all the materials overlying the wrinkle were carefully removed. The final height and width of the geomembrane wrinkle, GCL and sand were then measured using the profiler.

## PRELIMINARY RESULTS

The initial and deformed shapes from test 1 are plotted in Figure 5, while initial and final photographs of the GCL overlap are shown in Figure 6. Here and in all other tests, the datum of the elevation shown in Figure 5 is taken as the initial elevation of the top surface of the GCL. Points directly on the centre of the wrinkle deformed vertically downwards, while points mid-way along the side of the wrinkle deformed vertically downwards and horizontally towards the centre of the wrinkle. Consequently, the wrinkle experienced a decrease in height of 28 mm and a decrease in width of 100 mm from the application of load, but a void with a height of 44 mm and width of 98 mm remained beneath the wrinkle. A photograph of the grout filled zone beneath the wrinkle is shown in Figure 6b. These observations are similar to the results reported by Brachman and Gudina (2008) for otherwise the same conditions but without a GCL overlap and with the pressure held constant for only 10 hours instead of 100 hours. The remaining height and width (H and W) when normalized by the initial height and width ( $H_0$  and  $W_0$ ) were  $H/H_0 = 66\%$  and  $W/W_0 = 45\%$  in test 1 compared to respective values of 69% and 52% reported by Brachman and Gudina (2008). The slightly smaller final wrinkle in test 1 is attributed to pressure being sustained for a longer period of time.



**Figure 5 Initial and deformed shapes from test 1.**



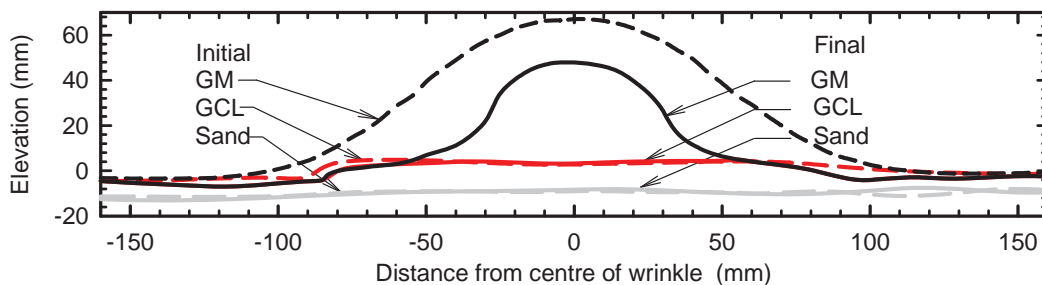
**Figure 6 Photographs taken before and after test 1.**

As expected with a firm foundation layer beneath the GCL, there was only small movement of the GCL induced by the movement of the underlying sand.

Figure 5 shows that in test 1 there was only small (less than 4 mm) downward vertical movement of sand beside the wrinkle and little (less than 6 mm) upward vertical movement (i.e. heave) of sand directly beneath the wrinkle. The heave results from small upward movements into the stress free zone beneath the wrinkle. Again, this is similar to what Brachman and Gudina (2008) observed for similar conditions but without a GCL overlap.

There was no discernable displacement or opening of the GCL overlap following application of the pressure in test 1. The small heave of foundation soil beneath the wrinkle, the inward displacement of points on the side of the wrinkle and compressive vertical stress on either side of the overlap where the deformed wrinkle was in direct contact with the GCL overlap produced physical conditions such that, for the specific conditions tested, there appeared to be no movement of the overlap that would be detrimental to its hydraulic performance.

The results from test 2 are plotted in Figure 7. Here, the GCL had a higher initial water content, but otherwise had the same configuration as test 1. This resulted in a higher and wider deformed wrinkle in the geomembrane, but again, no opening of the GCL overlap was observed. The major difference between tests 1 and 2 was that local reductions in thickness of the GCL from lateral bentonite extrusion were more prominent at the higher water content – see Dickinson and Brachman (2006, 2010) for a more detailed discussion of the nature and significance of these sorts of indentations.



**Figure 7 Initial and deformed shapes from test 2.**

The deformed shape from test 3, where the geomembrane wrinkle was oriented perpendicular to the GCL overlap, is presented in Figure 8. The deformed shape of the wrinkle is not significantly different to that from test 2. Figure 9 shows initial and final photographs of the GCL overlap. No movement of the GCL overlap was detected.

Figure 10 shows the deformed shape of the wrinkle from test 4, where the centre of the wrinkle was laterally offset from the GCL overlap. Given the limited dimensions of the test apparatus, it is likely that the wrinkle deformations in this test were impacted by the close proximity to the test cell boundary. It was observed that the reduction in wrinkle height was larger in test 4 than the other three tests. Despite the larger displacements, there was no measureable slippage at the GCL overlap.

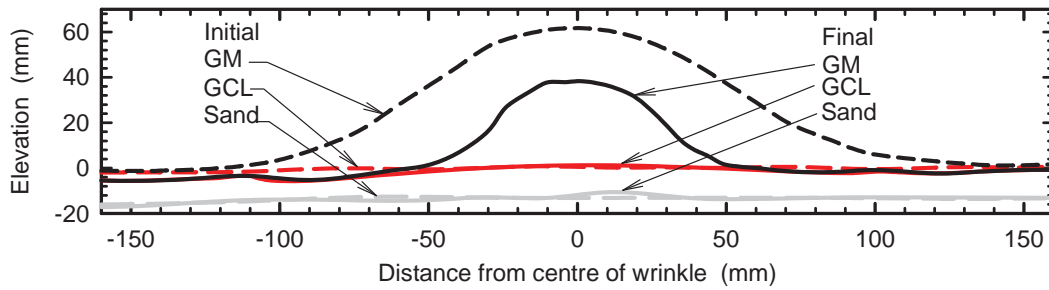


Figure 8 Initial and deformed shapes from test 3.

