EVALUATION OF THE CONTACT BETWEEN GEOSYNTHETIC CLAY LINERS AND GEOMEMBRANES IN TERMS OF TRANSMISSIVITY

The transmissivity of a geosynthetic clay liner (GCL)-geomembrane system was evaluated using a standard laboratory transmissivity system. The apparatus was used to measure the flow beneath a geomembrane with a manufactured hole in it. Various normal stresses were applied to the GCL-geomembrane to measure the flow allowed by varying degrees of intimate contact between the GCL and geomembrane. The head on the geomembrane hole was also varied to represent actual field conditions.

Test data indicates that the transmissivity of a GCL-geomembrane will decrease over time. This is due to the extrusion swelling of hydrated bentonite in the GCL and its sealing capabilities with the HDPE geomembrane. Comparison of test data with reported values for geomembranes and compacted clay liners found that GCL-geomembrane systems had significantly less transmissivities, which suggests that concern over intimate contact between GCLs and geomembranes is likely unjustified.

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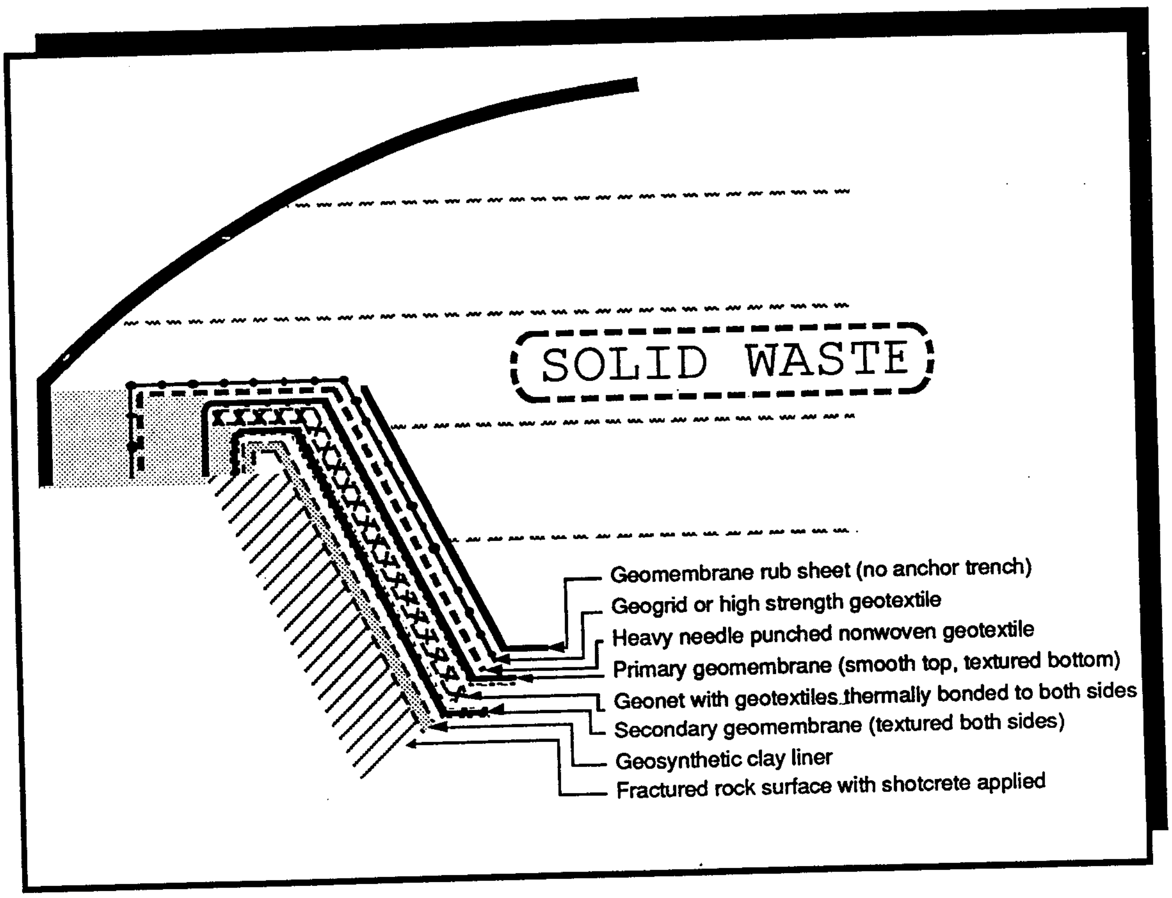

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EVALUATION OF THE CONTACT BETWEEN GEOSYNTHETIC CLAY LINERS AND GEOMEMBRANES IN TERMS OF TRANSMISSIVITY

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ABSTRACT

An apparatus is described which measures the flow beneath a geomembrane with a hole at its contact with a geosynthetic clay liner. The hole in the geomembrane is circular and the flow regime beneath it is radial. The testing technique allows for the application of various normal stresses to the contact between the geosynthetic clay liner and the geomembrane. The head on the geomembrane hole can be varied to represent field conditions. The flow is quantified in terms of transmissivity which can be calculated using either constant head or falling head conditions. Test results are presented for five commercially available geosynthetic clay liners under the two normal stresses of 7 and 70 kPa (1 and 10 psi). Values are compared to transmissivity between a geomembrane and a compacted clay liner and seem to be significantly lower for all geosynthetic clay liner products.

