# Study on the GCL's Response to Hydraulic Uplift

Mochamad Arief Budihardjo, Amin Chegenizadeh and Hamid Nikraz

***Abstract*—**Most of landfill sites in developed countries employ GCL as bottom liners to replace compacted clay liner. However, various water level and direction might be faced by GCL during its operation. These conditions can make the GLC to deform and decrease its hydraulic capability. In this experiment, the GCL was tested with two direction of water flow to see whether any deformation that causes the GCL to lose its hydraulic performance. The results showed that the hydraulic performance of the GCL was constant while facing a water flow coming from above even some area started to be slightly thinner than others. In contrast, the GCL started to uplift, curved and lost its hydraulic performance when the water pressure coming from underneath. The bentonite particles also moved aside from higher hydraulic pressure zone into lower pressure area creating diverse thickness.

***Keywords*—** Uplifting, GCL, hydraulic failure.

## I. Introduction

The main advantage of the geosynthetic lay liner (GCL) as liquid barrier compares to compacted clay liner is its hydraulic conductivity performance [1]. The GCL has been used for landfills liners in some developed countries to replace and substitute compacted clay liner (CCL) [2]. Geosynthetic clay liners are more water tight liner than compacted clay liners even the GCL is thinner than CCL and can be installed as a composite liner system [3].

However, the GCL still have been suspected to lose their ability to hold high gradient of water. A previous research on GCL [4] explored the ability of GCLs to maintain their hydraulic performance while facing a certain height of water level. It has been found that GCL was experiencing bentonite migration when a high gradient applied during its function as a composite liner [5]. The bentonite migration of GCL is also identified as internal erosion. It is a process where the bentonite particles in the GCL detach themselves from each other under large hydraulic gradients and are carried off by the flowing water when the GCLs are laid on its subgrade. Even GCL show a good hydraulic performance as a bottom liner, but Rowe and Orsini [4] suggested that a high water pressure coming from above of the GCL has made the GCL to lose its hydraulic performance and experiencing an internal erosion.

Previous researches [4] [6] mainly focused on the response of the GCL while experiencing water pressure coming from above to simulate a condition when leacheate level is rise. On the other hand, on site high groundwater level cannot be avoided in some landfill sites. This situation makes the GCL to challenge two directions of water pressure sequentially or even simultaneously. However, research on the GCL's behavior towards a high groundwater level has not been conducted yet.

The water pressure coming from underneath may give the GCL an uplift pressure. It is suspected that the hydraulic uplift pressure might cause the GCL to be lifted and start to deform, a similar condition that also happen in the soil [7], [8]. The deformation of the GCL when facing the hydraulic uplift pressure has a possibility to cause the GCL to lose its hydraulic performance.

At this stage, the concern was to investigate the uplifting phenomenon of the GCL while encounter an upward water flow. The experiment on the uplifting GCL was conducted subsequently after the downward pressure was applied. Thus, this study focuses on seeking the evidence of uplifting GCL and its surface deformation related to hydraulic failure of the GCL.

## II. Objective

This study is focused on the response of the GCL toward hydraulic uplift pressure after experiencing downward water pressure. The physical changes of the GCL during the test were monitored in line with hydraulic performance alteration of the GCL. A certain water pressure was applied to the GCL sample in accordance with possible condition that might be confronted by the GCL during its application as bottom liner. Any changes in the GCL's performance while experiencing water pressure were suspected to have correlation with the deformation of the GCL.

## III. Materials

The materials used in this study were GCL, sand and gravel. A needle-punched-reinforced GCL with woven carrier and non-woven cover was chosen as tested material. The yellow sand was employed as a subgrade along with gravel as the supported material for the sand. Mass per unit area of bentonite powder was 4000 gr/m$^2$ and the GCL total mass per unit area was 4380 gr/m$^2$. Referring to the technical data sheet,

Mochamad Arief Budihardjo is a PhD candidate of the Department of Civil Engineering, Curtin University, Perth, Australia (phone: +61452458288; e-mail: m.budihardjo@postgrad.curtin.edu.au
Amin Chegenizadeh, is a lecturer at the Department of Civil Engineering, Curtin University, Perth, Australia (e-mail: amin.chegenizadeh@curtin.edu.au).
Hamid Nikraz, is a professor and Head of Civil Engineering Department, Curtin University, Perth, Australia (e-mail: H. Nikraz@curtin.edu.au).

the hydraulic conductivity of the GCL was 3 x $10^{-11}$ m/s. The thickness of the GCL in dry state was ≈ 6 mm.

