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

Evaluation of the hydraulic transmissivity in soil liner-geomembrane interfaces

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ABSTRACT: An apparatus is described that allowed to estimate flow rates at the interface of compacted clay - geomembrane composite liners in the laboratory. Thank to the results obtained in terms of flow rates and aspects of the wetted areas, some values of transmissivities could be deduced. The results obtained allow to study the influence of the hydraulic head applied on top of the composite liner, of the placement of a geotextile at the interface, and of the influence of the compacted clay surface topography. It can be deduced that the measured values are not representative of field conditions but much more of a laboratory situation in which the soil surface is not flat and smooth.

1 INTRODUCTION

The hydraulic transmissivity of the interface of a composite liner is a key parameter to predict rates of liquid flow when the geomembrane is damaged, thanks to analytical solutions. One can find in the literature some experimental data for composite liners involving loamy soils (hydraulic conductivities in the range 10^{-8} to 10^{-6} ms^{-1}) (Fukuoka 1986, Brown et al. 1987, Liu 1998) or geosynthetic clay liners (GCLs) (Harpur et al. 1993) but there are no information for clayey soils used as mineral liners in many composite liners of landfills sites. The only solution at present is the use of empirical relationships linking the hydraulic transmissivity to the hydraulic conductivity derived form empirical solutions giving the rates of liquid flow for poor and good contact conditions (Rowe 1998).

The first objective of this paper is to show the experimental results obtained in a specially designed cell for three different clayey soils. The results obtained allow to study the influence of the hydraulic head and soil surface topography on the transmissivity.

In the following we first describe the experimental device, the materials tested and the tests conducted. Then some of the results are presented and compared to the literature. Results tend to show the influence of the local topography of the compacted soil surface on the flow patterns in the interface and on the interface transmissivity obtained. As a consequence, the hydraulic conductivity of the soil liner is not the only parameter to take into account to predict the interface transmissivity. All results obtained, except one, tend to show that the field contact conditions defined by Giroud & Bonaparte (1989) overestimate the transmissivities measured in the laboratory except in one case in which the soil surface was not as smooth and flat as in the other cases.

2 EXPERIMENTAL DEVICE

The cell shown in Figure 1 has been specially designed for hydraulic transmissivity measurements. In the bottom part of this cell six centimetres of soil are compacted. On top of it, one places a geomembrane with a circular hole 3 mm in diameter at its centre. The geomembrane is covered with granular materials, simulating the presence of the granular drainage layer. A normal stress can be applied on top of this experimental device.

Liquid flow measurements can be conducted in two different ways as described by Harpur et al. (1993): constant head tests are carried out when the radial flow rate at the downstream side of the interface is large enough to be measured by weighing. When no flow rate can be measured in this way, a falling head test is conducted with a glass tube 4 mm in inner diameter and then the total flow rate is measured.

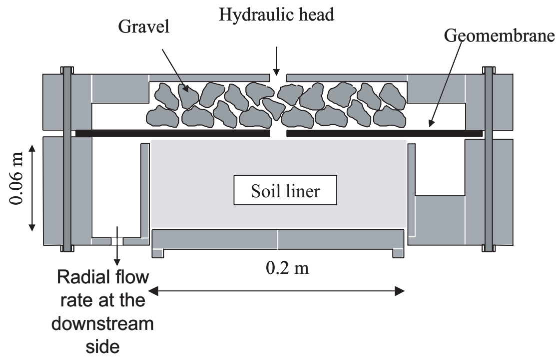

Figure 1. Schematic of the interface transmissivity measurement cell

3 MATERIALS TESTED

A smooth high density polyethylene (HDPE) and a flexible polypropylene (f-PP) geomembranes 2 mm and 1.5 mm thick respectively have been used and three different soil have been compacted in the cell. Clay 1 comes from the landfill site of Montreuil-sur-Barse. The hydraulic conductivity of this clay was measured to be 3×10^{-10} m s^{-1} on site (Berroir et al. 1997). Clay 2 was used for the realization of a large scale test experiment in the laboratory (Touze-Foltz 1999) and its hydraulic conductivity was measured to be 10^{-10} m s^{-1}. Clay 3 was used for large scale tests performed on a landfill site (Touze-Foltz 2001a) and its hydraulic conductivity was measured to be 2×10^{-10} m s^{-1} on site.

A needdlepunched geotextile, 300 gm^{-2}, was set at the interface of test 8 in order to check its influence on the flow rates at the interface.

4 TESTS PERFORMED

The constitution of the composite liners studied is shown in Table 1. All tests lasted about 2 weeks, a duration comparable to the one of the tests carried out by Harpur et al. (1993).