INTRODUCTION

For both hazardous waste and municipal solid waste containment, the required strategy of the U.S. Environmental Protection Agency is a composite liner. This liner is considered to be a geomembrane placed directly over a compacted clay liner (CCL). The essential reason behind this concept can be shown by the illustrations of Figure 1. With a CCL by itself, the entire area is available for flow by the leachate. With a composite liner, flow through a hole in the geomembrane is forced in a radial configuration which greatly reduces the net amount through the composite. Of course, lateral flow at the contact between the geomembrane and the compacted clay liner should be minimized. Quantification of the water flow at the contact has been evaluated in the laboratory in terms of transmissivity (Fukuoka, 1986, Brown et al, 1987 and Giroud and Bonaparte, 1989). These values will be used for comparative purposes later in the paper.

In recent years, geosynthetic clay liners "GCLs" are increasingly being chosen to replace compacted clay liners in various cases such as in the primary liner in double lining systems, as the lower component in single lining systems and in landfill caps. However, because most available GCLs consist of bentonite sandwiched between two geotextiles, their equivalency to CCLs with respect to intimate contact with the geomembrane is often questioned due to the presence of the upper geotextile. Clearly, there is a lack of transmissivity data for the geotextile used in the various products when bentonite is the

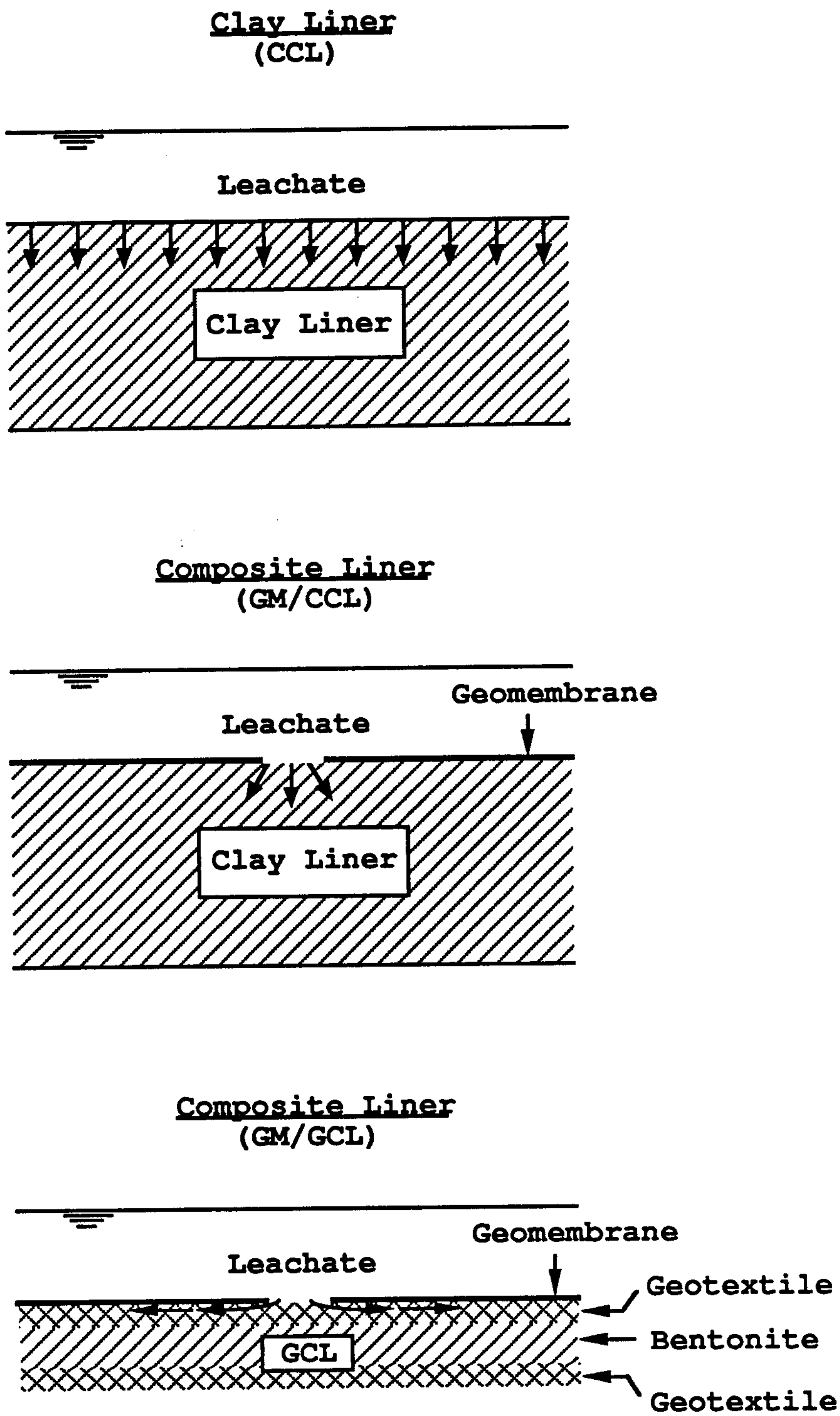


Fig. 1 Intimate Contact Issue for Composite Liners

material adjacent to them as in a GCL, see Figure 1. This paper focuses on the transmissivity of the contact between GMs and GCLs. An apparatus is described which measures the transmissivity under a radial flow regime through a hole in the geomembrane. Results of the tests on various GCL types are presented at two normal stresses. Early attempts to evaluate the flow at the contact were made by Shan (1990) using a flexible wall permeameter. Only one GCL product was tested and the results were presented in terms of an equivalent in-plane hydraulic conductivity of the GCL.

