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Hydration of geosynthetic clay liners from clay subsoil under simulated field conditions

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ABSTRACT

Use of Geosynthetic Clay Liners (GCLs) in landfill barrier design has been the focus of recent studies investigating their ability to prevent contaminant transport to groundwater. In this paper, the hydration of two GCL products placed in contact with clay subsoils at different initial moisture contents is described under both isothermal conditions at room temperature, and daily thermal cycles. The rate of hydration of the GCL and its final equilibrium moisture content were significantly influenced by the amount of moisture made available to it through the subsoil. The two types of GCLs were also found to exhibit different hydration behaviors under similar experimental conditions. The study revealed that GCLs undergoing daily thermal cycles absorbed much less moisture over time than the GCLs kept at constant room temperature (ratio 1:4). In comparison with other types of subsoils, the final equilibrium moisture content attained by the GCL from clay subsoil was significantly less than that for sand subsoil.

1. Introduction

Geosynthetic Clay Liners (GCLs) have been the focus of recent studies for their low hydraulic conductivity and ability to act as a barrier, in settings where transportation of contaminants is a concern. GCLs are widely used as environmental protection barriers in waste containment facilities, canals, surface impoundments and underground petroleum storage tanks. Typically, GCL consists of a layer of bentonite sandwiched between two layers of needle punched or stitch bonded geotextile fibers. After placement, the GCL absorbs pore water from underlying soil, swells and creates an effective hydraulic barrier to transportation of contaminants.

The hydraulic performance of a GCL is influenced by several factors, such as the bulk void ratio of the bentonite (Petrov et al., 1997), the degree of hydration (Rowe, 2005), and the self-healing behavior of bentonite used in GCLs (Babu et al., 2001). Insufficient GCL hydration was reported to cause high leakage rates through GCLs (e.g. Melchior, 1997). The rate of hydration of GCL from the underlying subsoil has received very little attention. Daniel et al. (1993) and Eberle and von Maubeuge (1997) have reported limited data on GCL hydration from sand subsoil. The type of bentonite (Bouazza et al., 2006) and the method of GCL manufacture (Beddoe et al., 2011; Rayhani et al., 2011) were shown to influence the GCL hydration. Chevrier et al. (2012) reported that the equilibrium moisture content of the GCL, from a sand subsoil, slightly decreased as the confining pressure increased from 7 to 28 kPa. The subsoil grain size distribution and initial moisture content were also shown to significantly affect the GCL hydration (Rayhani et al., 2011; Anderson et al., 2011). The GCL hydration from a clayey sand (SC) subsoil was slightly less than that for a poorly graded sand (SP) (Anderson et al., 2011).

The hydration behavior discussed above provides information for the case where the GCL is covered by a leachate collection system that protects the liner from exposure to thermal cycles. The liner, however, may be left exposed to solar radiation for a period of time (weeks to years depending on the situation) before being covered (Thiel et al., 2006). Therefore, it is important to consider the effect of thermal cycles on the degree and rate of hydration of the GCL during installation when the GCL is exposed. Rowe et al. (2011) and Anderson et al. (2011) have shown that daily thermal cycles significantly affected the hydration of GCL from sand subsoils.

In landfill applications, GCL is often used on materials with low permeability such as clays and silts to reinforce hydraulic barriers. To date there is no data in the literature examining GCL hydration from these fine grained soils under field conditions. Without a full understanding of the hydration behavior and subsequent hydraulic performance of the GCL, there are uncertainties for all GCL designers, manufacturer and users about the performance of GCLs used in a wide range of applications. Thus, this paper aims to investigate GCL hydration from a clay subsoil under both isothermal conditions, and when subjected to thermal cycles. The effect of the GCL manufacturing process, the initial moisture content of the subsoil and daily and seasonal thermal cycles on the degree of hydration of the GCL from underlying clay are described. The GCL

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hydration behavior on a clayey soil is also compared to the behavior on sandy soils based on data from previous studies (Anderson et al., 2011; Rowe et al., 2011).

2. Material properties

2.1. GCL

Two GCL products from two different manufacturers in North America were used in this study (GCL1 and GCL2 in Table 1). Both GCLs consisted of an essentially air dry, sodium bentonite (montmorilonite content of 50–58%) sandwiched between polypropylene geotextile layers. GCLs with montmorilonite content of less than 30% may lead to insufficient hydration and swelling (Guyonnet et al., 2009). The polypropylene fibers in the geotextile layers were held together as a composite material by the needle punching manufacturing process. The average dry reference mass per unit area of GCL1 was less (4377 g/m^2) than that of GCL2 (5275 g/m^2). The average initial thicknesses of the GCLs (as received from the manufacturer) were about 6 mm and 8.5 mm for GCL1 and GCL2, respectively. GCL1 contained fine grained bentonite with D_{50} of about 0.35 mm, while GCL2 contained coarse granular bentonite with D_{50} of 1.0 mm. The plasticity index of bentonite was measured at about 216% for GCL1 and about 262% for GCL2 according to ASTM D 4318. The cation exchange capacity of the bentonite was slightly higher for GCL2 (103 milliequivalents (meq) per 100 g of dry clay) compared to GCL1 (78 meq/100 g). The cation exchange has shown to deteriorate the hydraulic performance of GCLs used in landfill cover systems (e.g. Benson et al., 2007). The water retention curves for both GCLs were also different as measured by Beddoe et al. (2011) using high capacity tensiometers and capacitance relative humidity sensors. They reported that the screen reinforced, thermally treated GCL (GCL1) achieved a fully hydrated state at a lower moisture content and a much lower bulk void ratio than GCL2.

