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Experimental investigation of flow rates through composite liners at the metric scale

Touze-Foltz, N.
Cemagref, HBAN Unit, France

Barroso, M.
Laboratório Nacional de Enghenaria Civil, Portugal

Cartaud, F.
Scétauroute, France

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ABSTRACT: The hydraulic behaviour of 17 composite liners was investigated at the metric scale in the laboratory using 1 m diameter cells. A 0.27 m thick layer of clay was compacted in all cells. In 12 cases a geotextile was inserted at the interface between the clay and the HDPE geomembrane. In 3 cases a GCL was used under the geomembrane and in 2 cases the clay was in direct contact with the geomembrane. The influence of a geotextile in the interface was deeply investigated as it corresponds to a common practice in France and its real impact is unknown. A 4 mm diameter hole was drilled in the flat HDPE geomembrane in all experiments. The hydraulic head on top of the composite liner was equal to 0.3 m in all cases. Normal stresses in the range 6 to 134 kPa were used. The longest tests, that did not include geotextiles, lasted up to 9 months. The liquid used was either real leachate, a low ionic strength solution or distilled water. Flow rates were measured at the upstream side of the composite liners. In the case GCLs were used, the influence of the pre-hydration of the GCL at the beginning of the test was studied when the liquid used was real leachate. When comparing situations where geotextiles and GCLs were used, results tend to show that even if GCLs incorporate a geotextile the flow rates obtained with GCLs are clearly lower that flow rates obtained in the case there is a geotextile in the interface, even when the geotextile is not fully saturated. Flow rates obtained with clay and GCLs, measured with identical devices and under comparable normal stresses are comparable.

1 INTRODUCTION

Most landfill regulations require the use of a compacted clay liner (CCL) overlaid by a geomembrane (GM) for municipal solid waste (MSW) landfill bottom liners. In case no clay is available, some regulations allow the use of geosynthetic clay liners (GCLs) over a soil liner, more or less permeable provided that equivalence towards advective and diffusive transfers is demonstrated. The French regulation does not allow the full replacement of the 1 m thick CCL required by a GCL. Rather, the partial replacement of the CCL by a GCL is allowed. Following, GCLs are always associated to CCLs under GM of landfill bottom liners. In case no GCL is used, installers often use a geotextile (GT) at the CCL surface in order to prevent the GM from puncturing by the CCL and to make the seaming process easier. The question then arises of the hydraulic performance of the different types of composite liners in case the geomembrane is damaged. To investigate this point 17 liners were reconstituted in the laboratory at the metric scale. Results obtained will be presented and discussed in Section 4 of this paper, after a brief presentation of materials and methods in Section 2 and of the experimental program in Section 3.

2 MATERIALS AND METHODS

2.1 *Composite liners studied*

Three different kinds of composite liners were studied:

- GM/GCL/CCL composite liners;
- GM/GT/CCL composite liners; and
- GM/CCL composite liners.

2.2 *Geosynthetics*

A smooth 2 mm thick HDPE geomembrane was used in all composite liners.

The two GCLs used were natural sodium bentonite core sandwiched between a slit-film polypropylene woven geotextile and a polypropylene staple fiber non woven geotextile. Bentonite was granular in GCL1 and powdered in GCL2. Dry bentonite mass per unit area were 5.3 kg/m^2 and 4.67 kg/m^2 respectively for GCL1 and GCL2 with an initial water content equal to 9% and 9.5% with respect to dry weight respectively for GCL1 and GCL2. They were supplied by different manufacturers.

Three different geotextiles were used based on an enquiry reported by Cartaud et al. (2005) on the geotextile types used at the GM/CCL interface. The first one (GA) was the most frequently cited in the enquiry, with a mass per unit area equal to 300 g.m^{-2}. GB was also a non-woven needlepunched geotextile, 330 g.m^{-2} supplied by a different manufacturer. Finally, GC was a thin non-woven thermal-bonded geotextile, 130 g.m^{-2}.

