Experimental Set-up for Investigation of Internal Erosion in Geosynthetic Clay Liners

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Abstract— Some factors that can potentially reduce the performance of geosynthetic clay liners (GCLs) and trigger an internal erosion of the GCL are high gradient, subgrade and confining pressure. Previous studies mainly investigated the internal erosion occurrence by monitoring the hydraulic conductivity with water flow coming from above. In this research, the opposite directions of water pressure were also applied to the sample. This experiment also sought some visual evidences and behavior of bentonite migration. The result indicated that internal erosion did not occur in the GCLs sample, however further investigation should be carried out since a sidewall leakage happened during the test.

Keywords— Bentonite migration, GCLs, internal-erosion.

I. Introduction

GEOSYNTHETIC clay liners (GCLs) has replaced and substituted compacted clay liners (CCLs) since they have more benefits over CCLs and been used for landfills liners, in some developed countries [1]. The thin layer of bentonite in GCLs resulted in a more water tight liner than compacted clay liners [2], [3]. Geosynthetic clay liners were also used in combination with high density polyethylene (HDPE) geomembranes to form an effective barrier to contaminant transport in solid waste landfills [6].

However, even GCLs seem to be realiable as landfill liners, they still have been suspected to be experienced an internal erosion. Peggs and Olsta [5] and Rowe and Orsini [4] explored the internal erosion of GCLs, a process where the bentonite particles in the GCLs detach themselves from each other under large hydraulic gradients and are carried off by the flowing water when the GCLs are laid on gravel, geonet and sand. Even GCLs give a good impression on its hydraulic conductivity, but Rowe and Orsini [4] suggested that high hydraulic gradient has triggered internal erosion occurrence and significant increase of hydraulic conductivity. Moreover, no-uniform pressure generated by the solid waste will make the bentonite in the contacting areas to be pushed aside causing the GCLs in some areas to be thinner than other areas and lose their performance drastically [4].

Previous researches [4], [9] mainly focused on internal erosion occurrence of the GCLs when experiencing water pressure coming from the water above only. However, one vital issue that has been ignored is what happens when the GCLs are confronting water pressure not only from above them, but also pressure from underneath which is generated by the groundwater to performance of GCLs.

This research purposes to capture the internal erosion occurrence visually to provide a clear evidence and mechanism of internal erosion while experiencing pressure from opposite direction with water flow from above and underneath. The experiment also observes any physical changes on the GCL’s sample and the sand subsoil during the test.

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II. Objective

This experimental setup is purposed to capture bentonite migration of GCL using an apparatus that is developed based on the test kit that was used by Rowe and Orsini [4]. In this stage, a procedure to investigate an internal erosion occurrence of the GCLs is also being expanded to anticipate any other problems that might be raised in the following experiment. This first stage of the experiment also measures the hydraulic conductivity performance of the GCLs as an indication of the internal erosion occurrence as well as seeking any evidence of bentonite migration of the GCLs with water coming from opposite direction.

III. Materials

The main material used in this experiment was GCL which has woven carrier and non woven cover with powder sodium bentonite and needle-punched-reinforced. It measured approximately 6 mm in thickness when in dry conditions and ≈10 mm in thickness when fully hydrated. The other specifications of the GCLs are presented on TABLE I.

This experiment used sand as foundation layer. Sand was chosen since it has been recommended as subgrade by previous research [4] which provides adequate support to the GCLs. The type of sand was yellow sand from Western Australia.

TABLE I
GCL'S FEATURES

Feature	Description
Type of carrier	Woven geotextile
Type of cover	Non-Woven geotextile
Type of reinforcement	Needle-punched
Bentonite Mass (@ 0% moisture content)	4000
GCL Total Mass (@ 0% moisture content)	4380
Hydraulic conductivity	3×10^{-11} m/s
Suggested purposes	Landfill liner, hydrocarbon secondary containment, canal lining, pond/dam.
Recommended side slope	≤ 1V:3H

IV. TEST PROGRAM

A. Apparatus

The main concept which was used in this experiment was a bit modification to the concept coming from Rowe and Orsini [4] to measure hydraulic conductivity of some types of GCLs. The apparatus consisted of a transparent cell in cylindrical shape with two caps placed on top and bottom of the cylinder. The base and upper caps of the cell were then secured with retaining threaded rods. Each cap had a hole at the centre for a hose with water flowing in and out of the cylinder. The hose was connected to a transducer to regulate water pressure and a pressure gauge to present water head. The transducer was connected to another hose that supply water. The apparatus was designed to enable water flow in reverse directions from top and beneath the sample. A volumetric glass bottle was used to collect the water passing through the sample during the test which allowed visual particle observation and effluent quantity measurement (Figure 1).

