Abdelmalek BOUAZZA, William F. van IMPE, Patrick MENGE*

3 1

Hydraulic conductivity of a geosynthetic clay liner

Abstract

For several decades, the only practical means of waste containment was the construction of a hydraulic barrier consisting of a layer of compacted clay. Recent studies and technology development suggested that, certainly in case of slopes or cover systems, geosynthetic clay liners (GCLs) can be a 1a convenient substitute to clay liners. One of the attractive use of a geosynthetic clay liner (GCL) is in the double composite liner system. Indeed, it can be effectively used on a side directly above the geomembrane and thus reduce the risk of damaging this latter by compaction. The GCLs are thin blankets of bentonite clay attached to one or more geosynthetics materials (e.g. geotextile or geomembrane). Bentonite is a unique clay mineral with very high swelling potential and water absorption capacity.

In the present paper, a summary of a series of hydraulic conductivity tests carried out, at Ghent University-Soil Mechanics Laboratory, in a rigid wall permeameter on a geosynthetic clay liner 2 (GCL) of a geotextile type under different conditions are presented. All the tests are conducted with deaired water as permeant. The first serie of testing was on undamaged dry GCL, the second series on a GCL 15% strained to simulate any effects of differential settlement. It is shown that hydraulic conductivity of the GCL is not influenced by the hydraulic gradient and is not significantly altered when the GCL is strained to relevant levels.

Key words: CCL, GCL, Hydraulic Conductivity, Permeameter

permeation 4

Introduction

For several decades, the only practical means of waste containment, even on slopes, was the construction of a hydraulic barier consisting of a layer of compacted clay. Indeed, a recent study (Fahim & Koerner 1993] carried out in the United States on liners for municipal solid waste disposal facilities has shown that: i) simple compacted clay liners are used in 19 states; ii) compacted clay liners being part of a composite liner are used in 20 states; iii) compacted clay liners are used as single cover in 36 states; iv) compacted clay liners are used as a composite cover beneath a geomembrane in 6 states.

The concept of using compacted clay liners (CCLs) emphasized more the attenuation of the pollution migration than its containment. However, the emergence of the geomembrane technology in the 1980's made the concept of containment more realistic and attainable. After a de-

---

*Ghent University, Soil Mechanics Laboratory, Technologiepark 9, Ghent 9052, Belgium.

cade of technical progress, geomembranes are now accepted by most designers as a required component of landfill liners. Nowadays, most of the modern landfills are constructed with a composite liner system, in which a geomembrane is placed over a clay layer. Leakage rates through well constructed composite liners are for lower than through geomembranes or compacted clay liners (CCLs) individually. Recent studies and technology development suggested that geosynthetic clay liners (GCLs) can be a convenient substitute to clay liners or a supplement to a (CCL) based composite liner. Indeed, the GCLs can have different applications within a modern landfill liner system. The most common application is as a complete or partial replacement of a CCL. In this application, the GCL is located immediately below a geomembrane and acts to minimise leakage by isolating flow through any holes that may be present in the geomembrane it self (fig. 1 and 2). Another application involves the placement of the GCL in the cover system (fig. 3). The primary purpose of the GCL in this application is to minimise the infiltrations. More over, used as shown in the figures below the GCLs can represent the next step towards the aim of total waste containment.

GCLs description

As discussed earlier geosynthetic clay linears (GCLs) are relatively new type manufactured clay liner which can be used as a hydraulic barrier in liners and cover systems at waste disposal facilities. The GCLs are thin "blankets" of bentonite clay attached to one of more geosynthetics materials (e.g. geotextile or geomembrane). Bentonite is a unique clay mineral with very high swelling potential and water absorption capacity. Of the two major types of bentonite, sodium bentonite predominates in North American GCLs, while calcium bentonite is usually used in European manufactured GCLs [Koerner & Daniel 1994]. Geosynthetics clay liners are manufactured by laying down a dry bentonite approximately 5 mm thick, on a geosynthetic material and attaching the bentonite to the geosynthetic material. Two general configurations are currently employed in commercial processes:

- Type 1: bentonite sandwiched between two geotextiles either needle punched or non woven (fig. 4a).
- Type 2: bentonite glued to a geomembrane (fig. 4b).