APPARATUS

The apparatus is a modified version of the radial transmissivity device used by Koerner and Bove (1983) to evaluate the transmissivity of geotextiles in isolation. The GCL specimen is circular with a diameter of 108 mm (4.25 in). It is placed inside a rigid aluminum holder as illustrated in Figure 2. Pressure is applied to the GCL via a loading platen with a HDPE geomembrane bonded to its bottom surface. Loading is achieved with the aid of an air activated pressure system.

The GCL has access to water through a hole of 7.6 mm (0.3 in) diameter in the loading platen and in the underlying geomembrane. A constant head can be applied via an inlet valve to a water supply tank as indicated in Figure 2. The tank is mounted on vertical sliding rails thus allowing control of the head. The loading platen is also connected to a graduated burette allowing measurement of head changes. By closing the inlet valve, a falling head test can be performed whereas by keeping the valve opened, a constant head can be maintained. Collection of the boundary flow can be achieved via a sloping groove in the base of the loading frame which leads to an outlet hole. A rubber collar is fitted to the base plate which can be filled with water after plugging the outlet hole if it is desired to keep the GCL specimen submerged at any stage of the test.

TESTING PROCEDURE

The testing procedure which was used is summarized in the following steps:

(i) Cut the GCL specimen to size after wetting its perimeter. Wetting minimizes the loss of bentonite at the specimen boundary during the cutting operation and the placement of the GCL in the specimen holder.
(ii) Install the GCL inside the specimen holder such that its upper level is just above the holder wall. Spacers of different thicknesses are used depending on the thickness of the GCL.
(iii) Place the loading platen on top of the GCL specimen.
(iv) Apply the required normal stress.
(v) Plug the hole in the base plate and fill the rubber collar with water to a level just above the specimen.
(vi) Adjust the level of the supply water tank depending on the required head on the GCL specimen.
(vii) Open the inlet valve to fill the loading platen with water
(viii) Lower the graduated burette below the water level in the supply tank to allow flow of water and expulsion of any air bubbles. Note that the purpose of submerging the GCL is to fill any air voids in the GCL specimen. If the specimen is not submerged, air is attracted to the system from the GCL boundaries and air bubbles cannot be expelled from the system.
(ix) Place the burette in position when all air bubbles are expelled.

