Experimental study to evaluate soil water retention curve of HYPER clay geosynthetic clay liner

To cite this article: M K Khan et al 2022 IOP Conf. Ser.: Mater. Sci. Eng. 1260 012027

View the article online for updates and enhancements.
Experimental study to evaluate soil water retention curve of HYPER clay geosynthetic clay liner

M K Khan¹, M D Camillis, G D Emidio and A Bezuijen

¹Laboratory of Geotechnics, Ghent University, Technologiepark 905, 9052 Zwijnaarde, Belgium

E-mail: muhammadkhizar.khan@ugent.be

Abstract. Geosynthetic clay liners are widely used as hydraulic barrier due to their low hydraulic conductivity but bentonite in the liners loses its effectiveness due to significant thermal fluxes by both diurnal and seasonal heating and cooling cycles. Modified sodium carboxy methyl cellulose-based bentonite clay (HYPER clay) has shown better hydraulic performance in both situations. A possible reason for this improved performance of HYPER clay based geosynthetic clay liner is the improvement in the suction under changing thermal conditions. Thus, the relationship between soil suction and moisture content, also called the soil water retention curve, needs to be estimated. Therefore, we investigated the soil-water retention curve of the HYPER clay based geosynthetic clay liner and compared it with the untreated clay based geosynthetic clay liner. The article presents the suction test results on wetting path conducted on geosynthetic clay liner prototypes containing HYPER and untreated clay assessed by the contact filter paper method and the relative humidity sensor. The results showed that the geosynthetic clay liner containing HYPER clay has a high volumetric water content and thus, high water retention compared to untreated bentonite at a given suction value. In other words, the HYPER clay can be considered as a potential alternative to conventional bentonite due to its improved water retention capacity.

1. Introduction

Geosynthetic clay liners (GCL) have demonstrated the potential to act as a hydraulic barrier owing to their low hydraulic conductivity to water, which leads to many applications such as landfill liners, tailing ponds, dams, and railway liners [1]. To efficiently act as a hydraulic barrier the GCL must be sufficiently hydrated. Also, for long term use, environmental factors that can influence the performance of GCL must be considered. The most significant environmental factor controlling the durability is thermal changes due to both diurnal and seasonal heating and cooling cycles, which results in shrinkage and consequently, the loss of GCL panel overlap [2, 3].

The key constituent of GCL is bentonite, which controls their sealing properties. The bentonite showed very good performance in restricting the flow of water, however, in case of regular wet and dry cycles, its sealing performance declines with each cycle. Hence, Sodium Carboxy Methyl Cellulose (Na-CMC) treated bentonite clay, known as HYPER clay (HC), has been introduced which displayed better hydraulic properties than untreated bentonite clay (UC) [4]. Besides, the effect of wet and dry cycles on the hydraulic conductivity of HC and UC has recently been investigated [5]. The authors demonstrated that the HC barriers exhibited much lower hydraulic conductivity (three orders of magnitude) as compared to UC, after the fourth wet-dry cycle, which proved the improved behaviour of HC. The whole
The process of wetting and drying cycles involves the change in the moisture content of the GCL, thereby leading to unsaturated condition. To characterize the unsaturated hydraulic performance of GCL, the relationship between soil suction and moisture content, also called water retention curve (WRC), should be measured [6]. Soil suction is one of the most important parameters describing the conduct of unsaturated soils, which is a measure of the free energy of the pore-water in the soil. Indeed, soil suction describes the susceptibility of the soil to retain water, which is important to explain the long-term performance of the bentonite. Since the water retention of bentonite under changing suction determines its behaviour during wet and dry cycles. This underlies the need to investigate the WRC of the HC, which according to the authors' knowledge, has not been investigated yet.

This paper presents the preliminary study of the wetting WRC curve of HC and its comparison with that of UC, to stimulate the unsaturated condition during the heat waves and seasonal rainfalls, by using contact filter paper method. Furthermore, the HC and UC total suction measured by filter paper method and relative humidity sensor are also compared.

2. Materials and methods
The following sections describe the detailed procedure adopted to prepare and subsequently test the specimens of both HC and UC for WRC. The procedure used was based on a combination of the (American Society for Testing and Materials standard, D5298), ASTM D5298, Acikel et al., 2015; Risken, 2014 [7-9].

2.1. Specimen preparation
Extensive preparation of bentonite specimens is required to minimize disturbance, simulate field conditions, and maintain consistency with previous studies [7, 10]. GCL prototypes and powder samples of UC and HC were used to measure the water retention (i.e., wetting curve) by using filter paper method.

Samples were hydrated to target moisture contents before suction measurements under a 1.5 kilo Pascal overburden pressure. This load was meant to allow near free swell conditions yet promoting adequate contact between the specimens and the filter paper. The specimens were then sealed in two plastic bags. Some water was sprayed between the two plastic bags to further reduce moisture losses from the specimen due to diffusion [8, 10]. The samples were stored for 30 days in a temperature-controlled room of 20°C ± 2°C before suction measurements.

