Effect of the waste pressure on fluid migration through geomembrane defects

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ABSTRACT: Composite liners consisting of a geomembrane (GM), with a circular hole, a geosynthetic clay liner (GCL) and a compacted clay liner (CCL) were studied through laboratory tests. Flow rates at the interface between the GM and the GCL were measured and the correspondent interface transmissivities were calculated. The tests conducted aimed at studying the influence of the waste pressure on flow rates through composite liners due to defects in the GM. Several confining pressures, ranging from 25 to 200 kPa, were used. Results obtained indicate that, for the range of pressures used, the increase in waste pressure has a slight influence on flow rate and on correspondent interface transmissivity.

1 INTRODUCTION

Landfills are designed with a barrier system intending to control contaminant movement from any waste facility to levels that will result in negligible impact to the environment. In Portugal, this system typically includes a geomembrane (GM), a geosynthetic clay liner (GCL) and a compacted clay liner (CCL).

The effectiveness of composite liners in service conditions is closely related with the performance of the GM, as it provides the primary barrier to advective and diffusive transport of contaminants.

Critical issue on the performance of the GM is the unavoidable defects, occurring mainly due to inadequate construction activities, such as, puncture by stones, imperfect connections between GM and appurtenances, improper seaming, tears, cuts, etc.

Defects in the GM represent preferential advective flow paths for leachate migration, with the potential contamination of the subsurface (Rowe 1998, Touze-Foltz et al. 2008). Monitoring data collected in landfills constructed with double composite liner systems confirm that migration of leachate occurs (Majdi et al. 2002). Similar findings were reported by Figueiras et al. (2009), based on indirect measurements achieved through geophysical methods.

The impact of the defects in the GM can be minimised by proper design of the landfill liner. It is thus of primary importance to predict the flow rate through composite liners due to the existence of defects in the GM.

There are several parameters that influence the flow rate, such as the contact condition between the GM and the underlying liner (GCL or CCL), quantitatively expressed by the interface transmissivity, the shape and dimensions of the defect, the permeability and the thickness of the underlying liner, the hydraulic head above the GM and the effective confining pressure over the GM.

Although there have been several studies for determining the flow rate through composite liners consisting of a GM, a GCL and a CCL (e.g. Estornell & Daniel 1992, Harpur *et al.* 1993, Koerner & Koerner 2002, Barroso *et al.* 2006, 2008), the influence of pressure applied by the waste on the flow rate and on the interface transmissivivity requires further investigation. Thus, the purpose of this study was to ascertain the influence of the waste pressure on fluid migration.

Laboratory tests for measuring the flow rate at the interface between the GM and the GCL were conducted with six different confining pressures. Based on final flow rates, interface transmissivities were calculated.

2 MATERIALS AND METHODS

2.1 *Compacted clay liner*

The soil used in the experimental work came from a landfill located at the West of Portugal, from continental deposits of sedimentary Jurassic and Cretaceous formations. This soil was previously characterized by Barroso et al. (2006, 2008). Measured hydraulic conductivity of this soil was about 3×10^{-10} m^2/s.

2.2 *Geosynthetics*

A commercially available GCL was used in this study. It consisted of a layer of natural sodium bentonite powder supported by two geotextiles (GTX), held by needlepunched. The upper GTX, made of polypropylene (PP) fibres, was a nonwoven with 220 g/m^2, and the lower GTX, made of PP fibers, was a woven with 110g/m^2. The total mass per unit of area was equal to 5000 g/m^2. The values of hydraulic conductivity were estimated for the different confining pressures, based on results presented in Barroso (2005), except for 50 and 200 kPa, which were estimated based on ASTM D 5887. In overall terms, it ranged from 1.1×10^{11}, at 200 kPa, to 5.1×10^{-11} m^2/s, at 25 kPa.

As for the GM, a smooth one, HDPE, 2 mm thick, was used.

2.3 *Test method*

The tests were carried out in a circular Plexiglas cell designed to measure the flow rate through composite liners, which was already described by Touze-Foltz (2002). In brief, it includes a bottom plate for supporting the compacted soil layer, a base cylinder for accommodating the CCL and the GCL, a granular cover plate to simulate the presence of a granular drainage layer, and an upper part that accommodates the granular cover plate.