Thanks to the tests performed the influence of the hydraulic head could be evaluated. Moreover, we could study the influence of the existence of a large hole at the clay surface. Indeed, we noticed different aspects of the soil surface of clay 3. When compacted on a metal plate, some clods were pulled out of the clay surface resulting in the formation of a hole at the soil surface about 5 mm deep and 10 cm² of cross sectional area, not precisely described but certainly different from one test to the other. On the contrary, when the clay was compacted on a rubbery membrane the clay surface in contact with the geomembrane was as flat and smooth as possible visually, as with clays 1 and 2.

Table 1. Composite liners tested and results obtained at the end of the tests in terms of wetted areas and apparent transmissivities

Test Number	Clay	Geomembrane	Hydraulic head (m)	Normal stress (kPa)	Wetted area	Flow rate at the end of test (m^3s^{-1})	Apparent transmissivity (m^2s^{-1})
1	Clay 1	HDPE	0.30	3	Disc 3 mm in diameter	4.5×10^{-11}	0
2	Clay 1	HDPE	0.42	3	Disc 15 mm in diameter	6.3×10^{-12}	3.1×10^{-12}
3	Clay 2	HDPE	0.215	3	Disc 3 mm in diameter	2.1×10^{-12}	0
4	Clay 3	HDPE	0.18	10	Whole surface	9.1×10^{-11}	3.7×10^{-10}
5	Clay 3*	HDPE	0.18	10	3.8×1.4 cm^2	3.8×10^{-11}	1.4×10^{-10}
6	Clay 3	f-PP	0.18	10	Whole surface	5.7×10^{-9}	2.1×10^{-8}
7	Clay 3*	f-PP	0.18	10	Disc 3 mm in diameter	1.2×10^{-11}	0
8	Clay 3*	HDPE Geotextile at the interface	0.18	10	Whole surface	6.5×10^{-7}	2.4×10^{-6}

Symbol * indicates that Clay 3 was compacted on a rubbery membrane

5 RESULTS OBTAINED

Results obtained are presented in Table 1 in terms of quantitative information on the aspect of the wetted area, and a value of the apparent transmissivity. This parameter is calculated thanks to analytical solutions assuming an axi-symmetric geometry and is called apparent because it does not take into account the possible spatial variations in transmissivity in the soil-geomembrane interface (Touze-Foltz et al. 1999). We considered that the wetted area was the whole clay surface when there was a remainingdownstream flow at the end of the experiment even if we noticed preferential flow paths.

5.1 Influence of the hydraulic head applied

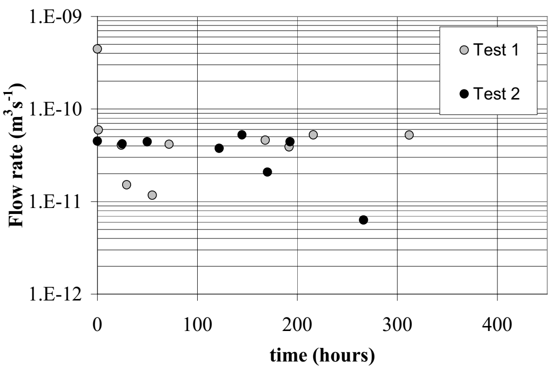

Figure 2. Comparison of flow rates obtained in Tests 1 and 2

Results of Tests 1 and 2 performed with the same materials but with different hydraulic heads can be compared (See Figure 2). At the end of test 1 we noticed that there was no lateral extension of the wetted area beyond the circular hole. As a consequence it seems that there was a perfect contact between the clay and the geomembrane in this test. Thus the apparent transmissivity was supposed to be 0. It corresponded to a measurable flow rate at the end of the test about 4.5×10^{-11} m^3s^{-1}.

On Test 2 the wetted area is approximately a disc 15 mm in diameter. As a consequence the apparent transmissivity in this case is not 0 but a value that can be calculated thanks to the flow rate value at the end of the test (6.3×10^{-12} m^3s^{-1}) using analytical solutions given by Touze-Foltz et al (1999). As one can notice, the flow rate obtained in test 2 is lower than in test 1. This could be explained by the variation in the hydraulic conductivity of the soil between both tests, the soil being recompacted for each test. As a consequence, the value of flow rate itself is insufficient to conclude on the transmissivity value and the aspect of the wetted area gives precious information. The result obtained thanks to these experiments is that an increase in the hydraulic head seems to result in an increase in the apparent transmissivity

