Effect of wet and dry cycles on lighter bentonite-polymer geosynthetic clay liners

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This study evaluated the hydraulic conductivity (K) of lighter bentonite-polymer (B-P) geosynthetic clay liners (GCLs) subjected to wet-dry cycles which simulated seasonal conditions on a GCL installed in a landfill cover system. Lighter bentonite-polymer composite (B-P) GCLs are manufactured with a lower mass per unit area of sodium bentonite (Na-B) (approximately 2.9 kg/m^2) than conventional Na-B GCLs (approximately $\geq$ 3.6 kg/m^2) which can reduce the transportation and installation costs compared to conventional Na-B GCLs. Hydraulic conductivity tests on lighter B-P GCL and Na-B GCL were conducted with a synthetic soil porewater leachate to represent wet season conditions on a landfill cover. Between hydraulic conductivity tests, GCL samples were placed in sealed chambers with a relative humidity of 75% until the water content of the specimens decreased to 55%, which represented dry season conditions of a GCL under a geomembrane in a cover system. Slight increases of the hydraulic conductivity were measured for both the Na-B and lighter B-P GCLs. After 5 wet-dry cycles K of the Na-B GCL increased from 3.1×10^{-12} m/s to 8.3×10^{-12} m/s, and K of the lighter B-P GCL increased from 1.6×10^{-12} m/s to 8.3×10^{-12} m/s.

1 Introduction

Geosynthetic clay liners (GCLs) are composite materials which consist of a layer of sodium bentonite (Na-B) sandwiched between two geotextiles. GCLs are commonly used in landfill cover and liner system applications due to the low hydraulic conductivity (K) of the bentonite layer, which swells during hydration [1-7]. Bentonite swelling under hydration reduces the intergranular pore space and causes low hydraulic conductivity [1]. However, GCLs used in landfill cover system layers are exposed to seasonal wetting and drying (WD) cycles. During dry seasons, the bentonite layer will desiccate and form cracks, which may not be able to completely re-swell to seal during wet seasons. These cracks can lead to an increase in the hydraulic conductivity of a GCL [2-8].

Bentonite within GCLs is commonly modified with polymer additives that improve the chemical compatibility and reduce the hydraulic conductivity of GCLs [9-16]. Bentonite-polymer (B-P) GCLs have shown to maintain lower hydraulic conductivities during wet-dry cycles compared to conventional Na-B GCLs, and exhibit greater ability to heal cracks [8,9].

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Conventional Na-B and B-P GCLs have a dry mass per unit area ≥ 3.6 kg/m^2 [1, 10, 11]. In an effort to reduce the costs associated with GCL transportation and installation, a novel and experimental GCL product, denoted as lighter B-P GCL, has been developed with a lower mass per unit area of bentonite than a conventional Na-B GCL. Lighter B-P GCLs have a polymer loading (polymer mass/bentonite-polymer composite mass) of approximately 4% and are produced with a mass per unit area of approximately 2.9 kg/m^2.

This study evaluates the hydraulic conductivity of lighter B-P GCLs subjected to wet-dry cycles. Landfill cover systems are exposed wet-dry cycles due to seasonal precipitation fluctuations. The wetting cycles were performed using hydraulic conductivity tests with a synthetic cover soil/topsoil porewater solution. The drying cycles were conducted at constant humidity in sealed chambers. Hydraulic conductivity tests were performed at 10 kilopascals (kpa) and with a hydraulic gradient of 3 times the maximum design leachate head on a landfill cover system.

2 Materials and methods

2.1 Geosynthetic clay liners

This study used a conventional sodium bentonite GCL (Na-B GCL) and a lighter bentonite-polymer GCL that had a polymer loading of 4% (lighter B-P GCL). Both GCLs contained a non-woven cover geotextile and non-woven carrier geotextile with needle-punched fibers between. The dry mass of sodium bentonite per unit area of the Na-B and lighter B-P GCLs were approximately 5.6 kg/m^2 and 2.9 kg/m^2, respectively. The swell index of Na-B was 28 mL/2g and of the lighter B-P was 42 mL/2g in DI water, per ASTM D5890. The GCL samples were provided by CETCO.

2.2 Permeant solutions

Relative abundance of monovalent and polyvalent cations (RMD) and Ionic strength (I) are known to affect the hydraulic conductivity of GCLs. RMD is defined by Eq. 1 **Error! Reference source not found. Error! Reference source not found. Error! Reference source not found.**:

$$RMD = \frac{M_M}{\sqrt{M_D}} \tag{1}$$

where M_M = total molarity of monovalent cations and M_D= total molarity of divalent cations. I is defined by Eq. 2:

$$I = \frac{1}{2} \sum_{i=1}^{n} c_i z_i^2 \tag{2}$$

Where c_i = molar concentration of ith ion in solution and z_i = valence of the ith ion.