2.1.1. Powder sample. UC and HC were evenly spread with a density of 4.5 kilogram per square meter (kg/m²) area, typical of GCL, in a 50-millimetre diameter cell. Figure 1 shows the stepwise procedure followed during the specimen preparation. The initial water content of the samples was determined to measure the exact dry mass and to calculate the water necessary to reach target water contents. An acrylic plate and ring were attached with the help of tape, to avoid loss of bentonite during handling. A stack of three dry filter papers Whatman number 42 were placed on the base of the cell. The outer two filter papers were used to protect the inner filter paper from bentonite. This method differs from previous research [8] as the filter papers were placed in contact with the soil from the hydration phase, as we used powder bentonite instead of GCL specimens. As can be seen in figure 1, the bentonite was carefully spread on the filter papers and two drainage layers were used to distribute the hydrating liquid and to hold the applied load. Deionized water was slowly poured on the first drainage layer in contact with the bentonite before applying the second drainage layer and the load.
2.1.2. **GCL prototypes.** The needle punched GCL prototypes specimens composed of a layer of UC or HC (abbreviated as GCL UC and GCL HC, respectively) sandwiched between a woven carrier and a non-woven cover geotextile was used. GCL specimens of 50-millimetre diameters were cut from the prototype rolls with scissor. Before cutting, the perimeter of the specimen was first wetted with a small amount of deionized water to minimize the loss of the bentonite. Half of the mass of water used was then accounted for the water content, considering that the other half of that water mass was absorbed by the GCL panel [8]. The initial water content of the bentonite present in the GCL sample was determined to predict the amount of water necessary to hydrate the GCL specimens to their target moisture contents. The perimeter of each GCL specimen was covered with weighted tape, thus reducing preferential drying on the edges. A single GCL specimen was used for each test. For instance, Barroso et al., 2006 [11] showed that using a single GCL specimen, it is possible to eliminate the moisture variation between dual GCL specimens. The water was distributed on both sides of the GCL. The GCL were placed on the acrylic plate with the carrier geotextile oriented downwards and the load was then applied. The setup was then sealed in two plastic bags and some water was sprayed between them to further reduce moisture losses from the specimen due to diffusion. The GCL specimens were hydrated for a period of 30 days in a temperature-controlled room (20°C ± 2°C).

2.2. **Measurement of soil potential using filter paper**

The principle of the filter paper test method is based on the moisture uptake by filter paper until there is a balance in potential between the filter paper and the soil [12]. The technique involved the use of filter papers in direct contact with the specimens, prepared according to Section 2.1 until suction equilibrium was attained. The filter papers were placed in contact with the specimens from the beginning of the hydration period (30 days) for the tests with powder bentonites. This choice was due to the difficulty of placing the filter papers between the dry powder bentonite and the acrylic plate. On the contrary, in the case of GCL samples, a stack of three filter papers was placed after hydration period. Subsequently, the specimens were kept for further 7 days for equilibrium after placing the filter papers, whereas, ASTM D5298 requires just 7 days of equilibrium period. Whatman Grade 42 filter papers were used throughout the experimental program. Besides, the total suction was measured on just GCL samples at 10% gravimetric water content. In this test, two filter papers were placed on GCL specimen, but isolated with the help of wire mesh, for 7 days after 30 days of hydration period (Figure 2). After the hydration and equilibrium period, the moisture content of the filter paper was measured according to the ASTM D5298, and the suction was calculated from the filter paper's moisture content using the pre-determined calibration curve specified in ASTM D5298.
2.3. Relative humidity sensor test

The relative humidity test was performed, for high total suction potentials, by relative humidity device “Model-Lascar EL-USB-2” equipped with relative humidity and temperature sensor. The sensor was inserted in the nested bags containing the specimens and activated on a computer. The sensor end of the relative humidity device was centered over the specimen surface (Figure 3). The sensor recorded relative humidity and temperature measurements every 5 minutes for a period of 12 hours which was typically enough time to attain humidity equilibrium in the plastic bag apparatus [8]. The suction was given by the following equation

$$h = -\frac{RT\rho}{M} \ln(R_h)$$

(1)

where,

- $h$ is suction in kilo Pascals (kPa),
- $R$ is the universal gas constant, which is equals to 8.31 Joule per mole kelvin ($J.mol^{-1}.K^{-1}$),
- $T$ is the temperature in Kelvin ($K$),
- $R_h$ is the relative humidity fraction,
- $\rho$ is the density of water in kilogram per cubic meter ($kg/m^3$) at temperature $T$ and $M$ is the molecular weight of the water, which is equals to 0.018 kilogram per mole ($kg/mol$).
3. Results and discussion
The section is divided into two parts. The first part highlights the powder WRC whereas, the second part explains the GCL WRC.

3.1. Powder soil water retention curve
The WRC of powder UC and HC relating to gravimetric water content are shown in figure 4. The volumetric water content was not calculated as the initial thickness was not measured to avoid sample disturbance. Both powder UC and HC presented increasing suction with decreasing water content. In general, high water content leads to relatively low suction. Besides, the moisture content is highly variable upon small changes in suction in both the samples. On the contrary, low water contents provide high suction values due to the small amount of water, which remained tightly adsorbed in the intra-aggregate voids and clay particle surfaces [13].

