Impact of calcium uptake on the performance of GCLs in landfill covers

Impact de la diffusion du calcium sur la performance du GSB dans les couvertures d'installations de stockage de déchets

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ABSTRACT

GCLs used in landfill cover applications typically contain natural sodium bentonite. To examine the effect of ion exchange on the performance of GCLs, tests were performed in 60 cm diameter cells with 1 m of calcium rich soil below the GCL and a confining stress of 15 kN/m^2. The uptake of moisture and calcium from the underlying soil caused the moisture content of GCL to increase to 86% in the first 279 days of the test and then decrease to 68% after 625 days. The hydraulic conductivity of the GCL changed with cation exchange of Ca^{++} for Na^+ and varied from 1-3 x 10^{-11} at the start of the test to 2 x 10^{-10} m/s after 625 days.

RÉSUMÉ

Les GSB utilisés dans les couvertures d'installations de stockage de déchets contiennent généralement de la bentonite sodique naturelle. Pour examiner l'effet de l'échange cat ionique sur la performance des GSB, des essais ont été réalisés dans des cellules de 60 cm de diamètre avec 1 m de déchet riche en calcium au-dessous du GSB et sous une contrainte de confinement de 15 kN/m^2. L'hydratation par le sol support a conduit à une augmentation de la teneur en eau du GSB jusqu'à 86 en 279 premiers jours de l'essai et diminuez alors à 68% au cours des 625. La conductivité hydraulique du GSB aévolué avec l'échange cationique de Na+ en Ca++ de 1-3 x 10^{-11} au début de l'essai à 2 x 10^{-10} m/s après 625 jours.

Keywords: sodium, bentonite, calcium, cation exchange, hydraulic conductivity, swelling index, unsaturated soil

1 INTRODUCTION

Geosynthetic clay liners (GCLs) most typically comprise a layer of bentonite sandwiched between two geotextiles held together by needle-punching. In some cases, a plastic film is added to the GCL while in others the bentonite is glued to a plastic film that becomes the carrier instead of the geotextile. The key component of a GCL is sodium bentonite, which has a hydraulic conductivity ≈ 10^{-11} m/s when permeated with deionized water (DI) or tap water under stresses typical in final covers (Shackelford 2005; Jo et al. 2001, 2005). GCLs present an attractive alternative to compacted clay liners as the hydraulic barrier layer in landfill cover systems because of their low hydraulic conductivity, ease of installation, and limited thickness. However, Shackelford et al. (2000) and Jo et al. (2001, 2005) reported that the bentonite in GCLs is sensitive to chemical interactions with the hydrating liquid, and ion exchange can significantly alter its physical properties.

Recent studies have suggested that, under some circumstances, the combined effects of ion exchange and physical dehydration can significantly increase the hydraulic conductivity of GCLs (Lin and Benson 2000; Benson et al. 2007), rendering the GCL ineffective as a hydraulic barrier. However, data confirming these effects have been limited. The objective of this study was to investigate the effect of ion exchange between a calcium rich soil and sodium bentonite upon the hydraulic conductivity, k, of a GCL in a simulation of the extreme field condition where the GCL is in direct contact with the calcium rich soil and hydrates from moisture in that soil.

2 BACKGROUND

Benson et al. (2007) tested GCL samples taken from a landfill final cover (with 760 mm of soil above the GCL) 4 to 15 months after installation. The hydraulic conductivity of the samples was found to be 5 x 10^{-7} m/s and they concluded that these high hydraulic conductivity values were caused by the exchange of Ca^{++} and Mg^{++} for Na^+ on the bentonite combined with dehydration. The overlaying and underlying soil were the source of Ca^{++} and Mg^{++} which diffused to the GCL from above and below. They found that the swelling index of the bentonite had decreased from the normal range (≥ 24 mL/2g) to between 7 and 15 mL/2g. They also examined the effect of the hydrating and permeant solution on the measured hydraulic conductivity and found that the hydraulic conductivity increased from 2.7 x 10^{-11} m/s when hydrated with deionized water (DI) to 2 x 10^{-10} m/s when hydrated with water containing $CaCl_2$ at a concentration of 100 mM.

