Influence of Prehydration Without Load on The Hydraulic Performance of Geosynthetic Clay Liners

Nathalie Touze, Jérôme Buessard, Gérard Didier, Véronique Norotte, Gérard Mazzoleni, Jean-Louis Mahuet

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N. Touze-Foltz. Unité HBAN, Cemagref, Antony, France. n.touze@cemagref.fr
J. Buessard. Unité HBAN, Cemagref, Antony, France. j.buessard@cemagref.fr
G. Didier, Insavalor, Lyon, France. gerard.dider@insa-lyon.fr
V. Norotte, Insavalor, Lyon, France. veronique.norotte@insa-lyon.fr
G. Mazzoleni, CETU, Bron, France. Gerard.Mazzoleni@equipement.gouv.fr
J.-L. Mahuet, Egis, Lyon, France. jean-louis.mahuet@egis.fr

ABSTRACT
Geosynthetic clay liners (GCLs) are used in a variety of geoenvironmental applications to ensure lining. In order to properly function GCLs have to be confined and hydrated. It is usually recommended that load be applied on top of the GCL immediately after installation. The question that arises is related with the potential impact of the hydration without load on the final hydraulic performance of the GCL as compared to a situation where it would have been hydrated under load. The paper will thus describe the impact of various hydration modes of a GCL.
Flow rates measurements were performed for virgin GCL samples and following the different modes of hydration. 5 different GCL coming from different manufacturers were used. The best performance was obtained with needle punched GCLs but the influence of prehydration without load was only significant for one of the two stitched GCLs tested.

1. INTRODUCTION

Geosynthetic clay liners (GCLs) are used in a variety of geoenvironmental applications to ensure lining for example in base liners or as part of capping systems for landfills, as liners for contaminated fluids, as barriers to contain past spills of hydrocarbons, as secondary containment around fuel tanks to prevent possible future contamination in the event of a tank rupture or equipment malfunction, as containment for fluids in heap leach pads (Rowe 2007) and for tunnel and underground and structures lining.

In order to properly function GCLs have to be confined and hydrated. It is usually recommended that load be applied on top of the GCL immediately after installation. Nevertheless, there are a number of situations in which such a practise is not possible and GCLs may be left exposed to wetting without being confined. This can also arise when it is thought that a sufficient amount of water will not be supplied from the underlying soil to the GCL to ensure hydration.

The question that arises is related with the potential impact for the hydration without load on the final hydraulic performance of the GCL as compared to a situation where it would have been hydrated under load. The load under consideration in this study is equal to 20kPa, simulating almost a 1m thick layer of soil.

The paper will thus describe the impact of various hydration modes of a GCL without load: (1) immersion during five days without load for GCLs in horizontal position, which will be representative of a wide range of uses in a number of applications including landfills and ponds for environmental protection; (2) heavy rainfalls for GCLs installed horizontally on tunnel extrados; and (3) heavy rainfalls for GCLs installed vertically on tunnel intrados.

Flow rates measurements were performed for virgin GCL samples saturated under a 20kPa load and GCL samples hydrated following the different modes upon request of the CETU, the French Centre for tunnel Studies. Three needle punched and two stitched GCLs were tested, all containing sodium bentonite.

