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Water retention curve of GCLs using a modified sample holder in a chilled-mirror dew-point device

Yi Lu [a], Hossam Abuel-Naga [b], Abdelmalek Bouazza [c, *]

[a] Department of Civil Engineering, La Trobe University, Bundoora, Melbourne, Vic., Australia
[b] Civil Engineering Discipline, La Trobe University, Bundoora, Melbourne, Vic., Australia
[c] Monash University, Department of Civil Engineering, 23 College Walk, Vic. 3800, Australia

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ABSTRACT

The aim of this study is to assess the feasibility of using a modified chilled-mirror dew-point apparatus to quantify the water retention curve of GCLs. The conventional configuration of the chilled-mirror dew-point device allows the measurements of water potentials under zero confinement pressure condition only. A simple approach is proposed in this study to enable the chilled-mirror dew-point device to measure GCLs water retention curves on the wetting path in terms of the upper and the lower boundaries of the confining conditions (i.e., free swelling and constant volume condition, respectively). The proposed method needs neither additional equipment nor special test procedures. The test results obtained from this study are discussed in the light of the results reported in the literature where emphasis was on the effect of confinement condition on the water retention curves of GCLs and a satisfactory agreement is observed.

1. Introduction

Geosynthetic clay liner (GCL) is a thin composite-structured engineering barrier (5 mm–12 mm in thickness) widely used in waste containment applications (Bouazza, 2002). It comprises a layer of bentonite clay sandwiched between two layers of geotextiles where needle-punching or stitch bonding method is used to hold the three layers together. The main function of the GCL is to prevent or slow the flow of fluids from the containment facility. In this respect, there is a wide body of work available on GCLs hydraulic/gas barrier performance (Shackelford et al., 2000; Bouazza and Vangpaisal, 2004, 2006, 2007; Benson et al., 2010; Gates and Bouazza, 2010; Mendes et al., 2010; Scalia and Benson, 2010, Bradshaw et al., 2013; Liu et al., 2013; Mazzieri et al., 2013; Abuel-Naga and Bouazza, 2011; Abuel-Naga et al., 2013; Makusa et al., 2014; Bouazza and Gates, 2014; Liu et al., 2014, 2015; Rowe, 2014; Rouf et al., 2015; Bradshaw et al., 2016; Rouf et al., 2016a, b).

The performance of a GCL as a hydraulic barrier is mainly controlled by its water saturation level. In common practice, initial hydration of GCL in barrier applications is achieved through a passive or active process in which water liquid/vapour is transferred from the subgrade to the GCL (Rayhani et al., 2011; Rouf et al., 2016a). There is a need to understand the factors controlling the GCL hydration behaviour, in particular its water retention property.

Several studies have been conducted in the last decade to quantify the water retention behaviour of GCLs (see Table 1). The laboratory techniques used for measuring the water retention curves of GCLs can be classified into two main categories: 1) suction control methods and 2) moisture control methods. Suction control methods involve subjecting the specimen to a predetermined suction, and then monitoring its response in terms of water content and volume change whereas moisture control methods involve adjusting the water content of the specimen, and then measuring the corresponding suction and volume change. Abuel-Naga and Bouazza (2010) discussed the suitability of both techniques and concluded that the moisture control method would better suit the GCLs configuration and conditions. Abuel-Naga and Bouazza (2010) proposed an advanced moisture control technique for measuring the water retention curve of GCL, under different confining pressure and temperature levels, where a needle system was attached to a conventional triaxial cap allowing in this way control of the moisture content of the GCL specimen on the wetting path. Thermocouple psychrometer and relative humidity sensors were used

* Corresponding author.
E-mail addresses: 18217027@students.latrobe.edu.au (Y. Lu), h.naga@latrobe.edu.au (H. Abuel-Naga), malek.bouazza@monash.edu (A. Bouazza).

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Table 1
Summary of previous studies on measurement of the water retention curve of GCLs.