The figure shows comparable suctions at high water contents for both samples. This can be due to the diffuse double layer of both bentonites which is sufficiently open with the high amount of deionized water leading to osmotic swelling. The gravimetric water content sharply decreased increasing the suction for UC. On the contrary, the decrease of the gravimetric water content of HC was more gradual. Thus, for the same water content, the suction is greater in HC as compared to UC and hence more retained water potential. The more retention potential signifies the durability of healing and better control of shrinkage cracking. However, at low water contents, the water retention of the polymer treated clay and UC was approximately the same.

![Figure 4. Suction versus gravimetric water content of UC and HC](image)

3.2. Geosynthetic Clay liners soil water retention curve
The WRC of needle punched GCL prototypes are presented in figure 5, which illustrates the volumetric water contents versus GCL_UC and GCL_HC suction. The volumetric water content was calculated to consider the volume change after hydration. Indeed, it provided more reliable results compared to the gravimetric water content as it considered the change in thickness of the samples. Strong evidence of the improved performance of the GCL_HC compared to GCL_UC can be seen, which shows that the water retention trend is shifted towards higher volumetric water contents. The volumetric water content of GCL_HC was higher, or similar, compared to the one of GCL_UC along with the all range of suction values investigated. In other words, HC can retain more water compared to UC. The continuous curve was derived by fitting the available data with Fredlund and Xing equation [14]. It is evident from the figure that the curve breakpoint of GCL_HC corresponds to a suction value higher compared to that of
GCL_UC. The suction related to the curve breakpoint might be identified as the air-entry value of the wetting path WRC, after which the water started to be replaced by air. Furthermore, it can also be observed that the residual suction of conventional GCL is lower compared to the one containing the HC. Therefore, in the presence of high suctions and similar environmental conditions, GCL_HC is more capable of retaining water in its structure, leading to better rehydration and lower hydraulic conductivity. The irreversible adsorption of the polymer in the bentonite structure enhanced water adsorption likely increasing the diffuse double layer thickness. These findings provided further support to the hypothesis that the polymer treatment had a beneficial effect on the swelling and hydraulic performance of bentonite liners [4]. Undoubtedly, this study demonstrated the improved adsorption and retention capacity yielded by the HC technology. A comparison with the water retention behaviour, reported by [15], is presented in figure 6 in terms of volumetric moisture content versus suction, which highlights the published values of the drying and wetting curves of a needle-punched GCL_UC.

In general, this comparison indicated that the results obtained in the present study for GCL_UC were lower than the ones obtained by Beddoe et al. (2011) [15]. The relationship between volumetric water content and suction is likely similar at high suctions. The different performance might be related to the test procedure and the possibility of sample disturbance in picking and placing the filter papers for the next targeted water content which might have disturbed the distribution of the pores and affected the results. Therefore, additional tests with more controlled conditions are required to validate these results.

Figure 5. Volumetric water content versus suction of GCL_UC and GCL_HC
Figure 6. Comparison of the results obtained in this study with the results published by Beddoe et al. (2011) [15]

3.3. GCL total suction
The total suction represents the combine negative potential of osmotic and matric suction. The total suction of GCL_UC and GCL_HC at 10% gravimetric water content is displayed in figure 7. It can be observed from the figure that the total suction of GCL_HC is more than GCL_UC attributed to higher matric suction since the water of same electrical conductivity was used in both the samples depicting same osmotic potential. Furthermore, the suction measured by the humidity sensor is higher than that of filter paper due to high sensitivity of measurements involved in filter paper test. Besides, with increasing suction beyond 100,000 kilo Pascals, the humidity sensor was preferred to use due to increasing accuracy as compared to filter paper test, which needs further investigation [16].

Figure 7. Total suction of GCL_UC and GCL_HC at 10% gravimetric water content
4. Conclusion
This study has several practical implications. Firstly, it demonstrated the enhanced retention capacity of the HC. Secondly, the residual volumetric water content of HC was higher compared to UC at a given suction. Finally, the current data provided insight into the understanding of the hydraulic performance of HC. Therefore, HC might be considered as a potential alternative to conventional bentonites due to its improved water retention capacity. This feature is of importance especially in the presence of unsaturated conditions and the occurrence of wet and dry cycles. Indeed, bentonite liners must act as a barrier against the passage of solutes and being able to withstand environmental changes, such as wet and dry cycles, for a longer period.

This research sets the basis for future studies on the moisture-suction behaviour of HC. In this framework, the drying path, the influence of electrolyte solutions, modification/changes in methodology, and the impact of wet and dry cycles on the constitutive relationship between moisture and suction need to be investigated.

References
[1] Bouazza A 2002 Geosynthetic clay liners Geotextiles and Geomembranes 20 3-17
[10] Beddoe R, Take W and Rowe R 2010 Development of suction measurement techniques to quantify the water retention behaviour of GCLs Geosynthetics International 17 pp 301-12