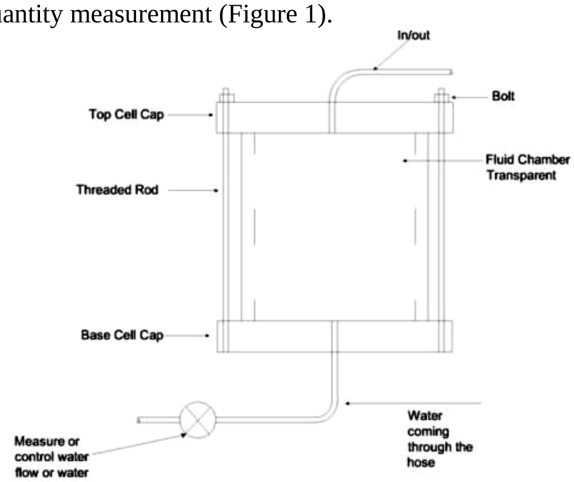

Fig. 1 Experiment apparatus

B. Sample preparation

The GCL's specimens were prepared using the method used by Jo et al. [8]. GCL specimens were cut into circular shape to fit the cylindrical cell using a cutter. A small volume of liquid was applied to the GCL along the inner circumference of the cutting ring before cutting to avoid loss of bentonite. Excess geotextile fibers along the edge of the GCL were trimmed with scissors.

The GCL sample was placed directly in the permeameter between the subgrade and protective material. Silicon sealant or bentonite powder was applied around the perimeter to prevent sidewall leakage. The tap water will be used as the permeant liquid. The sample was then allowed to hydrate for a period of time. The GCLs thickness was monitored during hydration and permeation.

C. Procedures

The sample of the GCL was placed on the top of the sand foundation after it had been hydrated for a couple of days until it had swollen to its maximum.

V. RESULT AND DISCUSSION

Four GCL's samples prepared for this experiment. Two samples were used for thickness measurement during hydration and other two samples were used to investigate the internal erosion experiment. After being cut, two samples of the GCL were hydrated for 7 days on a pan using tap water. 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 after being put on the apparatus.

The sample measured 9-10 mm in thickness after hydration. It was also found that the bentonite powder came out over the edge circumference of the sample. This is because there was no barrier to prevent the bentonite particles from moving away from the sample after being pushed by other bentonite particle inside the sample [7]. The swelling process of the sample happened at the highest rate during the first 2 days of hydration. There were no significant physical changes of the sample during the day three to seven.

The first test was conducted to measure the hydraulic conductivity of GCL using falling head method. The apparatus was filled with yellow sand with a density approximately 90-95% to half the height of the apparatus. A layer of bentonite paste was applied inside around the cylinder circumference to anticipate side wall leakage. A GCL's sample was then put inside the cylinder and placed on the top of the sand layer. To anticipate sidewall leakage, a bentonite paste was also applied around the bottom edge of the GCL. The final composition of the layers was gravel, yellow sand and the GCL sample. The apparatus was then connected to the falling head water column to run a falling test method (Figure 3). A digital camera was used to capture any changes in liquid turbidity and alteration of the GCL and sand subgrade form.

The water then was flowed into the apparatus to begin the hydration process of the GCL. The GCLs sample which had been put inside the apparatus experienced nearly the same hydration behavior as the samples which were hydrated in a pan. The bentonite particles also came out from the sample and flew up and down the edge since it hit the cylinder cell.


Fig. 2 Hydrated GCL


Fig. 3 Test apparatus

The hydraulic conductivity was conducted a week after the hydration phase using falling head method. The test started at a low flow rate using a falling head permeameter water column which was modified to fit the designed apparatus. The result showed that the hydraulic conductivity of the sample was 1.5 x 10^{-11} m/sec which was slightly higher than the technical data sheet value. Visual monitoring was conducted to see whether any bentonite migration would occur, indicating the occurrence of the internal erosion. However, during the test, there was no sign that any bentonite migration was occurred.

The GCL sample was then replaced with the new one and the testing was started over again from the beginning. The second experiment also resulted in the same GCL behavior and a number of hydraulic conductivity. At this stage, it was assumed that the water pressure was not strong enough to push the bentonite powder through the woven carrier.

The apparatus then connected into another water column that was already connected to a water tap and equipped with a pressure gauge to provide more water pressure on the sample (Figure 4). The water pressure was about 60 kpa which equivalent to ≈ 6 m water head. The pressure caused a deformation on the GCL's surface and caused the bentonite powder in the outer circumference moving down into the sand layer (Figure 5). There was a bentonite migration during the test, but it could not be categorized as internal erosion. It was considered as side wall leakage and this happened because the bentonite particles could not fully stick into the cylinder cell.


Fig. 4 Water column with pressure


Fig. 5 Sidewall seepage

The second experiment was then conducted by changing the water flow in the opposite direction. In this test, the water flowed through the sand subgrade first, and then continued to the GCL sample without any additional pressure. This direction of the flow changing affected the sand subgrade formation. The sand particles moved in an irregular direction and caused an air space under the GCL sample. However during this experiment the GCLs sample failed to be tested since it had lost its bond to the cylinder cell and started lifting up slightly (Figure 6). Additionally, the turbidity of the water above the sample increased quite significantly before the sample lifted. It was quite obvious that the bentonite particles started to mix the water, but the origin of the dissolved bentonite particles was uncertain, whether they came from inside the sample and passed to the unwoven geotextile or if those particles were already outside the sample.

