Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Hydraulic performance of a composite bottom liner in a municipal solid waste landfill

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ABSTRACT: A composite liner, about 900 m^2 has been continuously monitored since 1993 thanks to double lining. A measurement protocol used during two years allowed finding relationships between the hydraulic head on top of the composite liner and the resulting flow rates. Various hypotheses were formulated regarding the leachate table position and relationship between measured flow rates and hydraulic heads applied. As a consequence there are various scenarios allowing to explain the obtained values, using modified existing empirical equations, included in this paper. These scenarios are compatible with the results of leak location surveys previously carried out on this site.

1 INTRODUCTION

Bottom liners represent, in municipal solid waste landfills, the first protection against the contamination of soil and groundwater by leachate. Monitoring data from a secondary leachate collection system (SLCS) may provide insight regarding the effectiveness of the primary liners of double liners (Rowe 1998). However, the interpretation of hydraulic data from SLCS requires careful consideration of sources of fluid other than leakage from the landfill, especially for the case of composite primary liners (Gross et al 1990). The primary source of leakage as identified by these authors is construction water that infiltrates the leakage detection layer during construction but does not drain to the SLCS sump before start of landfill operation. The second one is water expelled from the SLCS later, as a result of compression under the weight of the waste, and this when the SLCS is made of granular materials. The third source of leakage can be water expelled from the clay component of the primary liner as a result of clay consolidation under the weight of the waste. Fourth, groundwater infiltration for a waste management unit whose base is located below the water table can be responsible of leakage. Finally, holes in the geomembrane will be responsible for leakage through the primary liner.

In order to compare the efficiency of different lining systems a group of laboratories has applied a research program at an experimental MSW landfill located in the east of France (Montreuil - sur - Barse). The hydraulic performance of a composite liner made of a HDPE geomembrane overlaying 0.6 m of compacted clay, has been continuously monitored since 1993.

After a brief description of the geometry of the composite liner and of the monitoring protocol, an analysis of flow rate data obtained for the liner is proposed. Leakage data for three different hydraulic heads will be discussed with reference to modified existing empirical equations.

2 PRESENTATION OF THE LINER STUDIED AND OF MONITORING

2.1 *Experimental cell design*

The liner has been installed in a full-scale cell, about 30×30 m^2 at the bottom, 50×50 m^2 at the top, having the geometrical configuration described in Weber et al. (1996). An intermediate trench, 1 m wide, is located 1.5 m from the bottom of the cell where the leachate is pumped. One of the roles of this trench is to drain water which could potentially leak on the upper part of the slopes. The hydraulic conductivity of the clay liner was measured to be 3×10^{-10} ms^{-1}.

2.2 *Monitoring*

The cell has been continuously monitored from 1993 to now. The top cover has been installed in October 1996. From 1993 to 1998, the hydraulic head in the cell fluctuated continuously between 0.3 m and 1.3 m at the lowest point of the cell. As a result, it was difficult to get an idea of the relationship between the hydraulic head applied on top of the liner and the leakage through it.

A solution to the correlation problems linked to the variations in hydraulic head was to “impose” a constant hydraulic head and to evaluate the evolution of flow rates at different hydraulic head values. Three hydraulic heads were tested in each cell: 0.38 m, 0.54 m, 0.72 m.

Table1. Scenarios adopted to interpret the obtained hydraulic data

Scenario	Description	Hydraulic head (m)	Flow rate (m^3s^{-1})
1	Systematic delay between hydraulic head applied and resulting flow rate	0.38	4.2×10^{-8}
		0.72	5.4×10^{-8}
2	No delay between hydraulic head applied and obtained flow rate	0.54	5.4×10^{-8}
		0.72	7.8×10^{-8}
3	Delay between hydraulic head applied and flow rate only for hydraulic head equal to 0.38 m	0.38	4.2×10^{-8}
		0.54	5.4×10^{-8}
		0.72	7.8×10^{-8}

