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Validation of the use of filter paper suction measurements for the determination of GCLs water retention curves

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ABSTRACT: Laboratory tests were carried out to study the suitability of the filter paper method to measure the suction of geosynthetic clay liners (GCLs). This issue was addressed under three axes: (i) comparison to previous works (ii) influence of the position of the GCL; and (iii) comparison to suctions obtained for geotextiles. Four different GCLs were used. Results obtained with filter paper showed a good agreement with previously published results. They also indicate that the position of the GCL does not affect the suction when the water content of the GCL ranges from about 10% to 115%. Finally, suctions obtained for GCLs differ from the suction obtained for geotextiles. These results suggest that the suctions measured concern the whole GCL and not only the geotextile in contact with the filter paper. This study concludes that the filter paper method can be used to measure a large range of suctions of the GCLs.

1 INTRODUCTION

Geosynthetic clay liners (GCLs) are widely used in bottom landfills liners as supplied. It is well recognized that after installed in bottom landfill liners GCLs will gradually saturate either by adsorption of water coming from the compacted clay liner on which they rest, or by infiltration of leachate due to defects in the geomembrane. Under unsaturated conditions, the flow through GCLs is a function of their suction and volumetric water content.

The relationship between the suction and the volumetric water content, known as water retention curve, is often represented by a model such as Mualem-van Genuchten model. This model is characterized by a set of parameters, which can be obtained by fitting the theoretical model to experimental data.

There are numerous devices capable of measuring the soil suction, such as tensiometers, thermocouple phychrometers, pressure plate extractors, filter paper, etc. Nonetheless, a literature review on this topic showed that the suitability of the filter paper to measure the suction of GCLs remains unstudied. Thus, laboratory tests were carried out to investigate this question. This study comprised three items: (i) comparison to results obtained by Daniel et al. (1993), who measured the relationship between water content and suction in the bentonite component of a geomembrane supported GCL using the thermocouple psychrometer and vapour equilibrium; (ii) study of the influence of the position of the GCLs; and (iii) comparison to suctions obtained for geotextiles.

2 MATERIALS AND METHODS

Four different GCLs were used in this study and are referred as GCL-1, GCL-2, GCL-3 and GCL-4. The main characteristics of these materials are presented in Table 1.

The first three products are geotextile-supported, whereas the latter is a geomembrane-supported GCL. GCL-4 was used for the sake of comparison to results obtained by Daniel et al. (1993). GCL-1 and GCL-3 were used to study the influence of the position of the GCL. Finally, GCL-1, GCL-2 and GCL-3 were used for the sake of comparison to suction results with geotextiles, with existing data on bentonite and with one GCL.

The suction of GCLs was evaluated based on an adaptation of ASTM D 5298. Briefly, prior to suction measurements, GCL specimens were prehydrated covering a range of moisture contents. Two techniques were used to prehydrate the specimens. The first one consisted in spraying a known mass of water onto the surface of the specimens. It was used to prehydrate the GCLs with water contents lower than 45%. For GCLs specimens with higher water contents, the specimens were immersed in water during the time necessary to achieve the specified water content. For

Table 1. Characteristics of the GCLs used according to the manufacturers.

	Specimens	GCL-1	GCL-2	GCL-3	GCL-4
Bentonite layer	μ (g/m^2)	4 670	4 670	5 000	4 900
	Type	Natural, Na^+, granular	Natural, Na^+, powdered	Na^+, granular	Natural, Na^+
Cover material (GTX or GM)	μ (g/m^2)	220	220	200	–
	Type	GTX, PP, NW, NP	GTX, PP, NW, NP	GTX, PP, NW, NP	–
Carrier material (GTX or GM)	μ (g/m^2)	110	110	125	–
	Type	GTX, PP, W	GTX, PP, W	GTX, PP, W	HDPE GM (0.5 mm)
GCL	μ (g/m^2)	5 000	5 000	5 300	–
	Type	NP	NP	Adhesive bond plus semi-NP	Adhesive bond
	Dry thick. (mm)	6	6	7	–
	k (m/s)		$\leq 5 \times 10^{-11}$	–	

Notes: GTX = geotextile, GM = geomembrane, PP = polypropylene, NW = non-woven; W = woven; NP = needlepunched, Na^+ = sodium; μ = mass per unit area, k = hydraulic conductivity

each water content, two GCL specimens were wrapped together in PARAFILM® M, and placed in isolated boxes during seven days, for water content homogenization purposes. Homogenisation took place without confining stress. At the end of the homogenisation period, it was assumed that the two GCL specimens had identical suction.