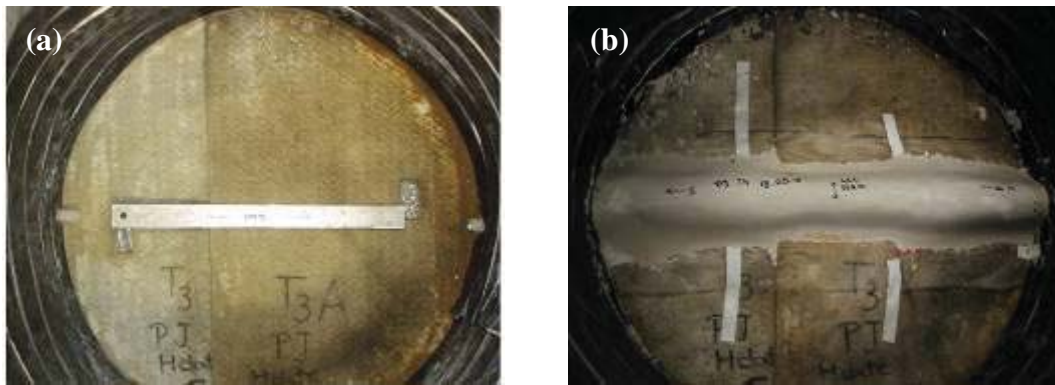


Figure 9 Photographs taken before and after test 3.

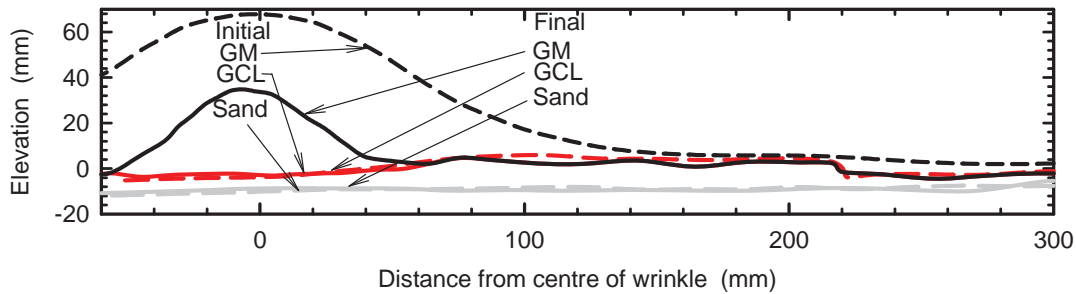


Figure 10 Initial and deformed shapes from test 4.

**DISCUSSION**

It is interesting at this point to take the preliminary results from tests 1-4 and examine how the physical conditions at a geomembrane wrinkle and a GCL overlap could possibly impact how significant the hydraulic performance of the GCL overlap may be to the leakage rate if there is a hole in the geomembrane wrinkle.

When the centre of the wrinkle was aligned with the centre of the GCL overlap, the nature of deformed shape in tests 1 and 2 was such that fluid in the wrinkle would not have access for direct entry into the GCL overlap, but would either have to flow downward through the upper GCL or laterally along the interface between the deformed geomembrane and upper GCL to then reach the interface. It is likely that the hydraulic performance of the GCL overlap would benefit from vertical

stress acting on the interface on either side of the remaining wrinkle (e.g., between 50 to 80 mm and -50 to -80 mm from the centre of the wrinkle in Fig. 5). It may be of interest to conduct permeation tests for this case where the GCL overlap is subjected to both confined and stress-free regions.

The conditions examined in test 4 were such that any fluid in the wrinkle would also not have access for direct entry into the GCL overlap, but would have to first flow laterally along the interface between the geomembrane and upper GCL of the overlap for the length of the overlap. This situation would also benefit from having vertical stress acting on the entire overlap from above (e.g., between 60 to 220 mm from the centre of the wrinkle in Fig. 10). A situation related to the test 4, but with the position of the upper and lower GCLs exchanged for each other in the overlap region (i.e. if the wrinkle formed on the other side of the overlap) would not be as favorable since any fluid in the wrinkle could flow preferentially along the GCL overlap.

Of the conditions tested, the orientation of geomembrane wrinkle at a right angle to the GCL overlap in test 3 would be expected to produce conditions where the resulting leakage rate would be most sensitive to poor hydraulic performance of the overlap. This is because any fluid beneath the geomembrane wrinkle would have direct access to the overlap. Further, a portion of the GCL overlap equal to the width of the deformed wrinkle would not be subject to any vertical stress. Thus there appears to be merit to conduct permeation testing of GCL overlaps under such physical conditions.

## SUMMARY

A series of preliminary physical tests were conducted to study the deformations of geomembrane wrinkles near GCL overlaps. It was found that the deformation of the geomembrane wrinkle was not significantly altered by the presence of the overlap and that for the conditions tested there was no discernable opening of the GCL overlap when subjected to 250 kPa of vertical stress. It is anticipated that the proximity and orientation of the geomembrane wrinkle relative to the GCL overlap and the stress conditions arising from the deforming wrinkle can influence the hydraulic performance of the GCL overlap. Additional testing is currently underway to confirm the preliminary results reported in this paper and assess the impact of geomembrane wrinkles near GCL overlaps on the overall hydraulic performance of these composite liners.

## ACKNOWLEDGEMENTS

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