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LABORATORY INVESTIGATION OF THE HYDRAULIC PERFORMANCE ON A GEOFILM WITH VARIOUS SIZED FLAWS

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Abstract

Leakage through flaws in geofilm was examined with laboratory tests by flexible wall permeameter. Samples cracks were cut open by the sharp blade, with the results that the widths of the flaws were the same while the lengths were different. During the research, a series of laboratory permeameter tests have been performed to determine the influence of the various factors on the leakage rate of water through the flaw at the center of geofilm. The impact of various parameters examined included the following conditions (i) the influence of the confining stress on the geofilm; (ii) the hydraulic pressure applied on top of the geofilm and (iii) the length of flaw. The results indicate that the flaw size, influenced by the confining stress and the hydraulic pressure, affects the flow rate in various conditions. In addition, the flow rate decreases with the increase in confining stress. The results also show that the flow rate increases when the hydraulic pressure increases along with the length of flaw in the geofilm.

Key words: confining stress, flow rate, geofilm flaws, hydraulic pressure

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1. Introduction

There have been many advances in the understanding of issues related to the use of geofilm as contaminant barriers. These applications range from the more traditional use geofilm as part of liners or capping systems for landfills, as liners for contaminated fluids, and as covers and liners for mine waste (Bonaparte, 1995; Rowe, 2007). The geofilm has a lot of advantages, such as its extremely low permeability, good resistance to most chemicals, high strength and seam characteristics, good performance at low temperatures. But, the disadvantage of the geofilm is poor puncture resistance. Despite all precautions regarding manufacturing, transportation, handling, storage and installation, defects in the geofilm can occur in sites where a strict construction quality program is implemented (Barroso et al., 2006). Although improper seaming is the main cause of the most of the defect, puncture from the supporting soil or construction equipment may also result in defects. Aging, interactions with leachate, ultraviolet light, and high energy radiation may degrade geofilms and cause defects over long time periods ((Bouazza et al., 2008; Barroso et al, 2006; Du et al., 2009; Walton et al., 1997). Defects in the geofilm represent preferential flow paths for leachate migration. For that it's of primary importance to predict the flow rate through defects in the geofilm.

Several studies have been carried out to quantify the flow rate. As early as 1997, an analytical method was proposed to evaluate the rate of liquid migration through geofilm with defect, which was overlain by a permeable medium and underlain by a highly permeable medium. The rate of liquid migration calculated using the proposed analytical

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method approaches based on the classical Bernoulli's equation (Giroud et al., 1997a). Some studies focused on the flow of leachate in a leakage collection layer due to defects in the overlying liner. It was showed that leachate flows in a zone of the leakage collection layer that was limited by a parabola. The relationship was established between the rate of leachate migration through the defect and the maximum thickness of leachate in the leakage collection layer. It was found that the relationship depends on the hydraulic conductivity of the leakage collection layer (Giroud et al., 1997b; Statescu et al., 2017). A built-up of leachate head in the landfill provides the driving force for advective flow through tears or holes in the geofilm (Thusyanthan et al., 2007). Fine sand was used as the porous material in the experiments. The theoretical and experimental leakage rates have indicated that under effective stress gaps close and flaws become filled in resulting in a decrease in leakage (Walton et al., 1997).

In prior studies, the shape of the defect is assumed to be a circular hole. But it may not correspond exactly to actual field conditions, because the shape of defect will be a flaw, especially when geofilm developed punctures, tears or other flaws will allow fluids to occur. Is there an expanded flaw under the hydraulic head? Few studies focused on the change in size of the flaw defect on the effect of the leakage through flaws in geofilm, meanwhile, the range of hydraulic heads are also limited. Thus, it is important to understand the controlling factors for the flow rate through the flaw. In this study, the flow rate through the geofilm with a flaw was measured under different confining stresses (range 20~100 kPa) and different hydraulic heads (range 20~100 kPa).

2. Materials and methods

2.1. Geofilm

A smoothly non-treated high density polyethylene (HDPE) geofilm, 0.4 mm thickness, was used in this study (Fig. 1). Mechanical performance characteristics of the tested geofilms were described in Table 1, as measured according to American Society for Testing Material Standards. The products are supplied by the same manufacturer and they are identical. In this study, all of the values were gathered from test in the lab, and not from the supplier data. In Table 1, the data are mean values. The mass per unit area of geofilm in this study is 797.0 g/m^2 and the hydraulic conductivity of the geofilm was determined by using a flexible-wall permeameter in according to the ASTM D 5084 standard by means of the falling head method under a confining pressure of 20 kPa during the test. The experimental result is 1.3×10^5 cm^3/s (Zhang et al., 2011).

