Resilience of Australian polymer-modified powdered sodium bentonite geosynthetic clay liners to downslope bentonite erosion

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Abstract. Loss of bentonite from geosynthetic clay liners (GCLs), installed as a component of a composite liner beneath an exposed geomembrane (GM) on the side-slopes of landfills and exposed to thermal cycling, has become a topic of some importance recently as it raises questions on the long-term durability of modern landfill lining products. Laboratory drip testing was used to evaluate the resilience of four GCLs containing polymer-modified powdered bentonite against down-slope bentonite erosion. Onset erosion features were observed only after 60-140 drip cycles. In all probability the polymer-modified bentonite can be expected to self-heal if no further erosion takes place at these initial stages. A detailed assessment of the drip test and comparison with known field test results, indicates that the drip rate and duration of the laboratory test conducted at ≈22 ºC is equivalent to in-field conditions where daytime temperatures of the GM/GCL may reach 65 to 75 ºC. Thus, meaningful accelerated testing of polymer-modified powdered bentonite GCL products is possible. The results need to be validated with in-field tests under local conditions because recoverable service-lives of GCL products ultimately depend on the in-field conditions where these materials are deployed.
Keywords: Geosynthetic clay liners, cyclical wetting and drying, cyclical heating and cooling.

1 Introduction

Downslope bentonite erosion within geosynthetic clay liners (GCLs) is of potential concern when composite liners (i.e. geomembranes (GMs) overlying GCLs), deployed on side-slopes, have been left exposed to diurnal temperature cycling for long periods of time, because cyclical heating and cooling of exposed composite liners can lead to bentonite migration coupled with water transfer within the composite liner. The mechanism is related to radiative heating from solar radiation (Malik et al., 1982) which causes water to move from the GCL and subgrade materials

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into the void space formed by wrinkles in the exposed GM (Chappel et al., 2012; Rowe et al., 2012). Condensation of this vapour on cooling results in excessive dripping and eventual down-slope migration of bentonite within some GCLs when installed on sides slopes beneath exposed GMs (Moreno and Neretnieks, 2011). Recent laboratory and field research has revealed that down-slope erosion of bentonite from some types of GCLs exposed on slide slopes of landfills may lead to long-term impairment of their hydraulic function (Rowe et al., 2014; Take et al., 2015; Rowe et al., 2016).

The forms of bentonite (e.g., powdered vs granular, fine granular vs coarse granular, polymer-modified vs unmodified) and also the type of GCL (geotextiles, scrim reinforcement) have been observed to behave differently with respect to both field and laboratory assessments (Rowe et al., 2016). However, given the recentness and resulting lack of reporting by other groups worldwide, some questions remain as to the full scale of this issue with some GCL products, particularly those containing polymer-modified powdered bentonite.

A series of laboratory drip tests were used to evaluate the resilience of Australian polymer-modified powdered bentonite GCL products against down-slope bentonite erosion. This paper reports on the most recent set of results.

2 Materials and Methods

The drip test by Ashe et al. (2014) has been adapted for this study. The X800, X1000, X2000 and X3000 GCLs used for this study were Australian manufactured, polymer-modified (anionic polymer), powdered GCL products. The X800/X1000 products are made with woven carrier and non-woven cover polypropylene geotextiles, while the X2000/X3000 products include scrim reinforced nonwoven carrier geotextiles. The X3000 contains the highest amount of bentonite of the four GCLs tested. 350 W x 550 L mm GCL coupons were cut from rolls (L in the roll direction), hydrated to ~100% gravimetric water content and then sealed in plastic to equilibrate for 24 hrs. Each coupon was then dried at 60ºC for >15 hours to induce desiccation cracking of the bentonite within the GCL. The top end and both sides were taped, and the lower edge was heat-sealed to minimise slumping of bentonite and to ensure that any bentonite erosion was associated with the drip. The coupons were then affixed to a transparent Perspex® sheet at a 3H:1V slope.

