DOWNSLOPE BENTONITE EROSION RESISTANCE: COATED GCL OR POLYMER MODIFIED GCL?

1. INTRODUCTION

During field studies at Queens University in Canada, Professor Kerry Rowe and his colleagues found a potential for internal down-slope bentonite erosion in the GCLs in composite liners (i.e. a geomembrane over a geosynthetic clay liner (GCL)) especially beneath geomembrane wrinkles. The down-slope erosion was attributed to thermal cycles that caused evaporation of moisture from the GCL on sunny days (when the black geomembrane heated to 60-70°C) followed by condensation of moisture onto the geomembrane at night when the geomembrane cooled. The condensed moisture would drip on the underside of the geomembrane and run down the slope. Repetition of this process over an extended period of time caused some erosion of bentonite (Brachman et al. 2014b).

Professor Kerry Rowe and his colleagues have completed various lab and full-scale long-term field tests at Queens University, Canada, investigating downslope bentonite erosion of GCLs in composite liners. A review of these projects was presented in a paper by Rowe et al. (2014c) entitled “Field and laboratory observations of down-slope bentonite migration in exposed composite liners”. This technical note reviews these tests and highlights the key findings from these studies with particular emphasis on important parameters and considerations for designers.

2. FIELD AND LIBRATORY TESTS BY KERRY ROWE ET AL.

2-1- Field test “QUELTS I”:

The Queen’s University Environmental Liner Test Site (QUELTS) was first constructed in 2006 (QUELTS I) to examine wrinkling of the geomembrane (GMB) and allow the comparison of the effect of smooth and textured black HDPE GMBs and shrinkage of four different commonly used GCLs when left exposed as part of a full scale composite liner under nominally identical conditions. After completion of the wrinkle study (Rowe et al. 2012; Chappel et al. 2012a, b), the liner was opened to conduct a full survey of panel movements due to shrinkage (Brachman et al. 2014a). At this time, significant down-slope erosion of bentonite due to moisture migration was observed (Take et al. 2014a, b; Rowe et al. 2014a). This in-plane erosion was quite different to the erosion that can occur with a GCL resting on a foundation layer. Unexpectedly, the site provided the first well-documented instance of significant downslope bentonite erosion for a composite liner with black GMB left exposed for almost 4 years (Take et al. 2014a; Rowe et al. 2014b). Four different needle-punched GCLs (GCL1–GCL4) were tested in
QUELTS I. GCL 1 and 2 were made of fine granular bentonite and GCL 3 and 4 were made of course granular bentonite (Figure 1, Rowe et al. 2014c).

Figure 1. QUELTS I during construction. Sections (west to east): GCL2, GCL3a, GCL2, GCL4, GCL1 and GCL3b (Rowe et al. 2014c)

2-2- Laboratory test:

To provide some insight into the factors affecting down-slope bentonite erosion, a laboratory technique was developed by Professor Kerry Rowe and Ashe for investigating the effect of dripping evaporative water on GCLs (Ashe et al. 2014; Rowe et al. 2014b, Ashe et al. 2015). To simulate this in a laboratory experiment, GCL specimens (350 mm wide by 550 mm long) were hydrated to a target gravimetric water content of 100%, left to hydrate with no confining load, and then dried in an oven at 60°C. The specimens were placed on clear Perspex trays inclined at 3H: 1V (unless otherwise noted) and clamped along the top edge. Water was then allowed to drip at a prescribed rate (deionised water at 3 L/h unless otherwise noted) from a height of 50mm above the GCL at the centre line of the specimen just below the restraint. The water was collected along the bottom edge of the tray (figure 2). An erosion experiment involved dripping water onto the GCL for 8 hours (referred to as the hydration phase) followed by 16 hours when the GCL was allowed to air dry at room temperature. This cycle was repeated until the end of the experiment. At the end of the hydration phase, a light was briefly placed below the tray while photographs were taken. The bentonite loss per cycle was quantified by monitoring bentonite in the outflow. The first erosion hole was typically observed after only 5 to 6 cycles and in some cases after as few as 3 cycles. Extreme erosion features with complete loss of bentonite were observed within about 6 to 8 cycles.
Ten different needle-punched GCLs including the four GCLs in QUELTS I (GCL1-GCL4), two new GCLs with powdered bentonite (GCL5 and GCL6), a GCL with polyacrylamide-based polymer-enhanced bentonite (GCL7) and a coated GCL (GCL8) were used in the laboratory test. Some of the GCLs were found to be more resistant against downslope erosion in the laboratory conditions. These experiments prompted the desire to construct a second field study (QUELTS II) to examine the issue in the real field condition.