2.3 *Soils*

Three different soils were used in this study. The first one called S1 was a mix of fine sand and clayey loam, 50% in dry mass each, which hydraulic conductivity was close to 10^{-9} m/s. The second one called S2 was a clayey soil coming from a Portuguese landfill (Barroso 2005) with a hydraulic conductivity measured to be 3×10^{-10} m/s. S1 and S2 were used in combination with GCL1 and GCL2 respectively. S3 was a dark clayey soil from a French MSW with a hydraulic conductivity equal to 2×10^{-10} m/s.

2.4 *Fluids*

Three different fluids were used:

- a low ionic strength NaCl solution (10^{-3} Molar) used as a pre-hydration fluid for GCL1 and noted PF;
- a real leachate (RL) sampled in the leachate collection pond of a French MSW landfill in operation for approximately 15 years (Guyonnet et al. 2005); and
- deionized water (DW).

2.5 *Methodology for flow measurement*

The experimental test set up was made of three identical 1 m diameter cells previously described by Cartaud et al. (2005) and presented on Fig. 1. The cells consist of three parts: (a) a bottom part with a round base plate fixed on the beam of a hydraulic press that applies the confining stress; (b) an intermediate 1 m diameter cylinder fixed on the base plate for accommodating the soil liner; and (c) an upper cylinder, 25 cm high, to accommodate the granular layer.

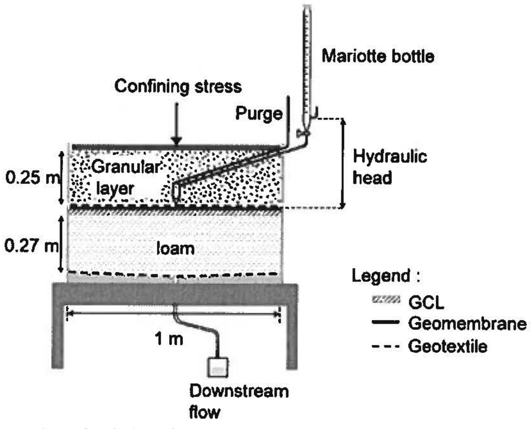

Figure 1. Principle of test columns in the case of a CCL/GCL/GM composite liner (Based on Barroso 2005).

The CCL (either S1, S2 or S3) was carefully compacted in 4 lifts using a light hammer. Its total thickness was 0.27 m. In the case of S3, never used in association with a GCL, the CCL surface was moulded using the protocol described by Cartaud et al. (2005) in order to get a CCL surface representative of in-situ compaction processes (See Fig. 2). Following, a GCL with the non woven GT on top or a GT either initially dry or hydrated, was placed above the CCL.

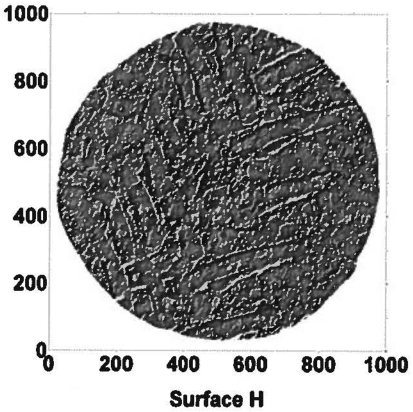

Figure 2. Shaded relief imaging of the rugosimetry data from the CCL surface molding (after Cartaud et al. 2005).

The GCL hydration was performed by immersion in PF during two hours and a half, without load. This time was necessary for the specimen to reach a gravimetric water content equal to 100%. This corresponds to recommendations given by the French Chapter of IGS as regards the minimum water content of the GCL to achieve prior to contact with leachate (Comité Français des Géosynthétiques 1998).

Then, a geomembrane specimen having a 4 mm diameter circular defect at its centre was installed above the GCLs, CCLs or GTs. A special "Y" connection was glued over the discontinuity in the geomembrane. Two pipes were then inserted in this connection, one connected to a Mariotte bottle to perform flow rates measurements and the other one used as a purge. A 828 g/m^2 geotextile was placed above the GM to protect it against puncturing by the gravel layer, 25/35 mm. Then, a stainless steel plate was placed above the gravel layer and a normal stress in the range 6 to 134 kPa was applied by the hydraulic press. Finally, the liquid supply was activated and the tests started. The tests were carried out with a hydraulic head equal to 0.3 m.