Hydration cycles consisting of a wetting phase using deionised water (mostly around 1 μS/cm but generally ≤10 μS/cm), at a drip rate of 3L/hr maintained for 8 hrs followed by a drying phase of 16 hrs at 20˚C were established to mimic a summer diurnal cycle. Tests were not run over the weekend. Drip rate and water quality were confirmed daily. At the end of each cycle, bright lamps (6 x 800 lumen LED) were used to illuminate the GCL sample so that backlit photos could be taken to gauge bentonite erosion (selected results shown in Table 1), and tests were stopped when at least two scores of ‘E’ or higher were measured. The magnitude of bentonite erosion was scored based on the approach taken by Brachman et al. (2015). Onset erosion was considered if any bentonite thinning was observed, and the width and length of any obvious erosion features within the GCL coupon were scored to gauge the progression of down slope erosion.

3 Results and Discussion

3.1 Drip Test Scores

Table 1 provides a summary of test scores on polymer-modified products. All products maintained scores of ‘h’ for up to 50 wet-dry cycles. Of the four products tested, the X1000 product, indicated onset of erosion (‘o’) after 50 drip cycles, irrecoverable erosion (‘EE’) after 70 cycles and irrecoverable extreme erosion (‘EEE’) thereafter. These erosion features were initially well away from the drip zone under which the bentonite continued to show good swollen gel stability. Previous tests carried out on X1000 indicated a hydrated (‘h’) state after 60 cycles. The X800 and X2000 products maintained ‘h’ status for at least 60 cycles, but a score of ‘o’ occurred within 70 cycles and ‘E’ (X2000) or ‘EE’ (X800) was noted within 80 cycles. The X3000 product maintained a hydrated state for up to 140 cycles, ‘o’ after 140 cycles, ‘E’ within 150 cycles and ‘EEE’ thereafter.

Table 1 Erosion scores for polymer-modified GCL products and X3000 erosion features.

<table>
<tr><th>Cycles</th><th>X800</th><th>X1000</th><th>X2000</th><th>X3000</th><th colspan="2">X3000 Erosion Features</th></tr>
<tr><td>20</td><td>h</td><td>h</td><td>h</td><td>h</td><td>Day 10-h</td><td>Day 140-o</td></tr>
<tr><td>40</td><td>h</td><td>h</td><td>h</td><td>h</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>50</td><td>h</td><td>o</td><td>h</td><td>h</td></tr>
<tr><td>60</td><td>h</td><td>o</td><td>h</td><td>h</td></tr>
<tr><td>70</td><td>o</td><td>EE</td><td>o</td><td>h</td></tr>
<tr><td>80</td><td>EE</td><td>EEE</td><td>e</td><td>h</td></tr>
<tr><td>90</td><td>EEE</td><td></td><td>E</td><td>h</td><td>Day 150-EE</td><td>Day 160-EEE</td></tr>
<tr><td>100</td><td></td><td></td><td>EE</td><td>h</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>110</td><td></td><td></td><td>EEE</td><td>h</td></tr>
<tr><td>140</td><td></td><td></td><td></td><td>o</td></tr>
<tr><td>150</td><td></td><td></td><td></td><td>EE</td></tr>
<tr><td>160</td><td></td><td></td><td></td><td>EEE</td></tr>
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3.2 Field Relevance and Estimated Expected Field Lifetimes

A recoverable service-life, defined as the estimated in-field life-time where the ability of the bentonite to self-heal is retained, will be ultimately dependent on the in-field conditions where the composite liner is deployed. Thus, an evaluation of how relevant the laboratory test may be compared to field conditions is critical. The only in-field measurements to date come from the field studies led by the Rowe group, conducted at the Queens University Environmental Liner Test Site (QUELTS) in Ontario Canada, which have provided some important research-based validation of the laboratory test. It must be noted that accurate and valid correlation between the laboratory test for predicting the real field conditions in Australia (or elsewhere) carries a high degree of uncertainty.

With these limitations in mind it is possible to approximate the number of equivalent cycles for an average month of QUELTS field conditions. GCLs 5 and 6 in Rowe et al. (2016) were powdered bentonite GCLs with similar cover and carrier configurations to X3000 (GCL5) and X1000 (GCL6). These samples lasted at least 60 cycles in laboratory tests before minor ‘e’ erosion was observed. Both GCL samples were observed to only have scores of ‘e’ after 15 months in the QUELTS experiment (Rowe et al., 2016), but after 28 months, at least one ‘EE’ and one ‘EEE’ features were observed. Thus, as a rule of thumb, we can expect 70 cycles of the laboratory test to be equivalent to 28 months, or 2.5 cycles per month. The four polymer-modified powdered bentonite GCL samples tested (Table 1) were all observed to have ‘e’ scores or less after a low of 60 cycles (X1000) and a high of 150 cycles (X3000). The first recorded ‘EE’ score was after 70 cycles (X1000), 80 cycles (X800), 100 cycles (X2000) and 150 cycles (X3000). Thus, the X1000 product can be projected to maintain a score of ‘e’ or less for down slope bentonite erosion for at least 24 months of exposure to conditions equivalent to the QUELTS experiment while X800 and X2000 products may attain 32 months (or more for X2000). For the X3000 GCL, the projection may be as long as 60 months of QUELTS equivalent conditions.