The sand type was the yellow sand from Western Australia which was believed to perform well to support the GCL sample during the test. The gravel which is placed on a perforated disc was function to prevent any sand migration along with the water flow.

## IV. Test Program

### A. Apparatus

This experiment used a modification apparatus which has been developed by Budihardjo et al [9] based on an apparatus which was employed previously by Rowe and Orsini [4]. The apparatus equipped with a sample holder which was consisted of two acrylic O-rings. The use of the sample holder was purposed to reduce the possibility of sidewall leakage.

The main component of the apparatus was a transparent cylindrical cell with 20 cm in diameter and 50 cm in height. The transparent cell provided a chance to monitor any physical alteration of the GCL during the test. A cap with a hole was secured at the top and bottom of the cylinder cell. Each cap was connected to a hose to let the water to flow in and out the apparatus. The hose was equipped with valves to control the water flow (Figure 1).

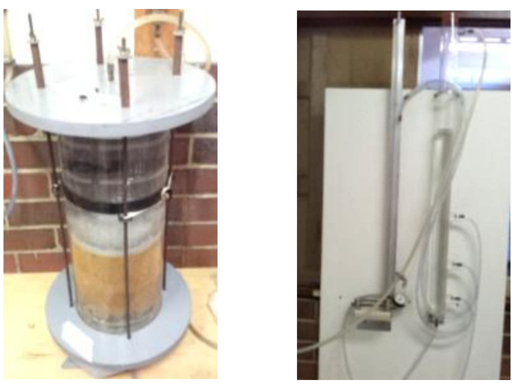

Fig. 1 Experiment apparatus

Two Pressure gauges were also installed in the system to provide water pressure measurement during the test. One of the hose was attached to modified falling head equipment while another hose was directed to a volumetric glass bottle which was used to collect the effluent.

### B. Sample preparation

There were 4 samples of GCL which were prepared in this experiment. The samples were prepared by cutting each sample into a circular shape with 25 cm in diameter and sandwiched between two 20 cm O-ring sample holder. The used of the sample holder was purposed to minimize the side wall seepage.

The yellow sand with 95% density was prepared to be used as subgrade. The height of the sand layer as the main subgrade was about 16 cm. Four cm height of gravel was laid at the bottom of the apparatus to provide adequate support to the sand subgrade and reduce the sand lost possibility during the test. The two layers of subgrade occupied nearly half of the height of the apparatus.

### C. Procedures

The GCL sample was placed inside the permeameter on the top of the subgrade. Silicon sealant was applied around the sample holder's perimeter to secure the sample holder and prevent sidewall leakage (Figure 2). The cap of the apparatus was placed, secured and tighten to prevent any leak. The experiment started a day after to allow the silicone paste to completely dry.

Fig. 2 Sample in the apparatus

The experiment started with a hydration process. The tap water was used as the permeant liquid. The water was flowed through a hose into the cylinder cell. The sample was then allowed to hydrate for a period of time. The other two samples which would not being used in the permeameter were hydrated using tap water in a pan to get its maximum swell. This specimen would become a control of thickness and physical changes of the GCLs during hydration. The reason of conducting this hydration process outside the apparatus was to make the precise measurement of the GCL's thickness since it was difficult to measure the sample's thickness of the GCL which was already installed in the apparatus.

The test started at a low flow rate using a falling head permeameter water column which was modified to fit the designed apparatus. Visual monitoring was conducted to see whether any bentonite migration would occur, also pressure drop indicating the failure of the hydraulic performance. A digital camera was used to capture any changes in liquid turbidity and alteration of the GCL and sand subgrade form. After being posed with downward water flow, the sample was tested with opposite flow direction to simulate the ground water flow.

