LOCAL DEFORMATION OF A GEOSYNTHETIC CLAY LINER FROM AN ISOLATED GRAVEL CONTACT

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ABSTRACT
Results are presented from experiments where a single gravel particle is in direct contact with a 63 mm diameter GCL specimen and subjected to load. The experiments were conducted to examine the influence of loading rate and initial water content on local GCL deformations. The results showed that the deformation of the GCL is largely independent of loading rate for the conditions examined since the majority of the deformations occurred immediately following placement of the first load increment. Also for all cases, the majority of the deformation occurred at low stress levels. In fact, in all tests, more than 50% of the total deformation of the GCL had occurred following the first of five equal load increments (154 N) and more than 95% of the eventual total deformation had occurred prior to the fourth load increment.

RÉSUMÉ
Le système de membranes composites constitue une partie intégrante des sites d'enfouissement moderne. Le montage laboratoire utilise ici permet d'évaluer les performances de ces membranes composites lorsque soumises a des poussées de terre. On reporte des déformations importantes sur les systèmes de membranes composites. La présence de geomembrane au -dessus des systèmes de membranes peut légèrement réduire les déformations. Les résultats expérimentaux ont démontres qu'en variant la durée de la charge, les déformations se produisent immédiatement après l'application de charge. Dans chaque cas, la plupart des déformations se développent lorsque la force de la charge est peu élevée.

1. INTRODUCTION

Geosynthetic Clay Liners (GCLs) are a manufactured product that consist of a thin layer of bentonite that may be encapsulated between two geotextiles and held together by needle-punching combined with thermal bonding. A GCL can be effectively used as part of a composite liner with geomembranes (GM) in landfill barrier systems. The available knowledge on the hydraulic performance and diffusive properties of GCLs is sufficient to permit the rational design of composite liner systems with a GCL (e.g., Rowe et al., 2004).

However, there remain some uncertainties on the physical response of a GCL in a landfill. For example, the coarse gravel backfill that is often used in the leachate collection system above a composite GM/GCL liner results in highly variable and potentially large contact forces acting on the liner. It has been hypothesized that these stress concentrations can cause hydrated bentonite to migrate to zones of lower stress (e.g., Stark, 1998). Dickinson and Brachman (2003) reported results from short-term experiments to quantify the thickness of a GCL located beneath a geomembrane and coarse gravel backfill when subject to an overburden pressure of 1000 kPa for 10 hours. A cross section of the apparatus used for their experiments is presented in Figure 1.

The thickness of the GCL when hydrated under free swell conditions was reduced by as much as 14.5 mm, to a final thickness of as little as 1.4 mm. These tests highlighted the necessity to provide an adequate protection layer above the geomembrane to not only prevent puncture of the geomembrane but also to limit the deformations of the GCL. They have found from further tests that a 150 mm thick layer of sand above the geomembrane can limit deformations to less than 7 mm for tests performed with an overburden pressure of 250 kPa.

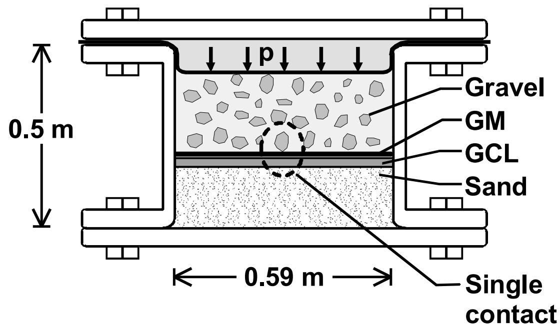


Figure 1. GCL and geomembrane (GM) backfilled with coarse drainage gravel in test apparatus.

The objective of this paper is to further study local GCL deformations and some of the factors that influence these deformations. Results from ten experiments where a single gravel particle is in direct contact with a 63 mm diameter GCL specimen are reported. The effect of loading rate and initial water content on GCL deformations is examined.