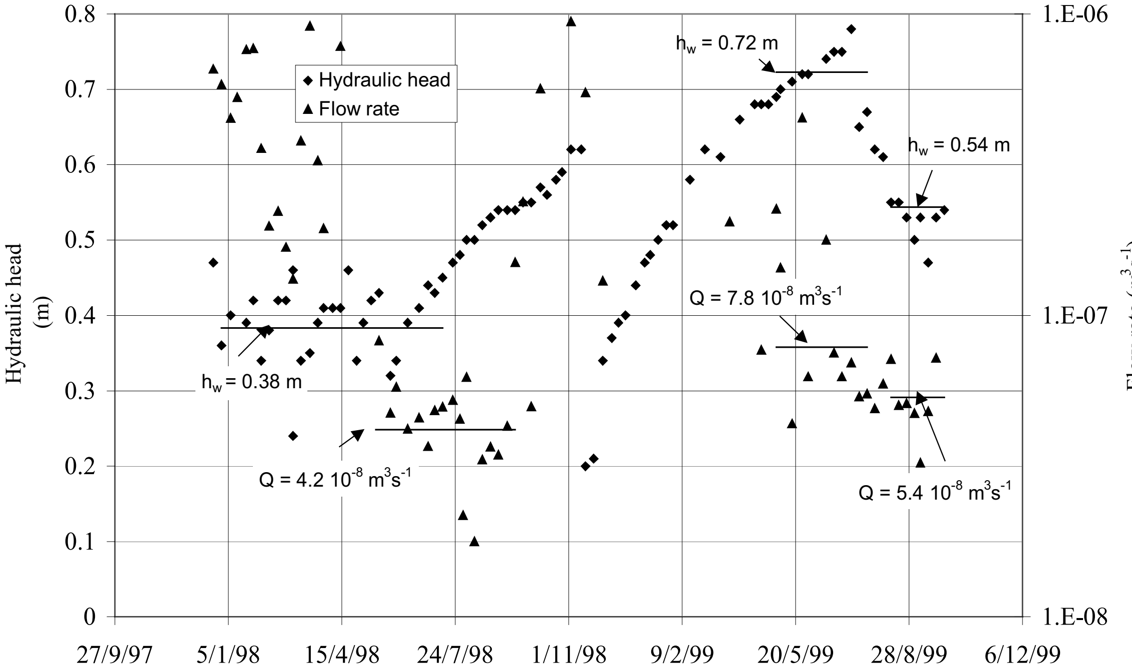

Figure 1. Hydraulic head on top of the GC liner and flow rate in SLCS from 1997/12/23 to 1999/10/12

3 RESULTS OBTAINED

3.1 *Hydraulic heads and flow rates*

As indicated previously, three different periods with rather constant hydraulic heads were obtained.

First, from December 30, 1997 to July, 13, 1998, the hydraulic head at the lowest point varied between 0.24 and 0.46 m, with an average value of 0.38 m (see Figure 1). The flow rate at that time was about $3\times10^{-7} m^3s^{-1}$ until May, 15, 1998, and then strongly decreased to 4.2×10^{-8} m^3s^{-1}. On this event it seems that flow rates obtained between December and May do not correspond to the hydraulic head applied at that time but to higher hydraulic heads applied before December. We noticed on previous events that a certain equilibrium time was necessary to get a decreasing flow rate when the hydraulic head was decreasing too. Thus, the interpretation here is that the flow rate corresponding to a hydraulic head of 0.38 m is differed and obtained from May to September 1998.

Second, from May, 3 to July, 22, 1999, the hydraulic head varies between 0.67 and 0.78 m with an average value of 0.72 m. The average value of flow rate during this period is 7.8×10^{-8} m^3s^{-1}.

Third, from August, 12 to September, 28, 1999, the hydraulic head varies between 0.47 and 0.55 m with an average value of 0.54 m. The corresponding flow rate is 5.4×10^{-8} m^3s^{-1}.

Three different scenarios can be made to interpret these data.

First, if one considers that there is a systematic delay between the variation in hydraulic head and the obtaining of the corresponding flow rate, then the flow rate equal to 5.4×10^{-8} m^3s^{-1} obtained from August to September 1999 must be attributed to the hydraulic head applied from May to July 1999, equal to 0.72 m (scenario 1).

Second, on the contrary under the assumption that that there is no delay, the flow rate obtained for a hydraulic head equal to 0.38 m does not seem to be due to leaks only, and this value will not be taken into account for the interpretations (scenario 2).