2-3- Field test “QUELTS II”:

In 2012, the liner system was removed and QUELTS II was constructed with a new series of 8 composite liners (Brachman et al. 2014b; Rowe et al. 2014a). Four sections with the four GCLs from QUELTS I plus four new sections with four new GCLs (examined by Ashe et al. (2015) in the laboratory test) were used at QUELTS II field test. Of the four new GCLs examined, two had powdered bentonite (GCL5 and GCL6) to establish whether their performance was similar in the field to that in the laboratory tests discussed earlier. One GCL (GCL7) had polyacrylamide polymer enhanced bentonite but was otherwise similar to GCL2 in QUELTS I. Finally, GCL8 had a coating placed facing up but was otherwise similar to GCL1 used in QUELTS I.

QUELTS II (Figure 3) was constructed in May 2012 to allow an evaluation of several points including the development of downslope erosion features with time from first construction, and the performance of four GCLs examined by Ashe et al. (2015) in the laboratory, under real site conditions.
3. SUMMARY OF THE FINDINGS

3-1- “QUELTS I” Field Test Results

As described, four different needle-punched GCLs (GCL1–GCL4) were tested in QUELTS I. GCL1 and 2 were made of fine granular bentonite and GCL 3 and 4 were made of course granular bentonite. GCL1 and GCL3 had a woven slit-film (W) carrier geotextile, GCL2 had a scrim reinforced needle-punched nonwoven (SRNW) carrier geotextile, and GCL4 had a needle-punched nonwoven (NW) carrier geotextile. Installed in September 2006, a full inspection of each GCL was conducted in May 2010 and June 2011. This included sampling and destructive testing (cutting the GCL to confirm tactile assessment of missing bentonite). Inspections and test results showed that all GCLs tested at QUELTS I were subjected to down-slope erosion and significant downslope erosion with deposition of bentonite at low spots in the base liner observed for each GCL (Figure 4). The field observations indicated that bentonite could be totally eroded from some local spots on the GCL within 1 year.

Figure 4. QUELTS I result. Significant downslope-bentonite erosion was observed at all areas highlighted with orange marks (Rowe et al. 2014c)

3-2- Laboratory Test Results

Different needle-punched GCLs including the four GCLs in QUELTS I (GCL1-GCL4), two new GCLs with powdered bentonite (GCL 5 and GCL6), a GCL with polyacrylamide-based polymer-enhanced bentonite (GCL7) and a coated GCL (GCL8) were used in the laboratory test by Ash et al. (2015) as described before.

Figure 5. Time lapse photos of GCL1 (W up) at the end of the hydration cycles (Ash et al. 2015)
A summary of the findings reported by Ash et al. (2014) and Ash et al. (2015) are:

- For coated GCLs with the coating facing up, no water penetrated through the coating, and no evidence of ANY erosion was seen.

- Where water was able to penetrate the internal bentonite layer of the GCL (un-coated GCLs), then some level of erosion occurred for ALL products tested.

- GCLs with polyacrylamide-based polymer-enhanced bentonite had a better performance than the GCLs with no polymer-enhanced bentonite and no coating, under laboratory conditions, but the polymer enhancement did not stop the erosion. The GCL products containing a polymer enhanced bentonite slowed the rate at which erosion features developed but did not stop erosion completely. The coated GCL had no evidence of any downslope erosion, stopping bentonite erosion completely.

- According to the test report (Ashe et al. 2015):

  With the GCLs with polymer-enhanced bentonite, some widened desiccation cracks were observed, indicating minor bentonite erosion at 45 cycles (Figure 6), but no erosion holes had formed with tests run up to 60 cycles but bentonite thinning was taking place. These results do not necessarily show that an erosion hole could not develop eventually, but they do show that the time to an erosion hole has been substantially increased with the polymer-enhanced bentonite.

![Figure 6. Widening desiccation cracks in polymer enhanced bentonite GCLs after Cycle 45 (Ash et al. 2015)](image)

- The research mentions that the performance of GCLS with polymer-enhanced bentonite in real field conditions is subject to field verification (Ash et al. 2015).

- Ashe et al (2015) also mention that:

  From the perspective of eliminating downslope erosion as an issue for an exposed composite liner, Coated GCL appears to be an excellent potential solution.

- The laboratory test was conducted on a 3H: 1V slope only. Ash et al. (2014) found that the steeper the slope is, the quicker the water flows over the GCL and the quicker the erosion features develops.

- The most important finding from this study is that after the GCL examined had been subjected to a wet-dry cycle, erosion due to the evaporation and condensation of water below an exposed composite liner can occur...
relatively quickly. How long this would take in the field would depend on many site-specific conditions (Ash et al. 2014). To investigate the real behaviour and performance of the GCL, a long-term full-scale field study is required.