The test method is detailed in Barroso et al. (2006, 2008). Briefly, first, the soil was compacted inside the base cylinder. Then, the GCL specimen was placed on top of the soil, with the nonwoven GTX on top, and, above it, a GM specimen, with a circular hole (3 mm in diameter) at its centre. Next, the granular cover plate was placed above the GM. The cell was then closed and installed in a mechanical press, where the required confining pressure was applied (25, 50, 75, 100, 150 and 200 kPa). Finally, the top cell was connected to a water supply reservoir, which fed the test during the first hours, when the water flow through the composite liner was large. When the water flow decreased, the water reservoir was replaced by a Mariotte bottle that is more accurate at low flows. All tests were conducted with a hydraulic head equal to 0.3 m (constant head tests). This value was chosen because it represents the maximum allowable leachate above the GM in most landfill regulations.

Each test (Figure 1) was run for a minimum period of 18 days. The tests were ended after the steady-state was reached.

The flow rate was calculated in two different ways: when the radial flow rate at the downstream side of the interface (effluent) was high enough to be measured by weighing, the flow rate was obtained by dividing the volume of effluent collected by the collecting time. When very low or no flow rates could be measured in this way, the total flow rate was calculated based on the volume change of water inside the Mariotte bottle over the time interval.

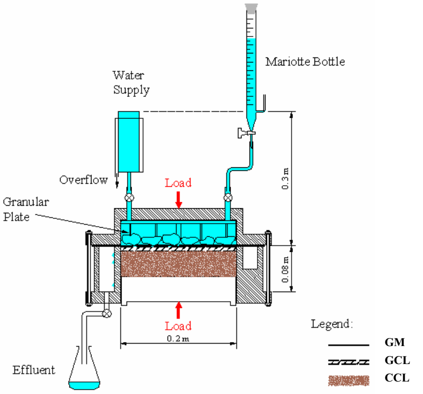

Figure 1. Scheme of the test apparatus (Barroso et al. 2006)

3 RESULTS

Figure 2 presents the evolution of flow rate for the tests conducted under different confining pressures. In order to reduce the scatter on flow measurements, the total flow rate was generally recalculated on a 24 hours basis. Also, values of flow rates contain the error bars corresponding to the uncertainty of measurement (uncertainty calculations are detailed in Barroso 2005).

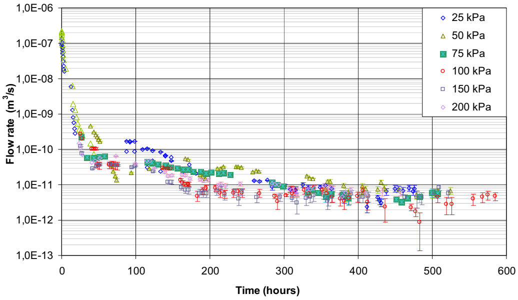

Figure 2. Evolution of the flow rate in the tests conducted with different confining pressures

It can be seen that, in overall terms, there is a discrepancy in the flow rates at the beginning of the tests, with the low confining pressures presenting higher flow rates than low confining pressures. However, the difference decreases over the test. Final flow rates, computed by averaging the last three consecutive flow measurements over a minimum time period of 36 hours, ranged less than half order of magnitude, which, by taking into account the uncertainties associated to these measurements, can be considered a slight difference.

Interface transmissivities (Table 1) were also estimated based on the final flow rates obtained. This property can be estimated by using analytical solutions, such as the ones given by Rowe (1998) or by Touze-Foltz et al. (1999), assuming that the GCL, the underlying liner and the interface are fully saturated, as well as that the flow at the interface is axisymmetric. In this study, the analytical solution given for the case where there is no radial flow at a radius distance equal to the radius of the wetted area (area wetted by the interface flow) was used.

Table 1 – Interface transmissivities

Test	Confining pressure (kPa)	Final flow rate (m^3/s)	Radius of wetted area (m)	Transmissivity (m^2/s)
1	25	7.3×10^{-12}	0.1*	1.4×10^{-11}
2	50	6.2×10^{-12}	0.1*	1.1×10^{-11}
3	75	5.1×10^{-12}	0.093**	9.0×10^{-12}
4	100	4.4×10^{-12}	0.092**	7.8×10^{-12}
5	150	4.8×10^{-12}	0.1*	9.0×10^{-12}
6	200	6.1×10^{-12}	0.1*	1.2×10^{-11}

* assumed to be equal to the radius of the physical test model.
** estimated based on Rowe (1998).

As can be seen, variations on interface transmissivities are slight for the confining pressure used in this study.