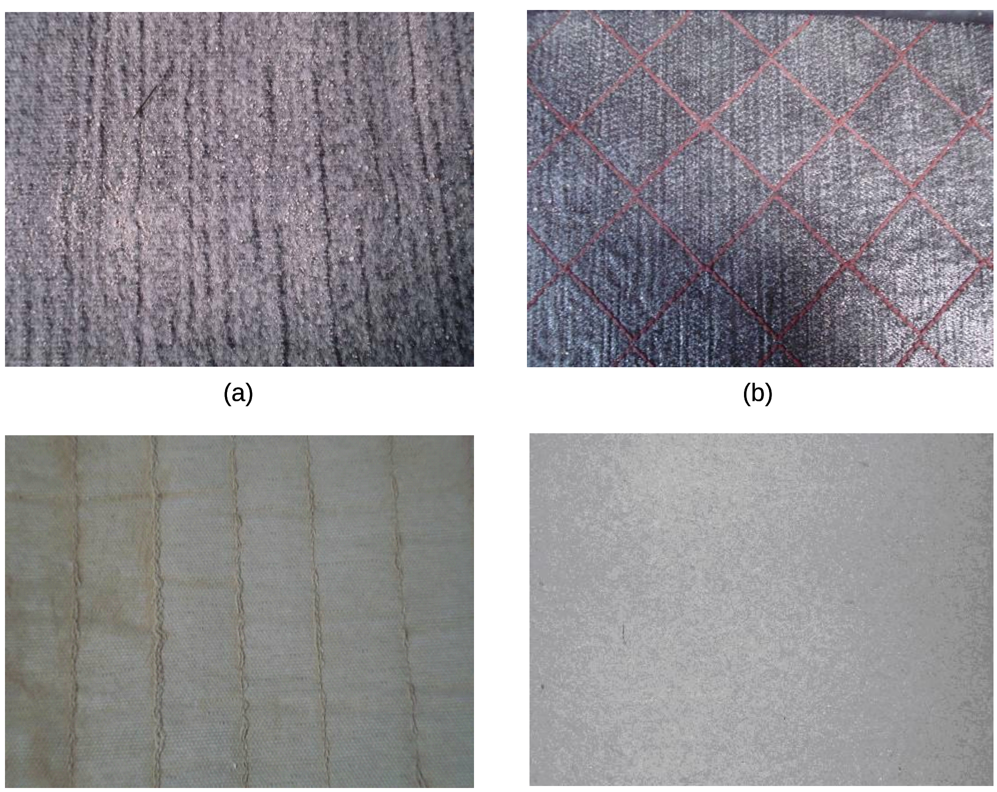
In the following we first describe the five GCLs under study. Then a description of the three different modes of hydration is given. Finally some results obtained in terms of temporal evolution of water content and thickness of the GCLs and hydraulic properties are given and discussed.

2. MATERIALS AND METHODS

2.1 Geosynthetic clay liners studied

Table 1. Features of the five GCLs tested.

	GCL1	GCL2	GCL3	GCL4	GCL 5
Cover geotextile	woven	woven	woven	nonwoven needle punched	nonwoven needle punched
Carrier geotextile	nonwoven needle punched	woven	woven	woven	woven
Assembly mode	Needle punched	stitched	stitched	Needle punched	Needle punched
bentonite	granular	granular	powdered	powdered	powdered
Minimum mass per unit area of dry bentonite (kg/m²)	5200	5000	4200	5200	5000
Swell index (ml/2g)	30	23	38	30	>24
Thickness under 20kPa (mm)	7.6	5.1	5.1	6.9	5.9



(a) (b) (c) (d)

Figure 1. Pictures of four of the GCLs studied (a) GCL1, (b) GCL2, (c) GCL3, and (d) GCL4

Five different GCLs coming from the five different manufacturers existing on the French market were selected. The all contain sodium bentonite with a mass per unit area of dry bentonite close to 5 kg/m². The features of the various GCLs are presented in Table 1. A picture of GCLs 1 to 4 is given in Figure 1. The mode of fabric of GCL5 is very close to the one from GCL4 and they almost look like the same.