• The laboratory research has been conducted with a low flow rate of 3L/h from 50mm above the GCL. The flow rates in the field can be different. Ash et al. (2014) found that once an erosion feature was initiated, higher flow rates caused more extensive erosion features.

• This test has only examined one (3H: 1V) slope, deionized water, and the response to down slope water movement on erosion of GCLs subjected to a defined wet/dry cycle. These factors all have the potential to affect down-slope bentonite erosion. Based on the finding of this study, it appears that a field trial would be warranted to investigate the field performance of the GCLs (Ash et al. 2014).

• The subgrade will affect the GCL hydration and the behaviour of the GCL. In field conditions, a GCL may need several months to achieve a stable hydration and behaviour (Bouazza et al. 2016). This test is conducted on the GCL installed on a plate (without considering the effect of subgrade). To study the real behaviour of the GCL against downslope erosion, a long-term field study is required.

• The laboratory test has been conducted under constant room temperature, and without any subgrade. The temperature in real field conditions, especially when the geomembrane is exposed, is much higher and is not constant. The increase in liner temperature results in a decrease in the final degree of saturation of the GCL, which leads to the development of suction in the GCL. This will result in the increased likelihood of cracking. This will affect the GCL moisture evaporation, desiccation resistance, and downslope erosion behaviour. Also the temperature can affect the subgrade condition which can again affect the GCL hydration and downslope performance. A full-scale long-term field test is recommended to investigate the real behaviour of the GCL against downslope erosion in real field conditions and temperature variations.

• Primarily, field full scale testing of various GCL products under different conditions is recommended (Ash et al. 2014).

• The samples for this laboratory test had been put through just one dry-wet cycle prior to the down-slope erosion test. As the multiple dry-wet cycles (as occurs at real condition) will affect the performance of a GCL and the down-slope erosion resistance of the bentonite, Ash et al. (2014) recommended that:

“More research into the suitability of polymer enhanced bentonite products for applications where an exposed composite liner may be subjected to wetting and drying cycles is needed. The increased swelling of the polymer enhanced bentonite raises the question that if the polymer enhancement causes greater swelling of the bentonite when in a hydrated state, does it, in turn, leads to greater shrinkage when subjected to drying cycles?”

The effect of dry-wet Cycling will be discussed more in section 4.

• Finally, this test studies the behaviour of the GCL against downslope erosion in the short term (up to 60 cycles), under a controlled and constant laboratory condition. To find out the GCL performance against downslope erosion in the long term and under real field conditions, a long-term field test is required.
3-3- “QUELTS II” Field Test Results

To study the long-term performance of the GCLs used in previous tests under the real field conditions, the four GCLs used in QUELTS I and four more GCLs from the laboratory test were used in this full-scale long-term field test. The four new GCLs included two GCLs with bentonite powder (GCL 5 and GCL 6), a GCL with polymer enhanced bentonite (GCL 7) and a GCL with coating (GCL 8).

The findings of inspections after 15 months include:

- Downslope erosion of the bentonite in GCLs in composite liners is most likely to occur at critical locations such as wrinkles in the geomembrane and at geomembrane seams.

- After 15 months in exposed conditions, there was NO evidence of any moisture movement or downslope erosion observed for the coated GCL (GCL8) with the coating facing up; while there was negligible erosion observed for the polymer enhanced GCL (GCL7).

- Covering the composite liner with 0.3m of gravel could protect the GCL against downslope erosion over a 15-month period.

- No holes had formed in the polymer enhanced GCL during this period, but some widening of desiccation cracks was observed indicating minor bentonite erosion in this GCL.

- GCL 5, GCL 6, and GCL 7 (with polymer enhanced bentonite) all had negligible downslope erosion.

Rowe and his team continued their investigation to realise the real behaviour of the Geosynthetics in the long term (minimum 2 years). The findings of inspections after 28 months include (Rowe et al. 2016b):

- There are many factors to consider for the GCL including: (i) grain size of the bentonite, (ii) presence/absence of a polymer additive, (iii) mass of the geotextiles, and (iv) if there is a coating on the geotextile or not.

- GCLs with powdered bentonite had less erosion compared to GCLs with granular bentonite.

- In the field, the performance of GCL7 (polymer enhanced) was very consistent with the laboratory study for the first 15 months but after 28 months of exposure, it had experienced erosion in the field.
• Between 15 months and 28 months of exposure, GCL7 (polymer enhanced) beneath a black geomembrane experienced irrecoverable erosion, EE, and irrecoverable extreme erosion, EEE, features, which may be a result of the washout of the polymer from the bentonite causing the GCL to be more susceptible to downslope erosion (Figure 8).