2. EXPERIMENTAL DETAILS

The experiments involving a single gravel particle in direct contact with the GCL were conducted by modifying a conventional oedometer apparatus. The experiments were conducted in a fixed ring oedometer cell. A specimen of GCL with a diameter of 63 mm was placed in the cell. The GCL was loaded by a single coarse gravel particle which was cut in half and glued to the underside of the loading platen. The gravel particle itself was approximately 45 mm in diameter where it was in contact with the loading platen and gently tapered to an approximate diameter of 27 mm at a distance of 13 mm from the loading platen. The stone particle then tapered to a point at a distance of approximately 17 mm from the loading platen. The gravel particle was taken from the crushed limestone with particle gradation between 75 mm and 19 mm and mean grain size D_{50} of approximately 50 mm used in the tests by Dickinson and Brachman (2003). Load was applied at various rates and the deformation of the GCL was monitored with time. The load rates were selected to be similar to those experienced by the GCL in the liner tests performed by Dickinson and Brachman (2003) and much longer to examine the influence of the load rate on local GCL deformations. In Tests 1 through 4, a force of 154 N was applied every 10 minutes until a total force of 770 N was reached, which was then held for a period of 10 hours to correspond with applied pressure increments used by Dickinson and Brachman (2003). In Tests 5 and 6, a much slower loading rate was used where 154 N was applied every 24 hours up to 770 N, which was also held for 24 hours. A cross section of the apparatus used for these experiments is presented in Figure 2.

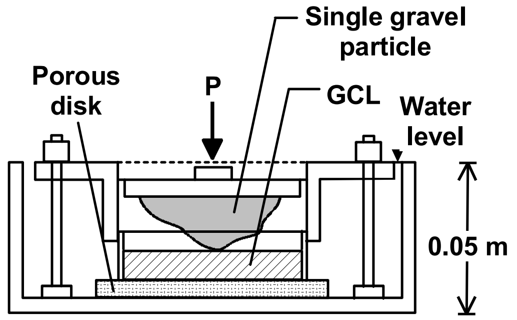


Figure 2. GCL and geomembrane (GM) backfilled with coarse drainage gravel in test apparatus.

Load in the liner tests performed by Dickinson and Brachman was applied by a uniform pressure across the top surface of the gravel in increments of 50 kPa. The actual contact forces acting on the GM and GCL are much greater but are unknown and possibly highly variable. The 154 N increment in force applied in the gravel isolation tests performed in this study was selected to be equivalent to an average applied stress of 50 kPa over the entire area of the GCL specimen (the actual contact stress between the gravel and GCL will be much greater).

The GCL used in these experiments consisted of sodium bentonite (4,721 g/m2) encapsulated between a slit-film woven carrier geotextile and a virgin staple-fibre nonwoven cover geotextile. This product was needle-punched and the fibres were thermally fused to the carrier geotextile. The GCL was installed in the oedometer cell with the woven geotextile facing down. The GCL specimens in Tests 1–6 were hydrated under zero vertical stress for a period of 14 days. To see the effect of the initial moisture content on the deformation of the GCL, Tests 7–10 were conducted on GCL specimens hydrated under a vertical stress of 20 kPa for 14 days. In Tests 1–6, the initial thickness of the GCL ranged from 12.5 mm in Test 4 to 13.5 mm in Test 2. In Tests 7–10, the initial thickness ranged from 7.9 mm in Test 9 to 9.2 mm in Tests 7 and 8. The initial thickness, initial water content and final water content of each GCL sample tested are presented in Table 1. In Tests 1–6, the average initial water content was 191% and the average final water content was 209%. In Tests 7–10, the average initial water content was 120% and the average final water content was 152%.

