Influence of the type of bentonite of GCLs on the transmissivity at GCL-geomembrane interfaces

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ABSTRACT: In municipal solid waste landfills, the Geosynthetic Clay Liners (GCLs) can be installed as a passive barrier and they are usually associated with a geomembrane (GM) which composes the active barrier. The use of a GCL associated with a geomembrane will limit the flow rate through the composite liner in case of damage in the geomembrane. When the GCL is hydrated and confined it presents good properties of sealing which vary according to the nature of the composing bentonite: in previous studies it was verified that hydraulic conductivity of GCLs containing calcium bentonite was greater than that the one of GCLs containing sodium bentonite. Based on that, this work aimed at investigating if the bentonite nature can influence the transmissivity in the interface between a GCL and a geomembrane in the way it can influence the hydraulic conductivity of the GCLs. Transmissivity tests were performed with a geomembrane (smooth HDPE, 2mm thick) with a 4 mm diameter puncture and GCLs coming from two manufacturers containing calcium or sodium bentonites. The test results show that for the materials studied, the bentonite nature and the GCL bonding process cannot influence the transmissivity at the GM-GCL interface as it can influence the hydraulic conductivities of GCLs.

1 INTRODUCTION

Geomembranes (GM) and Geosynthetic Clay Liners (GCLs) are often used in the base liners of municipal solid waste to accomplish function of liquid barrier. The small thickness of typical geomembranes make them susceptible to damages (Rowe 2007) which can occur even when a Construction Quality Control (CQC) and a Construction Quality Assurance (CQA) are employed (Bouazza et al. 2002). An underlining GCLs is often installed underneath the geomembrane, composing a passive barrier in order to reduce the leakage in case of damage in the geomembrane (Touze-Foltz et al. 2008)

GCLs are generally composed by a bentonite layer bonded by one or two geosynthetic layers (geotextiles or geomembranes). These layers are bonded together by adhesive, stitch bonding or needle punching. When confined and hydrated, GCLs exhibit very low hydraulic conductivities, with their performance depending, in most cases, of the bentonite (Bouazza 2002).

Several studies were conducted to investigate the most important factors witch influence the flow rate through the interface between a GM and the underlying GCL. Harpur et al. (1993) studied the influence of the GCLs features on the flow rate through composite liners. They verified that GCLs composed by granular bentonite bonded by adhesive to a carrier geomembrane (no geosynthetic covering the GCL) presented the lowest transmissivity compared to other GCLs composed by a bentonite core encapsulated between two geotextiles. In terms of type of bentonite, powdered or granular, they observed a better performance of powdered bentonite. The only GCL composed by a non woven geotextile at the upper surface presented transmissivity values still comparable to the other GCLs tested. Since the damaged geomembrane was in contact with a nonwoven geotextile, a higher transmissivity would be expected, what did not occur due to impregnation of powdered bentonite in this geotextile. As observed by Palmeira & Gardoni (2000), Gardoni & Palmeira (2002) and Palmeira & Gardoni (2002), stress levels and impregnation by bentonite might influence the permittivity and transmissivity of the geotextile cover layer of the GCL.

Barroso et al. (2006) also studied the influence of the GCL features on the GM-GCL interface transmissivity. Contrarily to the observations from Harpur et al. (1993), the results suggest that the type of bentonite, powdered or granular, has little influence on the flow rate though the composite liner.

In terms of hydraulic conductivity (flux normal to the GCL plane) Guyonnet et al. (2005) observed that GCLs composed by natural sodium bentonite performed better than GCLs composed by activated calcium bentonites. Other studies also showed the influence of the bentonite nature on the hydraulic conductivity of GCLs (Gleason et al. 1997, Guyonnet et al. 2009). According to Egloffstein (2002), natural sodium or activated calcium bentonites presents a more advantageous fine-dispersed microstructure compared to natural calcium bentonites while natural calcium bentonites present a more aggregated structure.

Based on the influence of the nature of the bentonite on the hydraulic conductivity, this work aims at verifying if the nature of the bentonite composing the GCLs can influence significantly the flow rate through a composite liner and the transmissivity at the GM-GCL interface.

2 MATERIALS AND METHODS

2.1 *Equipment*

Transmissivity tests were performed with the equipment presented in Figure 1 which was specially designed to measure the flow rate through a mechanical defect in a geomembrane overlying a geotextile or GCL with a compacted clay liner (CCL) as the bottom layer. The equipment was previously used by Touze-Foltz (2002), Touze-Foltz et al. (2002), Cartaud and Touze-Foltz (2004) and Barroso et al. (2006). It consists in a two parts perspex cell with internal diameter equal to 200 mm, a bottom plate and a top coarse drainage layer. The soil layer (CCL) is compacted in the bottom cylinder with the upper surface contacting a rigid metallic plate to ensure a smooth surface in contact with the GCL, which is also accommodated inside the bottom cylinder. A geomembrane with a circular defect at its centre overlies the GCL. The upper cylinder accommodates the top coarse drainage layer which is overlying the geomembrane. Both cylinders are linked to each other with bolts and the experimental setup is placed in a loading machine for application of a 50 kPa confining stress.