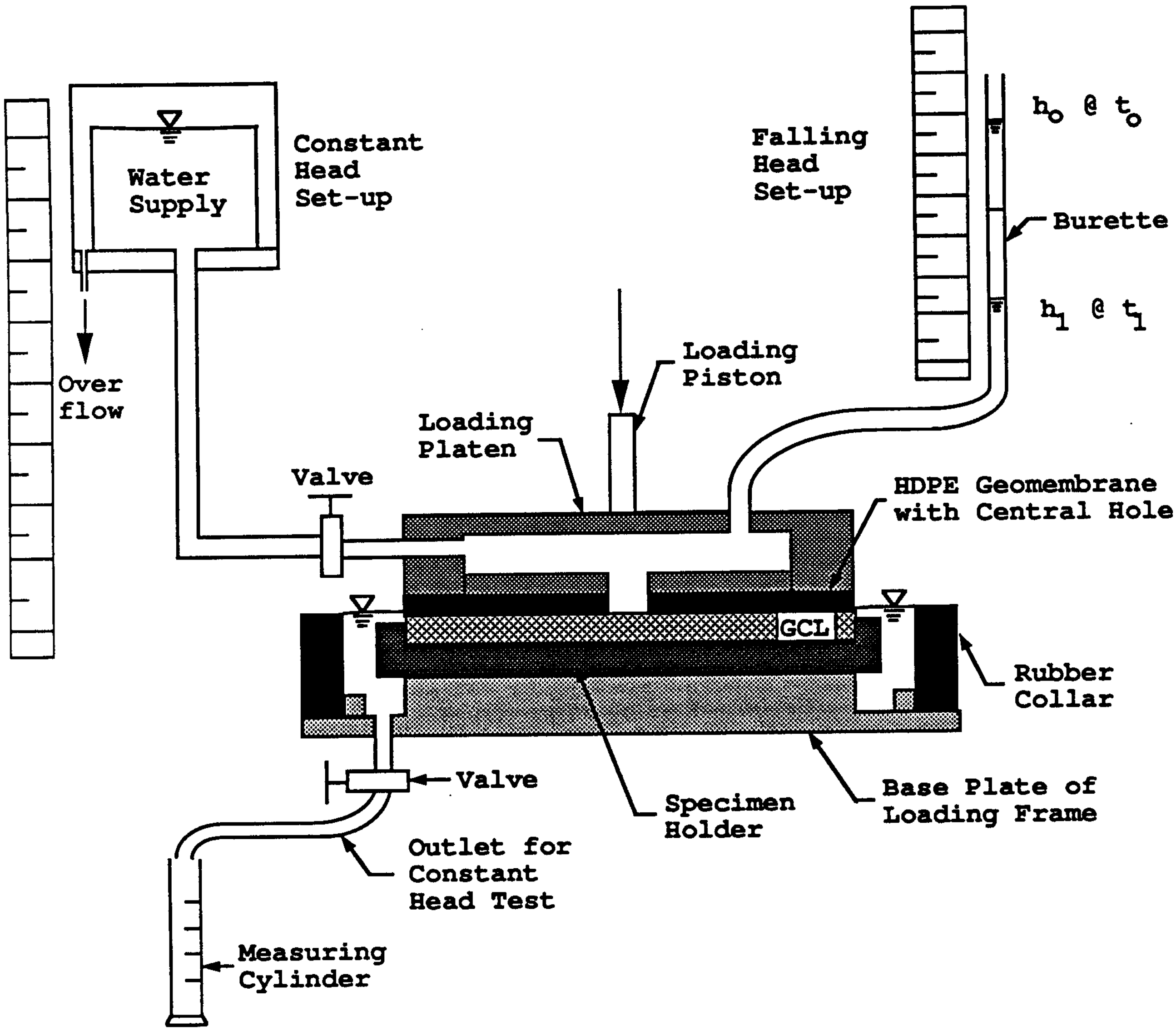


Fig. 2 Schematic of GRI's Transmissivity Apparatus

(x) Remove water from the rubber collar by unplugging the hole in the base plate.
(xi) To run a constant head test, measure the volume of effluent water within a specified time interval.
(xii) To run a falling head test, close the water inlet valve and add water to the burette to the desired initial head. Measure the time for the initial head to drop to the final required head.

Evaluation of the transmissivity from the test data is discussed in the following section.

TRANSMISSIVITY EVALUATION

The flow regime in the test specimen is complex. Under steady state conditions, the flow of water may take the following paths:

(i) flow in the interface between the overlying geomembrane and the upper geotextile of the GCL. This will be governed by the surface characteristics of both the geomembrane and the geotextile. This flow can be greatly reduced as a result of bentonite extruding through the geotextile voids and reaching the geomembrane surface. It may also be reduced using textured geomembranes although this possibility was not evaluated in the course of this study.
(ii) flow through the geotextile itself which will be governed by the geotextile transmissivity which in turn can be greatly affected by bentonite intrusion
(iii) flow at the contact between the upper geotextile and the underlying bentonite which again depends on the surface characteristics of the geotextile and the degree of intrusion of the bentonite
(iv) flow through the bentonite which depends on its hydraulic conductivity, the boundary conditions at the specimen holder edges and the pore water pressure variation within the clay.
(v) Although, unlikely in light of the above flow paths, the bottom geotextile may also have some effect in increasing the flow within the bentonite

Because of the low hydraulic conductivity of the bentonite and the relatively large transmissivity of the geotextiles used in their manufacture, it is expected that most of the flow will be due to the first three paths. However, because the test method does not distinguish between the flow through the various possible paths, the term "apparent transmissivity" will be used to describe the flow measured in the test. This term will be also used before and after steady state conditions are achieved. Clearly, such a computed transmissivity represents an upper bound value to the true transmissivity.

Neglecting the flow within the bentonite, the equations given below can be derived for constant and falling head tests.

<u>Constant Head Test</u>.

$$\theta = \frac{q \ln\left(\frac{R_2}{R_1}\right)}{2 \pi h} \tag{1}$$

Falling Head Test.

$$\theta = \frac{a \ln\left(\frac{R_2}{R_1}\right) \ln\left(\frac{h_o}{h_1}\right)}{2\pi t} \tag{2}$$

where

θ	=	apparent transmissivity (m^3/s-m or m^2/s)
h	=	difference between head at hole and head at specimen boundaries (m)
R_1	=	hole radius (m)
R_2	=	outer radius of specimen (m)
q	=	flow rate (m^3/s)
a	=	cross-sectional area of falling head burette (m^2)
h_o	=	initial head difference (m)
h_1	=	final head difference (m)
t	=	time interval (s)

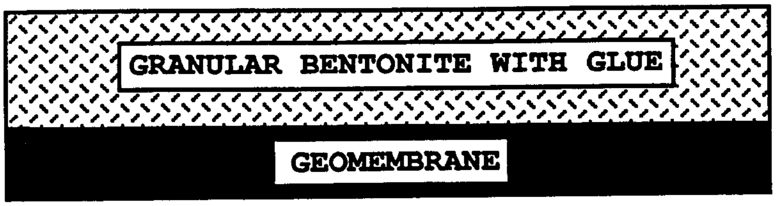
Constant head tests are carried out only within the first few hours of testing during which there is a relatively large volume of effluent water since the GCL is initially dry. As the flow decreases, the use of the falling head test becomes necessary due to its greater accuracy at low flow rates. Preliminary tests using the transmissivity device indicated that the amount of flow decreased greatly as the test progressed allowing evaporation at the specimen boundaries. As a result, cracks in the bentonite occurred with the possibility of increased water flow. To avoid evaporation, the rubber collar surrounding the base of the loading frame was filled with water just above the GCL top level in order to keep the sample submerged. The added water also helps in the rapid hydration of the whole GCL specimen and hence rapid attainment of the steady-state condition. Complete submergence was used in obtaining all the falling head test data reported in this paper.