Hydraulic conductivity tests were performed with a synthetic leachate representing landfill cover soil/topsoil porewater that landfill cover GCLs are typically exposed to. The leachate was created by taking the geometric mean of main ion concentrations in effluent from column elution tests of landfill cover soils permeated with synthetic rainwater solutions, reported in Benson and Meer (2009) [6]. The ionic strength (I) of the leachate was 0.003M and the relative abundance of monovalent and polyvalent cations (RMD) was 25 mM and 0.0328 M$^{1/2}$. The leachate was prepared by dissolving reagent grade NaCl and $CaCl_2$ in Type II DI water per ASTM D1193. This leachate was denoted as synthetic soil porewater.

2.3 Swell index

The Na-B and B-P composite were extracted from the Na-B GCLs and lighter B-P GCLs, respectively. Free swell index tests were conducted in accordance with ASTM D5890 with DI water and the synthetic soil porewater. Two grams of solid (Na-B or B-P composite) were added in 0.1 g increments to a 100 mL graduated cylinder of test solution. Per ASTM D5890, the graduated cylinder initially contained 90 mL of solution and was filled to 100 mL after 2 g of solid sample was added. The swell values were recorded 16 hours after completing the test.

2.4 Hydraulic conductivity tests (wetting cycles)

Hydraulic conductivity tests were conducted with B-P and Na-B GCLs in accordance with ASTM D5084 to simulate wetting of a cover GCL during rainy seasons. Geotextiles were placed above and below the GCL samples to distribute the permeant solution across the GCL and the samples were placed between acrylic plates. The samples were sealed using a flexible membrane which was secured to the top and bottom plates with silicon O-rings. Outflow solution was collected and stored in 60-mL polyethylene bottles. The hydraulic conductivity tests were conducted at 10 kPa and the hydraulic gradient was three times higher than the maximum hydraulic head a cover liner would experience under field conditions. Therefore, about 1 month of permeation was used to approximate a typical rainy season (3 months) [2, 17]. Each hydraulic conductivity test ("wet cycle") was permeated for at least four weeks to hydraulic equilibrium termination criteria per ASTM D5084, where the outflow to inflow volume (Q_{out}/Q_{in}) was within 0.75 and 1.25 for the last three consecutive flow measurements.

2.5 Drying cycles

Drying cycles simulated conditions of GCL under a geomembrane in a typical landfill cover system. The GCL samples were carefully removed from the hydraulic conductivity test cells and placed in sealed chambers with a relative humidity of 75% between each hydraulic conductivity test ("wet cycle"). The specimens were kept in the sealed chambers (except when briefly removed for mass measurement) until the water content of an individual specimen decreased to approximately 55%, based on periodic mass measurements of the samples.

3 Results and discussion

3.1 Swell index

The swell index of Na-B and lighter B-P in DI water and the synthetic soil porewater are shown in Figure 1. Swell index was performed on samples ground in a mortar and pestle prior to testing. The swell index of Na-B was 28 mL/2 g in DI water and 26 mL/2 g in synthetic soil porewater. Also, the swell index of B-P was 32 mL/2 g in DI water and 30 mL/2g in synthetic soil porewater. The swell index values of Na-B and B-P composite decreased with an increase in ionic strength ($I_{DI\text{-}water} < I_{soil\text{-}porewater}$). In addition, The B-P composite had higher swell index values to DI water and subgrade soil leachate than that of Na-B.

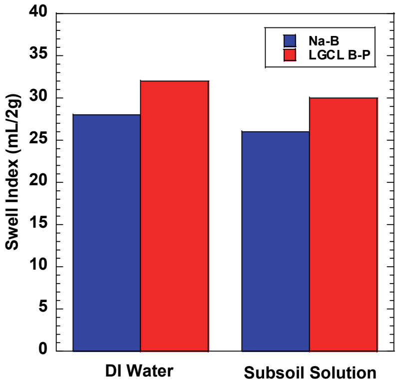

Fig. 1. Swell index of Na-B and lighter B-P in DI water and synthetic soil porewater.