Meer and Benson (2007) examined samples from 4 different landfill covers, with soil thicknesses of 0.75 to 1 m above the GCL, for water content, swelling index, and cation exchange capacity. They found that at two of the four sites the moisture content on exhumation was 30-60% and the hydraulic conductivity was 1.5 x 10^{-8} to 1.6 x10^{-6} m/s after 4-5 years. At one site, the moisture content was between 60 and 110% and the hydraulic conductivity was 1.8 x 10^{-10} to 1.4 x10^{-6} m/s after 5.6 years. At another site the moisture content was between 165 and 205% and the hydraulic conductivity was 1.1 x10^{-9} to 2.9 x 10^{-10} m/s after 11.1 years. The increase in hydraulic conductivity was attributed to the exchange of Ca^{++} and Mg^{++} cations with the Na^+ on the sodium bentonite of the GCLs. The swelling index of the exhumed GCLs ranged form 6.9 to 11 mL/2g (i.e. well below typical values of 34-36 mL/2g for new GCLs).

Meer and Benson (2007) concluded that the hydraulic conductivity of the samples taken from the 4 landfills was related to the change in GCL moisture content at sampling. High hydraulic conductivities (10^{-8} to 10^{-6} m/s) were reported for samples with moisture content less than 85%, while the hydraulic conductivity ranged between 10^{-10} to 10^{-9} m/s for samples with moisture content greater than 100%.

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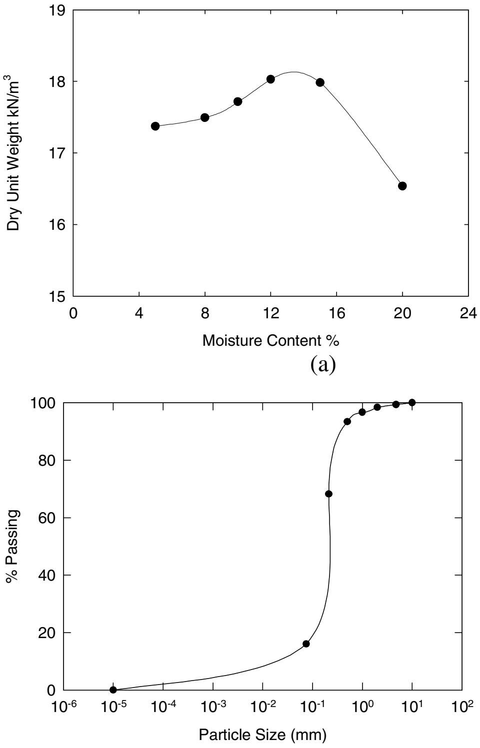
3 MATERIALS

3.1 GCL

Bentofix® Thermal Lock® NSL GCL was used in this study. The GCL contained granular sodium bentonite sandwiched between a woven carrier geotextile and a nonwoven cover geotextile. The mass per unit area of the air-dry GCL was 3.97 kg/m^2. The initial air-dry thickness of GCL ranged from 5.9 to 7.1 mm and the average air-dry moisture content of the bentonite was 10%. The granular bentonite in the GCL consisted of 12% course particle sizes larger than 0.075 mm (retained on sieve #200). The liquid and plastic limits for the sodium bentonite in the GCL were 520% and 42% respectively giving a plasticity index for the bentonite of 478%. The hydraulic conductivity of the GCL using DI water as permeant solution was 1-3 x 10^{-11} m/s under a stress of 15 kPa (i.e. equivalent to about 0.75-0.85m of overlying cover soil depending on soil unit weight).



(a)

(b)

Figure 1. (a) Standard proctor compaction curve for the waste soil; (b) Grain size distribution curve for the waste soil

3.2 Calcium-rich soil

A 100 cm thick layer of silty sand soil, compacted in 10 cm lifts at an optimum moisture content of 13.9% and maximum dry unit weight of 18 kN/m^3 was used as the soil upon which the GCL rested. The soil had 16% silty material finer than 0.075 mm (i.e. passing sieve #200), 19% in the fine to medium sand (0.075mm to 0.6 mm) range and 58 % medium to coarse sand with particle sizes 0.6mm to 4.75 mm. The compaction curve and the grain size distribution curve of the soil used are shown in Figures 1 (a) and (b) respectively. The water used to compact the soil had been spiked with calcium chloride to give a calcium concentration of 1500 ppm in the pore fluid to simulate a calcium rich soil that was to be covered, in this case, directly by the GCL as part of the landfill cover.