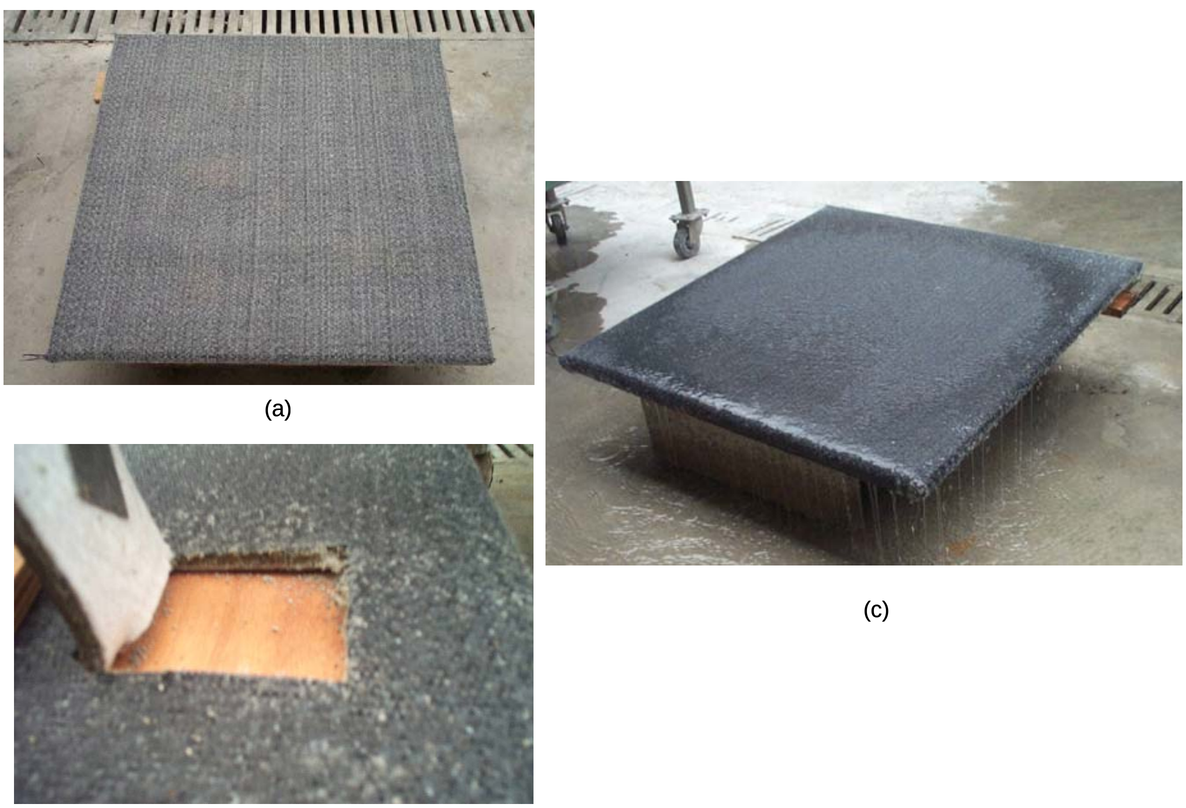
2.2 Hydration and hydraulic tests performed

2.2.1 Hydration methods

The effect on the hydraulic properties of the GCLs of the three different hydration methods without load were investigated in this study (see Figure 2).

The first one aims at reproducing a variety of applications including landfills and ponds for environmental protection where the GCL can be immersed in water prior to load application. Immersion was performed during five days in the oedopermeameters subsequently used for hydraulic parameters measurements that will be described in Section 2.2.2 of this paper. Sacrificial samples were used in order to determine the evolution of the water content and the thickness of the various GCLs with time.

The second hydration protocol aimed at simulating heavy rainfalls for GCLs installed horizontally on tunnel extrados. A 0.8mx0.8m piece of GCL was placed on a rigid plate nearly horizontal (slight slope). Rainfall events were simulated six hours a day during five days. On each day a 0.1mx0.1m GCL sample was removed for the testing pad at the bottom of the GCL in order to quantify water content and thickness. A 0.25m diameter sample was removed from the piece of GCL at its centre at the end of the hydration period in order to quantify the hydraulic parameters thanks to oedopermeater tests.