5.2 Influence of a geotextile at the interface

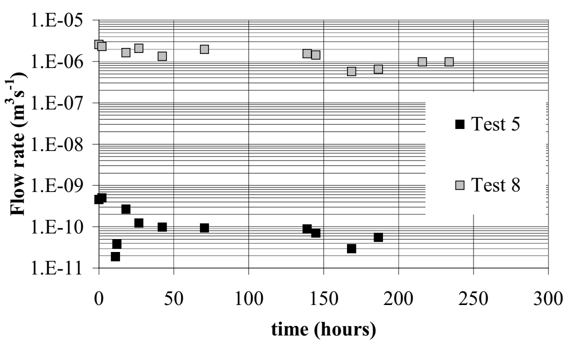

Figure 3. Comparison of flow rates obtained in Tests 5 and 8

Figure 3 gives a comparison of the results obtained in terms of flow rates for tests 5 and 8 involving the same clay compacted in the same way, and the same HDPE geomembrane. There is a difference of a factor around 10^4 between the flow rates obtained with and without a geotextile at the interface. This result is in contradiction with the one obtained by Fukuoka (1986) who obtained larger flow rates at the interface when there was no geotextile. But the soil hydraulic conductivity and surface topography, as well as the normal stress applied were very different from the one that we had in our tests. It seems that more research in needed to correctly estimate the influence of the placement of a geotextile at the interface on the resulting flow rates.

5.3 *Influence of the aspect of the soil surface*

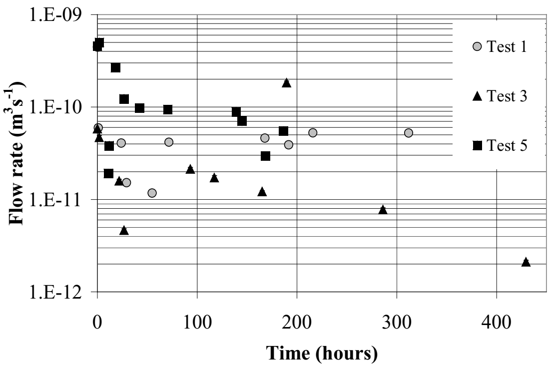

Figure 4. Comparison of flow rates obtained in tests 1, 3 and 5

One can try to compare the results obtained in Tests 1, 3 and 5 even if the hydraulic heads and the normal stresses were slightly different (see Figure 4). Indeed, we used the same HDPE geomembrane and the clay surface was as smooth and flat as possible visually in all tests. For clay 1 and clay 2, there was no lateral extension of the flow beyond the hole in the geomembrane, thus, the apparent transmissivity is 0 in these cases. But for clay 3, we noticed an approximately rectangular wetted area 38×14 mm^2 around the hole and preferential flow paths in various directions at the clay surface. Thus, even in the case where the clay surface is as smooth as possible visually, the wetted area is not necessarily a disc for a circular defect in the geomembrane. The difference in behavior noticed in the three tests could be linked with spatial variability at the soil surface that can not be measured by eye. Indeed, a value of transmissivity of 6.5×10^{-9} m^2s^{-1} (very good contact conditions as defined by Giroud & Bonaparte (1989)) corresponds to an interface thickness of 2×10^{-5}m, a domain in which an exploration cannot easily be conducted without improved tools. Dove (1996) indicates that the lower limit of unaided eye resolution in detecting vertical relief variations is about 10^{-4} m. The improvement of the interpretation of the results given here then requires the use of an improved equipment to describe the soil surface topography.

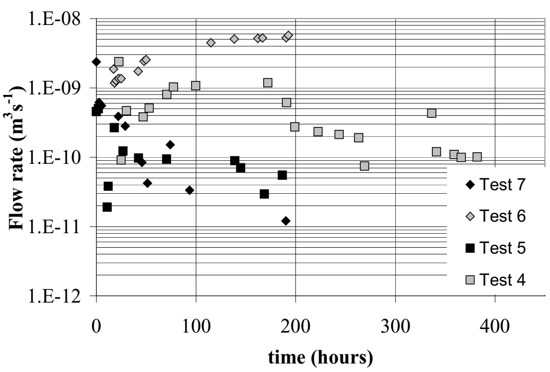

Figure 5. Comparison of flow rates obtained in tests 4, 5, 6 and 7

Interpretations are easier when comparing situations where the clay surface is as flat and smooth as possible and situation where there were some clods pulled out of the soil surface. This comparison can be made between tests 4 and 5 and 6 and 7 (see Figure 5). For both geomembranes, we noticed that (i) when the soil surface was flat and smooth, there was no longer any flow rate at the downstream side of the cell at the end of the experiment, whereas we noticed a downstream flow rate when there was a hole at the clay surface and (ii) the flow rates were lower when the soil surface was flat and smooth than in the other case: 3.8×10^{-11} m^3s^{-1} on test 5 as compared to 9.1×10^{-11} m^3s^{-1} on test 4 and 1.2×10^{-11} m^3s^{-1} on test 7 as compared to 5.7×10^{-9} m^3s^{-1} on test 6. As a consequence there seems to be a non negligible influence of the existence of a zone at high transmissivity in the interface on the flow rates and wetted areas.