4 TEST DESCRIPTION

The 0.6 m diameter cells designed and built for this study contained 1 m of soil (Figure 2). They were equipped with a hydraulic bladder to provide a pressure of 15 kPa to the top of the GCL to simulate the conditions that might be expected in a landfill cover where the GCL is overlain by a geomembrane and 0.75-0.85 m of cover soil. The bladder also sealed the system against moisture loss. In this configuration, GCL hydration could only occur from the underlying calcium rich soil. Eight gypsum blocks (GB) were installed along the center line of the cells at different depths to allow monitoring of the change of the soil suction and soil moisture profile with time during the test. Gypsum blocks were selected because: (a) they are an economic, fast and easy way to monitor the moisture profile, (b) gypsum (calcium sulfate) is very stable in calcium chloride rich soil, and (c) the treated surface of the blocks prevents the dissolving of the gypsum.

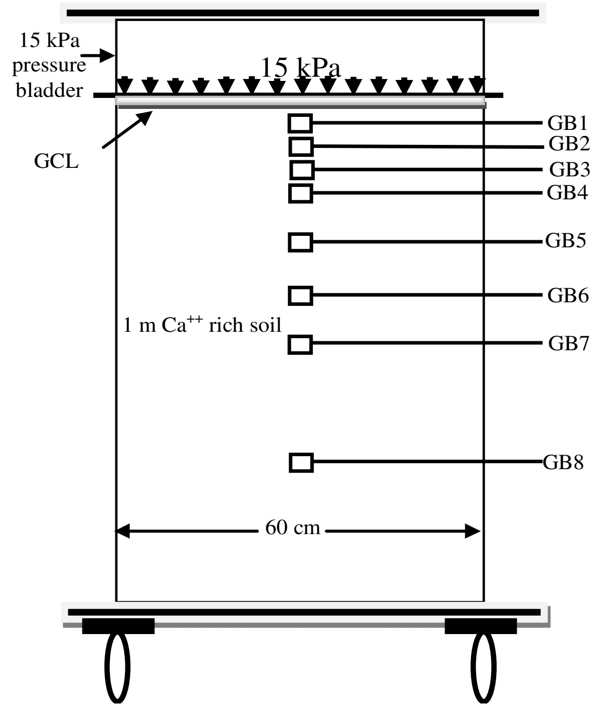


Figure 2. Schematic of diffusion test cell.

Since the GCL was installed on top of 1 m of Ca^{++} rich soil, prepared as described above, and allowed to hydrate by moisture uptake from the underlying soil, there may be two consequent effects: (1) transfer of calcium rich pore fluid to the GCL (to a greater or lesser extent depending on the grain size distribution, initial water content and initial pore water concentration of the soil layer); and (2) a decrease in the moisture content of the underlying soil layer. The pore water was transported to the bentonite in response to matric suction during the period of moisture uptake by the GCL (i.e. advective flow). In addition, cation exchange between the Ca^{++} in the pore fluid and the Na^{+} in the bentonite led to a reduction in Ca^{++} concentration in the pore fluid of the GCL and an increase in Na^{+} concentration in the pore fluid creating a concentration gradient and causing diffusive migration of Ca^{++} from the sand pore water to the GCL pore water. It is expected that the rate of diffusion (i.e. Ca^{++} transported) will depend on the water content (post hydration) of the soil below the GCL (Rowe and Badv 1996).

Cation exchange can be expected to cause some change in the physical, chemical and hydraulic properties of the bentonite. The change was anticipated to be rate-dependent and dependent on (i) the mass transfer of calcium to the GCL, (ii) the applied stress.

10 cm square GCL samples were taken from each cell on a periodic basis and replaced with samples of GCL from dummy cells prepared under the same test conditions. A 70 mm diameter circular sample was cut from each square sample for a flexible wall permeability test. The rest of the sample was used to obtain the moisture content and then the dry bentonite was used for the swelling index test after grinding to a suitable size according to ASTM D5890.

