Geotextiles and Geomembranes 42 (2014) 629–640

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Effect of stress on water retention of needlepunched geosynthetic clay liners

H. Bannour [a, 1], G. Stoltz [a, 2], P. Delage [b, 3], N. Touze-Foltz [a, *]

[a] Irstea, HBAN Unit, Antony, France
[b] Ecole des Ponts ParisTech, Navier/CERMES, France

ARTICLE INFO

Article history:
Received 19 March 2014
Received in revised form
8 July 2014
Accepted 9 September 2014
Available online 3 October 2014

Keywords:
Geosynthetics
Geosynthetic clay liner
Unsaturated conditions
Water retention curve
Suction
Confining stress

ABSTRACT

Geosynthetic clay liners (GCLs) are placed at the bottom of waste disposal facilities where they hydrate from the subsoil and eventually from a hydraulic head on geomembranes (GMs) defects. Predicting hydration behavior of GCLs requires knowledge of the water-retention properties of the GCL along wetting paths. Given that GCLs could be subjected to different ranges of vertical stresses that are induced by the weight of the supported waste, the confining stress could affect water-retention properties of GCLs and should be investigated. To do so, a laboratory methodology to establish the water-retention curves (WRCs) of needlepunched GCLs under stress was undertaken. Various constant vertical stresses corresponding to different weights of the supported waste were applied to GCL specimens placed in controlled-suction oedometers. Suction values were selected so as to mimic a wetting path from the initial dry state to zero suction. Suction was controlled by using controlled suction techniques with controlled humidity imposed by a saturated saline solutions and using the osmotic technique with polyethylene glycol (PEG) solutions. Measurements were undertaken on oedometer systems as to apply confining stresses and have been complemented by standard saturated oedometer swelling tests. The data obtained confirm that increasing the stress on to the GCL results in less, albeit faster, water uptake, which could emphasize on recommendations about rapidly covering GCLs after they are placed at the bottom of a waste disposal facilities. Finally, the potential validity of the state-surface concept, which was developed in unsaturated soil mechanics, is discussed using van Guenuchten's and Fredlund and Xing's equations for water retention curves.

1. Introduction

Geosynthetic clay liners (GCLs) are composite materials used in geotechnical and geoenvironmental engineering applications. Specifically, they serve as barrier systems in landfill liners, tailing ponds or dams (Bouazza, 2002). GCLs have gained worldwide acceptance because once they are hydrated and confined, they represent excellent hydraulic barriers. GCLs consist of a layer of bentonite inserted between two geotextiles linked together by various means (stitching, needle punching, heat bonding, wrapping, etc.). The suction of the bentonite contained in GCLs can be as high as 1000 MPa (Beddoe et al., 2010).

When installed in composite liners, GCLs hydrate under a compressive stress corresponding to the overburden load. After that, the GCL hydrates typically from both the liquid flux through defects in the geomembrane (GM) and the transfer of vapor and liquid water from the underlying soil through the GCL (Azad et al., 2011; Beddoe et al., 2010). Assuming a typical depth of waste deposits of between 20 and 30 m and adopting a density of 800–1000 kg/m^3 for the waste, vertical stresses applied to GCLs at the bottom of deposits may reach 300 kPa.

The capability of a GCL to serve as a barrier to fluids (either liquid or gas) is intimately linked to the uptake of moisture by the bentonite. However, there is no guarantee that the GCL will reach full hydration before leakage begins through a defective geomembrane. Accurately predicting the hydraulic behavior of composite liners requires knowledge of both the water retention curve (WRC) of the GCL and its volumetric changes during hydration.

---

* Corresponding author. Tel.: +33 1 40 96 60 39; fax: +33 1 40 96 62 70.
E-mail addresses: hajer.bannour@irstea.fr (H. Bannour), guillaume.stolz@irstea.fr (G. Stoltz), delage@cermes.enpc.fr (P. Delage), nathalie.touze@irstea.fr (N. Touze-Foltz).
[1] Tel./fax: +33 1 40 96 65 25.
[2] Tel.: +33 1 40 96 60 39; fax: +33 1 40 96 60 48.
[3] Tel./fax: +33 1 64 15 35 42.

http://dx.doi.org/10.1016/j.geotexmem.2014.09.001

Many experimental studies have investigated the water-retention properties of GCLs (Daniel et al., 1993; Barroso et al., 2006; Southen and Rowe, 2007; Abuel-Naga and Bouazza., 2010; Beddoe et al., 2010, 2011; Hanson et al., 2013; see Table 1). In addition, to quantifying the transient hydration of GCLs under experimental unsaturated conditions, Siemens et al. (2011, 2013) have done numerical simulations on the transient hydration of GCLs. They assessed the impact of two confining stresses (10 100 kPa) on the rate of hydration and the moisture equilibrium content of GCLs.

Most investigations into water retention in the wetting path (Daniel et al., 1993; Barroso et al., 2006; Beddoe et al., 2010, 2011; Hanson et al., 2013) have been done without considering the confining stress effect which affects the water-retention properties of the GCL (as observed in other bentonite-based materials). For example, in radioactive waste management, Yahia-Aissa et al. (2001) demonstrated that volume constraint of compacted bentonite leads to significantly less water retention at saturation. This effect was later confirmed by Lloret et al. (2003) and Villar et al. (2003), who used the same approach. Southen and Rowe (2007) investigated the effect on water-retention in GCLs of different confining stresses (3 and 100 kPa) applied along a drying path. The effect of confining stress applied along a wetting path was investigated by Abuel-Naga and Bouazza (2010) (with a single stress of 50 kPa) and by Beddoe et al. (2011) (with a small stress of 2 kPa). Siemens et al. (2013) numerically studied the effect of confining stresses of 2 kPa and 100 kPa on water retention in GCLs.