## V. Result and Discussion

The first stage of the experiment was the hydration process. All the samples (inside the apparatus and in a pan) were soaked with the tap water for a week. During the hydration process, the samples started to swell and became thicker. The significant changes of the samples thickness happened in the first two days and the thickness remained unchanged after day four. The thickness of the samples was minimum 9 mm and maximum 10 mm.

Following the hydration stage, a hydraulic performance test of the GCL was conducted using the test kit. The water was flowed into the apparatus trough a hose from above the sample with applied water pressure was equivalent to 6 m water head. The hydraulic conductivity was 1.5 x $10^{-11}$ m/sec and there was no sign of hydraulic failure during the test even though the sample became thinner in some areas.

Once being tested with water coming from above, the GCL was tested with reverse direction of water flow. The water flowed from underneath the apparatus, passed through subgrade layer and GCL. The applied pressure was 40 kPa which was equivalent to ≈ 4 m water head.

Fig. 3 GCL started to be lifted

During the experiment, the water pressure pushed the sample and the sample started to be lifted at the center and form a curve shape (Figure 3). This condition happened because of the hydraulic uplift pressure was greater than downward pressure. The following calculation explains the differences between downward and upward pressure.

Unit Weights (γ)

$$\gamma_{sat} = unit\ weight\ of\ saturated\ bentonite\ (\frac{kN}{m^3})$$
$$\gamma_{sat} = 12.68\ \frac{kN}{m^3}$$
$$\gamma_w = unit\ weight\ of\ water\ \frac{kN}{m^3}$$
$$\gamma_w = 9.81\ \frac{kN}{m^3}$$
$$\gamma' = submerged\ unit\ weight\ \frac{kN}{m^3}$$
$$\gamma' = \gamma_{sat} - \gamma_w$$
$$\gamma' = 12.68 - 9.81 = 2.87\ \frac{kN}{m^3}$$

Total Stress at below the sample (σ)

$$\sigma = h_1\gamma_w + h_2\gamma_{sat}$$
$$\sigma = 0.3(9.81) + 0.01\ (12.68) = 3.07\ \frac{kN}{m^3}$$

Gradient Hydraulic ($i$)

$$i = \frac{h_1}{h_2}$$
$$i = \frac{4\ m}{0.1\ m} = 40$$

Effective Stress below the sample ($\sigma'$)

$$\sigma' = z\,\gamma' - iz\gamma_w$$
$$\sigma' = 0.01\ (2.87) - 40\ (0.01)(9.81) = -1.933\ \frac{kN}{m^2}$$

Water Pressure below the sample ($u$)

$$u = \sigma - \sigma' = 3.07 - (-1.93) = 1.14\ \frac{kN}{m^2}$$

The effective stress at the bottom of the sample was $-1.933\ \frac{kN}{m^2}$ while the water pressure at this area was $1.14\ \frac{kN}{m^2}$. Summation of force shows that upward force was greater than downward force made the sample to be lifted. Since the edge of the GCL was hold by a sample holder, the GCL started to deform into a dome shape. In this case, the surface of the GCL might be stretched and cracked subsequently the water would flow up through the cracks.

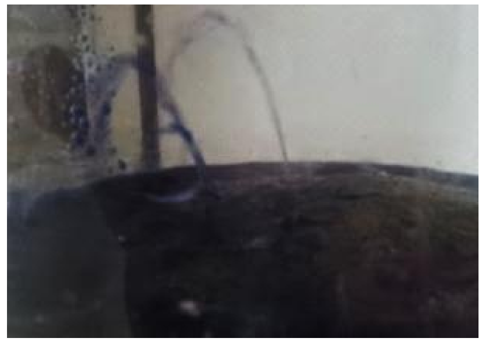

Fig. 4 GCL Failure

The GCL started to fail after undergoing water pressure for 3 days. The water just flowed easily through two small holes on the thinnest area of the sample (Figure 4). The water pressure was fall into 20 kPa in less than 5 minutes and the GCL's sample lost its capability to hold a certain water pressure any longer in 12 hours.