The primary purpose of the geosynthetic component is to hold the bentonite together in a uniform layer and permit transportation and installation of the material without losing bentonite or altering the thickness of the bentonite. However, the geosynthetic components may serve other important purposes, as well, such as adding tensile or shear strength to the material. The bentonite component of a manufactured GCL is essentially dry, and there are open voids between bentonite granules in the manufactured material. When the bentonite is hydrated with water, the bentonite swells and the woids between bentonite granules close. The swelling action of bentonite is crucial to attainment of low permeability. The GCL contains approximately 4.9 kg/m^2 of ben-

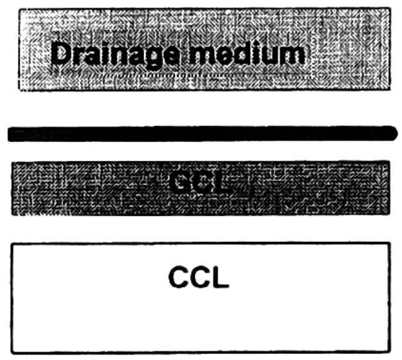

Fig. 1. Potential use of GCL in single composite liner

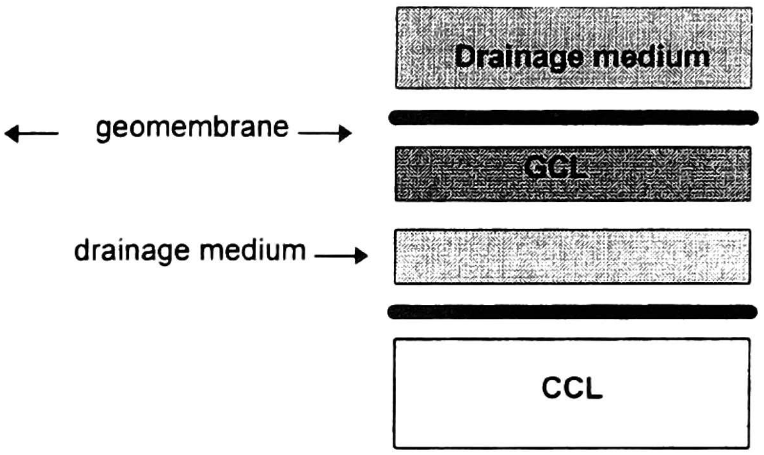

Fig. 2. Potential use of GCL in double composite liner

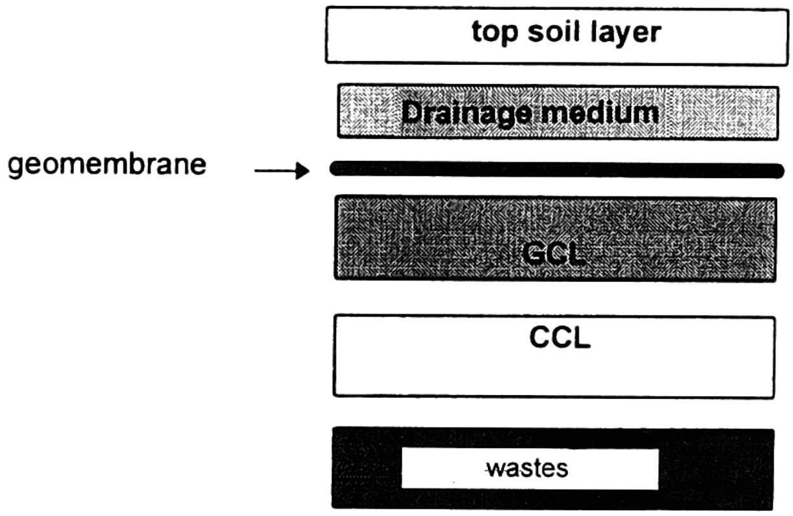

Fig. 3. Potential use of GCL in landfill cover

Fig. 4. Cross section of current available GCLs

tonite that has a hydraulic conductivity of approximately $1 \cdot 10^{-11}$ m/s. Continuous gravity percolation under unit hydraulic gradient throught a material with a hydraulic conductivity of $1 \cdot 10^{-11}$ m/s would result in an infiltration of 0.3 mm per year, or approximately 30 mm every 100 years, when only considering the simple advection phenomenon. For landfill covers, an intact GCL may in such case be considered essentially impermeable to water. The GCLs were first manufactured in the early 1980's and were initially used for foundation water proofing and for sealing water retention structures. The GCLs were first used for landfill liners in 1986. Since then, GCLs have been used for a variety of lining applications and also in several final cover systems for hazardous wastes, radioactive wastes, and non hazardous solid wastes [Koerner & Daniel 1994]. One of the attractive use of a GCL is in the composite liner system (fig. 2), where the use of a compacted clay liner on a side slope directly above the geomembrane can be very difficult and where the compaction process and continuous straining can deteriorate the geomembrane.