(a) (b) (c)

Figure 2. Heavy rainfalls for GCLs installed horizontally (a) piece of GCL1 before testing, (b) sampling of a 0.1m×0.1m GCL sample from GCL1, and (c) rain simulation on GCL1.

Heavy rainfalls for GCLs installed vertically on tunnel intrados were simulated and evaluated in the same way as for heavy rainfalls for GCLs installed horizontally except that the GCL was installed vertically (See figure 3).

Figure 3. Piece of GCL1 before testing in the heavy rainfalls situation.

2.2.2 Oedopermeameters tests

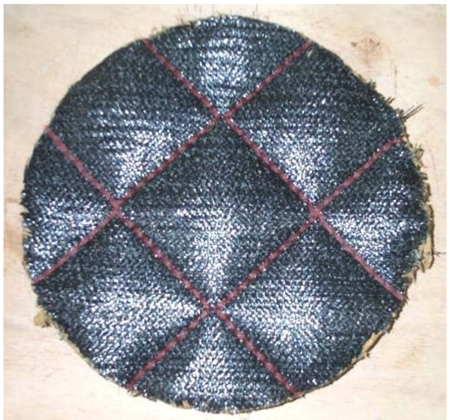
The quantification of the flow of water through the various GCLs was quantified thanks to oedopermeameters decribed in NF P 84-705 previously used by Norotte et al. (2004), Guyonnet et al. (2005) and Guyonnet et al. (2009) for quantification of leachate flow through GCLs.

The cell is composed of two parts, a base and a piston made of HDPE, equipped with 0.2m diameter minimum porous plates. A 0.25m diameter GCL sample is placed inside the cell and covered with the piston. Both parts can be fixed together with screws (constant volume mode).

Tests are usually divided into two phases: (1) a swelling phase; and (2) a percolation phase. In case of the three hydration modes previously described, the hydration phase was performed without load, inside the cell for the immersion mode and outside the cell for the simulation of heavy rainfalls either horizontal or vertical (see Figures 2 and 3). After the hydration phase a 20 kPa load was applied on the samples until stabilisation of consolidation of the samples could be reached. In the case of GCL2 and GCL3 samples exhibited a non uniform thickness as illustrated on Figures 5 and 6. It was thus necessary to add glass beads on top of the sample prior to load application thanks to the piston, as illustrated on Figure 7.

Those hydration modes were compared to the case of a GCL sample hydrated inside the oedopemeameter under a load equal to 20kPa. The swelling phase lasted until more than 90% of the final swelling was reached, as indicated by the displacement of the piston and the absorbed volumes of water. The related theory can be found in NF P 84-705 (AFNOR 2008).

Water is then supplied to the oedopermeameter using a Mariotte bottle allowing to apply a constant hydraulic head and perform flow rates measurements. Various hydraulic heads were applied ranging from a few centimetres to 1m depending on the GCLs tested and the impact of the hydration mode on the flow rates. Large hydraulic heads could not be applied when the GCLs had been heavily impacted thus resulting in very large flow rates that could not be measured thanks to the existing experimental devices used.



(a)

(b)

Figure 5. Aspect of the surface of (a) GCL2 (b) and GCL3 after 5 days of hydration

(a)

(b)

Figure 6. Aspect of the side of (a) GCL2 and (b) GCL3 after 5 days of hydration

Figure 7. Illustration of the use of glass beads to reach a flat surface on top of the GCL samples

3. RESULTS

3.1 Evolution of water content and thickness of GCLs

The evolution of bentonite water content with time for the various hydration modes is presented in Table 2 for GCLs 1 to 4. Those values are indicative as a variation can occur from sample to sample.
In the case of GCL2 the water content given in the table corresponds to an average. Indeed, the water content is lower at the location of stitch lines and larger between stitch lines.