Then, three stacked pieces of oven dried (105ºC) filter paper (Whatman®No. 42), cooled in a desiccant jar, were placed in between the two GCL specimens. The outer filter papers were slightly larger in diameter than the centre filter paper, in order to prevent the centre filter paper contamination by bentonite. Prepared GCL specimens were again wrapped together with a laboratory plastic film and sealed in an airtight container in order for the filter paper suction to reach the GCL suction. Once again, the homogenization took place for seven days and without confining stress. After the equilibration period, the filter papers were removed from the GCL specimens (Figure 1), and the water content of the centre filter paper was measured.

The matric suction of the GCL specimen was estimated from the calibration curve of filter paper presented in ASTM D 5298. It should be pointed out that the calibration curves included in that standard are applicable to the total suction. However, as GCLs present a low thickness the total and matric suction can be considered as equal. Thus, those calibration curves can be used to assess the matric suction, called suction in the following.

Figure 1. Removing the filter paper.

3 RESULTS AND DISCUSSION

3.1 *Comparison with the results obtained by Daniel et al. (1993)*

The suitability of the filter paper method was first Suctions obtained in this study are plotted together with those reported by Daniel et al. (1993) against gravimetric water content of GCL-4 in Figure 2. As shown, results obtained are consistent with those obtained by Daniel et al. (1993) despite of some scatter observed at low water contents. This suggests that the filter paper method can successfully be used to measure the suction of GCLs.

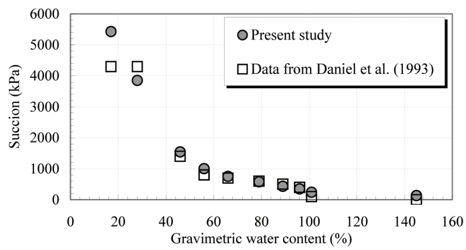

Figure 2. Comparison to results obtained by Daniel et al. (1993) for GCL-4.

3.2 *Influence of the position of the GCL*

To study the influence of the position of the GCL, the filter paper was placed between two pieces of GCL in three different positions: between two nonwoven geotextiles (NW/NW), between two woven geotextiles (W/W) and between a nonwoven and a woven geotextile (W/NW). GCL specimens were prehydrated at approximately 10%, 45% and 115%, both for GCL-1 and GCL-3.

Figure 3 depicts the results obtained for GCL-1. Similar results were obtained for GCL-3. It can be seen that, despite some scatter on suction corresponding to the lowest and highest water content, results show a close agreement regardless of the type of geotextile that faced the filter paper. The scatter

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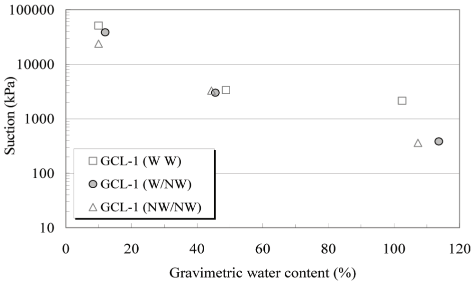

Figure 3. Suctions obtained with filter paper facing the GCL in three different situations.

obtained for the lowest and highest suction measurements may be related to some experimental difficulties found with this method for the water contents of the GCLs in this range, as discussed in Section 3.6.

Thus, it seems that the position of the GCL does not influence suction measurement for an intermediate water content value. This point should be validated for other water contents that do not correspond to the limits of validity of the test method, i.e. from 10 to 100 000 kPa according to ASTM D 5298.

Nevertheless, observations made during the tests disassembly suggest that the best contact between filter paper and GCLs is achieved when the filter paper is placed between two nonwoven geotextiles. Accordingly, in the following tests, it was placed in contact with the two nonwoven geotextiles.

3.3 *Water retention curves obtained for GCL-1, GCL-2 and GCL-3*

Water retention curves for GCL-1, GCL-2 and GC-3 are shown in Figure 4, which includes the van Genuchten parameters α and n obtained by fitting a theoretic water retention curve to the experimental data.

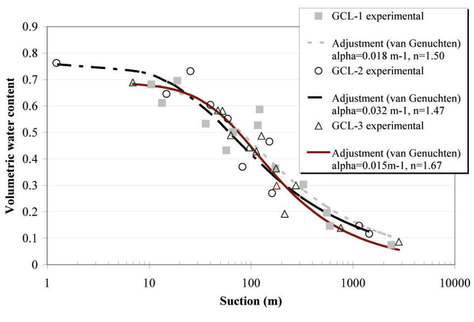

Figure 4. Water retention curves for GCL-1, GCL-2 and GC-3.

As can be observed, for GCL-1, the volumetric water content varied from 0.07 to 0.7, whereas the correspondent suction ranged from 2 379 m to 18.9 m (23 790 kPa to 189 kPa). For GCL-2, volumetric water content increased from 0.12 to 0.76 when the suction decreased from 1 443 m to 1.2 m (14 430 kPa to 12 kPa). Finally, for GCL-3, volumetric water content increased from 0.09 to 0.69, when the suction decreased from 2 821 m to 6.9 m (28 210 kPa to 69 kPa).

