Preliminary Investigation of the GCL's Boiling toward An Upward Water Flow

Mochamad Arief Budihardjo, Amin Chegenizadeh and Hamid Nikraz

***Abstract*—**The performance of GCL as liquid barrier depends on its hydraulic performance. During its application, the GCL may encounter high water level and opposite water flow from ground water that can cause the failure of the GCL in maintaining its water tight. In this experiment, the high water pressure coming from above pushed the GCL to be thinner in some part and trigger the bentonite powder to escape from its carrier. However, the GCL did not lose its capacity to retain the water flow. Meanwhile, the opposite direction of water pressure applied afterward had a significant effect to the GCL performance after three days. The hydraulic performance of the GCL dropped significantly alongside with some physical changes on the GCL's cover. The boiling of bentonite was built up during the failure of the GCL.

***Keywords*—** Bentonite boiling, GCL, failure.

I. Introduction

One of the main advantages of geosynthetic clay liner (GCL) among others liner materials is its hydraulic performance [1]. Comparing to compacted clay liner (CCL), the GCL is more impermeable and has been used as liquid barriers, for example, as landfill liner in some developed country [2] [3]. On site, the GCL might be installed in combination with other materials such as, geomembrane, high density polyethylene and geonet [3].

During its application as landfill's leachate barriers, the GCL might confront with a large hydraulic gradient which is generated by accumulation of leachate molding and also ununiform pressure which is created by solid waste in a landfill site [4]. As a result, the pressure will force the bentonite particles to move aside or even outside the carrier and disrupt the hydraulic performance of the GCL. The escaping of bentonite particles from their carrier by flowing water is also identified as internal erosion [5].

Rowe and Orsini [4] investigated the internal erosion of the GCL and the effect on its hydraulic performance while the GCL was lying on three different subgrades which were gravel, geonet and sand. Another research by Fox et al [6] also examined the hydraulic performance of the GCL when was placed under a gravel cover layer. It has been reported that the hydraulic performance of the GCL decreased during the test following the changes on its thickness. However, both researches used water pressure coming from above only while the effect of opposite water pressure to the GCL has not been considered yet. At present, the consequence of an upward water flow toward GCL has not been revealed yet.

In addition, an opposite direction of water flow has potential to create another form of fine particles migration which is known as a boiling condition. The boiling phase might occur in the soil layer when the soil confronts with an increased water pressure coming from underneath. The sand particle starts to flow upwards along with water flow direction [7]. The similar situation is presumed to occur in the GCL which contains fine bentonite particles.

In this preliminary study, any surface deformation and hydraulic failure of the GCL after facing an opposite direction of water flow at a certain pressure level were investigated. The previous testing method [8] was implemented and focused on seeking any boiling event on the GCL.

II. Objective

This preliminary investigation was purposed to examine the hydraulic performance of GCL as liquid barrier while facing some possible condition of water pressure in the opposite direction. At this point, the hydraulic performance of the GCL was tested in specific water level to simulate water level in landfill sites. The effect of ground water level was also considered by testing the GCL with water coming from underneath the layer. Any physical appearance change, specifically on boiling event of the GCL was monitored to provide a clear picture and explanation of the mechanism of the GCL's hydraulic failure.

III. Materials

The experiment used the GCL as the main material, yellow sand as the subgrade and gravel as the bottom layer. The GCL has a woven carrier and a non-woven cover with powder sodium bentonite and needle-punched-reinforced. In dry condition, the average sample's thickness was 6 mm and swelled into ≈9-10 mm when had been saturated for couple weeks. The sample specifications of the GCL is given on TABLE I.

The sand has been chosen as subgrade material since it has been proven by prior research [4] that it could perform well to support the GCL's sample during the test. The gravel was

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placed to retain the sand for being flowed away by water and rested on a perforated disc at the bottom of the test kit.

TABLE I
GCL'S FEATURES

Feature	Description Sample A and B
Type of carrier	Woven geotextile
Type of cover	Non-Woven geotextile
Type of reinforcement	Needle-punched
Mass per unit are of bentonite powder (gr/m2)	4000 gr/m^2
GCL Total Mass per unit area	4380 gr/m^2
Thickness (dry)	≈ 6 mm
Hydraulic conductivity	3 x 10^{-11} m/s

IV. TEST PROGRAM

A. Apparatus

The previous experiment [8] has developed an apparatus to examine the internal erosion of the GCL with two directions of water flow based on a test kit employed by Rowe and Orsini [4] while examined the hydraulic performance of some GCLs. The previous study showed that side wall seepage was occurred during the test. Therefore, it was suggested to use two O-rings as sample holder and putting silicone grease to avoid any leakage.