Table 1. Thickness and water content of GCL

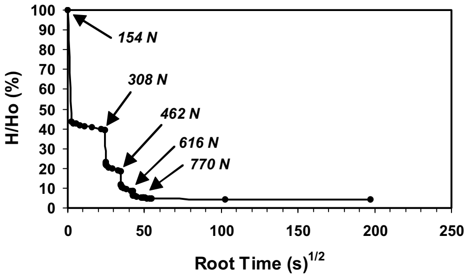
Test	Initial GCL Thickness Ho (mm)	Initial Water Content (%)	Final water content (%)
1	13.3	193	193
2	13.5	185	208
3	12.6	201	210
4	12.5	191	214
5	12.8	180	214
6	12.8	196	214
7	9.2	124	160
8	9.2	120	164
9	7.9	114	133
10	8.5	120	150

3. RESULTS

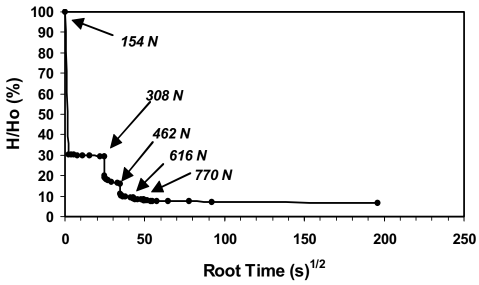
3.1 Local deformation of GCL

The results from Tests 1–4 corresponding to the liner test loading rate are presented in Figure 3. The results from the longer term tests 5 and 6 are presented in Figure 4 and the results from lower initial water content tests 7–10 are presented in Figure 5. GCL thickness H, expressed as a percentage of the initial thickness Ho is plotted against duration of the test expressed as square root time. Arrows indicate the beginning of each load step. A summary of GCL deformations (where the deformation is expressed as H-Ho) for all tests is given in Table 2.

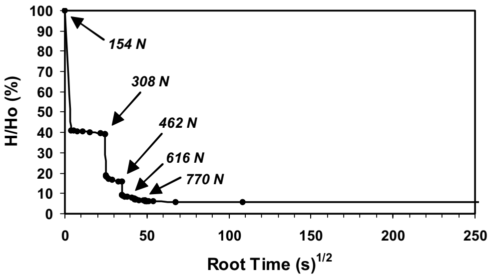
For all of the cases plotted in Figures 3–5, most of deformation occurred immediately after the load was applied. For example, the first load increments of Tests



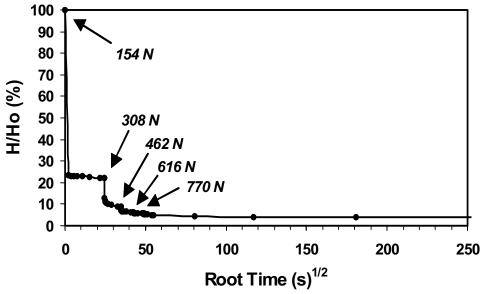
(a) Test 1



(b) Test 2

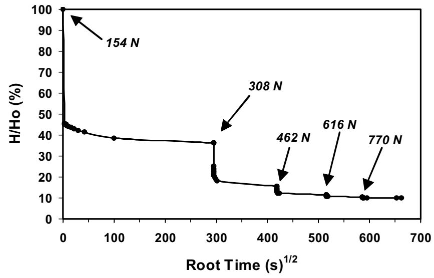


(c) Test 3

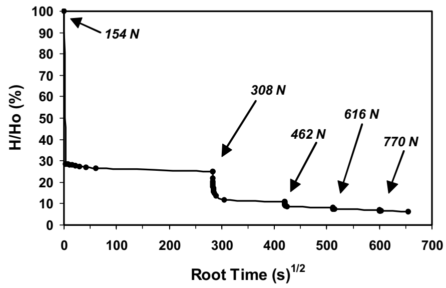


(d) Test 4

Figure 3. Measured GCL deformations from Tests 1–4.



