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Effect of water salinity on the water retention curve of geosynthetic clay liners

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ABSTRACT

The effect of water salinity on the water retention curve of geosynthetic clay liners (GCLs), under constant volume condition is examined. The results indicate that at a constant gravimetric moisture content the total suction increases as the salinity of the wetting liquid increases. Furthermore, the difference in total suction between the GCL hydrated by saline water and distilled water is greater than the difference in the osmotic potential of the wetting water. This behaviour is possibly caused by the matric suction being affected by the expected chemically induced pore size change of the bentonite component of the GCL.

1. Introduction

Geosynthetic clay liners (GCLs) are industry-manufactured low permeability barriers used extensively in waste containment facilities to minimize the escape of pollutants into soil and groundwater (Bouazza, 2002; Guyonnet et al., 2005; Katsumi et al., 2007; Benson et al., 2010; Bouazza and Gates, 2014; Liu et al., 2015; Bouazza et al., 2017a). GCLs are made of a thin layer of bentonite contained between two layers of geotextile, commonly held together by needle-punching. The sealing performance of GCL is provided by the bentonite once hydrated (Gates et al., 2009; Beddoe et al., 2011). However, Bouazza et al. (2017a) suggested that the gravimetric water content of GCLs should not be less than 100% to ensure that GCLs can perform adequately its hydraulic barrier function. In typical field applications, the bentonite component of a GCL is hydrated by adsorbing water from the compacted subsoil that is usually prepared before the GCL is placed on top of it (Rayhani et al., 2011; Lu et al., 2017). This hydration process is mainly controlled by the ability of the subsoil to release enough water for the GCL to hydrate. Recent studies have shown that the initial water content of the subsoil and the nature of the subgrade and its mineralogy tend to regulate the amount of water available for the GCL (Rayhani et al., 2011; Anderson et al., 2012; Bouazza et al., 2017b; Acikel et al., 2018).

The key to this moisture exchange is the water retention properties of the GCLs and the subsoil material as they control the moisture transfer from subsoil to GCLs and describe the evolution of hydraulic conductivity of GCLs as its moisture content changes. While the water retention properties of compacted bentonite (for radioactive waste) are widely documented (He et al., 2016; Chen et al., 2015; Delage et al., 1998; Cui, 2017, among many others), those of GCLs are less and if available they were mostly investigated using distilled or deionised water (Barroso et al., 2006; Southen and Rowe, 2007; Abuel-Naga and Bouazza., 2010; Beddoe et al., 2011; Bouazza et al., 2013, 2014; Bannour et al., 2014; Acikel et al., 2015; Ali et al., 2016; Lu et al., 2017). However, several researchers have reported that there are site conditions where the pore water in the subsoil will contain high salt concentrations which might potentially affect the water retention properties of GCLs (Bradshaw et al., 2012; El-Zein et al., 2014; Indrawan et al., 2016; Bouazza et al., 2017b). Interestingly, several studies have been conducted to assess the effect of pore water salinity on the hydraulic conductivity of GCLs (Petrov and Rowe, 1997; Shackelford et al., 2000; Bouazza and Gates, 2014). However, very limited data is currently available in the literature on the effect of pore water salinity on water retention properties of GCLs. Thus, the objective of this paper is to explore the impact of saline pore water on the water retention properties of a GCL and assess its effect on the water retention curve (WRC).

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Table 1
Summary of properties of GCL.

Montmorillonite content	≥ 80 wt% (XRD)
Carbonate content	≤ 1–2 wt%
Bentonite form	Natural Na-bentonite
Particle size	Powdered (i.e., 80% passing 75 μm sieve)
Cation exchange capacity	≥ 70 meq/100 g (or cmol/kg)
Free swell index	≥ 24 ml/2 g
Fluid Loss	≤ 18 ml
Mass per unit area, total GCL (@ 0% Moisture) (g/m^2)	≥ 4200
Thickness GCL, total (mm)	≥ 5.4 mm
Peel strength (N/m)	≥ 360
Static puncture strength (N)	≥ 1800
Hydraulic Conductivity (m/s)	≤ 2×10^{-11}
Mass per unit area, cover nonwoven (g/m^2)	≥ 200
Mass per unit, carrier woven (PP) (g/m^2)	≥ 100
Mass per unit area, powder sodium bentonite layer (@ 0% Moisture) (g/m^2)	≥ 3700
*Measured GCL Mass per unit area (g/m^2)	4138 to 4452
*Measured Thickness under 2 kPa Stress (mm)	5.8 to 6.4
*Natural Gravimetric Water Content (%)	6.56 to 9.01

Note: * means the value measured in the laboratory.