3.2 Hydraulic conductivity

Hydraulic conductivity of Na-B and lighter B-P GCLs under wet and dry cycles are shown in Figure 2. The hydraulic conductivity of both the Na-B and lighter B-P GCL exhibited a slight decreasing trend during the beginning of each wetting cycle, which is due to rehydration of the GCL sample. The hydraulic conductivity at the end of each wetting cycle, for each GCL, is shown in Figure 3.

The hydraulic conductivity for Na-B GCL at the end of each wetting cycle exhibited an overall increasing trend from WD-1 to WD-5 (e.g., K = 3.1 x 10^{-12} m/s to 8.3 x 10^{-12} m/s). However, the hydraulic conductivity at the end of WD-2 was lower at K = 1.3 x 10^{-12} m/s and did not reflect the overall trend. The observed increase in hydraulic conductivity was less than one order of magnitude. The hydraulic conductivity at the end of each wet-dry cycle for lighter B-P GLC also exhibited an overall increasing trend. The hydraulic conductivity of lighter B-P GCL increased from the end of WD-1 to WD-5 (e.g. K = 1.6 x 10^{-12} m/s to K = 8.3 x 10^{-12}) and was within one order of magnitude. However, between WD-3 and WD-4, the hydraulic conductivity of lighter B-P GCL slightly decreased from K = 3.8 x 10^{-12} m/s to K = 3.4 x 10^{-12} due to clogging effect of polymer elution [18].

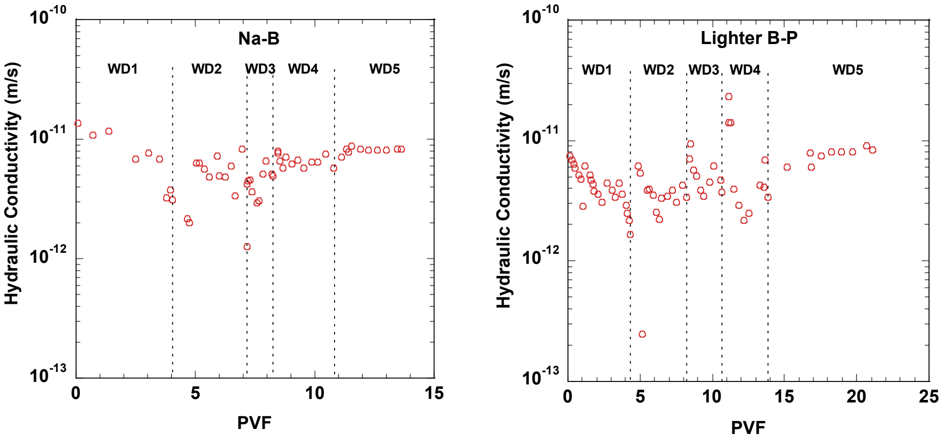

Fig. 2. Hydraulic conductivity of (a) Na-B GCL and (b) Lighter B-P GCL under wet-dry cycles. Wet dry cycle numbers are noted as WD.

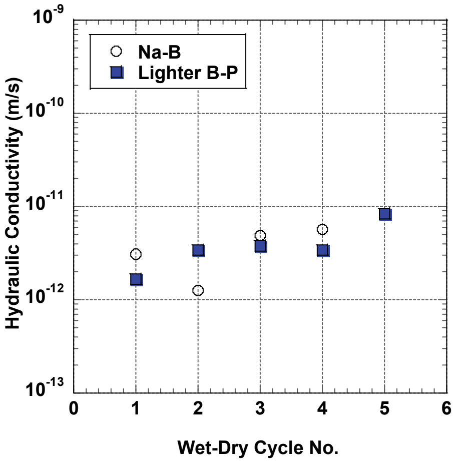

Fig. 3. Hydraulic conductivity of at the end of each wet-dry cycle for Na-B and lighter B-P GCLs (Na-B and lighter B-P GCL K values were approximately equivalent at the end of WD-5).

The hydraulic conductivity of Na-B and lighter B-P GCLs at the end of each wetting cycle exhibited a similar increasing trend between WD-1 and WD-5. The hydraulic conductivity values for Na-B and lighter B-P GCLs at the end of each cycle were within less than one order of magnitude. The hydraulic conductivities of both the Na-B and lighter B-P GCL were approximately equivalent at the end of WD-5 (e.g. K = 8.3 x 10^{-12} m/s). Wet-dry tests are currently ongoing.