2.2. Flow rate tests

Geofilms are those commonly used geosynthetics in landfill liner systems. The hydraulic conductivity (i.e. the ability to transmit a flow of water normal to the plane) is the major factor in selecting an appropriate geosynthetic. In this study, there would be the advective flow through the geofilm defect.

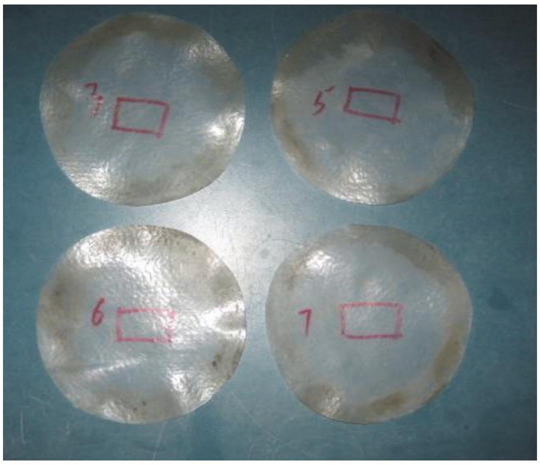


Fig. 1. High-density polyethylene geofilm

Some studies used a home-built apparatus capable of producing both transmissivity and permittivity (normal to the plane) results under load. They describe a method for determining the hydraulic conductivity of geosynthetics normal to the plane, when subjected to normal compressive stress (Hufenus and Schrade, 2006). Compared with the rigid wall permeameters or self-made equipment, flexible-wall permeameter has the following advantages: (1) side-wall leakage prevented or minimized; (2) stress on specimen can be controlled; (3) volume changes or deformation can be measured (Daniel, 1994). Fig. 2 shows the schematic diagram of the flexible-wall permeameter. Specimens for the flow rate test were prepared by clipping a circular sample (101 mm in diameter) with cracks cut open by a sharp blade in the center of the geofilm. So the flaws shared the same widths while different lengths (3mm, 5mm, 6mm and 7mm). And then the specimens were put into distilled water for 24 hours, subsequently, the Vaseline was smeared on the edge of the geofilm to prevent sidewall leakage. Before the test, the specimens were placed between filter papers and porous stones, then sheathed in a rubber membrane and finally set in a flexible-wall permeameter.

Distilled Water (DW) was used in preparing and saturating the geofilm. DW was also used as the penetrant fluid of the test at the room temperature 20~25°C. After the specimen fully saturated, the flow rate tests began, and four different length flaw geofilms were determined in this test, each of which would last about for 24 hours. Geofilms are non-porous media. The objective of this test is to address the quantification of flow rates through geofilm. The flow rate of the flawed geofilm is mainly dependent upon the size of the flaw. And the size of the flaw can be determined by analyzing its load conditions. In this paper, the hydraulic pressure and the friction force were concerned, and the analysis of the force applied to the flawed geofilm can be seen in Fig. 3. Take the 7mm flaw for example.

Table 1. Mechanical property of the geofilm used

Characteristic	***CBR* push- through force***	***Breaking strength***		***Elongation at standard strength***		***Tear force***		***Peel strength***	
	(kN)	(kN/m)		(%)		(kN)		(N/cm)	
		MD**	CMD***	MD**	CMD***	MD**	CMD***	MD**	CMD***
Results	3.56	19.48	17.90	65.79	85.18	0.60	0.59	20.04	25.37
Stardard of experiment	ASTM D 3787	ASTM D 6337		ASTM D 6337		ASTM D 4533		ASTM D 6337	

CBR: California Bearing Ratio; MD: Machine Direction; CMD***: Cross Machine Direction.*