The upper cylinder was connected to a distilled water reservoir which supplied the cell during the first hours of testing, when relatively high flow rates are observed. When the flow rates decreased, the reservoir was replaced by a Mariotte bottle. Both provided water supply at a constant hydraulic head equal to 0.3 m.

The flow rates through the geomembrane defect were measured for approximately 250 to 300 hours which was found to be a sufficient period to reach steady state conditions of flow (Barroso et al. 2006).

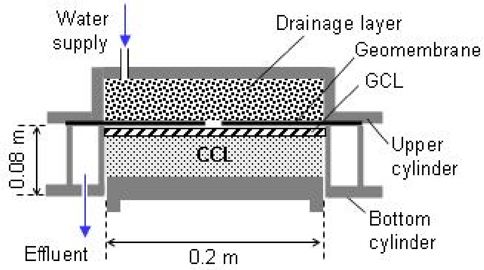

Figure 1. Test apparatus

2.2 *Materials tested*

2.2.1 *Geomembrane*

A high density polyethylene (HDPE) smooth geomembrane 2 mm thick was used in the tests. The specimens exhibited a central 4 mm diameter defect.

2.2.2 *Geosynthetic Clay Liners (GCL)*

Four GCLs coming from two different manufacturers were tested. Table 1 present the main features of the GCLs studied. GCLs coming from the first manufacturer were composed by a powdered bentonite core encapsulated between two layers of a polypropylene woven geotextile (with 110 g/m^2 of mass per unit area) which were stitch bonded together (SB). GCLs from the second manufacturer were composed by a polypropylene woven geotextile (100 g/ m^2 of mass per unit area) as the carrier material, a granular bentonite core and a polypropylene non woven geotextile (200 g/ m^2 of mass per unit area) as the covering material. The layers were bonded by needle punching (NP). For both manufacturers the type of bentonite was either natural sodium (Na) or natural calcium (Ca).

Table 1. Main features of the GCLs tested

	SB-Na	SB-Ca	NP-Na	NP-Ca
Type of bentonite	Natural Sodium	Natural Calcium	Natural Sodium	Natural Calcium
Thickness under 10kPa (mm)	7.0	11.7	7.7	8.4
Mass per unit area (g/m^2)	5410	10590	7400	5730
Hydraulic Conductivity* (m/s)	$3.2x10^{-11}$	$6.9x10^{-10}$	$1.6x10^{-11}$	$5.8x10^{-8}$
Bonding process	Stitch bonding	Stitch bonding	Needle punching	Needle punching

* NF P 84-705 (AFNOR 2008)

2.2.3 *Compacted Clay Liner (CCL)*

The CCL was composed by a soil proceeding from a landfill located in the western region of Portugal, the main features of which are presented in Table 2 (Barroso et al. 2006). Approximately 4.5 kg of soil with a gravimetric moisture content of 12% was compacted in three lifts 1.5 kg each inside the bottom cylinder of the cell. The final thickness of the CCL in the cell was 60 mm.

Table 2. Main features of the soil composing the CCL.

Atterberg Limits			Modified Procto r		Hydraulic Conductivity (m/s)
LL (%)	LP (%)	PI (%)	w_{opt} (%)	$\gamma_{d\,max}$ (%)	
54.2	23.7	30.5	13.6	19.1	$8x10^{-11}$

3 RESULTS OBTAINED

3.1 *Flow rates through the composite liners*

The tests performed simulated a composite liner with a geomembrane overlying a GCL on top of a CCL. Figure 2 presents the flow rates versus time for composite liners using the GCLs described above. Similar curves were obtained for all GCLs tested, whichever was their bentonite nature or the bonding process.

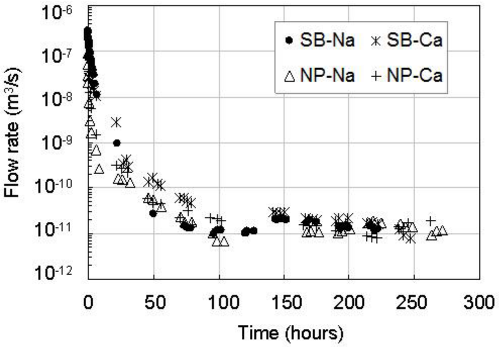

Figure 2. Flow rate versus time of the composite liners

In the beginning of the tests, the flow rates were relatively high, ranging between 10^{-7} and 10^{-6} m^3/s and a significant decrease of three orders of magnitude was observed in the first 50 hours of test. The water passing through the geomembrane puncture, did not find much difficulty to flow along the GM-GCL interface in the very beginning of the test, when the bentonite is still dry, but while this water began to hydrate the GCL, yielding to the bentonite expansion, the gap between the geomembrane and GCL was strangled and consequently the flow decreased. The flow rate continued decreasing slowly until reaching the steady state, approximately 200 hours after the beginning of the tests, reaching a final flow rate of approximately 10^{-11} m^3/s.