Table 2. Evolution with time of water content in % for the various GCLs

GCL	Hydration	Time (d)	1	2	3	4	5
GCL1	Immersion		150.9	222.7	225.9	221.8	232.3
	Vertical rainfall		53.9	70.1	76.2	82.5	85.7
	Horizontal rainfall		53.3	72.0	82.4	84.3	112
GCL2	Vertical rainfall		243.4	255.8	-	255.1	254.3
	Horizontal rainfall		161.6	212.0	-	225.6	234.1
GCL3	Immersion		184.8	297.4	368.2	446.4	365.7
	Vertical rainfall		90.3	133.4	160.7	200.2	212.8
	Horizontal rainfall		112.7	173.4	225.3	317.6	280.7
GCL4	Immersion		107.7	148.3	195.4	176.8	171.7
	Vertical rainfall		32.8-69.7	84.0	92.8	95.7	96
	Horizontal rainfall		42.8-76.1	98.0	106.1	112.8	113.8

In the case of GCL3, the bentonite is encased in a container inside both geotextiles making it difficult to separate the bentonite from the geotextile. The water content is thus calculated neglecting the geotextile and geocontainer mass. In this GCL the variation of water content (stitch lines and between stitch lines is lower than for GCL2.

Those results evidence the variation of thickness of the samples for both stitched GCLs, mainly as regards GCL2.

3.2 Hydraulic properties of the GCLs for the various hydration modes

Figures 8 to 12 illustrate the evolution of flow rates measured through the various GCL samples depending on the hydration mode. All tests were performed under a 20kPa load.