4 DISCUSSION

4.1 *Influence of the confining pressure*

Results obtained suggest that the increase in waste pressure has a negligible influence on flow rate and on the correspondent interface transmissivity, for the confining pressures investigated. This trend appears to be related to the expansion of the bentonite within the GCL. The bentonite swelled as much as the confining pressure allowed, which resulted in the creation of a close contact between the GM and GCL, or, in the sense of Giroud & Bonaparte (1989), of perfect contact conditions, that, in practice, leads to small variations in interface transmissivity.

Although the contact conditions between the GM and GCL appear to have been always perfect, the behaviour of the GCL was different, depending on whether the confining pressure was below or above 100 kPa. To understand this issue, one has to be aware of the behaviour of clay minerals of smectite group, where bentonite is included.

Briefly, the clay minerals of smectite group, due to an extensive ionic substitution, have charge deficiencies. To balance the charge deficiencies, clay minerals hold water molecules and cations between unit layers (interlayer). This water behaves as a solid, only being removed under the effect of temperature (typically removed for temperatures between 120 and 300ºC, as shown by Gomes 1986). Theoretically, in presence of water, and absence of load, smectites can swell indefinitely.

The differences found on GCLs behaviour seem to be linked with the relationship between the expansion of the bentonite and the load (confining stress). Determinations of the thickness and moisture content of the GCLs, carried out at the end of the flow rate tests in order to assist the interpretation of the results and not included in this work for the sake of brevity, tend to support this judgment. Details about those determinations can be found in Bergamini (2009) and in Bergamini et al. (2009). Indeed, it could be observed that the expansion of the GCLs decreased when the confining pressure increased from 25 to 100 kPa, remaining almost constant on tests carried out with confining pressures of 100, 150 and 200 kPa.

The small impact of the confining stress obtained in this study is consistent with the findings reported by Harpur et al. (1993), as well as by Barroso et al. (2006), while they tested non-prehydrated GCLs.

4.2 *Comparison with field contact conditions*

The interface transmissivity can also be estimated based on empirical expressions, by knowing the hydraulic conductivity of the foundation layer below the GM. The non-uniformities of the composite liner interface are included in a contact quality factor, typically termed as “contact conditions”. They were defined in qualitative terms by Rowe (1998), for two cases: poor and good contact conditions. These quantitative definitions were then extended by Touze-Foltz & Giroud (2003), for excellent contact condition, and by Touze-Foltz & Barroso (2006), for GM/GCL contact condition.

Interface transmissivities obtained in this study are plotted against hydraulic conductivity of the GCL in Figure 3. This figure also includes the synthetic results (straight lines) obtained using empirical expressions presented in literature, respectively, for poor, good, excellent and GM/GCL contact conditions, as well as the experimental data reported by Barroso (2005) and by Barroso et al. (2008).

As can be seen, all experimental values are located below the lines corresponding to the transmissivity calculated on the basis on existing empirical expressions, including the corresponding GM/GCL Contact Condition. These data suggest that even the later empirical expression may overestimate the value of transmissivity. Accordingly, in this study, it is proposed to update the GM/GCL contact condition, here termed as “modified GM/GCL contact condition”, which, from a mathematical point of view, can be represented by the following expression:

$$\log\theta = -2.7667 + 0.7155\log k_{GCL} \quad (1)$$

It should be mentioned that, for the sake of consistency with the existing empirical expressions, it is assumed that the “modified GM/GCL contact condition” it is also represented by a straight line in log-log scale parallel to the straight lines representing poor, good and excellent contact conditions.

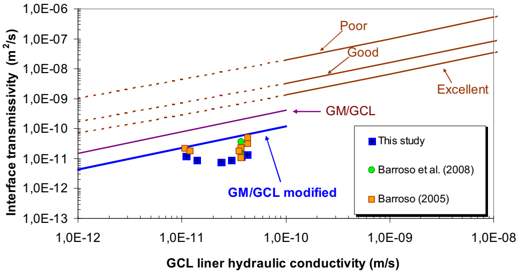

Figure 3. Comparison of experimental results to field contact conditions

5 CONCLUSIONS

This paper presented and discussed the experimental work performed on flow rates through composite liners due to GM defects. Composite liners consisted of a GM, with a circular defect, a GCL and a CCL. The main purpose of this research was to study the influence of the waste pressure on flow rates on the corresponding interface transmissivity. Six confining pressures were used: 25, 50, 75, 100, 150 and 200 kPa.

Results obtained suggest that the increase in waste pressure has a minor influence on flow rate and on correspondent interface transmissivity, for the range of pressures used. It also suggests that the previous empirical expressions used to estimate the transmissivity for different contact conditions may overestimate the value of this property. Hence, an update of the empirical expression used for the case GCL/GM contact condition was proposed.

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