Hydraulic conductivity of the GCLs

Testing equipment

Hydraulic conductivity tests on the GCL of type 1 have been carried out in a rigid wall permeamater as shown in figure 5. The dry and prehydrated samples were permeated from bottom to top. All the tests have been carried out under a pressure of 15 kpa. Deaired water was used as permeant. The hydraulic conductivities were determined on achievement of stationary flow.

Results and discussion

The results of flexible wall hydraulic conductivity tests reported by Estornell and Daniel (1992) and Shan (1990) are shown in table. It can be seen that hydraulic conductivities to water of all the GCLs varied approximately between $3\cdot10^{-12}$ to $6\cdot10^{-11}$m/s, depending on the compressive stress. The test carried out in a rigid wall permeameter at Ghent University (Soil Mechanics Laboratory) on a GCL ($k = 3\cdot10^{-11}$ cm/s) shows an excellent agreement with the results obtained at Texas University (USA). It should be pointed out that the test conditions in both universities were different. On testing the GCL in a rigid wall permeameter care was taken to avoid any side wall leakage. One

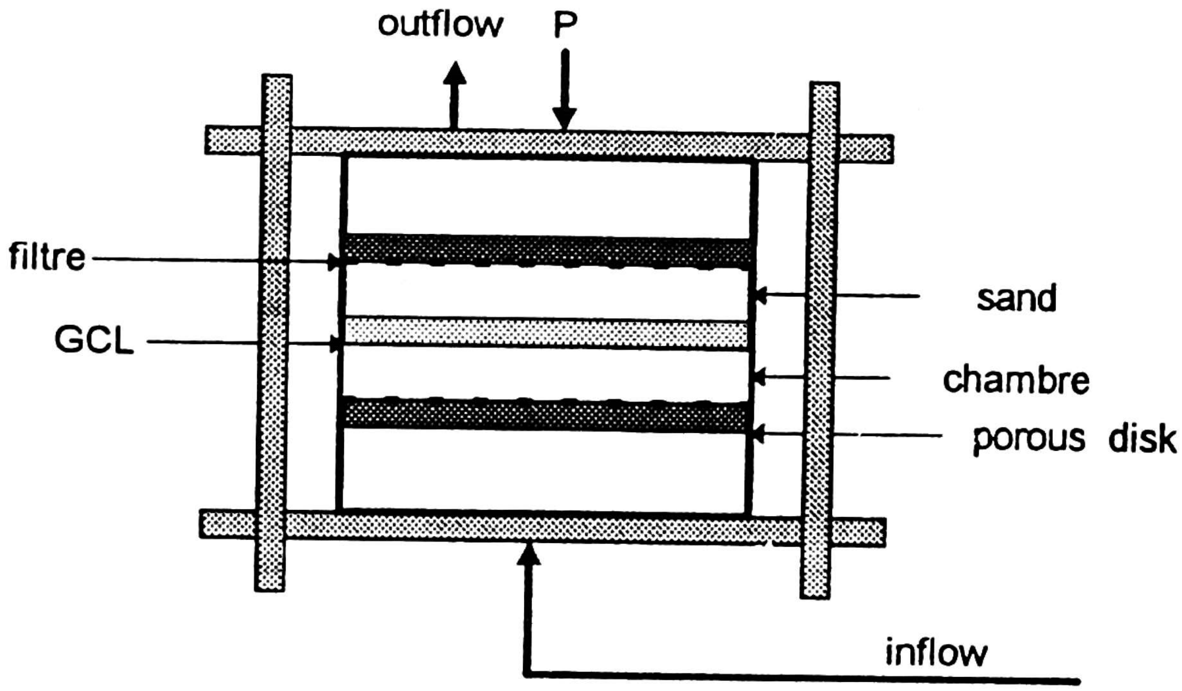

Fig. 5. Rigid wall permeameter set up

Table. Results of laboratory hydraulic conductivity tests

Effective stress σ' (kpa)	Hydraulic conductivity (m/s)	Type of test	Sources
15	$3 \cdot 10^{-11}$	flexible wall permeametre	Estornell & Daniel (1992)
34	$3 \cdot 10^{-11}$		
35	$1 \cdot 10^{-11}$		
69	$1 \cdot 10^{-11}$		
73	$1 \cdot 10^{-11}$		
91	$1 \cdot 10^{-11}$		
15	$3 \cdot 10^{-11}$	rigid wall permeametre	present study
24	$2 \cdot 10^{-11}$	flexible wall permeametre	Estornell & Daniel (1992)
200	$4 \cdot 10^{-12}$		
207	$8 \cdot 10^{-12}$		
207	$7 \cdot 10^{-12}$		
15	$2 \cdot 10^{-11}$		Shan (1990)
34	$1 \cdot 10^{-11}$		
69	$6 \cdot 10^{-12}$		
138	$3 \cdot 10^{-12}$		

should also bear in mind that when comparing hydraulic conductivities of the GCLs, compressive stress should be taken into account.

The results compiled in table are presented in figure 6 in terms of the ratio k_{15}/k_β, where k_{15} is the hydraulic conductivity of the GCL at an effective stress of 15 kpa (the lowest compiled in table) and k_β is the hydraulic conductivity of the GCL at a given effective stress. It is observed that the decrease in the hydraulic conductivity is more pronounced at low effective stresses (15 kpa $\leq \sigma' \leq$ 70 kpa) whereas the decrease at higher effective stresses is much lower. This suggests that beyond an effective stress referred to as the threshold effective stress (σ'_{trh}) the decrease in the hydraulic conductivity of a GCL is not very significant.

Hydraulic conductivity tests were carried out first on the dry GCL itself to establish a reference baseline (fig. 7) a value of (k) around $3 \cdot 10^{-11}$ m/s was obtained after 11 days of permeation and it stabilised to this value. It should be pointed out also that the values obtained between 0 and 3 days corresponds to the time that the bentonite needed to hydrate. As matter of fact, they are not hydraulic conductivity values but they could represent the amount of water the bentonite was sucking to hydrate. After this process, the GCL thickness varied from 5.4 mm to 10.3 mm.

Figure 8 shows the variation of the hydraulic conductivity with hydraulic gradient. One can see clearly that the k values of the GCL alone are not significantly dependent on the hydraulic gra-