Third one can assume that there can be a delay for the hydraulic head equal to 0.38 m due to a lack of pumping of the leachate during the previous period and not for the other two hydraulic heads, phenomena observed on previous data in this experimental cell (scenario 3).

A synthesis of these three scenarios is made in Table 1.

3.2 *Hole location in the geomembrane*

Two electrical leak location surveys were conducted on the geomembrane in 1993 after the installation of the granular drainage layer. They allowed detecting various punctures and defective seams which location is presented in Figure 2. The authors feel that there could be some remaining holes in this geomembrane. Indeed, in case of the existence of many holes, several surveys are necessary to be sure to detect all of them and two surveys may not be enough. Furthermore there were many wrinkles in the geomembrane after installation, that could be entrapped under the granular layer. The detection of holes located on wrinkles strongly depends on the capability of the electrical current to flow through them so that some holes could remain undetected.

As a flow rate was obtained for a hydraulic head equal to 0.38 m, the assumption made is that there is one or more remaining hole(s) in the lowest zone of the cell where most of them were detected, at an average distance of the lowest point of the cell equal to 0.23 m.

Hydraulic heads larger than the ones tested could allow checking if there are remaining holes in the upper part of the cell as well.

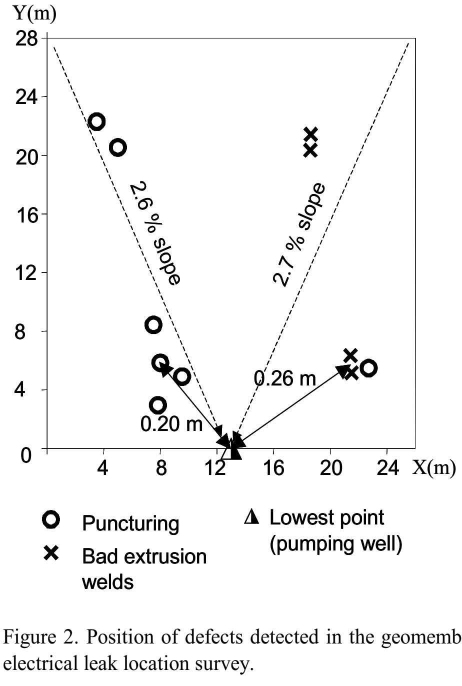

Figure 2. Position of defects detected in the geomembrane thanks to an electrical leak location survey.

3.3 *Leachate table position*

Two assumptions were made regarding the leachate table position in waste. It is assumed that it is either horizontal or parallel to the geomembrane surface. Reality may be intermediate between the two situations studied.

3.4 *Possible sources of leakage*

It is necessary to evaluate all possible sources of water in the SLCS. No groundwater nor consolidation water from the SLCS is expected. Then, six years after the site construction, the only possible sources of liquid flow are water expelled from the clay component of the primary composite liner, as a result of clay consolidation, and leaks through the composite liner.

Following the theory of consolidation by Therzaghi (Schlosser 1988), and considering the dates of filling the cell with waste and covering, all consolidation water should have been expelled from the clay layer in the early days of 1998. As a consequence, flow rates measured in the SLCS can be attributed to leaks through the composite liner.

This assumption is consistent with the fact that flow rates obtained for both hydraulic heads – 0.72 and 0.54 m – in 1999 are lower than flow rates obtained during previous periods of operation of the landfill, for which the hydraulic head was about 0.4 m (Touze-Foltz & Poignard 2000)

4 INTERPRETATION OF RESULTS OBTAINED

Empirical equations proposed by Giroud (1997) for the case of a circular hole in a flat area (axi-symmetric case) of geomembrane and an infinitely long defect (two-dimensional case) were compared to analytical solutions developed by Touze-Foltz et al (1999) through a parametric study. Values of transmissivity used were taken from Rowe (1998) who gave empirical equations linking transmissivity to soil liner hydraulic conductivity for good and poor contact conditions. Some differences were observed but it is shown that the power indexes proposed in the empirical equations are consistent with the results of the analytical solutions. It is shown as well that even for hydraulic heads as large as 3 m it is better in the axi-symmetric case to neglect the variation in hydraulic gradient under the geomembrane than to use the one proposed by Giroud (1997). Finally it was found out that empirical equations proposed for the case of an infinitely long defect can be extended to long wrinkles (two-dimensional case) while modifying the value of the contact quality factor. Thus to get the minimal difference between the empirical equations and analytical solutions it is suggested that in a preliminary step the empirical equations from Giroud (1997) be modified as follows in the axi-symmetric case (Touze-Foltz 2001) :