It can also be seen that the values of n are quite similar for GCL-1, GCL-2 and GCL-3. They vary between 1.47 and 1.67. As regards α, it varied between 0.015 and 0.032 m^{-1}.

Suctions obtained in this study are consistent with results reported by Southen & Rowe (2004) for a needlepunched GCL (cover geotextile impregnated with bentonite powder), for the range of values that is possible to compare, as they measured the suctions for a narrow range of volumetric water contents (0.62 to 0.76). Suctions reported by these authors varied between 80 m and 0.1 m (800 kPa to 1 kPa).

3.4 *Comparison with the results obtained for geotextiles*

In order to study if the suction measured concerned the whole GCL or the geotextile in contact with filter paper, a comparison was made between values obtained for GCLs and for geotextiles. In that framework, suction measurements were also conducted for two different geotextiles. Both products are part of GCL samples (GCL-1 and GC-2), corresponding to carrier and cover geotextiles, respectively. Suction measurements of the geotextiles were carried out according the methodology described by Cartaud et al. (2005).

For both geotextiles (nonwoven and woven), suctions obtained ranged from 0 to 0.25 m. These values are consistent with results reported by Cartaud et al. (2005) for three geotextiles (values deduced from wetting phase). Suctions in the same range were also reported by Iryo & Rowe (2004).

Van Genuchten parameters α and n, and saturated volumetric water (Θ_{sat}) obtained for the GCLs and geotextiles are listed in Table 2.

Table 2. Comparison of the van Genuchten parameters obtained in this study and reported in literature.

	$\alpha(m^{-1})$	n	Θ_s
GCL-1	0.018	1.50	0.70
GCL-2	0.032	1.47	0.76
GCL-3	0.015	1.67	0.69
Nonwoven geotextile	100	2.10	0.36
Woven geotextile	118	1.44	0.59
Babu et al. (2002)	0.010	1.85	0.74
Southen & Rowe (2002)	0.015	1.30	0.76
Southen et al. (2004)	0.030	1.50	0.85

As can be noticed, values obtained for geotextiles greatly differ from those obtained for GCLs. These results suggest that the suctions measured in the present work regard the whole GCL and not only the geotextile in contact with the filter paper.

3.5 *Comparison with the van Genuchten parameters reported in literature*

The van Genuchten parameters and Θ_{sat} obtained in this study are also compared in Table 2 to some values of α and *n* that have been used in numerical simulations carried out in the topic of GCLs desiccation by several authors (e.g. Babu et al. 2002, Southen & Rowe 2002, Southen et al. 2004). In general, values of α and *n* reported in literature for GCLs were adapted from suctions measurements carried out on clayey soils.

Reasonable agreement can be observed between the van Genuchten parameters obtained from the experimental work carried out and data reported in the literature.

3.6 *Difficulties found in water retention curves estimation*

As regards suction measurements, some scatter could be observed for low gravimetric water contents (8–10%) of the GCLs. This scatter might be related to the fact that, for these gravimetric water contents, the measured water content of the filter paper was close to the lower values for which the calibration curve can reliably be used. In some cases, the suctions obtained were larger than the limit of validity of the filter paper method (100 000 kPa) and were not taken into account in the analysis performed. In addition, in some filter papers, fungal growth was observed. This occurred mainly in protective filter papers and for gravimetric water contents of the GCLs higher than 115%. When the fungi were observed on the central filter paper used to evaluate the suction of the GCL, the suction was generally less than the low limit of validity of the filter paper method (10 kPa). These results suggest that the fungi may affect the suction measurements. Suctions estimated from centre filter papers with fungi were not considered in final results.

Difficulties were also encountered to determine the volumetric water content of GCLs. These difficulties came from the measurement of specimen area. The GCL specimens were cut with scissors and thus their final shape was irregular. As a result, estimated values of the area were not very accurate, which caused scatter on experimental measurements. To avoid this problem, it is recommended to cut the specimens using a cutting shoe and a mechanical press.

4 CONCLUSIONS

Experimental work was carried out to study the suitability of the filter paper method to assess the suction of GCLs. This issue was analysed under three aspects: comparison with previous works, influence of the position of the GCL, and comparison with suctions obtained for geotextiles and previous data existing in the literature.

Results from filter paper agree fairly closely with the results reported in literature for GCLs. They also indicate that the position of the GCL does not affect the suction when the water content of the GCL ranges from 10% to 115%. Finally, suctions obtained for GCLs differ from the suction obtained for geotextiles, suggesting that the suctions measured concern the whole GCL and not only the geotextile in contact with the filter paper. Results obtained in this study thus indicate that the filter paper method can be used to measure a large range of suctions of the GCLs.

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