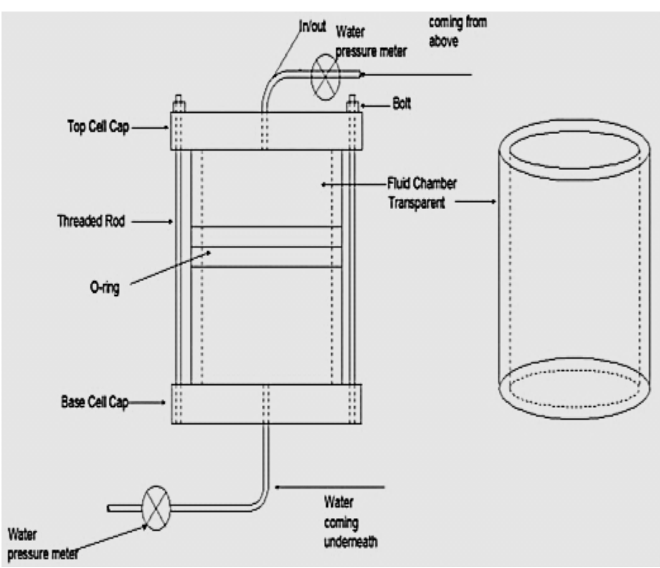

Fig. 1 Experiment apparatus

In this experiment, the purposed apparatus by Budihardjo et al [8] was constructed. The apparatus composed by six main components which were a transparent cylinder cell, a sample holder, two caps, hose, water pressure regulator and water pressure gauge (Figure 1). Each cap was connected into a hose which accommodated water flow in both directions during the test. The effluent was collected using a volumetric glass bottle for flow rate calculation. A timer was also used to monitor the time.

B. Sample preparation

Four samples were arranged for the experiment. The samples were cut into a circular shape with 25 cm in diameter. The GCL's sample preparation was based on method used by Jo et al. [9]. Two samples (A1 and A2) were prepared to run the experiment inside the apparatus while the others (B1 and B2) were used to conduct thickness measurement outside the apparatus during hydration. Sample A1 and A2 were sandwiched between two O-rings with 20 cm in diameter. The O-ring was used as sample holder to minimize any side wall seepage.

After being placed in the sample holder and secured by some bolts and nuts, the excess GCL was trimmed using a sharp cutter. Silicone paste was applied around the circumference and allowed to dry for one day. The other two samples (B1 and B2) were put into a pan for hydration monitoring and thickness measurement.

C. Procedures

Four cm of height of gravel was laid at the bottom of the apparatus, to provide adequate support for the sand subgrade and reduced the chance of sand escaping during the test. The yellow sand was compacted to reach 95% compaction inside the apparatus. The height of the sand layer as the main subgrade was about 16 cm. The two layers of subgrade occupied nearly half of the height of the cell.

The GCL sample was placed neatly inside the apparatus on the top of the subgrade. Silicon sealant was applied around the perimeter to secure the sample holder and prevent any sidewall leakage (Figure 2). The cap was installed, secured and tighten using a treated rod to prevent any leak. The experiment was started on the next day to allow the silicone paste to fully dry.

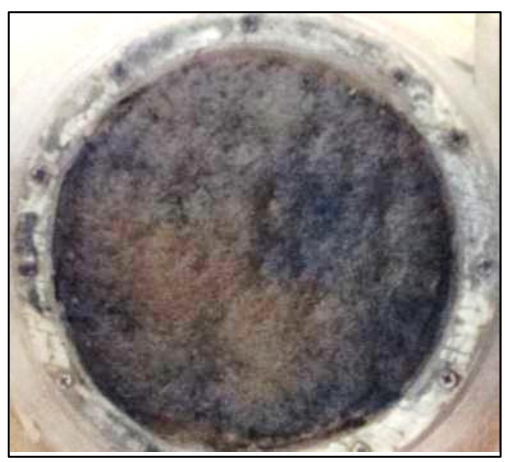

Fig. 2 Sample placement

The first stage of the experiment was a hydration process. The tap water was used as the permeant liquid. The water was flowed into the cylinder cell through a hose. The sample was then allowed to hydrate for couple weeks. The other two samples were hydrated using tap water in a pan to get its maximum swell. The specimens were monitored for any thickness and physical change during hydration. The reason of conducting the hydration process outside the apparatus was to obtain a precise measurement of the GCL's thickness, since it was difficult to measure the sample's thickness of the GCL inside the apparatus.

After being hydrated, the GCL was tested 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 sample deformation and also pressure drop which was indicated the failure of hydraulic performance. The hydraulic conductivity was also calculated during the test. After being posed by downward water flow with a certain pressure, the sample was tested with opposite flow direction.