(a) Test 5

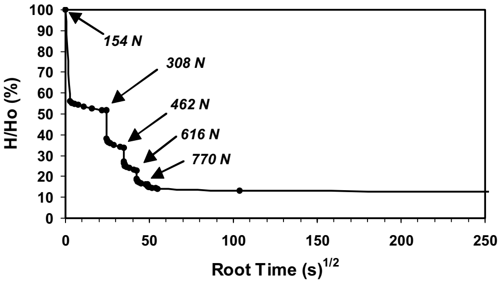


(b) Test 6

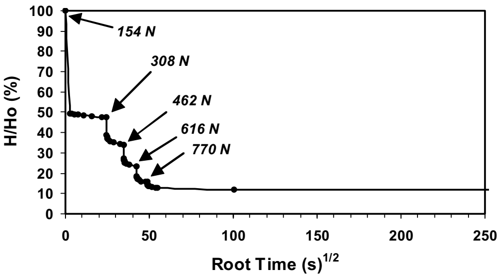
Figure 4. Measured GCL deformations from Tests 5 and 6.

1–4 (Figure 3) show that more than 90% of the deformation for that increment occurred within 6 seconds, with only a small increase for the duration of the remainder of the increment. This demonstrates that the deformation was largely a result of lateral extrusion of bentonite beneath the gravel contact and is consistent with the observations and explanations of Dickinson and Brachman (2003).

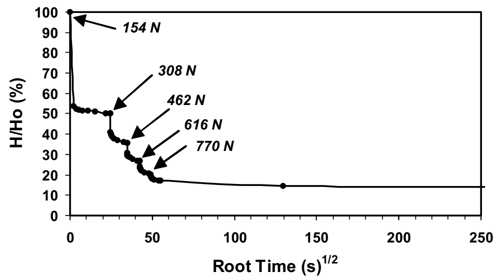
Also for all cases, the majority of the deformation occurred at low stress levels. For example in all tests, more than 50% of the total deformation of the GCL had occurred following the first load increment and more than 95% of the eventual total deformation had occurred prior to the fourth load step (462 N). This observation is also consistent with the results obtained from the liner tests performed by Dickinson and Brachman (2003), where deformations resulting from tests conducted at 250 kPa were found to be very similar to those from tests conducted at 1000 kPa.



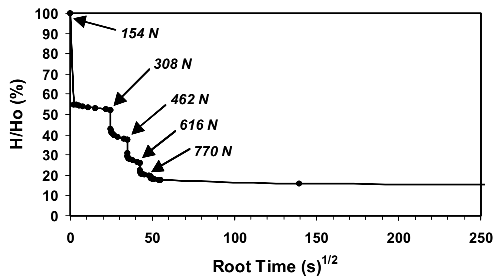
(a) Test 7



(b) Test 8



(c) Test 9



(d) Test 10

Figure 5. Measured GCL deformations from Tests 7-10

Table 2 – Summary of deformation data

Test	Initial Thickness (mm)	Total Def. (mm)	Total Def. (% initial thickness)	Def. following first load increment (% initial thickness)
1	13.3	12.7	96	57
2	13.5	12.5	93	70
3	12.6	11.9	94	59
4	12.5	12.0	96	77
5	12.8	11.6	90	54
6	12.8	12.0	94	71
7	9.2	8.0	87	45
8	9.2	8.1	88	51
9	7.9	6.8	86	46
10	8.5	7.2	84	45

3.2 Effect of loading rate on local GCL deformation

The results from Tests 1–4 can be compared to those from Tests 5 and 6 to examine the effect of the loading rate on local GCL deformations. Such a comparison indicates that the GCL deformations were largely independent of time. For example, the average total deformation of 95% for Tests 1–4 is only slightly larger than the average of 92% for Tests 5 and 6. This suggests that the observations and data obtained from the short term liner tests (10 min load steps) performed by Dickinson and Brachman (2003) are a real phenomenon (i.e. not merely an artifice of the short loading rate) and likely do not substantially differ if the liner tests were conducted for a longer period of time. The load rate used in the liner tests produces a slightly more severe response relative to a slower rate, but it is believed that they may be used to infer the long term response of GCLs when in contact with coarse gravel backfill.