It must be reiterated that any such projection of service life from laboratory tests would have a very high uncertainty if extrapolated to field conditions outside those typical of those experienced during the study at the QUELTS in Ontario, Canada. Factors such as the overall temperature ranges and relative humidity variation in the laboratories, as well as the purity of the water used, can have significant impacts on the number of cycles to which a particular GCL product may maintain a score of ‘o’ or less in lab tests, and this would then be expected to add to the error of the projection to expected field service life. For example, Rowe et al. (2016a) discusses how for a sample that eroded within a few drip cycles with deionized water, just 35 ppm Ca^{2+} in the drip water nullified the effects of deionized water and no erosion was observed even after a considerable number of drip cycles.

Compared to various locations in Australia (Table 2), the biggest differences are related to the amount and time of precipitation (snow and rain in Ontario, no snow in most of Australia) and average annual and seasonal highs and lows (Canada much colder, with freezing temperatures for up to four months out of the year). In this regard, while total precipitation at Olympic Park in Sydney is similar to QUELTS, significant differences in temperatures, and expected thermal fluxes can be expected on exposed composite liners sited in similar climatic conditions. There might also be differences in the development and extent of wrinkles in the GM due to differences in base temperatures between sites rather than temperature differentials within sites. For example, Rowe et al. (2012) and Chapel et al. (2012) indicated that thermal expansion of exposed GMs resulted in several km of connected wrinkles and associated void space at QUELTS. While this has not been fully confirmed elsewhere in other field trials, it may be, for example, that in Australia many more km of connected wrinkles exist, and thus the amount of water per drip point may be largely reduced leading to less water per drip point impacting the GCL. Any such extrapolations would obviously carry excessive uncertainty until sufficient field data is collected.

We can still gain some appreciation for how informative these measurements may be and how realistically they may represent or estimate in-field down slope erosion. Firstly, it is obvious that 30 months exposure to QUELTS field conditions will be different from 30 months exposure to Australian field conditions. Due to the mild continental climate in Ontario, Canada (i.e., the high temperatures are less extreme and less desiccating compared to typical Australian conditions, Table 2) subgrade soils used there likely retain optimal moisture contents for longer times prior to installation of the GCL. The mean summer daytime high and mean summer daytime low temperatures given in Table 2 indicate that some Australian conditions are harsher than Canadian conditions in terms of total thermal flux that drives the solar still effect. While two of the four Australian sites (NSW and VIC) have similar annual and summer temperature differences as in Canada, two (SA and WA) have significantly higher overall temperatures as well as larger temperature differentials. The QLD site is overall warmer and wetter but has a lower summer temperature difference. Thus, while more water may be available for hydrating GCLs or moving into the void spaces of the composite liner, the temperature extremes within the composite liner are likely less important in moving water vapour at the QLD site. On the other hand, less water may be available in the subgrade in a SA or WA landfill at the time of GCL installation due to higher day time temperatures. Furthermore, the water that is present in a subgrade in SA or WA will be more susceptible to thermal induced migration due to the higher temperature differences between daytime highs and daytime lows (Table 2).

Additionally, there is some indication that the total amount of water available may be sufficiently lower in Australia to decrease the threat posed. For example, Adelaide, SA has less than half the rainfall as Kingston Ontario, and thus insufficient water might be available to contribute to the solar still moisture cycle. Due to the generally warmer climate, any day throughout the year can potentially create the solar still effect in NSW, and the VIC site probably has a similar number of days per year as QUELTS in which the solar still effect can take place. Both WA and SA will have limited solar still effect during the dry season. Finally, the subgrade soil type at the QUELTS site, reported as non-plastic with negligible clay (Rowe et al, 2016), will release more water far more readily than a soil containing a higher clay content, as are often used in Australia (Bouazza et al., 2017).