MATERIALS TESTED

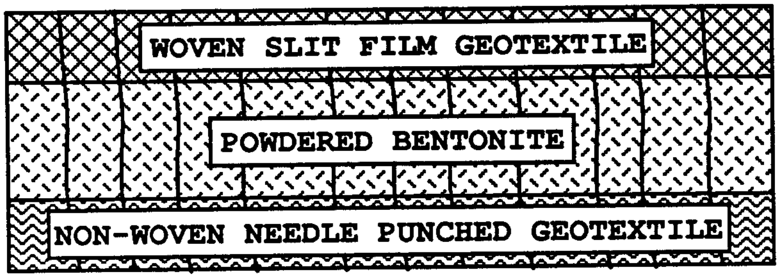
Five different types of GCLs were tested beneath a 60 mil HDPE geomembrane with a centrally located 7.6 mm (3.0 in) hole. The composition of the tested materials which will be designated as "A", "B", "C", "D" and "E" is shown in Figure 3. The top side of each GCL in the figure is the side facing the geomembrane in the transmissivity tests. With the exception of product "A" which consists of bentonite glued to a lower geomembrane, all other tested GCLs consist of bentonite sandwiched between two geotextiles. Note that in principle, any geotextile type can be used to manufacture GCLs, thus the data to be reported is for the specific product evaluated.

TEST RESULTS AND ANALYSIS

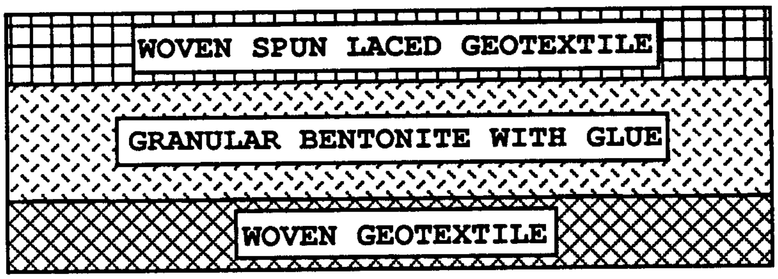
Each GCL was tested for a period of two weeks. The choice of the testing period was based on the fact that the calculated transmissivity was found to vary somewhat above and below a certain average value near the end of this period. The behavior under time periods



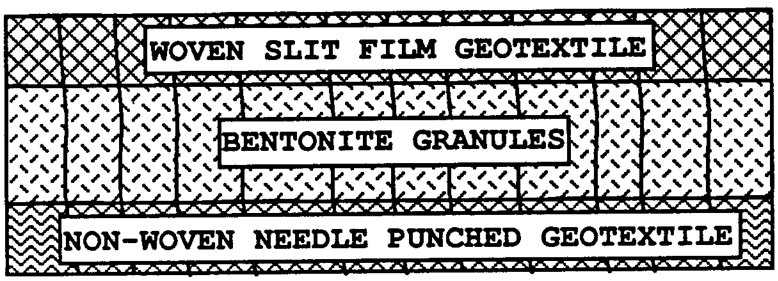
GCL "A"



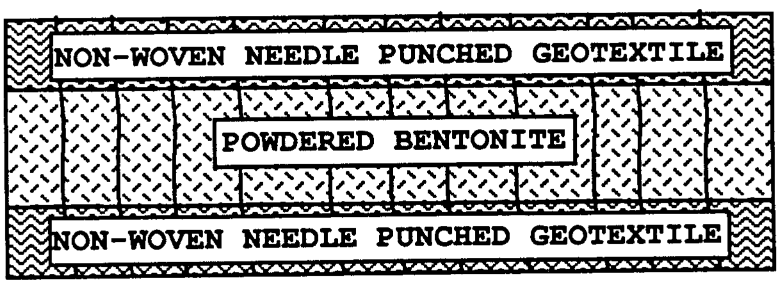
GCL "B"



GCL "C"



GCL "D"



GCL "E"