3.3 GCL thickness

The thickness of each GCL was measured at the end of each hydraulic conductivity test (wet cycle). The GCL thickness at the end of each cycle is shown on Table 1 and represents an average of 6 measurements. The average thickness of both the Na-B and lighter B-P GCL slightly decreased after 5 wet-dry cycles, where the Na-B GCL average thickness decreased by 0.50 mm and the lighter B-P GCL average thickness decreased by 0.16 mm. The average thicknesses of the Na-B and lighter B-P GCL specimens decreased by 4.63% and 1.88%, respectively between WD-1 and WD-5.

Table 1. Average GCL thickness at the end of each wet cycle.

End of wet cycle no.	Na-B GCL	Lighter B-P GCL
1	10.80 mm	8.50 mm
2	10.60 mm	8.54 mm
3	10.56 mm	8.52 mm
4	10.42 mm	8.60 mm
5	10.30 mm	8.34 mm

4 Conclusions

Hydraulic conductivity tests were conducted on conventional Na-B GCLs and novel lighter B-P GCLs to evaluate the hydraulic performance of the GCLs to seasonal wet-dry cycles. Between hydraulic conductivity tests, samples were dried in a sealed chamber with a humidity of 75%, to a water content of 55%. Wet cycles consisted of hydraulic conductivity tests using a synthetic soil porewater solution. Five wet-dry cycles were conducted to simulate seasonal field conditions that a GCL layer in a landfill final cover is subjected to. The following conclusions may be drawn:

1. The swell index of the lighter B-P GCL in DI water and soil porewater solution was greater than the swell index of Na-B in respective solutions. The greater swelling is due to the polymer present in lighter B-P GCL. Additionally, the swell index values for the lighter B-P GCL in DI water and soil porewater solution were both greater than the swell index for Na-B in DI water soil porewater solution.
2. Both Na-B and lighter B-P GCLs exhibited an increasing trend between the end of WD-1 and WD-5, and at the end of WD-5 the hydraulic conductivity of both GCLs was equivalent ($K = 8.3 \times 10^{-12}$ m/s). The total change in hydraulic conductivity of the Na-B and lighter B-P GCL was less than one order of magnitude after 5 wet-dry cycles.
3. The average thickness of the Na-B and lighter B-P GCL specimens decreased by 4.63% and 1.88%, respectively, between WD-1 and WD-5.

References

1. C.D. Shackelford, C.H. Benson, T. Katsumi, T.B. Edil, L. Lin. Geotex. and Geomem., **18**, 133-161 (2000)
2. L.C. Lin, C.H. Benson. J.G.G.E., **126**, 40-49 (2000)
3. R.J. Petrov, R.K. Rowe. Can. Geotech. J. **34**, 863-885 (1997)
4. S.L. Bradshaw, C.H. Benson, J. Scalia IV. J.G.G.E., **139**, 526-538 (2013)
5. S.R. Meer, C.H. Benson. J.G.G.E., **133**, 550-563 (2007)
6. C.H. Benson, S.R. Meer. J.G.G.E., **135**, 349-358 (2009)
7. J. Scalia IV, C.H. Benson. J.G.G.E., **137**, 1-13 (2011)
8. F. Zangl, W.J. Likos. J.G.G.E., **142**, 04016063:1-9 (2016)
9. M. De Camillis, G. Di Emidio, A. Bezuijen, R.D. Verástegui-Flores. Geotex. and Geomem., **44**, 739-747 (2016).
10. M. De Camillis, G. Di Emidio, A. Bezuijen, D.V. Flores, J. Van Stappen, B. Cnuddle. App. Clay Sci. **142**, 52-59 (2017)
11. K. Tian, W.J. Likos, C.H. Benson. J.G.G.E., **145**, 04019071:1-10 (2019)
12. B. Zainab, C. Wireko, D. Li, K. Tian, T. Abichou. Geotex. and Geomem., **49**, 1129-1138 (2021)
13. D. Li, B. Zainab, K. Tian. Env. Geotechnics. **40**, 1-12 (2021)
14. J. Chen, H. Salihoglu, C.H. Benson, W.J. Likos, T.B. Edil. J.G.G.E. **145**, 0419038:1-12 (2019).
15. Q. Li, J. Chen, C.H. Benson, D. Peng. Geotex. and Geomem., **49**, 420-429 (2021)
16. J.C. Chai, N. Prongmanee. Geotex. and Geomem., **48**, 392-399 (2020)
17. D.K. Adams, A.C. Comrie. Bulletin of the Amer. Meteor. Soc., **78**, 2197-2213 (1997).
18. J. Scalia IV, C.H. Benson, G.L. Bohnhoff, T.B. Edil, C.D. Shackelford. J.G.G.E., **140**, 04013025:1-13 (2014).