The evaporation was recorded in a 4 mm diameter vertical pipe located in the vicinity of the test device In order to check that the fluid level decrease in the Mariotte bottles was actually due to flow through the liner.

3 EXPERIMENTAL PROGRAM

Table 1 is a synthesis of the experimental conditions of the 17 hydraulic tests performed.

Table 1. Synthesis of tests performed.

Test number	Soil liner	GCL or GT	Liquid	Load (kPa)	Flow rate (m^3/s)
1	S1	GCL1	PF + RL	50	1×10^{-12}
2	S1	$GCL1_{PH}$	PF + RL	50	6×10^{-12}
3	S2	GCL2	DW	50	2.7×10^{-12}
4	S3	–	DW	6	7×10^{-6}
5	S3	–	DW	64	5×10^{-12}
6	S3	GA	DW	64	1×10^{-9}
7	S3	GA_{PH}	DW	64	5×10^{-8}
8	S3	GB	DW	64	4×10^{-8}
9	S3	GB_{PH}	DW	64	4×10^{-8}
10	S3	GC	DW	64	1×10^{-9}
11	S3	GC_{PH}	DW	64	1×10^{-9}
12	S3	GA	DW	134	9×10^{-10}
13	S3	GA_{PH}	DW	134	2×10^{-7}
14	S3	GB	DW	134	2×10^{-8}
15	S3	GB_{PH}	DW	134	2×10^{-8}
16	S3	GC	DW	134	1×10^{-9}
17	S3	GC_{PH}	DW	134	1×10^{-9}

$_{PH}$: pre-hydrated; PF: pre-hydration fluid; RL: real leachate; DW: deionized water

3.1 *GM/CCL composite liners*

Tests 4 and 5 were performed using S2 compacted according to the experimental protocol described by Cartaud et al. (2005). A moulding process was used in order to obtain a CCL surface similar to the one depicted on Fig. 2. For a very low normal stress equal to 6 kPa, the interface between the GM and CCL is widely opened. Consequently, a large flow rate was measured, equal to 7×10^{-6} m^2/s. This flow rate does not correspond to infiltration into the CCL during the 2 hours of experiment but rather to flow at the outlet of the cell where free flow is allowed. Under 64 kPa, the flow rate, plotted in Fig. 3 was very small and a period of 4 months was required to monitor the flow evolution. Steady-state flow stabilized at a rate close to 5×10^{-12} $m^3.s^{-1}$. Another flow feature observed during the experiments was the time at which the liquid appeared at the periphery of the interface. Under 6 kPa, the fluid appeared about 1 minute after starting the test whereas under a normal stress of 64 kPa, no flow was observed at the cell outlet within the 4 months of the test. These results show that even for the case of a CCL surface representative of in situ conditions, very low flow rate can be obtained, similar to those obtained when a GCL is incorporated to the composite liner.

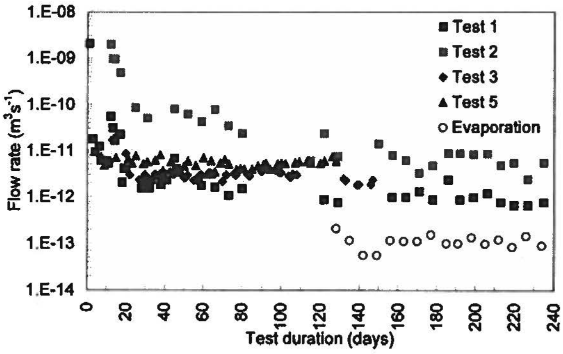

Figure 3. Temporal evolution of flow rates measured for tests 1, 2, 3 and 5 as compared to evaporation.

3.2 *Influence of a GT in the interface*

Flow rates were performed during 8 hours as this was approximately the time required to reach a steady-state flow.

The impact of the GT pre-hydration prior to installation into the cell was studied. Pre-hydration did not impact the behaviour of GB and GC, whatever the normal stress applied, whereas flow rates obtained with GA in the interface were deeply impacted by the pre-hydration as shown in Table 1 and Fig. 4. According to Cartaud et al. (2005) these results are linked to the retention curves of the GT studied and following their ability to hydrate or dehydrate. These results show evidence that geotextiles having similar macroscopic features do not necessarily behave hydraulically in the same way.