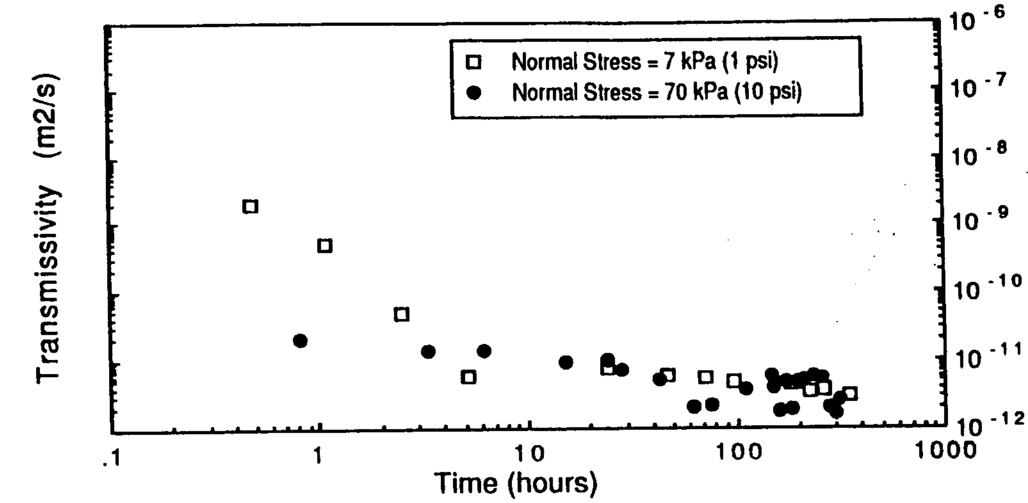
Fig. 3 GCLs Evaluated in this Study

longer than two weeks has not been investigated. All the tests were carried out under normal stresses of 7 and 70 kPa (1 and 10 psi). Because the maximum allowable head over the liner in most landfill regulations is 300 mm (12 in), this head was chosen for carrying out all constant head transmissivity tests. In conducting falling head tests, the maximum applied head was taken equal to 330 mm (13 in) in the early stages of the test and 320 mm (12.5 in) in the final stages. The degree of dependency of the transmissivity on the applied head is not known and therefore it was decided to keep the head as close as possible to that specified in landfill regulations.

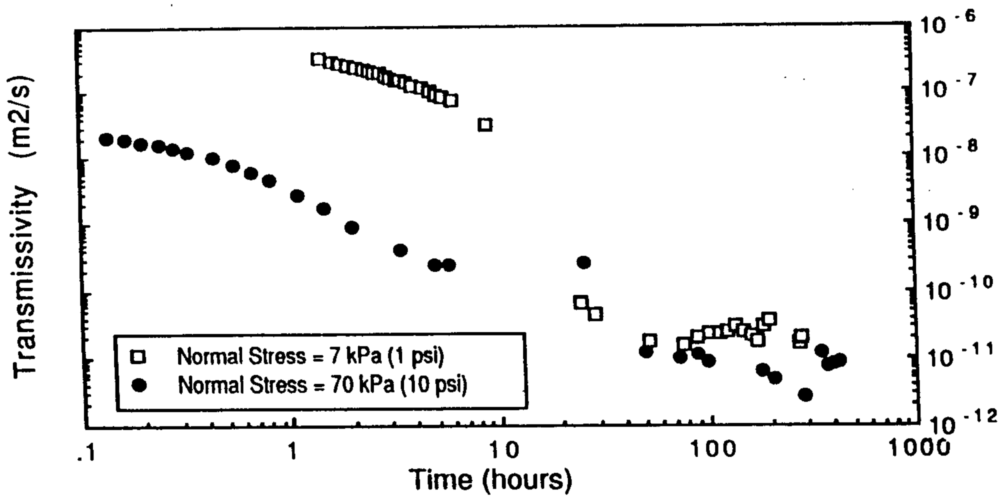
The variation of the apparent transmissivity with time is shown in Figure 4 for the five tested GCLs. It can be seen that initially, the transmissivity is high in most GCLs since it is governed by the relatively large transmissivity of the geotextile and the relatively large size air channels in the bentonite in its initial dry state. As expected, however, the apparent transmissivity at the initial stages is significantly lower under a normal stress of 70 kPa compared to that at a normal stress of 7 kPa. With time, the transmissivity reduces greatly under both normal stresses. This can be explained by the fact that intrusion of the bentonite into the geotextile and extrusion of the bentonite through the geotextile obstructs the flow of water. Simultaneously, any air channels within the initially dry bentonite will be closed due to swelling.

Figure 5 gives the average transmissivity at the end of the testing period under 7 and 70 kPa. The calculation of these values involved some degree of judgment due to the scatter in the data at this stage of the test. Therefore, they should be viewed in terms of orders of magnitudes rather than absolute values. As already mentioned, no investigation was made to examine the behavior at periods of time longer than two weeks. As expected, GCL "A" provides the lowest transmissivity of all GCLs tested since no geotextile is present between the bentonite and the geomembrane. GCL "B" and GCL "D" are both made of the same geotextile. However, as shown in Figure 3, the former GCL comprises powdered bentonite whereas the latter includes bentonite granules. The ratio between the transmissivity of GCL "B" to that of GCL "D" is equal to about 0.1 indicating a better performance of the powdered bentonite. GCL "E" has a needle punched geotextile in contact with the geomembrane which is known to have a large transmissivity. However, its transmissivity is still comparable to other GCLs with a woven geotextile which would be expected to have much less transmissivity. The reason is that the needle punched geotextile in GCL "E" contained a considerable amount of powdered bentonite in its dry state. Although, this was not a direct result of the manufacturing process, it was possibly due to the effect of vibrations occurring during transportation of the material. The greatest effect of normal stress is associated with GCL "C". Inspection of the bentonite surface after peeling the overlying geotextile indicated a highly irregular surface especially at high normal stress. This irregularity may be viewed as evidence of significant intrusion of the bentonite into the geotextile.