V. Result and Discussion

The hydration process took couple weeks to complete and the GCl's thicknesses (samples in the pan) were measured using a vernier caliper. The thickness was about 9-10 mm and there were no significant changes on the both side of the sample. The sample inside the apparatus appeared to swell, but the thickness could not be determined.

TABLE II
Hydraulic Conductivity

Sample	Head (m)	Hydraulic Conductivity (m/sec)
GCL	6	1.5×10^{-11}

The apparatus then connected into a water column that was attached into a water tap and equipped with a pressure gauge to provide water pressure on the sample. The water pressure was about 60 kpa which was equivalent to ≈ 6 m of water head.

Fig. 3 Deformation of GCLs surface

The hydraulic conductivity of the GCL's sample was 1.5 x 10^{-11} m/sec (Table II). The result was slightly lower than the technical data sheet value (Table I). The downward water pressure caused a deformation on the GCL's surface after three days and affected the sample to be thinner in some areas (Figure 3). However, the hydraulic performance was remaining the same.

The second stage experiment was conducted immediately by changing the water flow in the opposite direction with an additional pressure. In this test, the water flowed through the sand subgrade first and continued to flow into the GCL sample. The applied pressure was 40 kPa which represented 4 m water head approximately. This changing direction of the water flow affected the GCLs appearance. The sample started to be curved since there was no pressure on the top of the sample excluding the water inside the cylinder cell.

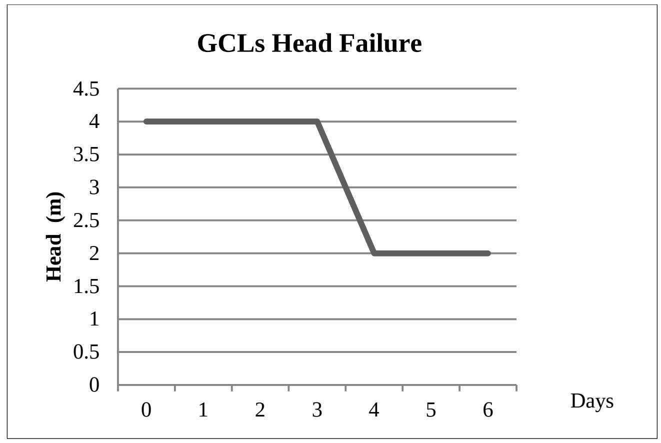

Fig. 4 Head Failure

After being pushed by the water pressure for about three days, the GCL's sample started to collapse, and could not hold the 4 m of water head applied. In 24 hours, the water head dropped into 2 m and remained constant to another three days (Figure 4). During the test, there was a significant change on the sample surface. The bentonite started to boil in the surface of the cover layer. The biggest diameter of bentonite boiling was 3 cm and the height was about 1.5 cm (Figure 5).

Fig. 5 Bentonite boiling

The boiling phenomenon happened in the bentonite is similar to soil boiling. The soil boiling can happen when the soil was encountered with an upward water flow, makes the soil particle lose its shear strength. The condition may also occur in cohesive soils subjected to excess pore water pressure [7]. In this case, the surface of the GCL might stretch out and crack thus the water could pass through the cracks.

The high stress in the area under the GCL sample which was generated by the water pressure seemed to be the reason for the boiling of bentonite. During the built up of bentonite boiling, the GCL failed to hold an upward water pressure equal to 4 meters water head after three days. The bentonite particles started to boil on day four simultaneously with a hydraulic failure of the GCL. The bentonite stopped to boiling when the water head dropped into two meters which significantly reduced pressure to the GCL.

At this level of water pressure, there was no further physical change on the surface of the sample. This condition can be explained because the bentonite particles ware retained by its cover layer. The water pressure was not strong enough to push the bentonite particles to pass its cover layer which was made from non- woven geotextile.

VI. Conclusion

It can be concluded from the experiment on the GCL as follows:

1. The GCL performed remarkably well while posing the water flow coming from above. It could hold the water pressure equivalent to 6 m height of the water level.
2. The hydraulic performance of the GCL was a bit lower than the technical data sheet provided which was 1.5 x 10^{-11} m/s. The GCL could also hold up the water pressure even there were some physical deformations on its surface area.
3. The changing of water flow direction affected the hydraulic performance of the GCL. The GCL lost its capability to hold 40 kPa water pressure in three days. However, the GCL was able to maintain its ability to hold 20 kPa water pressure for the next days.
4. The hydraulic performance failure of the GCL was followed by bentonite boiling on the surface of the sample. The high pressure from underneath the GCL caused the bentonite to lose its internal shear strength and trigger the boiling of bentonite on the GCL surface.

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