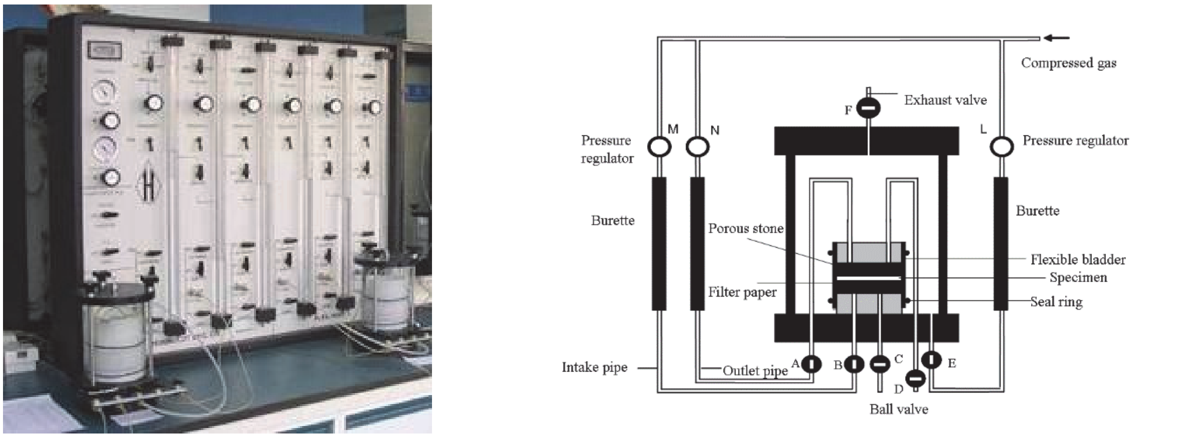


Fig. 2. Flexible-wall permeameter and schematic diagram

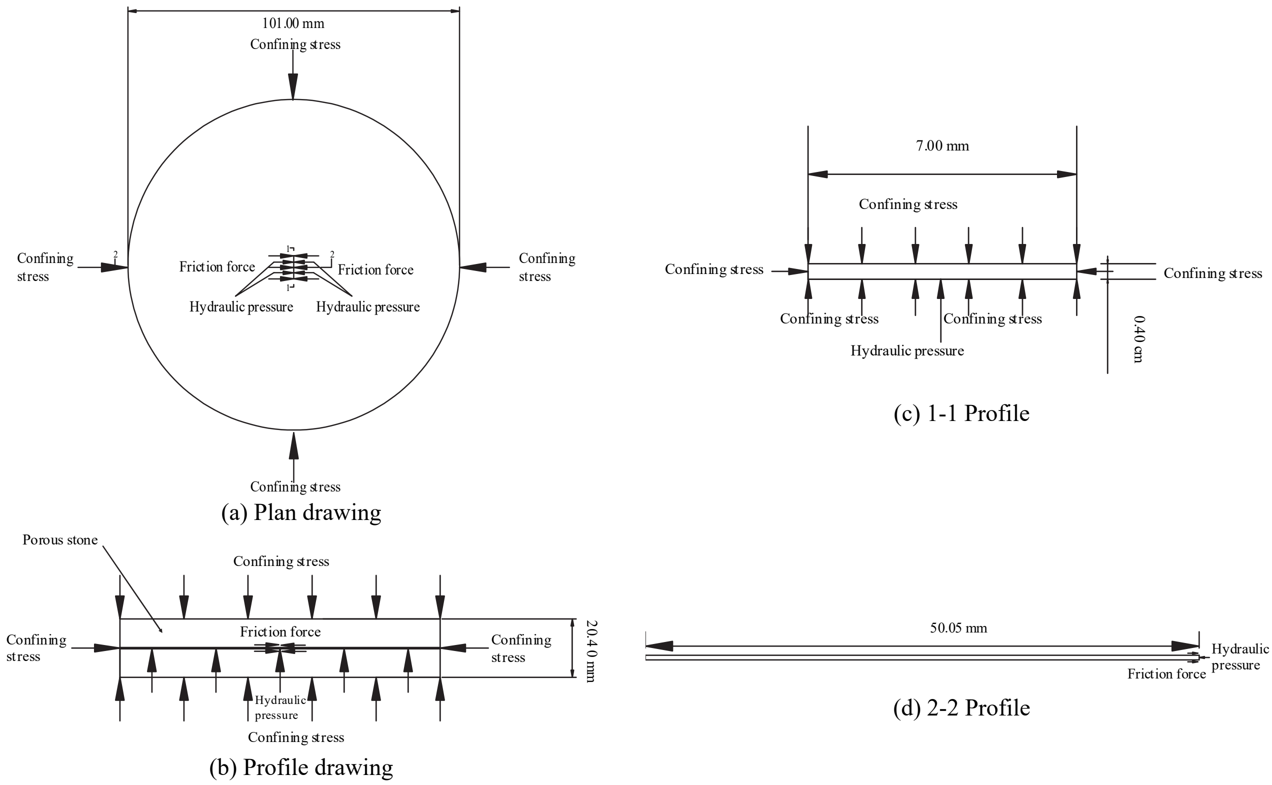


Fig. 3. Analysis of force applied to geofilm with a flaw (length of 7mm)

3. Results and discussion

A series of tests were conducted to determine the influence of the flaw on the leakage rate, during which, several factors, such as size of the flaw, confining stress, hydraulic head and considered to be of significant influence to the flow rate of geofilm with a flaw, were studied.