3.2 *Interface transmissivity*

The values of interface transmissivity were calculated using the analytical solution proposed by Touze-Foltz et al. (1999) which assumes that (i) the interface of flow rate is uniform; (ii) the flow rate in the interface is radial; (iii) the flow occurs in a steady state condition; (iv) The CCL, GCL and GM-GCL interface are saturated; (v) the flow rate through the passive barrier (CCL+GCL) is one-dimensional and vertical.

For the boundary conditions of the present work, where the hydraulic head is null in a distance *R* from the geomembrane defect (where *R* is the cell radius), Equations 1 to 4 can be used to determine the GM-GCL interface transmissivity.

$$Q = \pi r_0^2 k_s \frac{h_w + H_s}{H_s} - 2\pi r_0 \theta \alpha \left[A I_1(\alpha r_0) - B K_1(\alpha r_0) \right] \quad (1)$$

Where: Q is the flow rate in steady-state conditions; r_0 is the puncture radius of the defect in the geomembrane; k_s is the equivalent hydraulic conductivity of the passive barrier (CCL + GCL); h_w is the hydraulic head; H_s is the thickness of the passive barrier; θ is the GM-GCL interface transmissivity; $I1$ and $K1$ are modified Bessel's functions of first order and α, A and B are parameters given by Equations 2 to 4:

$$\alpha = \sqrt{\frac{k_s}{\theta H_s}} \quad (2)$$

$$A = \frac{h_w K_0(\alpha R) + H_s\left(K_0(\alpha R) - K_0(\alpha r_0)\right)}{K_0(\alpha r_0) I_0(\alpha R) - K_0(\alpha R) I_0(\alpha r_0)} \quad (3)$$

$$B = \frac{h_w I_0(\alpha R) + H_s\left(I_0(\alpha R) - I_0(\alpha r_0)\right)}{K_0(\alpha r_0) I_0(\alpha R) - K_0(\alpha R) I_0(\alpha r_0)} \quad (4)$$

Where: K_0 e I_0 are modified Bessel functions of zero order and R is the wetted area radius which, in the present work, is equal to the internal radius of the cell.

Table 3 presents the hydraulic conductivity of each GCL, the equivalent hydraulic conductivity of the passive barrier (GCL+CCL), the flow rates in steady state measured in the tests performed as well as the transmissivity values back calculated by the analytical solution presented above. Despite the three order magnitude difference among the hydraulic conductivities of the GCLs studied, the flow rates at steady state were in the same order of magnitude as well as the GM-GCL interface transmissivity. Indeed, the behaviour of the passive barrier cannot be directly associated with the hydraulic conductivity of the GCL, i.e. the nature of the bentonite did not influence the GM-GCL interface transmissivity (liquid flow along the plane) as well as it can affect the hydraulic conductivity of the GCL (liquid flow normal to the plane).

Table 3. Flow rates and transmissivity values

GCL	k_{GCL} (m/s)	k_{EQ} (m/s)	Q measured (m^3/s)	θ analytical solution (m^2/s)
SB-Na	$3.2x10^{-11}$	$6.9x10^{-11}$	$1.3x10^{-11}$	$2.6x10^{-11}$
SB-Ca	$6.9x10^{-10}$	$9.4x10^{-11}$	$1.4x10^{-11}$	$2.8x10^{-11}$
NP-Na	$1.6x10^{-11}$	$5.5x10^{-11}$	$1.2x10^{-11}$	$2.4x10^{-11}$
NP-Ca	$5.8x10^{-8}$	$9.3x10^{-11}$	$1.5x10^{-11}$	$3.0x10^{-11}$

4 CONCLUSIONS

This work was dedicated to verifying the influence of the GCLs features on the flow rate through composite liners and the transmissivity at the GM-GCL interface. Tests performed to measure the flow rate through liners composed by different types of GCLs showed no significant different behaviour among the GCLs tested whichever was the type of bentonite or the bonding process. The transmissivity values of the GM-GCL interface, back calculated with the analytical solution, were also similar for the four configurations tested. These results show that the type of bentonite, which influences markedly the hydraulic conductivity of the GCLs, has not the same impact on the transmissivity at the interface between the geomembrane and the GCL in a composite liner. It should be pointed out, however, that these results were obtained for specific conditions of testing (50 kPa of confining stress, 0.3 m of hydraulic head and 4 mm diameter defect in the geomembrane) therefore they should not be extrapolated to other conditions.

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