Table 2 Climatic information for QELTS from Government of Canada, (2017); for Australia forty-year averages. Source: Australian Bureau of Meteorology (2017).

	QUELTS *	VIC	QLD	NSW	WA	SA
Annual precipitation	952	709	1452	973	564	389
Annual daytime high (ºC)	12.1	19.8	25.0	23.3	24.8	23.6
Annual night time low (ºC)	3.6	10.2	15.3	12.2	11.9	9.7
Annual day-night difference (ºC)	8.5	9.6	9.7	11.1	12.9	13.9
Summer daytime high (ºC)	25.9	26.1	28.5	28.5	32.0	31.8
Summer daytime low (ºC)	16.3	14.4	20.3	17.6	16.7	14.9
Winter daytime high (ºC)	-2.6	13.7	20.6	17.4	17.9	15.3
Summer day-night difference (ºC)	9.6	11.7	8.2	10.9	16.3	16.9
Winter night-time low (ºC)	-11.4	6.2	9.1	6.3	7.4	5.2
Winter day-night difference (ºC)	-8.8	7.5	11.5	11.1	10.5	10.1

*QUELTS is ~40km NNW of Kingston, Ontario, Canada; Vic: Moorabbin Airport, Melbourne, Victoria; QLD: Southport, Gold Coast, Queensland; NSW: Olympic Park, Sydney, New South Wales; WA: Guilford, Fremantle, Western Australia; SA: Roseworthy, Adelaide, South Australia.

4 Conclusions

Based on the available evidence, exposed composite liners utilizing the polymer-modified powdered bentonite GCLs used in this study should maintain full integrity for at least 24 months (X1000) under conditions equivalent to the QUELTS field site. Only minor onset bentonite erosion that can still self-heal in a few locations of an exposed composite liner could be expected up to 24 month exposure of an X1000 GCL product. Depending on the factors listed above, erosion may be quite prevalent across the exposed composite liner surface after 30 months with X1000 products.

Exposures longer than 30 months will result in increased risks of loss of X1000 liner integrity such that irrecoverable erosion should be expected in at least one location of the exposed composite.

The more robust GCL products (X2000, X3000), usually recommended for side slope constructions, can be projected to maintain integrity for more than 30 months if left exposed. The X2000 product should be expected to suffer only minor bentonite erosion in a few locations after 30 months exposure and that this will self-heal if the composite liner is covered. All available evidence suggests that the X3000 product is strongly resistant to down slope bentonite erosion and that it can be expected to last at least 60 months in an exposed condition before irrecoverable erosion could be expected to be a significant problem.

5 Recommendations

A number of factors need to be tested to clearly show how they influence a service life prediction from the laboratory drip test. These include drip rate, drip duration, desiccation temperature and duration, thermal regime of the site, aspect of the exposed composite liner, and the source of initial hydration water (i.e. the subgrade soil water retention properties). Clearly the drip rate (3L per hour) and dripping regime in the laboratory test is extreme in terms of the amount of water that drips over a period of time on a single point. In a real exposed composite liner, drip rates may sometimes exceed 3L/hour and therefore be a continuous flow, but only for a short time duration during the initial condensation phase of the solar still. Further experimental input is required to determine if short duration, continuous flow, which may occur in real exposed composite liners could result in different behaviour than observed in laboratory tests.

The dehydration regime of each wet-dry cycle of the laboratory drip test is probably too gentle compared to Australian climatic conditions, where ambient air temperatures routinely exceed 35 ºC in the GCL. For example, an exposed liner in Melbourne on a southeast facing slope will undoubtedly experience cooling earlier in the afternoon than a northwest facing slope in Adelaide. The drip rate that would occur after the initial flush of condensate would be dependent on the on-going liquid-to-vapour phase transfer of water from the subgrade and GCL products. At this time, this is largely an unknown factor for exposed composite liners, and future research should focus on determining these variables.

Regardless of the results and reasoned arguements presented herein as to the resilience of polymer-modified powdered bentonite based GCLs, it is recommended that composite liners be covered as soon as possible to prevent issues related to exposure to solar radiation.

6 References

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