These studies did not investigate water retention along a wetting path for the larger range of confining stresses that corresponds to deeper waste deposits (for example in the case when a hydraulic head exist on the GM overlying the GCL is presenting holes).

To better understand the hydromechanical response of GCLs, this paper presents the results of an experimental program designed to investigate the effect of confining stress applied along the wetting path of the WRC of GCLs. The WRC was determined based controlled suction techniques adapted to oedometer equipment with saturated saline solutions and osmotic technique with polyethylene glycol (PEG) solutions. Measurements were complemented by standard saturated oedometer swelling tests to obtain water retention properties at zero suction. In the following, WRCs at the wetting path, their experimental determination, and their relevance with respect to GCL issues are first briefly introduced. Second, the suction-control methods that were applied to the GCL are described. Finally, the results obtained are presented and compared with published data. Two well-known WRC equations (van Guenuchten's and Fredlund and Xing's) are fit to the data obtained and an explanation of the effect of stress is proposed.

Table 1
Published investigations of GCL water-retention curves.

Authors	Used technique	Confining stress (kPa)	Water cycle
Daniel et al. (1993)	Thermocouple psychrometer (SCM) and vapor equilibrium (MCM)	0	Wetting path
Southen and Rowe (2004)	Pressure plate technique (SCM)	0	Drying
Barroso et al. (2006)	Filter paper (MCM)	0	Wetting path
Southen and Rowe (2007)	Pressure plate (SCM) and pressure membrane extractors (SCM)	0-0.5-3-100	Drying path
Abuel-Naga and Bouazza (2010)	Thermocouple psychrometer (MCM) and a capacitive relative humidity sensor (MCM)r	50	Wetting path
Beddoe et al. (2010)	High-capacity tensiometers (MCM) and capacitive relative humidity sensors (MCM)	2	Drying path
Beddoe et al. (2011)	High-capacity tensiometers (MCM) and capacitive relative humidity sensors (MCM)	2	Wetting/Drying path
Hanson et al. (2013)	Pressure plate-filter paper and relative humidity methods	0	Wetting/Drying path

“SCM” stands for “suction-control method” and “MCM” stands for “moisture-control method”.

2. Water-retention curves

2.1. Water-retention along wetting path in geosynthetic clay liners

GCLs have a composite structure consisting of geotextiles and bentonite. When the GCL is under unsaturated conditions, Abuel-Naga and Bouazza (2010) modeled the structure of a GCL as a double-porosity material with two distinct air-entry values and two residual water contents corresponding to that of the geotextile and that of the bentonite. Based on the fact that GCLs present composite structures, along the wetting path, the GCL's bentonite will swell and could squeeze out to occupy some of the pore space of the geotextile component with the confining stress.

In this context, it is important to find a suitable methodology for investigating the water retention of GCLs along the wetting path over the entire relevant suction range by examining the effects of confining stress on GCL water retention.

2.2. Techniques to determine water-retention curve of geosynthetic clay liner

Some methods recently adopted to determine the WRCs of GCLs have been described by Abuel-Naga and Bouazza (2010), Beddoe et al. (2010), and Zornberg et al. (2010). Based on Fig. 1, it is recommended to combine at least two different techniques to cover the entire suction range of GCLs. As seen in Table 1, methods used to determine the WRC of GCLs include (i) vapor equilibrium (Daniel et al., 1993) and (ii) axis-translation techniques based on plates or membrane extractors (Southen and Rowe, 2004, 2007; Hanson et al., 2013). (iii) thermocouple psychrometer (Daniel et al., 1993; Abuel-Naga and Bouazza, 2010), (iv) the filter-paper technique (Barroso et al., 2006; Hanson et al., 2013), (v) high-capacity tensiometers (Beddoe et al., 2010; 2011), and (vi) capacitive relative-humidity sensors (Abuel Naga and Bouazza, 2010; Beddoe et al., 2010; 2011; Hanson et al., 2013).

Some methods have shown their limitations for use with GCLs. For example, sensors such as thermocouple psychrometers are irrelevant at low suction (<1 MPa), particularly because of their significant temperature sensitivity (Daniel et al., 1993; Abuel Naga and Bouazza, 2010), and fungi that develop on filter paper could affect the results of the filter-paper technique if test protocol is not followed (Barroso et al., 2006).

This study used to present an original methodology for establishing water retention curve of GCLs under wetting path and confining stress that takes into account the composite structure of GCLs.

3. Materials and methods

3.1. Geosynthetic clay liner properties and preparation

A needle-punched GCL containing granular sodium bentonite was used. The cover geotextile was woven and the carrier geotextile was needlepunched. The mass per unit area M_b of bentonite was 5.80 kg/m^2. The average thickness of the GCL was 7 mm. The basic features of the measurements done to determine the WRCs of the GCL are summarized in Table 2. The GCL sample was cut into 7-cm-