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# Effect of boundary conditions on deflection of GM wrinkles in a GM/GCL composite liner

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ABSTRACT: Short-term deformations of a geomembrane wrinkle overlying a geosynthetic clay liner are reported when subjected to the physical stress conditions expected at the base of a landfill. The effect of the axial and lateral geomembrane boundary conditions on the deflection of the wrinkle are examined. The axial boundary condition consisting of an intentional gap between the geomembrane and test cell wall is shown to provide known and reproducible end condition. The results also show the importance of providing lateral end restraint to the geomembrane to obtain known and more repeatable boundary condition relative to no lateral restraint.

## 1 INTRODUCTION

A composite liner comprised of a geomembrane (GM) overlying a geosynthetic clay liner (GCL) can be used to provide effective environmental protection when part of a properly designed barrier system at base of landfill. While much is known on the potential contaminant transport through either a geomembrane or GCL (e.g., Rowe et al. 2004), there is little data on the physical response of composite GM/GCL liners when subject to burial conditions expected at the base of a landfill. For example, wrinkles may develop in the geomembrane during installation. Wrinkles induce local strains in the geomembrane from changes in curvature and may also increase the effects of local gravel contacts beside the wrinkle. Wrinkle deformations with sand above and below the geomembrane have been reported by Soong and Koerner (1998) and Brachman and Gudina (2002), indicating that the wrinkle is not eliminated, even when subject to vertical pressures up to 1100 kPa.

Testing of geomembrane wrinkles in composite GM/GCL liners poses a few additional challenges relative to the previous tests with sand above and below the geomembrane. For example, the relatively low interface strength between the geomembrane and GCL may result in lateral slip along this interface (if not restrained) and thereby effect the wrinkle deformations.

The objective of this paper to present results from seven short-term experiments to examine the effect of boundary conditions on the deflection of wrinkles in GM/GCL composite liners. The influence of the axial and lateral boundary conditions for the geomembrane on the measured deformations of a wrinkle is presented.

## 2 EXPERIMENTAL DETAILS

Figure 1 shows a cross-section through the test cell developed by Brachman and Gudina (2002) and used for this testing. The test cell is a cylindrical steel pressure vessel with a diameter of 590 mm and height of 500 mm. Vertical pressures is applied using a rubber bladder. Horizontal stresses corresponding to zero lateral strain conditions are developed by limiting the outward deflection of the sidewalls. The sidewalls were treated to reduce pressure loss due to boundary friction to less than 5%. For reference, x = 0 and y =

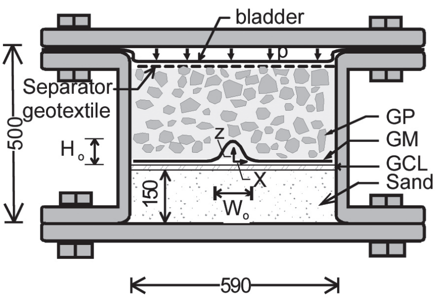

Figure 1. Cross section through test cell (dimensions in mm).

0 are at the centre of the test cell, while z = 0 is at the elevation of the flat portion of the geomembrane.

A foundation layer consisting of 150 mm of dry poorly-graded medium sand (SP) was placed beneath the GM/GCL in all tests. It was installed at a dry density of 1.75 g/cm$^3$. A GCL with sodium bentonite (4,721 g/m$^2$) between a slit-film woven carrier geotextile (110 g/m$^2$) and a virgin staple fibre nonwoven cover geotextile (241 g/m$^2$) was tested. It was needle-punched and these fibres were thermally fused to the carrier geotextile. The GCL was installed with the woven geotextile facing down. Two GCL water contents were investigated. Tests P1-P5 was conducted with the GCL essentially dry with a water content of $\omega = 7\%$. The average initial thickness of the dry GCL was 5.8 mm. In Tests P6 and P7, the GCL was hydrated for 14 days under a confining stress of 20 kPa. This produced a GCL with an average initial thickness of 7.8 mm and initial water contents of 115 and 126% for P6 and P7.