$$Q = C_{qo} a^{0,1} k_s^{0,74} \left(h_w\right)^{0,9} \tag{1}$$

and in the two-dimensional case (Touze-Foltz 2001)

$$Q = N\left(1 + 0,2\left(\frac{h_w}{H_s}\right)^{0,95}\right) L(2b)^{0,1} K_L^{0,87} h_w^{0,45} \tag{2}$$

where C_{q0} and N = contact quality factors respectively for the axi-symmetric and two-dimensional cases; a = circular hole surface; 2b = wrinkle width; L = wrinkle length; k_s = CCL hydraulic conductivity; H_s = CCL thickness; and h_w = hydraulic head on top of holes, which will differ depending on the assumption regarding the leachate table position.

These equations have to be used with the basic S.I. units. C_{q0} is 0.21 for good contact conditions and 1.15 for poor contact conditions as defined by Giroud (1997). N is 0.94 for good contact conditions and 2.2 for poor contact conditions (instead of 0.52 and 1.22 for infinitely long defects).

Using Equations (1) and (2) and assuming that the leachate table is parallel to the geomembrane surface, 16 circular holes 10^{-3} m in diameter or two wrinkles 6.5 m long and 0.3 m wide would be necessary to explain the flow rates under good contact conditions. 3 circular holes 2×10^{-3} m in diameter or one wrinkle 5.5 m long and 0.3 m wide are necessary to explain the results obtained in the case of poor contact conditions whatever the hypotheses regarding the association between hydraulic heads and flow rates.

Assuming an horizontal leachate table, 21 holes 4×10^{-3} m in diameter or two wrinkles 0.3 m wide and 9 m long for good contact conditions or 4 holes 4×10^{-3} m in diameter and a wrinkle 0.3 m wide and 7.5 m long for poor contact conditions could explain the flow rates obtained, again whatever the associations of flow rates and hydraulic heads among the three proposed. A synthesis of these results is made in Table 2.

The number of holes obtained with the axi-symmetric hypothesis assuming good contact conditions is high and seems inconsistent with the number of holes detected. Thus the hypotheses of one or two damaged wrinkles is much more probable. The authors checked that two damaged non-interacting wrinkles could be positioned in the geomembrane.

Table2. Number of defects necessary to interpret the hydraulic data obtained. Poor contact conditions in bold and good contact conditions in light

Leachate table	Axi-symmetric case	Two-dimensional case
Horizontal	21 holes 4×10^{-3} m in diameter	2 wrinkles 0.3 m wide and 9 m long
	4 holes 4×10^{-3} m in diameter	**1 wrinkle 0.3 m wide and 7.5 m long**
Parallel to geomembrane surface	16 holes 10^{-3} m in diameter	2 wrinkles 0.3 m wide and 6.5 m long
	3 holes 2×10^{-3} m in diameter	**1 wrinkle 0.3 m wide and 5.5 m long**

The difficulty here is that it is impossible to validate one of the hypotheses made, as we do not have any idea of the possible remaining holes location nor on their size and the quality of contact between the geomembrane and the CCL or the hydraulic conductivity of the CCL. A higher value (10^{-9}) would lead to a different interpretation (Touze-Foltz & Poignard, 2000). And one could imagine as well a third hypothesis, combining the axi-symmetric and two-dimensional ones.

5 CONCLUSIONS

This paper gives some improved forms of existing empirical equations to predict advective flow rates through composite liners. Based on these equations there are various hypotheses allowing to interpret the experimental results, in spite of the difficulty to link hydraulic heads and flow rates. The axi-symmetric hypothesis seems to be far less plausible than the two-dimensional one regarding the number of holes involved.

6 ACKNOWLEDGEMENTS

The research reported in this paper was funded by the French Environmental Agency (Ademe). The authors would like to thank ONYX-VALEST to propose the experimental cell.

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