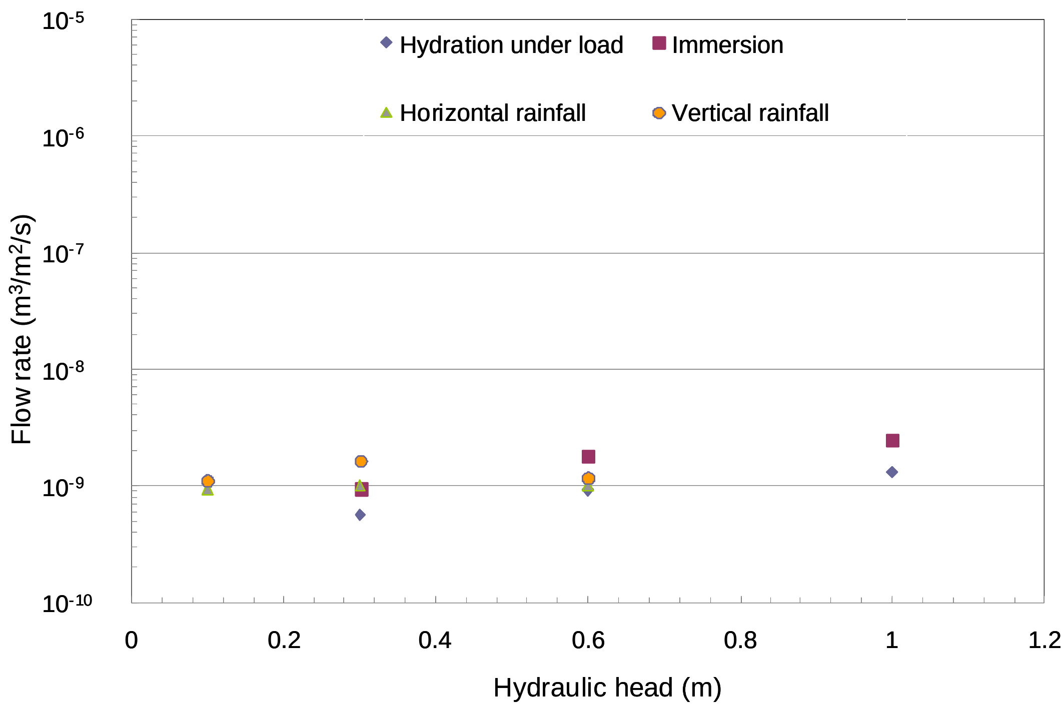


Figure 8. Flow rates obtained for GCL1 depending on the hydration mode

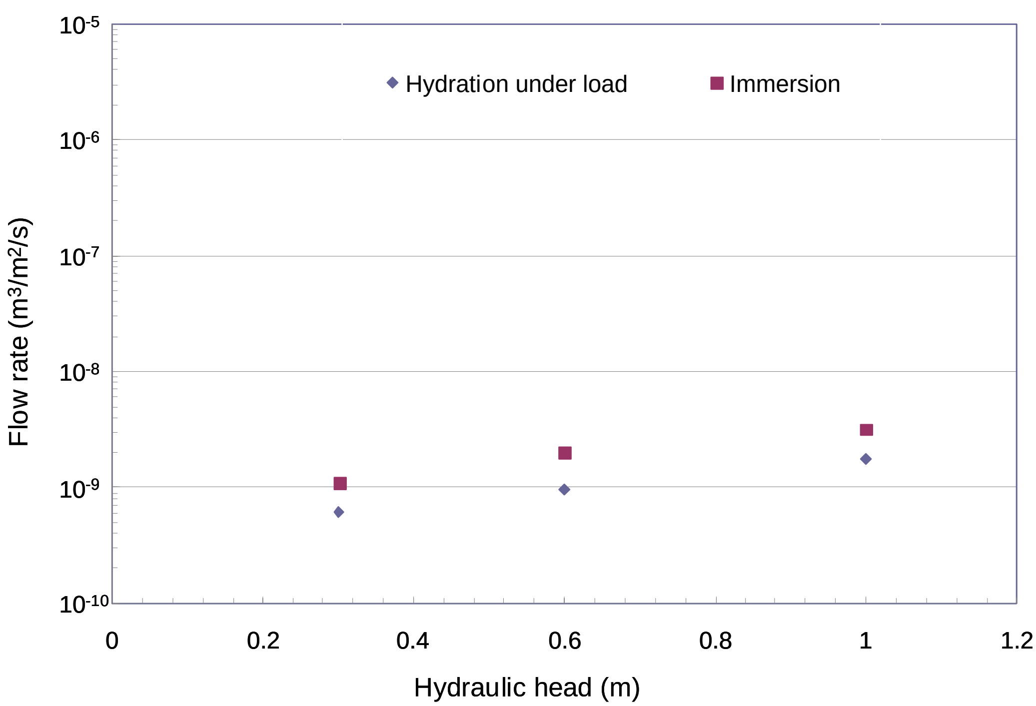


Figure 9. Flow rates obtained for GCL4 depending on the hydration mode

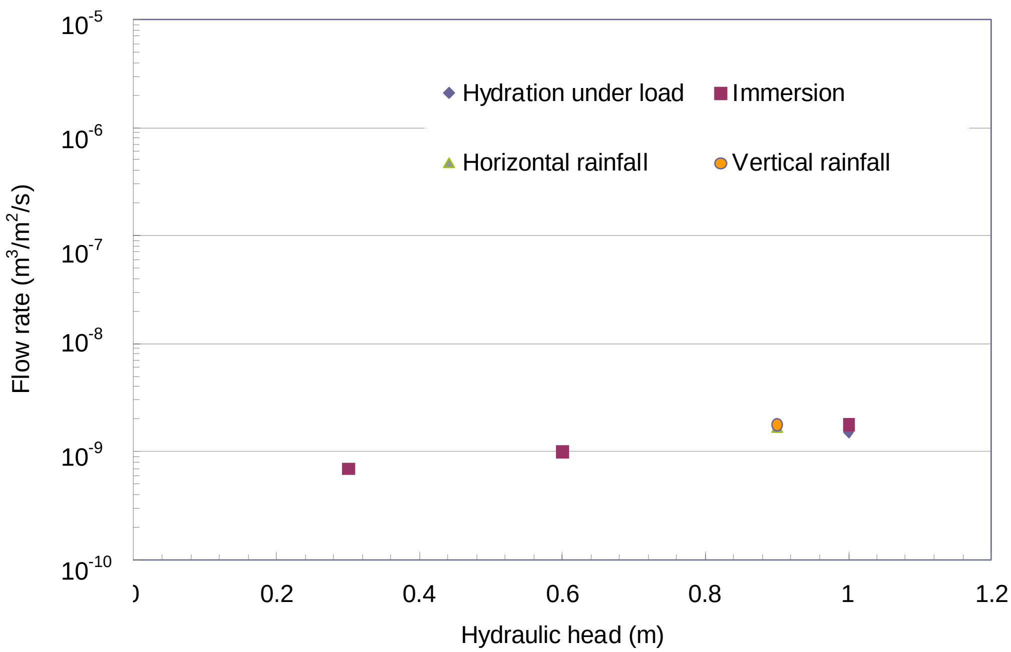


Figure 10. Flow rates obtained for GCL5 depending on the hydration mode

Results presented on Figures 8 to 10 illustrate that for the three needle punched GCLs the hydraulic performance of the GCL is only slightly affected by hydration without load in the experimental conditions presented in this paper. Indeed in the worst case a factor two was obtained between the flow rates measured for prehydration under load and the immersion case which is the most detrimental case of all.