A 1.5 mm thick smooth high-density polyethylene geomembrane was placed above the GCL. A wrinkle with an initial height $H_o = 60$ mm and width $W_o = 240$ mm was artificially formed in the geomembrane. The geometry of the wrinkle was measured to an accuracy of ± 0.1 mm using a profiler consisting of a series of displacement transducers. Although in the field there would most certainly be some sort of protection layer between the geomembrane and overlying coarse gravel layer, no protection layer was included in these tests to serve as a reference for other tests (not reported here) where a protection layer was used.

The 300 mm thick granular layer a consisted of coarse gravel (GP) that was placed uncompacted (dry density of 1.5 g/cm$^3$) above the geomembrane. This gravel meets landfill regulations in the Province of Ontario, Canada. The gravel was obtained from crushed limestone and as a result, the gravel particles were rough and angular. The particle gradation was between 75 mm and 19 mm with a mean grain size $D_{50}$ of 50 mm. Above the gravel, a separator geotextile and a 50 mm thick sand layer were placed to protect the bladder from puncture. The 3 mm thick gum rubber bladder was then placed and secured between the flange and lid of the test cell.

Vertical pressure was applied in increments of 50 kPa every 10 minutes until the maximum test pressure of 250 kPa was reached. The maximum applied pressure of 250 kPa corresponds to burial under approximately 18 m of waste (assuming a unit weight of waste of 13 kN/m$^3$ and accounting for 5% loss in applied pressure from boundary friction). The maximum pressure was maintained for 10 hours. A low-shrinkage grout made from plaster of Paris was injected into the remaining gap beneath the geomembrane to preserve the final wrinkle geometry. The final wrinkle geometry was also recorded using the profiler. A temperature of 22°C was maintained for all tests.

## 3 RESULTS

### 3.1 *Wrinkle deflections*

Initial and deformed shapes of the geomembrane are plotted in Figures 2-5. In all cases, the geomembrane wrinkle experienced a decrease in height and width when subject to vertical pressure. However, the gap between the geomembrane and GCL remained in all tests at an applied pressure of 250 kPa. Although not reported in this paper, gap the also remained in similar tests conducted up to 1000 kPa.

The final wrinkle height and width as a percentage of the initial values are summarized in Table 1. The deformed shape of the wrinkle had a final normalized height ($H/H_o$) ranging from 42-68% and final normalized width ($W/W_o$) between 46-54% for the composite GM/GCL liner tested. For comparison, tests with sand above and below the geomembrane wrinkle produced a slightly shorter and much narrower wrinkle with $H/H_o = 52\%$ and $W/W_o = 35\%$ (Brachman and Gudina 2002).

The measured wrinkle deformations from the tests with lateral GM restraint ($\delta x = 0$) were very similar for Tests P1 & P2 ($w = 7\%$) and P6 ($w = 126\%$) indicating that the two different initial water contents of the GCL do not appear to have a significant influence on the wrinkle deformations, and thereby geomembrane strains. The initial GCL water content did have an effect on local deformations of the GCL

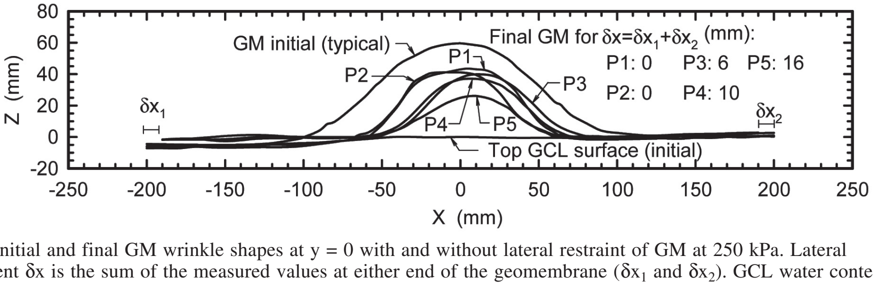

Figure 2. Initial and final GM wrinkle shapes at y = 0 with and without lateral restraint of GM at 250 kPa. Lateral displacement $\delta x$ is the sum of the measured values at either end of the geomembrane ($\delta x_1$ and $\delta x_2$). GCL water content =7%.