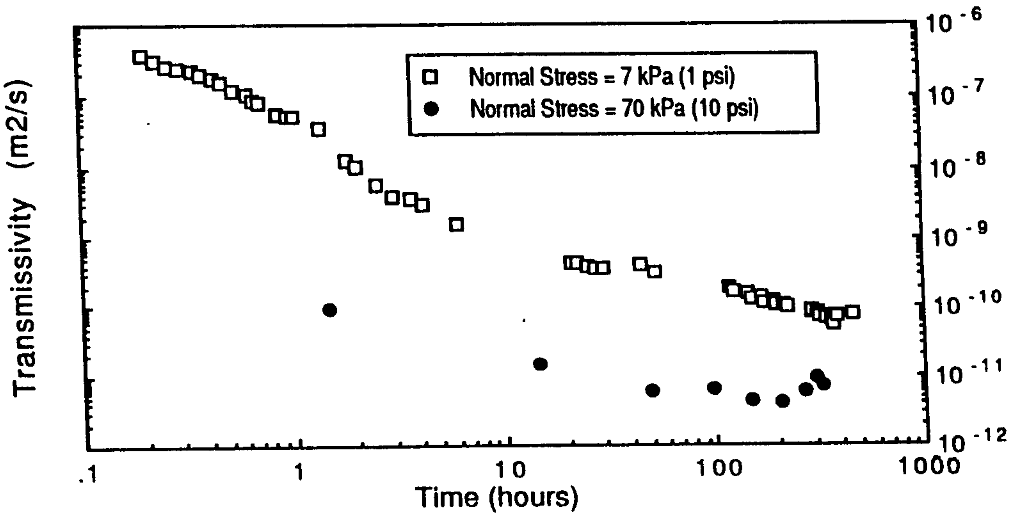
It is difficult at this stage to compare the transmissivity of GCLs and CCLs in contact with geomembranes since very limited data is available for geomembrane/compacted clay liner interfaces. However, it is interesting to note that the transmissivity of the contact between a compacted clay liner having a hydraulic conductivity of 10^{-9} m/s and a HDPE geomembrane was estimated for design purposes by Giroud and Bonaparte (1989) based on the data of Brown et al (1987). They suggested that the transmissivity for such material under excellent field conditions can be obtained assuming a spacing of 0.02 mm between the geomembrane and the CCL. Using Newton's viscosity law for the flow between two smooth parallel plates, it can be shown that this spacing corresponds to a transmissivity of 6.4×10^{-9} m^2/s. This value is superimposed on Figure 5 where all of the GCLs tested show significantly lower values. Also



(a) GCL "A"

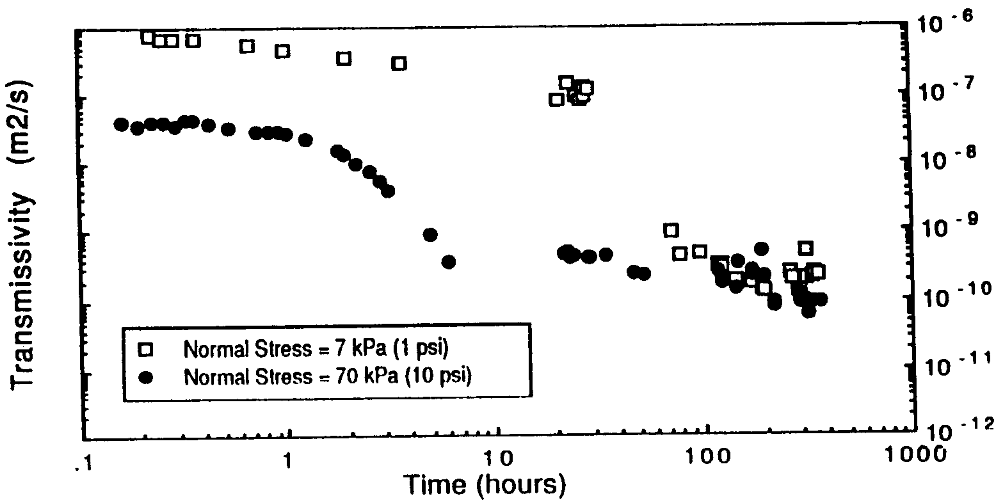


(b) GCL "B"

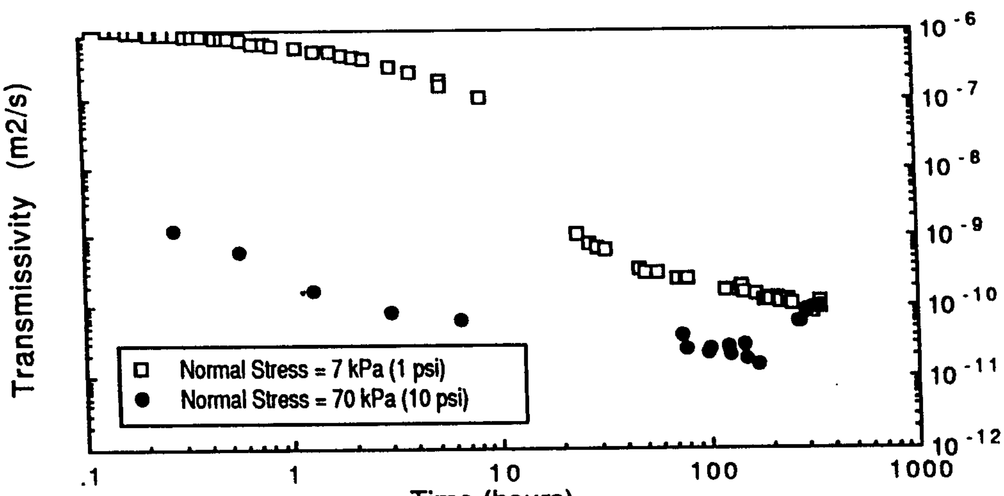


(c) GCL "C"