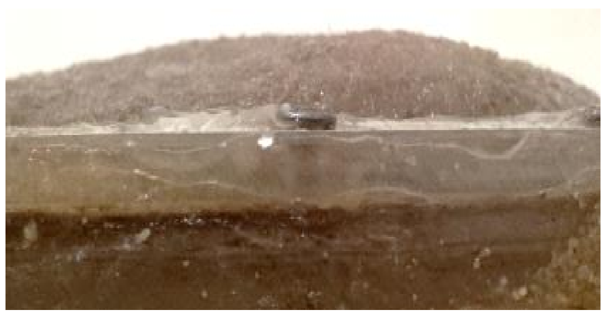

Fig 5. Sample after being tested

An observation of the GCL's sample was conducted by taking the sample out of the apparatus and followed by a thickness measurement. It obtained that the height of the top of the GCL was about 24.7 mm (Figure 5). The sample then was placed on the flat surface and the GCL bottom was leveled on the surface. It was acquired that the thickest area of the GCL was 15.8 mm while the thinner area was 3.2 mm (Figure 6).

Fig. 6 The final GCL form

It was also found that the uplift hydraulic pressure has triggered the bentonite particles to move aside into some areas where the pressure was not as high as the thinner areas of the GCL. This condition made the GCL to lose its capability to hold the water pressure during the experiment. However, some bentonite particles were also indicated to move away outside the GCL cover by water flow which caused the drop of the water pressure in a short period of time.

## VI. Conclusion

It can be concluded from the experiment on the GCL's response to hydraulic pressure uplift as follow:

1. The hydraulic pressure in the area below the sample was 1.14 $\frac{kN}{m^2}$ which was greater than the downward pressure as there was no additional weighting above the sample except the water in the apparatus and the sample itself.
2. The hydraulic pressure coming from underneath the GCL has caused the GCL to be uplifted and formed a dome shape while the GCL's edge was remained clamping on the sample holder.
3. The bentonite particles has moved from the highest pressure area into the lower pressure area of the sample and created ununiformed thickness of the sample.
4. The deformation of the GCL has made the GCL to lose its performance drastically in a short period time.

## References


[1] Bouazza, A., Geosynthetic clay liners. Geotextiles and Geomembranes, 2002. 20(1): p. 3-17.

[2] Shan, H.-Y. and R.-H. Chen, Effect of gravel subgrade on hydraulic performance of geosynthetic clay liner. Geotextiles and Geomembranes, 2003. 21(6): p. 339-354.

[3] Rowe, R.K., Long-term performance of contaminant barrier systems. Geotechnique, 2005. 55(9): p. 8.

[4] Rowe, R.K. and C. Orsini, Effect of GCL and subgrade type on internal erosion in GCLs under high gradients. Geotextiles and Geomembranes, 2003. 21(1): p. 1-24.

[5] Touze-Foltz, N., Discussion on paper entitled "Migration behaviour, of landfill leachate contaminants through alternative composite liners" by G. Varank, A. Demir, E. Sekman, A. Akkaya, K. Yetilezsoy, M.S. Bilgili. Sci Total Environ, 2012.

[6] Fox, P.J., D.J. De Battista, and D.G. Mast, Hydraulic performance of geosynthetic clay liners under gravel cover soils. Geotextiles and Geomembranes, 2000. 18(2–4): p. 179-201.

[7] Terzaghi, K., R.B. Peck, and G. Mesri, Soil Mechanics in Engineering Practice. Third ed. 1996, United States: John Wiley & Sons. 592.

[8] Wudtke, R.-B., Failure Mechanisms of Hydraulic Heave at Excavations, in 19 th European Young Geotechnical Engineers' Conference2008: Győr, Hungary.

[9] Budihardjo, M.A., A. Chegenizadeh, and H. Nikraz, Experimental Set-up for Investigation of Internal Erosion in Geosynthetic Clay Liners. International Journal of Biological, Ecological and Environmental Sciences (IJBEES), 2012. 1(3): p. 4.