It is evident that the size of the defect on geofilm should be the main reason for flow rate. As can be seen from Fig. 4, the flow rate is changed to the differential hydraulic heads across the geofilm at a range of flaws under a confining stress 20 kPa, which clearly indicates that the leakage rate is governed by the length of the flaw, and it is also apparent that at lower length (<6 mm) the flow remains essentially constant, less than 10×10^{-5} cm^3/s. As for the 7 mm length of flaw, the water leakage rate is also found to increase dramatically as the hydraulic head from 20 kPa to 100 kPa.

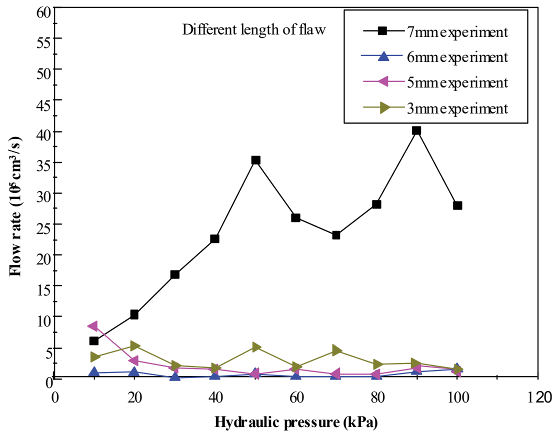
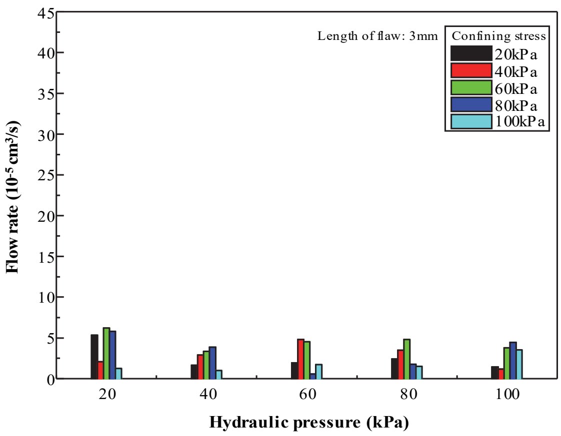


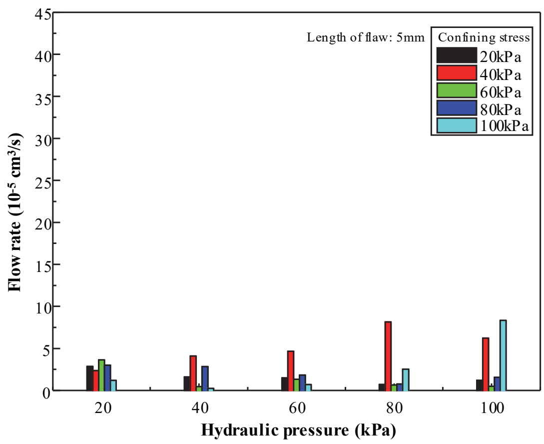
Fig. 4. Variation of flow rate to differential pressure across the geofilm with different length flaw under confining stress 20 kPa

The large increase in flow with increase in flaw length likely occurred because the greater flaw length can allow misalignment of the material, thus causing a greater cross section of area for the flow to occur (Walton and Sagar, 1990).