6 COMPARAISON OF THE RESULTS OBTAINED TO THE LITERATURE

Figure 6 is a synthesis of the results existing in the literature and of the tests presented in this paper for which the apparent transmissivity was different from 0, without a geotextile in the interface. The various results are presented in axes corresponding respectively to the soil hydraulic conductivity and the measured or calculated transmissivity. Empirical formulations given by Rowe (1998) were added to experimental results for good and poor contact conditions as defined by Giroud and Bonaparte (1989), as well as the values of transmissivity proposed by Brown et al. (1987) for the perfect contact conditions. The uncertainty on the measurement, on the transmissivity or the clay hydraulic conductivity is given each time this data is mentioned. The uncertainties calculated on the flow rates measured in our experiments were rather low (Touze-Foltz, 2001b) and thus no uncertainty was calculated for the apparent transmissivities given. As Harpur et al. (1993) did not mention the hydraulic conductivity of the GCLs tested their values could not be mentioned in this figure.

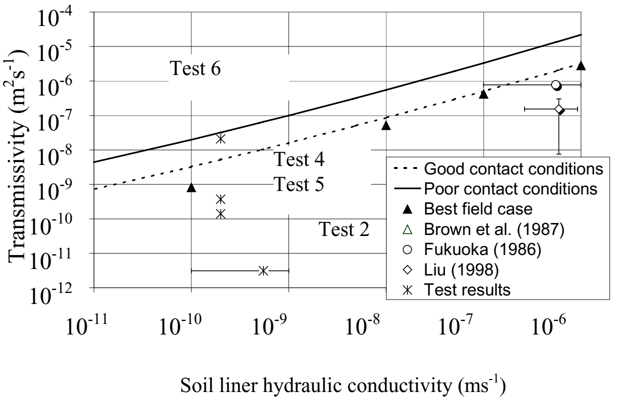

Figure 6. Synthesis of the various existing experimental results and comparison to excellent, good and poor contact conditions

Except the point corresponding to Test 6, all results are located under the criteria given for excellent field contact conditions. The result obtained by Fukuoka (1986) is the nearest from the excellent field contact conditions. Results obtained by Brown et al. (1987), Liu (1998) and test 4 could be located on a line parallel to the ones obtained for the good and poor contact conditions which could define the laboratory conditions in which the soil surface was not as flat and smooth as possible: pulling out of soil clods in test 4 and excess soil scrapped off for the tests conducted by Brown et al. and certainly by Liu, taking into account the large size of the measurement device used.

Results obtained for tests 1, 2, 3, 5 and 7, with the best soil surface possible in our experimental conditions are located under this laboratory contact conditions for soil surfaces that are not entirely flat and smooth. One can notice that the results thus obtained in the laboratory are really lower than the transmissivity values obtained for good and poor contact conditions. As a consequence, there is a real questioning regarding the representativity of the interface transmissivity measurement in the laboratory in order to predict flow rates for on site conditions.

Could the results obtained in the laboratory be extrapolated, and in which conditions to field situations, knowing that the soil surface topography proved through these experiments to have a non negligible effect on the results obtained, all the more as the soil and geomembrane surfaces will be very different on site from the ones obtained in the laboratory? Any attempt to extrapolate the results then seems unwarranted.

7 CONCLUSIONS

Results obtained through the transmissivity measurements carried out tend to show that an increase in the hydraulic head results in an increase in the apparent transmissivity. This result obtained on a single couple of tests needs to be confirmed.

Results obtained in the laboratory tend to show that even for a soil surface as smooth and flat as possible, the resulting wetted area for a circular defect in the geomembrane is not necessarily a disc. As a consequence, it is inapropriate to try to define a transmissivity for the whole surface based on analytical solutions of mathematical models assuming that the soil and geomembrane surfaces are two flat and smooth parallel planes.

In order to correctly investigate the relationship between the soil surface topography and the transmissivity, a description of this topography is a crucial point. This conclusion is all the more valid as the results obtained in the laboratory do not seem to be extrapolable to site conditions due to the differences existing between the topography of the soil and geomembrane surfaces in both conditions.

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