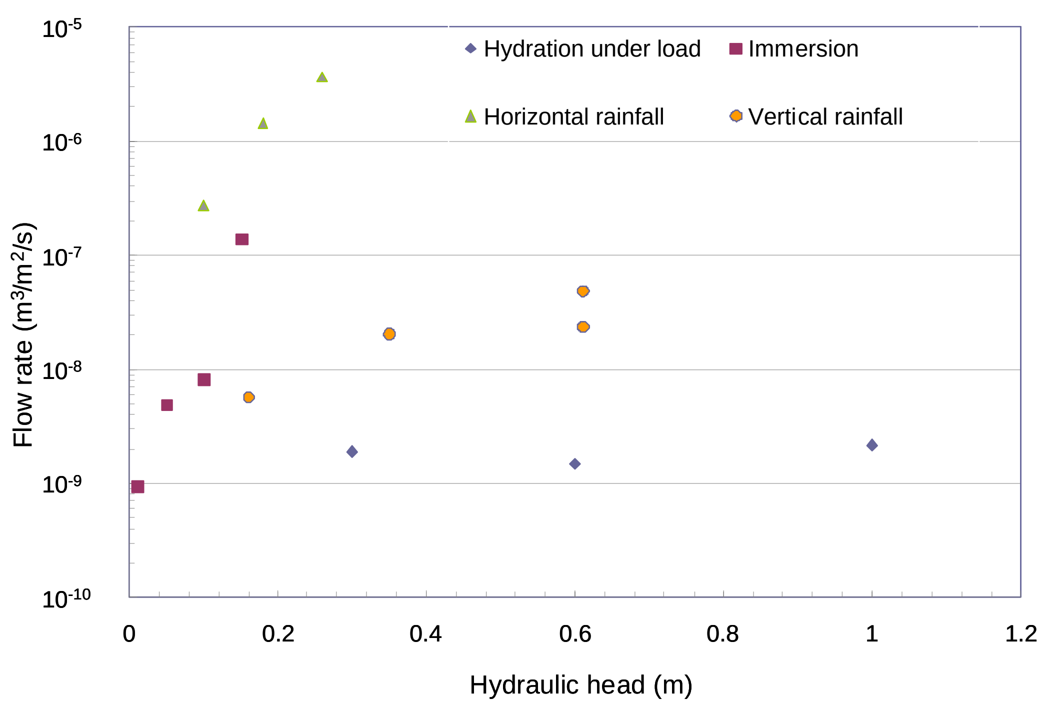


Figure 11. Flow rates obtained for GCL2 depending on the hydration mode

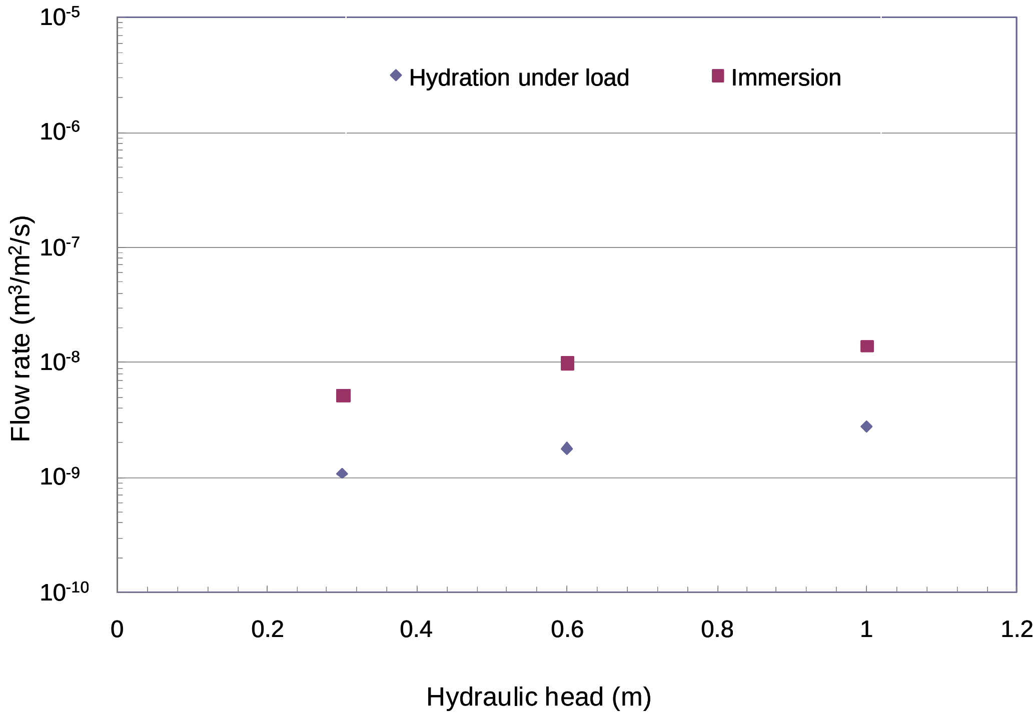


Figure 12. Flow rates obtained for GCL3 depending on the hydration mode

Results obtained for the two stitched GCLs are significantly different for the two products. Indeed, the immersion of GCL2 was really detrimental to the GCL and no flow rate could be measured for hydraulic heads larger than 0.3m as they became too large. The flow rate measured under a 0,26m hydraulic head was equal to 3.7×10^{-6} $m^3/m^2/s$. In this case this GCL does no longer perform its lining function. It is thus necessary to recommend that this particular GCL always be hydrated under load.
Results obtained with the second stitched GCL, GCL3, are significantly different. Indeed, even if an increase in the flow rate is observed between the situation where the GCL is hydrated under load and the case where it is immersed for the hydration without load, the increase of flow is only by a factor 5.

4. CONCLUSIONS

The tests performed in this study aimed at testing a variety of hydration conditions of GCLs that can occur after installation and prior loading. 5 different GCLs containing sodium bentonite were tested, three needle punched and two stitched GCLs. Hydraulic results obtained under a 20 kPa as compared to an hydration under load show a very little effect, by a factor 2 on the flow rate for needle punched GCLs. Results obtained for the stitched GCLs were more variable depending on the mode of fabric, resulting in a very detrimental effect of the immersion for one of those GCLs. Results obtained in this study cannot be extended to other modes of fabrication, other products or other loads than the ones tested in this study.

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