• Although more research is needed to establish the reason, it is hypothesised that the polymer was leached out of the bentonite at locations of higher flow some time between 15 and 28 months and once the polymer was removed the bentonite was free to erode.

• It is a warning that bentonite additives may not last forever.

• GCL8 (Coated GCL) performed better than any other GCL product in both the laboratory tests and in the field. GCL8 showed no signs of erosion after 60 cycles in the laboratory experiment and no evidence of any erosion after 28 months in the field (Figure 9).

• In the laboratory, the PE coating prevented the constant water source from infiltrating through the upper geotextile and washing out the bentonite. In the field, an intact coating prevented moisture from passing through the upper geotextile which removed the erosion water source altogether.

Figure 8. GCL7 (Polymer enhanced) beneath black geomembrane on slope, after 28 months of exposure, September 2014 inspection, classified as irrecoverable extreme erosion (Rowe et al. 2016b)

Figure 9. No evidence of erosion on GCL8 (Coated GCL) beneath a black geomembrane after 28 months exposure (September 2014) (Rowe et al. 2016b)
4. GCL DESICCATION AND THE EFFECT OF DRY/WET CYCLING

Desiccation is one of the risks associated with using GCLs, especially if they do not have sufficient confining stress. One of the main advantages of the coating on coated GCLs is to protect the GCL against possible desiccation. Test results on Bentofix® coated GCL has verified that the coating can protect the GCL against desiccation even under low confining pressure (von Maubeuge 2013).

International test results show that dry/wet cycling has a negative effect on the performance of polymer modified GCLs. Mazzieri (2011) concluded that:

“The major impact of dry/wet cycling was apparently the removal of added polymer.”

In losing the added polymer, the hydraulic conductivity of the GCL increases and the GCL may no longer function as a suitable lining system.

To conclude, polymer modification cannot stop or reduce GCL desiccation unless long term test results can be provided verifying that added polymer can stop desiccation and also that the added polymer will not be removed through dry/wet cycling.

5. DURABILITY AND LONG TERM PERFORMANCE

The durability of the GCL as a lining system depends on the durability of its components. The durability of the coating can be tested in accordance to GRI-GCL3 recommendations for verification.

All the provided tests on the polymer-modified bentonite are short term only. According to international references and research projects (Scalia et al. 2014), the added polymer can be eluted after about two years:

“Bentonite-Polymer Composite (BPC) elutes polymer during permeation regardless of the permeant solution”

He also mentioned that:

“However, the solution thresholds to which Bentonite-Polymer Composite (BPC) will maintain low hydraulic conductivity are currently unknown.”

After the polymer has been eluted, the GCL cannot act as a proper impermeable lining system.

To conclude, long-term test results (minimum 2 years) should be provided verifying the added polymer will not be eluted and the hydraulic performance of the GCL will not change under site conditions and long term dry/wet cycles.

6. PEEL STRENGTH AND INTERNAL SHEAR STRENGTH

The peel strength and internal shear strength of the GCL is an important parameter for the stability of the GCL on slopes. Test results show high peel strength and shear strength between the coating and the GCL for the Bentofix® coated GCL (von Maubeuge 2013).
In polymer modified GCLs, it is difficult to control the amount of added polymer. According to UK ENVIRONMENT AGENCY (EA) Publication: Using Geosynthetic Clay Liners in Landfill Engineering, ver.3 (LFE3, 2014):

“Using excess polymer can cause excessive swelling of the clay/polymer filling in needle-punched GCLs pushing the geotextile apart and allowing bentonite migration and subsequently loss of integrity.”

Using excess polymer can lead to low peel strength and internal shear failure of the GCL, especially after several dry/wet cycles in the long term.

7. ENVIRONMENTAL EFFECTS

As the added polymer can be eluted after several years, there is a risk of negative effects by the eluted polymer on the surrounding environment and water resources.

The data sheet of the polymer modified GCL should show the type, nature and amount of the added polymer. In addition, test results should be provided to verify that the added polymer will not be eluted in the long term and the added polymer does not have a negative effect or reaction when in contact with chemicals or leachate. Further, the environmental effect of the added polymer should be addressed in the safety data sheet. This is in line with the requirement of EA guideline for using GCLs in landfill engineering and also GRI-GCL5: Design Considerations for Geosynthetic Clay Liners (GCLs) in Various Applications.