Study	Suction measurement/ control method	Vertical stress (kPa)	Path	Bentonite type	Same specimen for WRC	Bonding	Cover geotextile	Carrier geotextile	GCL mass per unit area (kg/ m^2)
Acikel et al. (2015)	Filter paper	1.0	Wetting	Granular sodium	No	Needle punched	Non-woven	Woven	4.69
Bannour et al. (2014)	Osmotic	10,50,100,200	Wetting	Granular sodium	No	Needle punched	Woven	Nonwoven	6.1
Beddoe et al. (2011)	High-capacity tensiometer + relative humidity sensors	2.0	Wetting/ drying	Granular sodium	No	Thermally needle punched/needle punched	Woven/non-woven	Nonwoven	4.1
Abuel-Naga and Bouazza (2010)	Relatively humidity sensor + thermocouple psychrometer	50	Wetting	Powder sodium	Yes	Thermally treated needle punched	Impregnated nonwoven	Nonwoven reinforced by silt film	5.5
Southen and Rowe (2007)	Axis translation	0,0.5, 3, and 100	Drying	Granular/ powder sodium	No	Thermally treated needle punched	Virgin staple fibre nonwoven/ impregnated nonwoven	Slit-film woven	4.5
Bouazza et al. (2006)	Thermocouple psychrometer	0	Wetting	Powder sodium	No	Thermally treated needle punched	Impregnated nonwoven	Nonwoven reinforced by silt film	5.5
Barroso et al. (2006)	Filter paper	0	Wetting	Powder/ granular sodium	No	Needle punched	Non-woven	Woven	5
This study	WP4C	Constant volume & free swelling	Wetting	Powder sodium	Yes/no	Thermally treated needle punched	Non-woven	Woven + Non-woven	4.95
				Granular sodium	No	Needle punched	Slit-film woven	Non-woven	3.9

to measure suction ranging between 1.0 and 100 MPa (Abuel-Naga and Bouazza, 2010).

This paper presents the outcome of a study aimed at assessing the feasibility of using a modified chilled-mirror dew-point method (moisture control technique) to measure the water retention curve of a GCL under different confining conditions (free swell, constant volume) where a chilled-mirror dew-point method is used to measure suction as it could cover the suction measuring range of thermocouple psychrometers and relative humidity sensors.

2. Chilled-mirror dew-point method and calibration

Several researchers have used the chilled-mirror dew-point method for determining the water retention curve of soils (Leong et al., 2003; Cardoso et al., 2007; Ali et al., 2014; Ferrari et al., 2014) as well as GCLs (Rouf et al., 2015). The chilled-mirror dew-point device is shown schematically in Fig. 1. The specimen of interest is placed into a sample cup (38 mm in diameter and 11 mm height) which then is positioned in the device housing chamber under sealed condition to achieve vapour equilibrium with the surrounding environment. The chamber includes an infrared thermometer to measure the specimen temperature, and a controlled cooled surface (chilled-mirror) where the temperature at which a condensation begins (dew-point) can be detected carefully using an optical sensor. The dew-point and the specimen temperature are used to determine the total soil suction according to Kelvin's equation. The WP4C chilled-mirror dew-point device manufactured by Decagon was used in this study to measure suctions in the range of 1–300 MPa. Campbell et al. (2007) showed that the resolution of this device is ±0.1 MPa, which is 5% of the reading at 2 MPa and 10% of the reading at 1 MPa. Therefore, it is not recommended to use this device for suction measurements below 1 MPa. The device can also measure total suction of the specimen under a controlled temperature ranging from 15 to 50 °C.

The conventional configuration of WP4C device only allows measurement of total suction under no confining pressure (free swell). However, it is known that the confining pressure level can affect the water retention behaviour (Lloret et al., 2003; Villar et al., 2003). As it is technically hard to add a confining pressure system into the WP4C housing chamber, a simple modification of the sample cup is proposed in this study to allow measurement of total suction under constant volume condition as shown in Fig. 2. This particular technique involves adding a threaded perforated metal lid (1.5 mm thick) to constrain the volume of the specimen under a wetting path (focus point of this study) as the volume of the specimen tends to increase as suction decreases. In general, the swelling pressure of GCLs under constant volume condition is between 150 and 200 kPa (Abuel-Naga and Bouazza, 2013). Therefore the possible volume change of the WP4C confining cup under the GCL swelling pressure is insignificant. It should be mentioned that Seiphoori et al. (2014, 2016) developed a similar WP4C cell. However, the cell design by Seiphoori et al. (2014) only allow testing of a specimen with 7 mm thickness whereas the proposed cell design in this study allow testing specimen with different thickness up to 7 mm.

As the WP4C device uses an infrared thermometer to measure the specimen temperature the surface emissivity coefficient of the perforated lid should be similar to the surface emissivity coefficient of soils in order to obtain accurate temperature measurements. As the surface of metals has a low surface emissivity coefficient compared to soils, the lid was painted in black to reach an emissivity value close to the soil emissivity coefficient.

A calibration program was conducted to assess the accuracy of the WP4C suction measurements with and without the perforated lid at temperature of 25 °C (room temperature). For this purpose, the sample cups, with lid and without lid, were filled with different salt solutions of known water potential and suction values were obtained. Fig. 3 shows the results of the calibration program. Different correlation relationships were obtained for both cases (with and without lid). The observed differences may be attributed to the difference in the surface emissivity coefficient of each case.