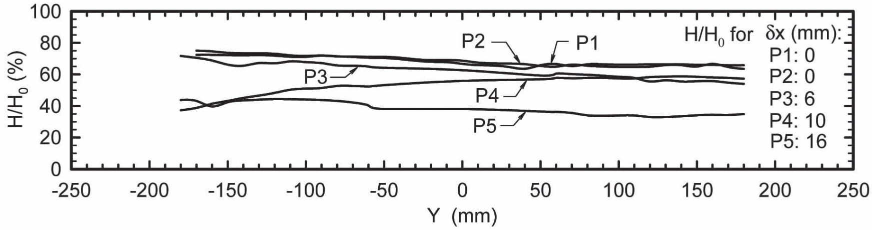

Figure 3. Final wrinkle height along x = 0 with and without lateral restraint of GM at 250 kPa. GCL water content = 7%.

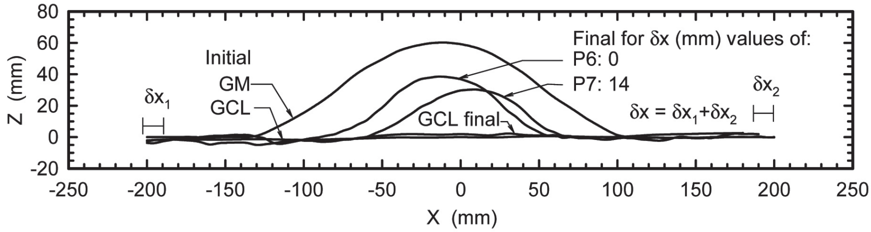

Figure 4. Initial and final GM wrinkle shapes at y = 0 with and without lateral restraint at 250 kPa. GCL ω = 115 and 136%.

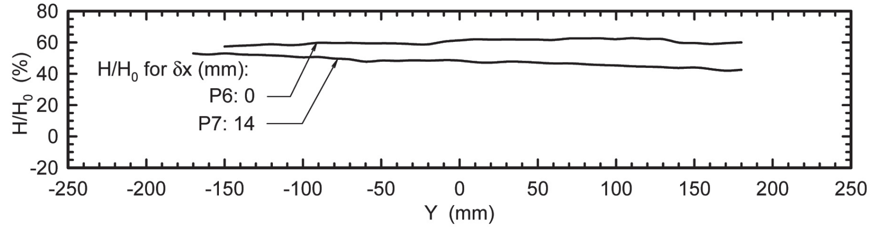

Figure 5. Final wrinkle height along x = 0 with and without lateral restraint of GM at 250 kPa. GCL ω = 115 and 136%.

Table 1. Summary of results.

| Test | ω<br>% | δx<br>mm | H/H$_o$ at Y = 0<br>% | W/W$_o$ at Y=0<br>% |
|---|---|---|---|---|
| P1 | 7 | 0 | 68 | 52 |
| P2 | 7 | 0 | 67 | 52 |
| P3 | 7 | 6 | 65 | 50 |
| P4 | 7 | 10 | 62 | 48 |
| P5 | 7 | 16 | 42 | 46 |
| P6 | 126 | 0 | 65 | 54 |
| P7 | 115 | 14 | 48 | 50 |

beneath gravel particles, with increasing deformations with increasing water content (Dickinson and Brachman 2003).