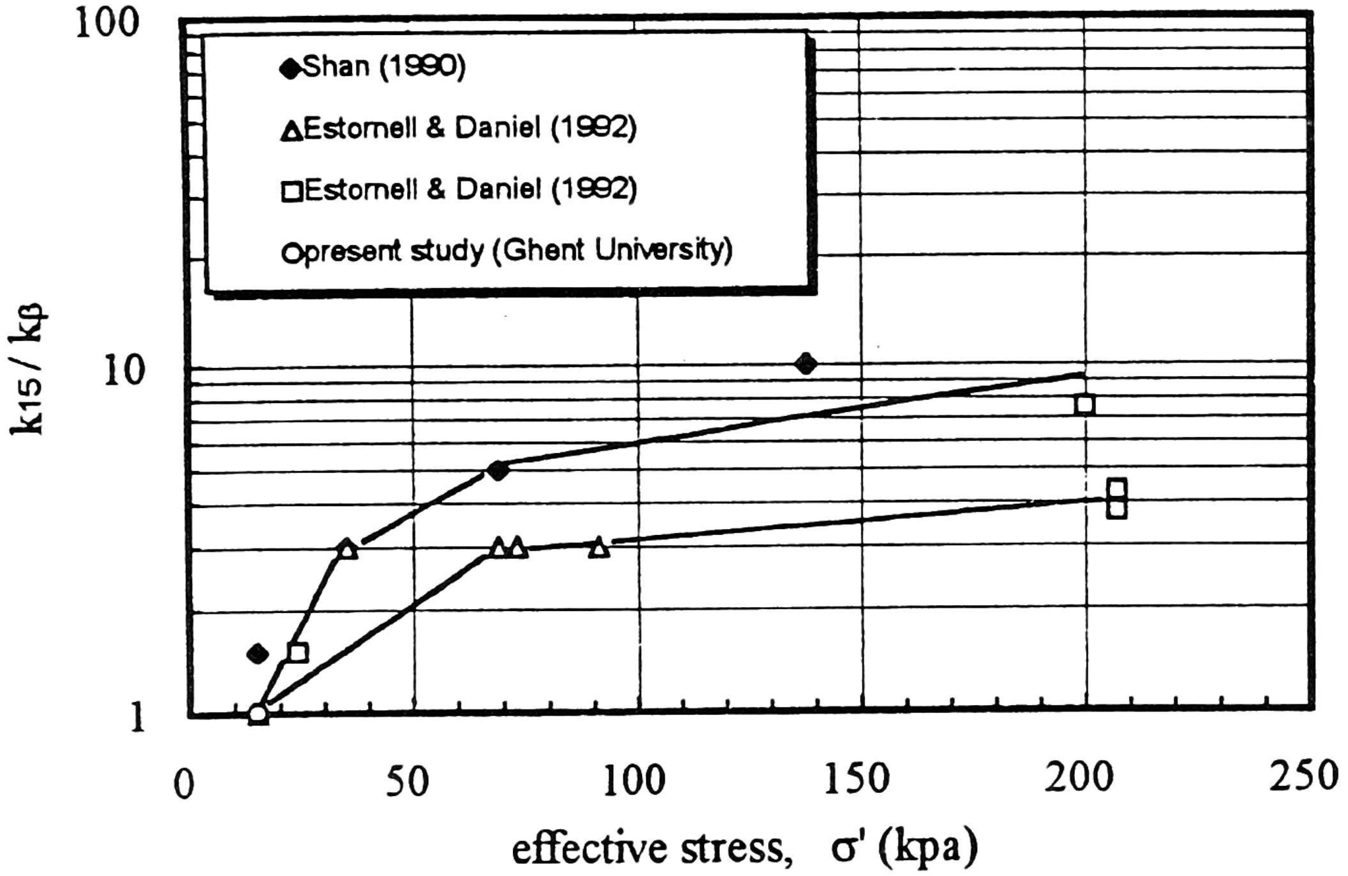

Fig. 6. Relationship between hydraulic conductivity and effective stress

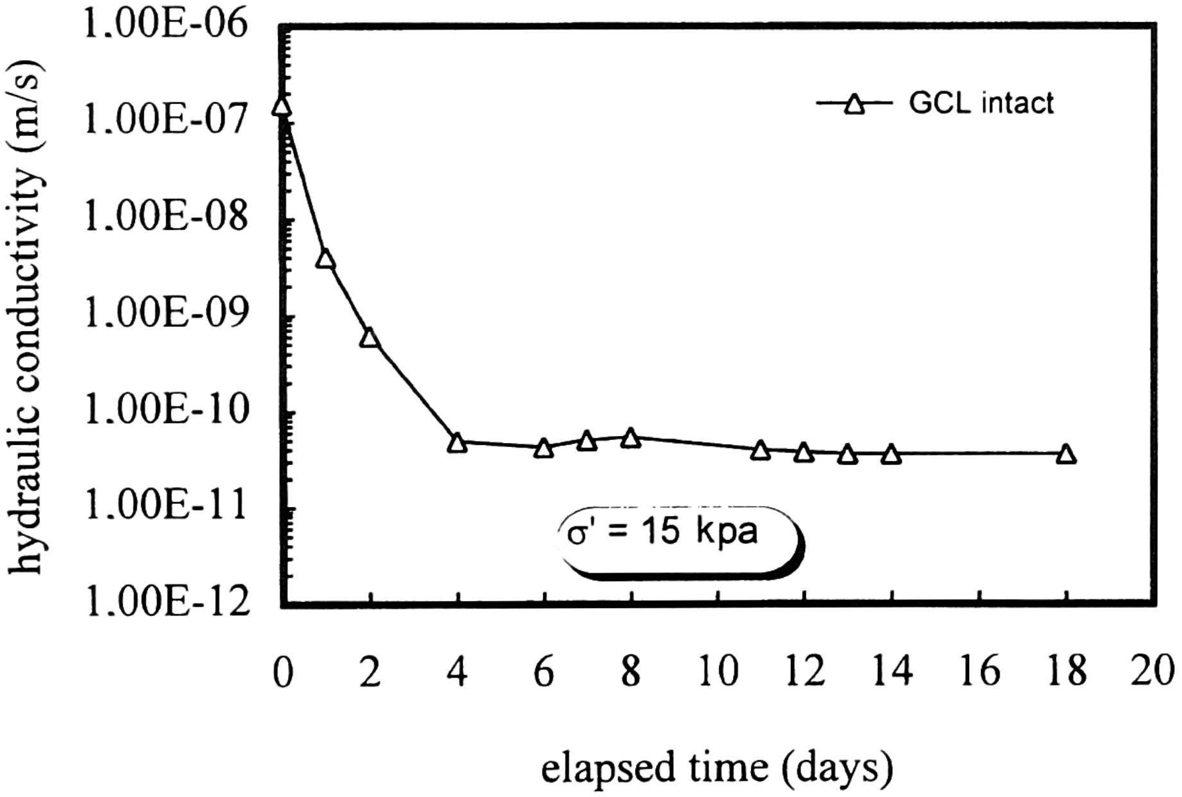

Fig. 7. Variation of hydraulic conductivity with time

dient. The increase of flow speed resulting from the increase of the pressure head may, however, lead to particles of bentonite migrating through the geosynthetic supporting layer. However, the present results did not show any evidence of