The flexible wall permeability tests were conducted in accordance with ASTM D5084. The tests were carried out at a hydraulic gradient of 75 and effective stress of 15 kPa except for the samples for the virgin GCL which were tested at hydraulic gradients of 25 and 200 yielding hydraulic conductivities ranging from 1 to 3 x 10^{-11} m/s. A stainless steel cutting ring was used to cut the GCL. A small amount of water was applied to the edges of the cutter to provide a seal and prevent bentonite loss during sampling. Bentonite paste was applied around the edges of the samples when installed in the cell to prevent side leakage (as per Benson et al., 2007).

5 RESULTS AND DISCUSSION

5.1 Moisture uptake

The GCL moisture content was measured and recorded with time as shown in Figure 3. Starting from an initial air-dry moisture content of 10 %, the GCL hydrated to a maximum moisture content of 86% after 279 days. The GCL moisture content then began to decrease and had dropped to 68% after 625 days (under the applied pressure of 15 kPa) despite the fact that this was a closed system under constant temperature. This change in the GCL moisture content was considered to be a consequence of the cation exchange between the calcium from the soil layer with the sodium in the bentonite.

5.2 Hydraulic conductivity

The variation in hydraulic conductivity, k, with time for samples taken from the test cell at different times are shown in Figure 4 and given in Table 1. The hydraulic conductivity increased from 1-3 x 10^{-11} initially to 1.8 x 10^{-10} m/s over a test period of 625 days.

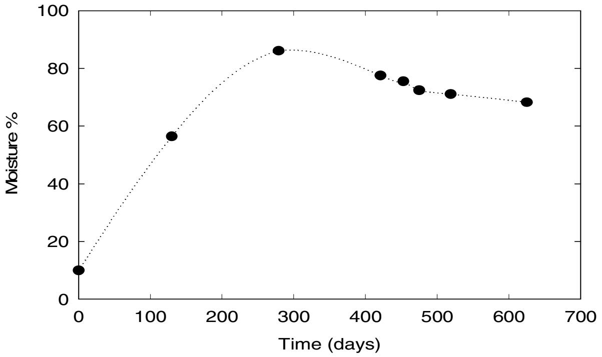


Figure 3. Moisture content of GCL samples subject to Ca^{++} uptake with time.

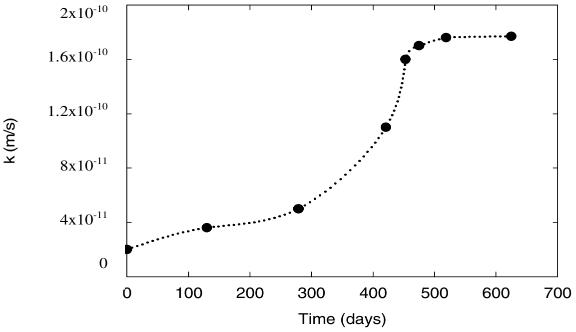


Figure 4. Variation in GCL hydraulic conductivity with time during Ca^{++} uptake.

5.3 Swelling index

Swelling index tests were carried out on bentonite from the virgin GCL and GCL samples taken regularly from the test cells. The tests were conducted in accordance with ASTM D5890. De-ionized water was used in this test as standard water. Figure 5 shows the variation in the swelling index with time.

The swelling index decreased from that of the new GCL (26.5; Table 1) to about 16.75 after 475 days as a result of cation exchange between the Ca^{++} and Na^{+}. As can be seen from Table 1, there was a strong correlation between the decrease in swelling index and the increase in hydraulic conductivity with the two stabilizing after about 475 days.

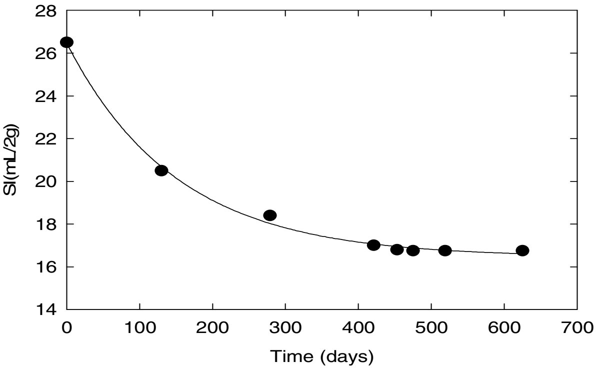


Figure 5. Swelling index for bentonite from GCL with time during Ca^{++} diffusion test.