### 3.2 *Effect of axial boundary condition*

When selecting the axial boundary condition for the geomembrane wrinkle, consideration was given to two options. The first option was to provide axial restraint to the wrinkle in order to reproduce the axial plane strain conditions that would be expected to prevail for a long and prismatic wrinkle in the field. However, the concern with such a boundary condition in the laboratory is that it may prevent the geomembrane from freely moving in the vertical direction because of potential binding against the test cell wall and thereby influence the measured wrinkle deformations.

The second and adopted option was to intentionally leave a gap between the end of the wrinkle (y = ± 295 mm) and the test cell wall. The intent of this axial gap was to permit the geomembrane to freely deform in the vertical direction and obtain known stress conditions (i.e. zero axial stress) for the geomembrane. The possible effects of this gap on the wrinkle were examined with three-dimensional finite element analysis (Brachman and Gudina 2002). They found that provided the wrinkle was 500 mm or longer there was negligible difference (less than 2%) in vertical deflection of the wrinkle and stresses in the geomembrane at the central section of the specimen with and without the axial gap.

The measured deflection of the wrinkle crest (H/H$_o$) plotted in Figures 3 and 5 show no abrupt changes in the final wrinkle height at the ends of the wrinkle. Thus no binding of the geomembrane was observed for the adopted axial boundary condition. The observed local variations in $H/H_o$ along the length of the wrinkle arise from the irregular loading and support provided by the overlying coarse gravel.

### 3.3 *Effect lateral boundary condition*

The importance of providing lateral restraint to the ends of the geomembrane was also investigated. There was concern that if lateral displacement of the geomembrane was permitted at the ends of the specimen ($\delta x$), the low interface strength between the geomembrane and GCL may lead to slipping along this interface, thereby altering the deformed shape of the wrinkle relative to the laterally extensive conditions expected at the base of a landfill. Two conditions were investigated. In Tests P1, P2 and P6, lateral restraint was provided by casting small plaster blocks between the ends of the geomembrane and the test cell wall ($x = \pm 295$ mm). No lateral restraint was provided in Tests P3-P5 and P7.

The results in Figure 2 show that essentially identical results were obtained from the two tests with lateral restraint (P1&P2), whereas large variations in wrinkle height and width were found when no restraint was provided in otherwise identical tests (P3-P5). The observed variations in deformed wrinkle shape arise from differing amounts of lateral deflection at the end of the geomembrane which varied between 6-16 mm. The coarse gravel above the geomembrane likely results in highly variable normal stress acting on the geomembrane, resulting in variable slip along the GM/GCL interface, and consequently variable lateral end deflection. Thus providing lateral restraint results in a more repeatable boundary condition.

The results in Figures 2 and 4 also show that not providing lateral restraint leads to larger wrinkle deformations (relative to with lateral restraint), with the effect most prominent for the largest amount of lateral displacement of 16 mm from Test P5. Since such lateral displacement is not expected for a wide geomembrane in the field, providing lateral restraint is important to obtain a realistic simulation of field conditions in the laboratory.

## 4 CONCLUSIONS

Results from seven short-term experiments involving a wrinkle in a GM/GCL composite liner subjected to applied vertical pressure were reported to examine the influence of the geomembrane boundary conditions on the measured wrinkle deformations. Overall, the geomembrane wrinkle experienced a decrease in height and width when subject to vertical pressure; however, the gap between the geomembrane and GCL remained in all tests at an applied pressure of 250 kPa, for the particular conditions tested. The axial boundary condition was selected to provide known and reproducible zero axial stress conditions for the geomembrane. Measured vertical deflections of the wrinkle showed that this approach successfully prevented binding of the geomembrane against the test cell wall. The results also demonstrate the importance of providing lateral restraint to the ends of the geomembrane in these experiments. Tests with lateral restraint produced known and more repeatable boundary conditions than those without restraint. When tested without lateral restraint, slip along the GM/GCL interface resulted in larger wrinkle deflections (i.e. a smaller final wrinkle) and more variable results for otherwise identical test conditions.

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