bentonite migration. The heterogeneous waste composition and ageing process (wa-

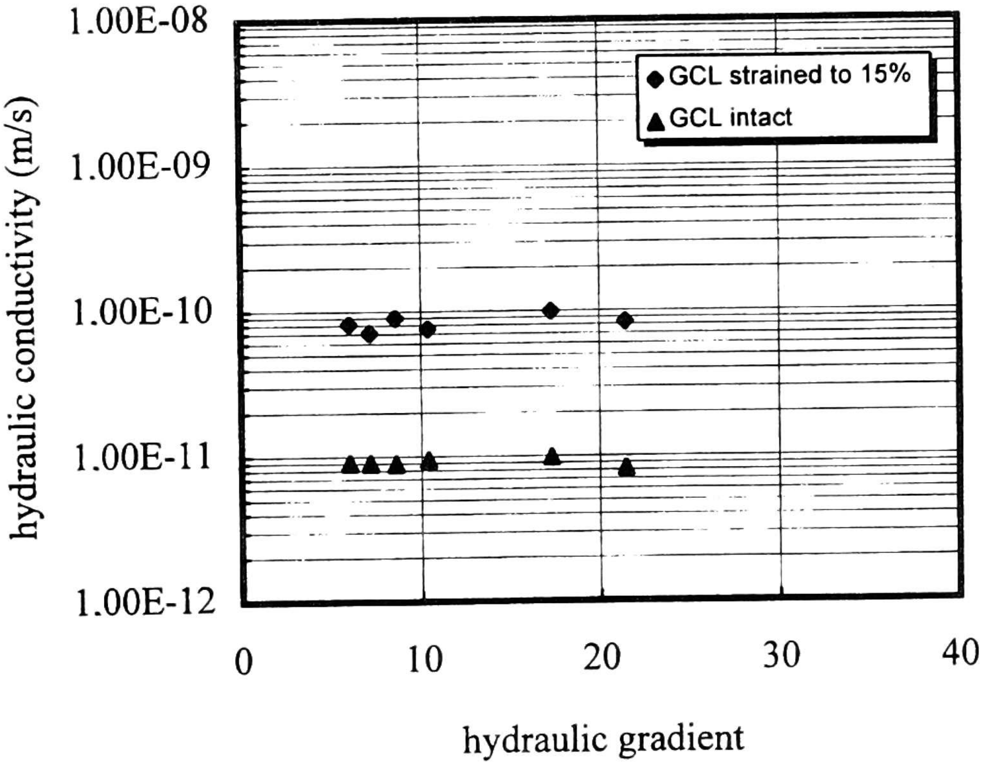

Fig. 8. Variation of hydraulic content with hydraulic gradient for a GCL 15% strained

ste biodegradation) can lead to substantial differential settlement in a landfill. In this case, the GCL is subjected to distortion which produces tension and can lead to cracking. In the present study, The GCLs were hydrated and permeated after straining to 15%, a difference of almost one order of magnitude in the hydraulic conductivity was found when compared to an undamaged GCL. The present results are in contradiction with the findings of LaGatta (1992) and Boardman (1993). However, this can be explained by the fact that in their tests the GCL was strained to 6% only. However, in the above case, the final value is still in agreement with most of the minimal values required by the regulations.