3.3 Effect of initial GCL water content

The initial and final water contents for all tests are presented in Table 1. In order to examine the effect of the initial GCL water content on local GCL deformation, the results from Tests 1–4 (zero stress during hydration) were compared to those from Tests 7–10 (20 kPa stress during hydration). In Tests 7 through 10, the observed deformations were less than in Tests 1 through 4. This is as expected, with a lower initial water content producing smaller GCL deformations. This is encouraging since most GCLs in the field are likely to be under some level of stress during hydration. However, it is interesting to note that even though the deformations are smaller for samples of lower water content, they are still quite large. In Tests 7–10, the average total deformation was 86% of the initial GCL thickness compared to 95% for Tests 1 through 4, a reduction of only 9% for an average reduction in initial GCL water content of 73%. This would suggest that large GCL deformations may still develop in GCLs hydrated under 20 kPa of stress if they are exposed to coarse gravel backfill without adequate protection.

3.4 Final GCL water content

In Tests 1–10, evidence that the GCL deformations were primarily by the lateral extrusion of bentonite as opposed to drained primary consolidation of the bentonite can be seen by comparing the initial and final water contents of the GCLs. If drained primary consolidation was the dominating component of deformation of the samples, the water content of the GCLs would be reduced as a result of the expulsion of pore water. This did not occur in any of these tests. In fact, in all tests but one, the final water content was significantly greater than the initial water content and in no test did the water content decrease. This is believed to occur as the unloaded portion of the GCL specimen continued to hydrate during testing.

4. SUMMARY AND CONCLUSIONS

Measurements of local deformations of a 63 mm diameter specimen of GCL (needle-punched, thermally fused, with slit-film woven carrier geotextile and staple-fibre nonwoven cover geotextile) when subject to loading from a single isolated gravel contact were presented. Experiments were conducted to examine the influence of loading rate and initial water content on local GCL deformations. The results showed that the deformation of the GCL under the conditions examined is largely independent of loading rate since the majority of the deformations occurred immediately following placement of the first load increment. In these tests the deformations were as a result of lateral extrusion of bentonite with very little primary consolidation of bentonite. Thus the observations and data obtained from the liner tests using 10 min load increment of Dickinson and Brachman (2003) are a real phenomenon (i.e. not merely an artifice of the short loading rate) and likely do not substantially differ if the liner tests were conducted for a longer period of time. The load rate used in the liner tests produces a slightly more severe response relative to a slower rate, but it is believed that they may be used to infer the long term response of GCLs when in contact with coarse gravel backfill.

As expected, hydration under lower stresses (producing a higher initial water content) resulted in larger local GCL deformations. Deflections corresponding to 95% and 86% of the initial GCL thickness were found for hydration of the GCL under zero stress and 20 kPa, respectively. However, the concern regarding potential large local deformations remains even with hydration under 20 kPa of stress. There would still be a need to reduce these deformations with an adequate protection layer. In order to minimize these deformations a suitable protection layer would need to be placed above the liner to redistribute stresses from the gravel contacts and minimize the lateral extrusion of bentonite. Work is currently underway by the authors to quantify the effectiveness of various protection layers to limit deformations of the GCL.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Dickinson, S., and Brachman, R.W.I. 2003. Thickness of a GCL Beneath a Geomembrane Wrinkle and Coarse Gravel Backfill under Large Pressure, 56th Canadian Geotechnical Conference, Winnipeg, MB, pp. 465-472.

Rowe, R.K., Quigley, R.M., Brachman, R.W.I., and Booker, J.R. 2004. Barrier Systems for Waste Disposal Facilities, Taylor & Francis Books Ltd / Spon Press, 560 pp.

Stark, T.D. 1998. Bentonite Migration in Geosynthetic Clay Liners, Sixth International Conference on Geosynthetics, Atlanta, USA, pp. 315-320.