2.2. Subsoil

Fine grained soil from the foundation soil at the Navan Landfill in Ottawa was used as the subsoil for the experiments. The grain size distribution of the subsoil, obtained according to ASTM D 422 hydrometer test is given in Fig. 1a. The plasticity index of the soil was measured at about 22% based on ASTM D 4318 Atterberg test. As noted, the soil can be classified as low plastic clay (CL) in the USCS classification system (ASTM D 2487). The maximum dry density of the soil was obtained, using the standard proctor compaction test (ASTM D 698), as 1.43 Mg/m^3 at the optimum gravimetric water content of 28% (mass of water/mass of solids). The soil water retention curve was inferred based on the soil grain size distribution and saturation moisture content, using the data point function in Geo-Slope program (Geo-Slope International Ltd., 2007) (Fig. 1b).

Table 1
Index properties of GCLs examined.

GCL properties		GCL1	GCL2
Mass/area	Avg. dry mass/area (g/m^2)	3965	5375
Carrier	Type	SRNW	W
	Avg. mass/area (g/m^2)	240	125
Cover	Type	NW	NW
	Avg. mass/area (g/m^2)	210	270
Structure	Interlocking	NPTT	NP
	Avg. peel strength (N)[a]	260 ± 17	204 ± 35
Bentonite	Aggregate size (mm) D_{50}	0.35	1.0
	Liquid limit (%)	265	334
	Plasticity index (%)	216	262
	Swell index (ml/2 g)[a]	24	23
	Montmorilonite content (%)[b]	50–55	53–58
	Cation exchange capacity (meq/100 g)[a]	78	103

W = Woven, NW = Nonwoven, SRNW = Scrim reinforced nonwoven, NP = Needle punched, NPTT = Needle punched and thermally treated.

[a] Tests performed by M. Hosney, Queen's University.

[b] Data from Bostwick L.E. (2010).

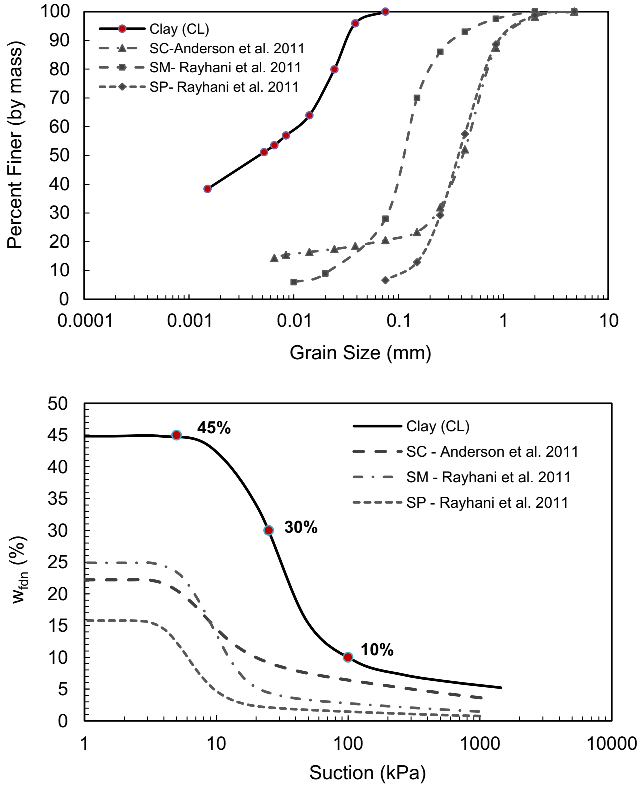

Fig. 1. (a) Grain size distribution and (b) Inferred water retention curve for the subsoil examined (w_{fdn} is subsoil's gravimetric moisture content; SC, clayey sand; SM, silty sand; and SP, poorly graded sand).

3. Experimental program

3.1. Sample preparation

Polyvinyl chloride (PVC) cells 150 mm in diameter and 300 mm in height were used to simulate a typical composite liner profile in the lab. This profile consisted of 250 mm of subsoil compacted to a specific moisture content, a GCL, a geomembrane, and a steel block to provide 1 kPa of normal stress on the GCL (Fig. 2). The subsoil moisture contents modeled in the experimental cells consisted of a moisture content close to the average moisture content present in the field (65%), a moisture content near saturation (45%), a moisture content close the optimum moisture content (30%) and a moisture content near the residual moisture content (i.e., near the wilting point) (10%) (Fig. 1b).

The dry clay samples were manually mixed with tap water having an average calcium concentration of 40 mg/L (similar to that reported by Rayhani et al. (2011) and Anderson et al. (2011)) to bring their moisture contents (w_{fdn}) to 10%, 30% and 45%. The subsoil was compacted using a compaction hammer into the PVC cylinders to a dry density of 1.36 Mg/m^3 (95% maximum dry density), sealed to provide a closed-system (i.e. constant mass of moisture within the cell), and left for 24 h to achieve moisture equilibrium before the GCL specimen, measuring 150 mm in diameter, was