Hydraulic Conductivity of Bentonite-Polymer Geosynthetic Clay Liners Subject to Wet-Dry Cycles Used for Landfill Cover Applications

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Abstract. This study evaluated the hydraulic conductivity of bentonite–polymer (B–P) geosynthetic clay liners (GCLs) subjected to wet–dry cycles designed to simulate seasonal climatic variations experienced by GCLs in landfill cover systems. Hydraulic conductivity tests were performed on B–P GCLs and Na-bentonite (Na-B) GCLs under a confining stress of 10 kPa following ASTM D5084. Wet–dry procedures were applied to represent field exposure scenarios. For Na-B GCL, hydraulic conductivity increased progressively over five wet–dry cycles. However, the B–P GCL consistently exhibited substantially lower hydraulic conductivity after sixteen wet–dry cycles. After four wetting–drying cycles, the hydraulic conductivity of the B–P GCL ($K = 4.8 \times 10^{-12}$ m/s) was five orders of magnitude lower than that of the Na-B GCL ($K = 3.3 \times 10^{-7}$ m/s). These findings indicate that B–P GCLs maintain superior hydraulic performance under seasonal wetting and drying, suggesting enhanced suitability for use in landfill cover systems compared with conventional Na-B GCLs.

1 Introduction

Geosynthetic clay liners (GCLs), consisting of sodium bentonite (Na-B) encapsulated between two geotextiles, are widely used in landfill cover systems due to their low hydraulic conductivity[1–3]. This low conductivity results from bentonite swelling upon hydration, which reduces intergranular pore spaces. However, desiccation during dry seasons can cause shrinkage and cracking within the bentonite matrix, and rehydration may not fully seal these cracks, leading to increased hydraulic conductivity over successive wet–dry cycles[2–3]. To improve durability, polymers have been incorporated into bentonite to produce bentonite-polymer GCLs (B-P GCLs), which exhibit enhanced swelling, reduced cracking, and improved long-term performance[4–5]. The polymer hydrogel clogging mechanism enables B–P GCLs to maintain low hydraulic conductivity even when bentonite swelling is suppressed by cation exchange. In addition, hydrogel swelling enhances the self-healing capacity of the bentonite–polymer composite, allowing B–P GCLs to retain low hydraulic conductivity under wet–dry cycling. Despite these advancements, limited research has evaluated B-P GCLs under realistic landfill cover wet–dry conditions. This study investigates the hydraulic conductivity of B-P GCLs subjected to wet–dry cycle procedures simulating seasonal field conditions. One B-P GCL containing 2% of a novel polymer blend and one Na-B GCL were tested. Hydraulic conductivity tests were conducted at 10 kPa following ASTM D5084.

2 Materials and Methods

2.1 GCLs

Two commercial GCLs were used in this study, including one conventional Na-B GCL and one B-P-2 GCL. The B-P GCL was created by dry polymer mixing with same bentonite. B-P GCL containing 2% of a novel polymer package named as B-P-2. The nature of the polymers used is proprietary to the manufacturer. Both GCLs consist of one non-woven cover geotextile and one non-woven carrier geotextile. The swell index of the GCLs was determined following ASTM D5890.

2.2 Permeation solutions

Tests were conducted with one synthetic leachate, named Ca-Rich leachate, which represented the most aggressive leachate (highest I and lowest RMD) collected from landfill cover soil permeating with synthetic rainwater, as discussed in Benson et al. (2009) [3]. The definition of I and RMD was shown in Benson et al. (2009) [3]. The concentration of major cations and

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anions in synthetic leachate are Na^+, Ca^{2+}, and Cl^-. The synthetic solution was prepared by dissolving 1.19 g of CaCl2·2H2O and 0.04 g of NaCl in 1 L of Type II DI water. The I and RMD are 25 mM and 0.007 $M^{1/2}$, respectively. The synthetic leachates were prepared by dissolving reagent grade NaCl and $CaCl_2$ in Type II DI water as per ASTM D1193.

2.3 Wet-dry method

For each wetting-drying cycle, hydraulic conductivity tests on GCLs were permeated for at least four weeks. The hydraulic gradient in the tests was approximately 90, which is three times higher than that of the leachate head under field conditions (~ 30 cm). Therefore, the 1-month test represents a 3-month permeation period under field conditions, that is, one wet season. After permeation (wetting), the specimens were dried in a sealed chamber at a relative humidity of 75% until the water content of the GCL specimens dropped to approximately 55% based on Benson et al. (2009)[3].

2.4 Hydraulic conductivity tests

Hydraulic conductivity tests were conducted with B-P-2 and Na-B GCLs at 10 kPa in accordance with ASTM D5084. The hydraulic gradient of tests was three times higher than the leachate head under field conditions. Thus, the one-month test represents a three-month permeation of GCL in the field conditions, i.e., one wet season. Hydraulic conductivity tests of GCLs were terminated when hydraulic equilibrium was met per ASTM D5084. ASTM D5084 was adopted in this study because the duration and frequency of wet-dry cycles under field conditions are inherently variable and cannot be reliably replicated within the fixed cycle framework required by ASTM D6766.