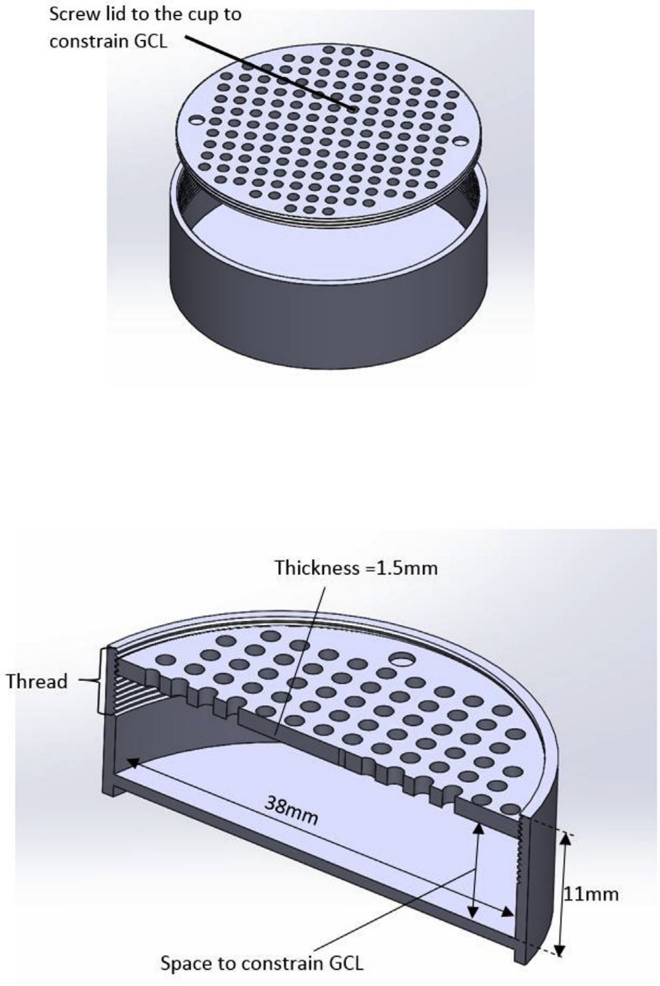

Fig. 1. Schematic drawing of WP4C (a) cup cross-section (dimension in mm); (b) 3D view of the cup and lid.

2. Materials and methods

Table 1 lists the engineering properties of the needle punched GCL used in this study. Although several experimental methods are available to evaluate the water retention curve of soils, not all of these methods are valid for GCLs due to their particular composite structure. Abuel-Naga and Bouazza (2010) discussed the suitability of the different testing techniques and suggested that a moisture control method could better suit the GCLs configuration. This method involves adjusting the water content of the specimen and then measuring the corresponding suction and volume change. Seiphoori et al. (2016) and Lu et al. (2017), based on the above suggestion, proposed a simple method to determine the WRC of GCL under constant volume condition using a modified sample holder in a chilled-mirror dew-point device, WP4C, which measures total suction at different imposed water content levels. Lu et al. (2017) showed that, for some GCL types, the difference between the WRC under free swell and constant volume condition was very small. This behaviour was attributed to the high internal mobilised confining pressure generated by the reinforcing fibres of GCL under the free swell condition and the range of suctions investigated.

The testing method described by Lu et al. (2017) was used in the current study to measure the GCL WRC under constant volume condition. This method involved adding a threaded perforated metal lid (1.5 mm thick) to the sample holder of the WP4C, which allowed wetting the GCL specimen under constant volume condition as shown in Fig. 1. However, it should be mentioned that as GCL is a multi-layered composite material, its carrier and cover geotextile layers are different from the bentonite clay layer, therefore, the applied constant volume condition only controls the total volume of the GCL. In other words, under wetting condition, the expected swelling pressure of the bentonite can compress the geotextile layers and fill some of its pores with bentonite.

A sharp knife was used to cut the GCL specimens to a diameter of 38 mm. The initial GCL thickness was measured under an applied normal stress of approximately 2 kPa using a Vernier heightgauge. The test preparation procedure involved injecting the GCL specimen with an incremental amount of water, then storing it under sealed condition for 10–15 days to condition it to the target moisture content (Bouazza and Vangpaisal, 2003; Bouazza et al., 2017b). Then, total suction and moisture content measurement were performed on the conditioned specimens. The process of injection/storing/suction and moisture measurements was repeated for a single GCL specimen until the total suction-water content relationship was established. The injection process involved using a thin needle that could be inserted into the GCL specimen through the holes of the perforated lid. The penetration depth of the needle was limited to the thickness of the top geotextile layer to keep the bentonite layer intact during the wetting process. The injected liquid included distilled water (DW), and saline water (SW) having various sodium chloride (NaCl) concentrations (0.1M, 0.2M, 0.3M, 0.5M and 2M).

Although special care was taken not to lose any bentonite from the outer edge of the GCL sample during the cutting process of the specimens, it is believed that having zero bentonite loss is almost impossible. The possible bentonite loss and non-uniformity of bentonite distribution in the GCL was verified by measuring the dry density of the GCL specimens. In the current study, the dry density of the GCL specimens varied between 0.85 and 0.95 g/cm^3. To assess the effect of the initial dry density on the total suction readings, total suction measurements were obtained for four different GCL samples, in terms of their dry density, at constant moisture content and insignificant effect on the total suction was observed, as shown in Fig. 2.

A Scanning Electron Microsope (SEM), Model TM3030 Hitachi Tabletop was used to assess the effect of water salinity on the microstructure of the bentonite. Imaging was performed using an accelerating voltage of 15 kV and back scattered electron (BSE) and secondary electron (SE) images combined to show topographic information.

The swelling pressure of GCL saturated with water of different