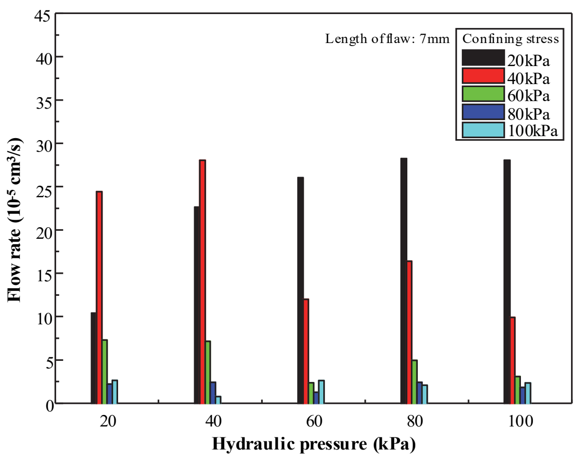
As a flexible membrane, geofilm overlaying a compacted soil liner or a geosynthetic clay liner (GCL) as composite liner consisting of a geofilm, is used in a variety of applications including liquid containment and solid waste landfills. As the geofilm and soil liner are in perfect contact, the leakage rates per unit length of defect for a GCL composite liner,there is an approximate linear relationship between the leakage rates and width of defect (Jayawickrama et al., 1988; Walton and Sagar, 1990). From the data it is obvious that an increase in either flaw size or hydraulic head will result in increased flow through the flaw. Fig. 5 shows the rate of water leakage through a geofilm with flaw for different hydraulic head conditions and under different confined stresses. It can be seen from Figs. 5(a-b) that the flow rate of the geofilm with a 3 mm or 5 mm length flaw is not significantly different when the hydraulic head increased from 20 kPa to 100 kPa. All of the flow rates are less than 7.5×10^{-5} cm^3/s.



(a)



(b)



(c)

Fig. 5. (a) Variation of flow rate to differential pressure across the geofilm with 3 mm length flaw under different confining stress; (b) Variation of flow rate to differential pressure across the geofilm with 5 mm length flaw under different confining stress; (c) Variation of flow rate to differential pressure across the geofilm with 7 mm length flaw under different confining stress

Fig. 5(c) shows that variation of flow rate with 7 mm length flaw. Under such confined stress range from as 60 kPa to 100 kPa, the flow rate remains essentially constant and less than 7.5×10^{-5}cm^3/s. But when the confined stress range from 20 kPa to 40 kPa, the flow rate is much higher than the confined stress range from 60 kPa to 100 kPa, and the flow rate is range from 10×10^{-5}cm^3/s to 30×10^{-5}cm^3/s. So, the size of the 7 mm length flaw may be expanded by the hydraulic head when the confined stress range from 20 kPa to 40 kPa. The large increase in flow with increase in flaw length likely occurred because the greater slit length can allow misalignment of the material, thus causing a larger cross section of area for the flow to occur.

The results confirmed that the confined stress may be expected to have significant effect on the flaws width and therefore on the leak rate. When the confined stress range from 20 kPa to 100 kPa, it was found that the 7mm flaw may be the critical value. As is noted above, because the confined stress has an appreciable restriction effect on the geofilm, the flow rate was found decreased as the confining stress increased to a certain extent.

4. Conclusions

Flow rate tests were performed on a geofilm, where the geofilm contained a flaw, besides, the leakage rate of a geofilm with a flaw was affected by the size of the flaw, meanwhile, confined stress (range 20~100 kPa) and different hydraulic heads (range 20~100 kPa) were also concerned.

There is no good linear relation between the flow rate to the size of defect and hydrulic head. It is found that at a lower flaw length (< 6 mm) the flow remains essentially constant, less than 10×10^{-5} cm^3/s. As for 7 mm length flaw, the water leakage rate is found to increase as the differential hydraulic heads increased from 20 kPa to 100 kPa when the confining stress is 20 kPa. The 7 mm length flaw may be a critical length when porous stone was put on each side of geofilm. The pressure induced by the hydraulic head may expand size of the flaw, which increases the flow rate of the geofilm with a flaw.

A similar relationship can be seen the flow rate of geofilm with 3 mm or 5 mm flaws is essentially constant, where the hydraulic head ranges from 20 kPa to 100 kPa under a confining stress change between 20 kPa and 100 kPa. As for the 7 mm length flaw, the tests indicated that the flow rate under 20 kPa and 40 kPa confined stress is significantly higher than the flow rate under confined stress ranging from 60 kPa to 100 kPa. This is because the confined stress has an appreciable restriction effect on the width of the flaw in geofilm and hence the leak rate. Overburden stress to some extent mainly depends on the landfilled solid waste depth is capable of restricting leachate flow from defects. In this study, the thickness of membrane is 0.04 cm.

For the geofilm, deformation of flaw cannot be ignored when there are hydraulic heads and confining stress. It may be useful for researchers or engineers who design drainage layer for landfills and other liquid containment facilities, such as the importance of confining stress in restraining the flow rate from hydraulic defects with the same dimensions.

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