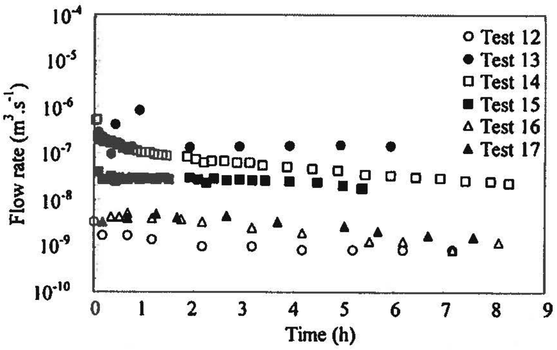

Figure 4. Flow rate in composite liners as a function of the geotextile used in the interface, under a 134 kPa normal stress.

3.3 *Behaviour of composite liners containing a GCL*

Figure 3 shows results obtained in tests 1, 2 and 3 involving GCLs.

The first observation that can be made is that 4 months were necessary in each case to reach steady-state. Flow rates measured are for all three tests significantly greater than the evaporation measured in the laboratory during the testing period thanks to a plastic pipe similar to the one used for the purge. Consequently, flow rates measured are significant and represent a real infiltration into the composite liners. Flow rates measured at steady–state are approximately equal to 10^{-12} m^3/s for test 1 whereas the mean flow rate test in T2 is close to 6×10^{-12} m^3/s. The higher flow rate obtained on this latest column is supposed to be linked to the mode of pre-hydration of GCL1 for test 2, without load. Indeed, Petrov et al. (1997) showed evidence that the pre-hydration under load was leading to lower bulk void ratios, and that lower bulk void ratios lead to lower hydraulic conductivities. Results presented here show the detrimental effect of pre-hydration without load on the resulting flow rate in the composite liner.

A comparison of results obtained in tests 1 to 3 shows that they are in the same range, which means that on the scale time of the study performed the percolation of RL does not impact the flow as compared to DW. A deep comparison of the results cannot be undertaken as the constitution of Test 3 differs from the one of tests 1 and 2 as regards the GCL and CCL used.

3.4 *Comparison of flow rates obtained in the presence of a geotextile and a GCL*

In tests incorporating GA initially dry, GC and GCLs, no flow was ever noticed at the cell outlet during the test duration. As a result, flow rates measured are only due to infiltration into the composite liners.

Different behaviours were observed for composite liners incorporating either single GT or GT that were part of GCLs. Indeed in the case of single GT, steady-state was achieved in about eight hours in all cases, and the lowest flow rates measured with needlepunched GT were 10^{-9} m^3/s.

On the contrary for all composite liners incorporating GCLs, 4 months were necessary to reach steady-state. Furthermore, flow rates obtained at steady-state ranged between 1×10^{-12} and 6×10^{-12} m^3/s making it clear that GT behave in the different way whether used alone or as part of a GCL. Possible explanations for this phenomena are bentonite extrusion in the geotextile, and the potential for swelling of the natural sodium bentonite especially when confined thus potentially reducing the in plane flow capacity of the geotextile. Further research is needed to investigate these possible explanations.

4 CONCLUSIONS

The hydraulic behaviour of composite liners at the metric scale was investigated for various types of composite liners. Results tend to show that if large flow rates can be obtained for GM/CCL composite liners in case of very low normal stresses, flow rates obtained under 64 kPa are in the same range as flow rates obtained in case the CCL is covered by a GCL.

The impact of the geotextile on the flow rate depends on whether it is used on its own on the CCL or as part of a GCL. Significantly larger flow rates were obtained in the case a GT was set at the interface, as compared to the case of a CCL alone or a CCL/GCL soil liner.

The impact of the GT also depends on its fabric.

Results also show that pre-hydrating the GCL without load results in a flow rate six times greater than in the case the GCL is not pre-hydrated prior to liquid percolation.

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