Table 1. Summary of Physical Properties of GCL Samples taken at different times.

GCL Sample	Time (days)	Exhumed Moisture Content %	Swelling Index	k (m/s)
New	0	96.0*	26.50	1-3 x 10^{-11}
Exhumed	130	56.4	20.50	3.6 x 10^{-11}
“	279	86.1	18.20	5.0 x 10^{-11}
“	421	77.5	17.00	1.1 x 10^{-10}
“	453	75.5	16.80	1.6 x 10^{-10}
“	475	72.4	16.75	1.8 x 10^{-10}
“	519	71.1	16.75	1.8 x 10^{-10}
“	625	68.2	16.75	1.8 x 10^{-10}

[*Moisture content of virgin GCL samples used for k tests.]

6 CONCLUSIONS

GCL samples were taken from a large scale test cell and tested for water content, hydraulic conductivity, and swelling index. GCLs hydrated by moisture uptake from the underlying calcium rich soil experienced an increase in moisture content of the GCL to 86% in the first 279 days of the test. The moisture content subsequently dropped from 86% to 68% after 625 days due to the effect of the Ca^{++} exchange with Na. The cation exchange causes a change in the GCL hydraulic conductivity from 1-3 x 10^{-11} to 2 x 10^{-10} m/s over a period of 625 days.

Cation exchange caused the swelling index to drop from the range typical of sodium bentonite used in the new GCL (SI > 24) to 16 which is greater than, but approaching, a value typical of calcium bentonite (~ 10 ml/2 g).

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REFERENCES

Benson, C., Thorstad, P. A., Jo, H. Y. and Rock, S. A. 2007. Hydraulic Performance of Geosynthetic clay Liners in a Landfill Final Cover. *Journal of Geotechnical and Geoenvironmental Engineering, July,* 133-7: 814-827.

Jo, H. Benson, C. and Edil, T. 2006. Rate-limited exchange in thin bentonite barrier layers. *Canadian Geotechnical Journal*, 43: 370-391.

Jo, H., Benson, C. and Edil, T. 2004. Hydraulic conductivity and cation exchange capacity in nonprehydrated and prehydrated bentonite permeated with weak inorganic salt solutions. *Clays and clay minerals*. 52-6: 661-679.

Jo, H. Y., Benson, C. H., Shackelford, C. D., Lee, J. M., and Edil, T. 2005. Long term hydraulic conductivity of a Geosynthetic clay liner permeated with inorganic salt solutions. *Journal of Geotechnical and Geoenvironmental Engineering*. 131-4: 405-417.

Jo, H., Katsumi, T., Benson, C., and Edil, T. 2001. Hydraulic conductivity and swelling of nonprehydrated GCLs permeated with single-species salt solutions. *Journal of Geotechnical and Geoenvironmental Engineering*. 127-7: 557-567.

Lee, J. M. and Shackelford C. D., 2005. Impact of Bentonite Quality on Hydraulic Conductivity of Geosynthetic clay Liners. *Journal of Geotechnical and Geoenvironmental Engineering, January*. 131-1: 64-77.

Lin, L., and Benson, C., 2000. Effect of wet-dry cycling on swelling and hydraulic conductivity of GCLs. *Journal of Geotechnical and Geoenvironmental Engineering, January*. 126 – 1: 40-49.

Meer, S.R. and Benson, C.H., 2007. Hydraulic Conductivity of Geosynthetic clay Liner Exhumed from Landfill Final Cover. *Journal of Geotechnical and Geoenvironmental Engineering, May*, 133-5: 550-563.

Rowe, R.K. and Badv, K. 1996. Advective-diffusive contaminant migration in unsaturated sand and gravel, Journal *of Geotechnical Engineering*, 122-12: 965-975.

Shackelford, C., Benson, C., Katsumi, T., Edil. T., and Lin, L. 2000. Evaluating the hydraulic conductivity of geosynthetic clay liners permeated with non-standard liquids. *Geotextile and Geomembrane*. 18: 133-162.