The permeability of the GCLs when acted upon by chemical solutions is of a paramount importance. Shan & Daniel (1991) describe tests in while one GCL was permeated with a variety of chemicals. They found that the liner maintained low hydraulic conductivity to a broad range of diluted chemicals when the bentonite was fully hydrated with fresh water prior to introduction of the chemical. The results showed also pure organic chemicals (methanol) caused decreases in hydraulic conductivity. They pointed out that this result is contradictory to the findings of most other investigations [Foreman & Daniel 1987, Uppot & Stephenson 1989] suggesting that pure methanol increased the hydraulic conductivity of clayey soils. However, Fernandez & Quigley (1988) found that the hydraulic conductivity of their compacted clay samples decreased when permeated with pure methanol in flexible wall permeameters. Uppot & Stephenson (1989) found that the hydraulic conductivity of kaolinite and Mg-montmorillonite decreased during the first pore volume of flow when permeated with pure methanol. On the other hand, Shan & Daniel (1991) pointed out that since less than 1 pore volume of methanol passed through the test specimen, it is possible that hydraulic conductivity of the GCL would have increased had there been more flow. Heyer (1994) showed also that the GCLs advection behaviour is dependent of the water content or degree of swelling of the bentonite.

Conclusions

In this study, results from hydraulic conductivity tests with water showed the following:

- At a given stress level, no difference is found between results from rigid wall permeameter and flexible wall permeameter, if care is taken to avoid any side leakage.
- Straining the GCL to 15% does affect its hydraulic conductivity.
- The hydraulic conductivity of the GCL is not dependent on the hydraulic gradient.
- This type of material implements some desirable liner characteristics and warrant further testing and evaluations.

Acknowledgments

The financial and material support provided to the first author by the Soil Mechanics Laboratory, Ghent University is gratefully acknowledged.

References

BOARDMAN B.T. 1993: *The potential use of geosynthetic clay liners as final covers in arid regions.* M.S. Thesis, University of Texas, Austin, Texas (USA).

ESTORNELL P., DANIEL D.E. 1992: *Hydraulic conductivity of three geosynthetic clay liners.* Journal of Geotechnical Engineering, ASCE, 118 (10), 1592–1606.

FAHIM A., KOERNER R.M. 1993: *A survery of state municipal solid waste (MSW) liner and cover systems.* GRI Report 11, Drexel University (USA).

FERNANDEZ F., QUIGLEY R.M. 1988: *Viscosity and dielectric constant controls on the hydraulic conductivity of clayey soils permeated with water soluble organics.* Canadian Geotechnical Journal, 25, 582–589.

FOREMAN E.F., DANIEL D.E. 1986: *Permeation of compacted clay with organic chemicals. Journal of Geotechnical Engineering.* ASCE, 112 (7), 669–681.

HEYER D. 1994: *Basic examination on the efficiency of GCLs.* Proc. Int. Symp. on Geosynthetic Clay Liners, Nürnberg (Germany), 101–111.

KOERNER R.M., DANIEL D.E. 1994: *A suggested methodology for assessing the technical equivalency of GCLs to CCLs.* Proc. Int. Symp. on Geosynthetic Clay Liners, Nurnberg (Germany), 73–98.

LAGATTA M.D. 1992: *Hydraulic conductivity tests on geosynthetic clay liners subjected to differential settlement.* M.S. Thesis, University of Texas, Austin, Texas (USA).

SHAN H.Y. 1990: *Laboratory tests on a bentonitic blanket.* M.S. Thesis, University of Texas, Austin, Texas (USA).

SHAN H.Y., DANIEL D.E. 1991: *Results of laboratory tests on a geotextile-bentonite liner material.* Proc. Geosynthetics 91, Atlanta (USA). Vol. 2, 517–535.

UPPOT J.O., STEPHENSON R.W. 1989: *Permeability of clays under organic permeants.* Journal of Geotechnical Engineering, ASCE, 115 (1), 115–131.