8. NATIONAL AND INTERNATIONAL LANDFILL GUIDELINES AND REFERENCES

The following extracts clearly state the precautions of using polymer modified bentonites in GCLs for landfill containment applications. They are all from current best practice guidelines;

EPA VICTORIA Best Practice Environmental Management (BPEM) Publication 788.3, 2015 – page 93: Appendix E2.1.1.2 – Bentonite Form;

“…other additives, such as polymers or pH modifiers, may be added to improve the swelling and sealing capability of sodium activated bentonites. However, the nature and suitability of these additives is difficult to check. If used, the manufacturer should provide their details and demonstrate their nature, suitability and long-term durability.”

THE GEOSYNTHETIC RESEARCH INSTITUTE (GRI), USA GRI-GCL5, 2013 – page 23: Clause 11.7 - Design Considerations for Geosynthetic Clay Liners (GCLs) in Various Applications;

“It should be noted that there is presently (2011) several ongoing research efforts in modifying both sodium and calcium bentonites, primarily (but not exclusively) with polymer additives. The goals of these efforts are to reduce cation exchange. Of course, the long-term performance of these polymers needs to be addressed, as well as the environmental impact. If polymers are added they should be noted in the product data sheets.”

ENVIRONMENT AGENCY (EA), UK EA Publication: Using Geosynthetic Clay Liners in Landfill Engineering, ver.3 (LFE3, 2014) – page 5: Clause 2.4

“2.4 Additives
Some GCL manufacturers use additives to enhance certain characteristics such as initial swell and leachate resistance in reinforced GCLs, or in the form of glues in unreinforced liners. The nature and suitability of these additives is difficult to
ascertain. As a result, we would prefer they were not used unless the manufacturer is able to demonstrate their nature, suitability, and long-term durability. Manufacturers must provide details of all additives used in the manufacture of their GCLs. Where the additive is a polymer, you must ascertain the manufacturer has not used excess polymer during the manufacture of the GCL. Excess polymer can cause excessive swelling of the clay/polymer filling in needle punched GCLs pushing the geotextiles apart, and allowing bentonite migration and subsequently loss of integrity.

THE GEOSYNTHETIC RESEARCH INSTITUTE (GRI), USA GRI-GCL3, 2016 –Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs);

GRI-GCL3 is the reference in many landfill guidelines including BPEM. GRI-GCL3 provides specification and minimum requirements for coated GCL as an acceptable GCL type to be used. There are no reference or acceptance criteria or specification for polymer modified GCLs in GRI-GCL3.

9. CONCLUSION

Downslope bentonite erosion of various GCLs in exposed composite liners was investigated through long-term field and laboratory tests. Test results show a potential of downslope bentonite erosion for all GCL types except the coated GCL. Test results can be summarised as below:

- Downslope bentonite erosion in the GCL is most likely to occur at critical locations such as beneath the wrinkles or at geomembrane seams.

- Using powdered bentonite will reduce the rate of the internal erosion compared to granular bentonite.

- The real behaviour and long-term performance of GCLs in accordance to downslope erosion in the field, is different from their behaviour in the laboratory. The real behaviour of GCLs needs to be investigated in the field during long-term field tests (minimum 2 years).

- According to the field results after 28 months, the laboratory test does not model the real behaviour of GCLs against downslope erosion. Therefore, it is not suitable and should not be used for design purposes and for comparing the performance of different products.

- The long-term field test results showed that standard GCLs, polymer enhanced GCLs, and coated GCLs do not perform the same.

- Long-term field results show that polymer enhanced GCL beneath a black geomembrane experienced irrecoverable erosion features between 15 and 28 months, which may be a result of the washout of the polymer from the bentonite causing the GCL to be more susceptible to downslope erosion. Once the polymer was removed, the bentonite was free to erode.

- Bentonite additives may not last forever.

- Coated GCL performed better than any other GCL product in both the laboratory tests and in the field. Coated GCL showed no evidence of any erosion after 28 months in the field.
It can be concluded that polymer modified GCLs are not a suitable solution due to the risk of downslope bentonite erosion under field conditions, and also several other critical concerns including:

- Type and quantity of the polymer can affect the performance of the polymer enhanced GCL. The type, nature and quantity of the added polymer should be published on the product data sheet.
- Durability of the added polymer.
- Long term performance of the polymer enhanced bentonite.
- The effect of dry/wet cycling on the performance of the polymer enhanced GCLs.
- Desiccation of polymer enhanced GCLs.
- The elution of the polymer from the enhanced bentonite in the long term.
- The effect of the polymer enhancement on the peel strength and internal shear strength of the GCL.
- Following international Environmental Protection Agencies and Geosynthetic references and specifications about polymer modification.

10. REFERENCES


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