Fig.4 Variation of Apparent Transmissivity with Time for the Five GCLs Evaluated in This Study



(d) GCL "D"



(e) GCL "E"

Fig.4 (cont.) Variation of Apparent Transmissivity with Time for the Five GCLs Evaluated in This Study

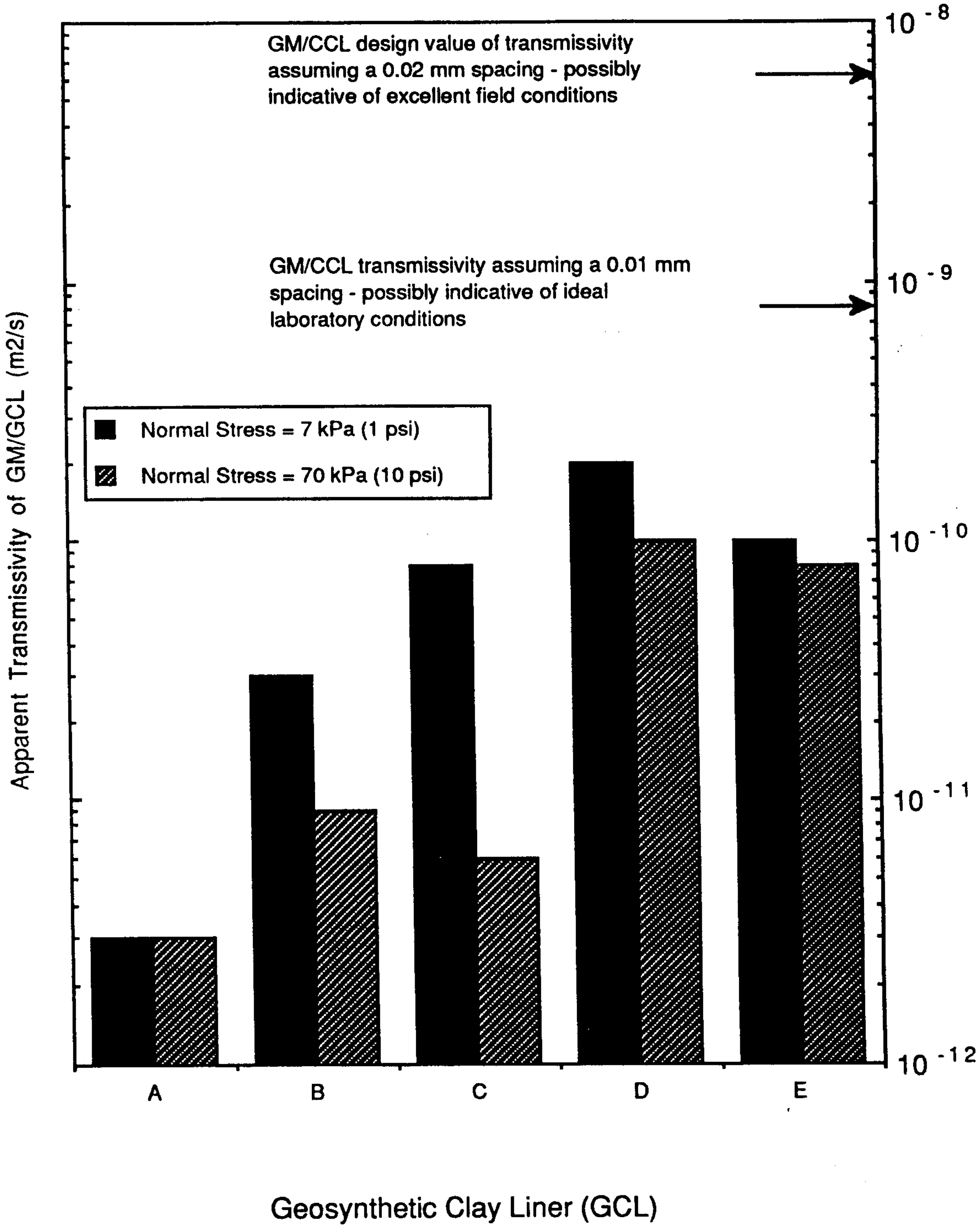


Fig. 5 Apparent Transmissivity of Geomembrane-to-Geosynthetic Clay Liner Interface

on Figure 5 the transmissivity corresponding to a spacing of 0.01 mm is indicated. This value may be more indicative of ideal laboratory conditions. However, it is still significantly higher than the transmissivity of all the tested GCLs, see Figure 5. Additional evaluation is certainly warranted in this regard.

CONCLUSIONS

An apparatus is described for measuring the transmissivity of the contact between a geomembrane and a geosynthetic clay liner under a radial flow regime. Five geosynthetic clay liners were tested using this technique and their apparent transmissivities were evaluated. Their values ranged between 3.0×10^{-12} and 2×10^{-10} m^2/s. Comparison with reported values for geomembranes to compacted clay liners suggests that the concern over intimate contact between GMs and GCLs is probably not justified. However, more testing is still required to assess the transmissivity of both CCLs and GCLs in composite liner situations in order to accurately quantify the differences between the two materials with respect to the transmissivity at their contact with a defective geomembrane.

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