The next test was carried out after the GCL sample was placed properly into the sand layer. The water flowed from above and generated a side wall easily. This happened because there was an airspace in the sand layer surface close to the cylinder which provided an insufficient support to the GCL sample (Figure 6).

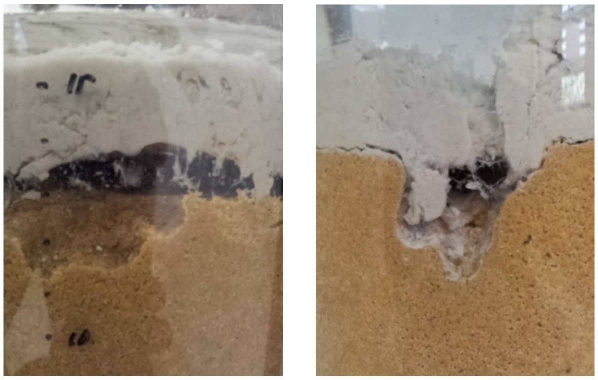

Fig. 6 Floating GCLs sample and air space under sample

The experiment was continued by draining the water from the apparatus and letting the GCL sample to dry for three days. After three days, the water was then flowed into the apparatus using falling head water column. The flowing water in the non-fully hydrated GCL caused the GCL particle to move down and started to fill the air space (Figure 7). The water kept flowing for the next two days in the tunnel even after the GCL had hydrated fully. This result showed that after being fully hydrated, the GCL's particles tended to maintain their bonding to others [10] but failed to create a bonding with cylinder cells. Again, the internal erosion occurrence could not be investigated during this experiment.

Fig. 7 Floating GCLs sample and air space under sample

Based on the experiment that has been done, the upcoming experiment will employ two rings to stop the side wall seepage and keep the GCL sample in place while facing water pressure from opposite directions. Silicon grease will be applied around circumferences when the GCL sample was in a dry condition. The changing water direction will be done continuously to see whether any GCL deformation following changing in sand subgrade formation. The GCL sample will also be tested in combination of fully and un-fully hydrated cycle with opposite water directions to simulate the condition that might be faced by GCLs during their application.

VI. Conclusion

The following conclusions were attained as a result of the first stage of investigation on internal erosion of the GCL:

1. The hydraulic performances of both GCLs samples were slightly lower than the provided technical data sheet which was 1.5 x 10^{-11} m/s. There was no indication of internal erosion during the test when water was flowing from above the GCL.
2. Increasing water pressure up to 6 meter head triggered sidewall seepage and caused water to pass between the cylinder cell and the GCL sample. The bentonite migration at the edge of the sample close to the cylinder cell was categorized as a side wall seepage and could not be considered as internal erosion. The water pressure coming from underneath the GCL caused some bentonite particles to move and mix with water, but the origin of the particles remained uncertain whether they escaped from the sample or had already been outside the sample.
3. Side wall leakage has become a crucial issue during the experiment and should be anticipated for the upcoming experiment to investigate the internal erosion. In the next experiment, two rings will be installed around the sample's circumference and sealed with silicone grease to stop the water from flowing to the side wall and keep the sample in place. A continuous change in direction of the water flow will be applied as well as the water flow cycle to replicate the real situation.

References

[1] 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.

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

[3] Lake, C.B. and R. Kerry Rowe, Swelling characteristics of needlepunched, thermally treated geosynthetic clay liners. Geotextiles and Geomembranes, 2000. 18(2–4): p. 77-101.

[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] Peggs, I.D., Olsta, J.T., A GCL and incompatible soil case history: a design problem. Proceedings of the 12th GRI Conference, Philadelphia, PA, USA, 1998. pp. 117–138

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

[7] Li, X., Y.M. Shu, and X.R. Wu. Characteristics of Self-healing of GCL. in Geosynthetics in Civil and Environmental Engineering. 2008. Shanghai, Cina: Springer Berlin Heidelberg.

[8] Jo, Ho Young, Takeshi Katsumi, Craig H. Benson, and Tuncer B. Edil, "Hydraulic Conductivity and Swelling of Nonprehydrated GCLs Permeated with Single-Species Salt Solutions." Journal of Geotechnical and Geoenvironmental Engineering 2001, 127 (7): p557-567.

[9] Fox, P.J., De Battista, D.J., Mast, D.G., Hydraulic performance of geosynthetic clay liners under gravel cover soils. Geotextiles and Geomembranes, 2000. 18(0): p. 179-201.

[10] Daniel, D.E., H.Y. Shan, and J.D. Anderson. Effects of partial wetting on the performance of the bentonite component of a geosynthetic clay liner. in Geosynthetics '93. 1993. Vancouver, BC: IFAI.