3 Results and discussions

The hydraulic conductivity of Na-B GCLs and B-P-2 GCLs under wetting-drying cycles is shown in Fig. 1. The hydraulic conductivity of Na-B GCLs gradually decreased at the starting point of each WD cycle due to hydration process. After, the Na-B GCLs under each WD cycle achieved hydraulic equilibrium within 1-2 PVF per ASTM D5084. The hydraulic conductivity of Na-B GCLs under WD-1 and WD-2 cycle was similar, e.g., $K = 3.4 \times 10^{-12}$ m/s to 3.3×10^{-12} m/s. After, the hydraulic conductivity gradually increased to 3.3×10^{-7} m/s after WD-5 cycles (Fig. 1a). A similar hydration process was observed for hydraulic conductivity testing of B-P-2 GCL under WD method (Fig. 1b). The B-P-2 GCL maintain a low hydraulic conductivity (e.g., $K = 1.8 \times 10^{-12}$ m/s to $= 2.7 \times 10^{-11}$ m/s) under all WD cycles. The hydraulic conductivity of B-P-2 GCL ($K = 4.8 \times 10^{-12}$ m/s) was five orders of magnitude lower than that of Na-B GCL ($K = 3.3 \times 10^{-7}$ m/s) under WD-5 cycle.

Swell index of Na-B and B-P-2 to Ca-Rich leachates is shown in Fig. 2. The swell index of Na-B was 24 mL/2 g originally and significantly decreased to 6 mL/2 g after WD-5. The swell index of B-P-2 was 26 mL/2 g originally and decreased to 16 mL/2 g after WD-16. The swell index of B-P-2 was higher than that of Na-B at final stage due to polymer hydrogel can maintain its swell ability during wetting-drying cycles.

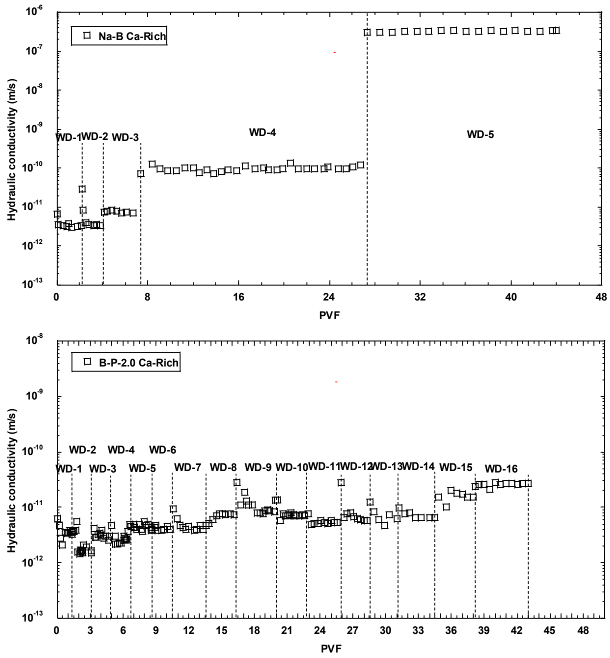

Fig. 1 Hydraulic conductivity of GCLs to Ca-Rich cover soil leachates subjected to permeation-drying cycles for: (a) Na-B GCLs and (b) B-P-2.0 GCLs

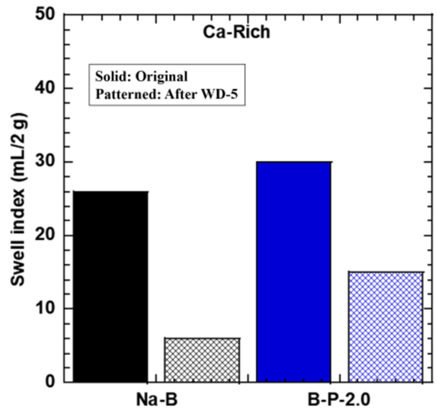

Fig. 2 Swell index of GCLs subjected to wetting–drying cycles to Ca-Rich cover soil leachate

4 Conclusion

Hydraulic conductivity tests were conducted on bentonite–polymer (B–P) geosynthetic clay liners (GCLs) to evaluate their hydraulic performance under wet–dry cycles. For Na-B GCLs, hydraulic conductivity increased progressively over five wet–dry cycles. In contrast, B–P GCLs consistently exhibited substantially lower hydraulic conductivity even after sixteen wet–dry cycles.

The swell index of Na-B GCL decreased to 6 mL/2 g after five wet–dry cycles, whereas the swell index of B–P-2 GCLs was maintained at 16 mL/2 g after sixteen wet–dry cycles. These results suggest that the novel polymer package in this new type of B–P GCL helps

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retain swelling capacity during wetting and drying, thereby effectively sealing cracks within the bentonite matrix that are generated during the desiccation process.

References

1. Shackelford, C. D., Benson, C. H., Katsumi, T., Edil, T. B., & Lin, L. (2000). Evaluating the hydraulic conductivity of GCLs permeated with non-standard liquids. Geotextiles and Geomembranes, 18(2-4), 133-161.
2. Lin, L. C., & Benson, C. H. (2000). Effect of wet-dry cycling on swelling and hydraulic conductivity of GCLs. Journal of Geotechnical and Geoenvironmental Engineering, 126(1), 40-49.
3. Benson, C. H., & Meer, S. R. (2009). Relative abundance of monovalent and divalent cations and the impact of desiccation on geosynthetic clay liners. Journal of geotechnical and geoenvironmental engineering, 135(3), 349-358.
4. De Camillis, M., Di Emidio, G., Bezuijen, A., Flores, D. V., Van Stappen, J., & Cnudde, V. (2017). Effect of wet-dry cycles on polymer treated bentonite in seawater: swelling ability, hydraulic conductivity and crack analysis. Applied Clay Science, 142, 52-59.
5. Tian, K., Likos, W. J., & Benson, C. H. (2019). Polymer elution and hydraulic conductivity of bentonite–polymer composite geosynthetic clay liners. Journal of Geotechnical and Geoenvironmental Engineering, 145(10), 04019071.