Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Estimation of performance of pre-hydrated geosynthtic clay liner for use in irrigation ponds

I. NATSUKA, National Institute for Rural Engineering, Japan
T. KONAMI & S. NAKAMURA, Okasanlivic CO.,Ltd., Japan

ABSTRACT: Pre-hydrated geosynthetic clay liner (PH-GCL) has been used in irrigation ponds in Japan. We have estimated the performance of PH-GCL in scenarios relevant to its application in irrigation ponds, based on its impermeability when in contact with different surfaces and slope stability. Permeability tests under several conditions revealed that leakage along the vertical contact face of PH-GCL and concrete, and in the region of overlapping sheets of PH-GCL, was significant. A simple method of estimating permeability at the contact face is proposed. The slope of the irrigation ponds also affects the performance of PH-GCL and, as such, we calculated shear strengths and estimated the slope stability of PH-GCL. We calculated the shear properties of PH-GCL associated with bentonite, the boundary of geotextiles to bentonite, and the boundary of geotextiles to the covering soil. Results indicated that the bentonite layer in PH-GCL had the weakest shear strength. Moreover, the trial calculations of slope stability indicated the importance of the anchoring geotextiles.

1 INTRODUCTION

Recently, there has been an increase in the number of deteriorating ponds that require maintenance (approximately 210,000 ponds). Pre-hydrated geosynthetic clay liner (PH-GCL) has been trialed as a waterproof liner of irrigation ponds. The waterproof component of PH-GCL is bentonite, a mineral that is expected to self-seam without deterioration. In addition, PH-GCL can be installed easily, without the use of complex technology.

In order to test the efficacy of PH-GCL as an irrigation pond liner and to support potential widespread use of this material in pond maintenance and restoration, we carried out impermeability tests and shear box tests on PH-GCL. The waterproof performance in regions where liners overlapped or made contact with another surface, and the concrete, were quantitatively examined in the impermeability tests. Shear box tests were conducted to establish an appropriate limit for the maximum slope on which GCL could be installed.

2 TEST METHOD

2.1 *PH-GCL*

PH-GCL was used for the experiments. PH-GCL is composed of 5-mm thick, pre-hydrated, and compressed bentonite and two different geotextiles (Natsuka et al. 1998). Pre-hydration allows the bentonite to maintain uniformity and prevent initial immediate seepage. The standard two geotextiles used to protect bentonite are non-woven and woven polypropylene. Thin non-woven polypropylene may be used for the side in contact with concrete tnstead of the woven.

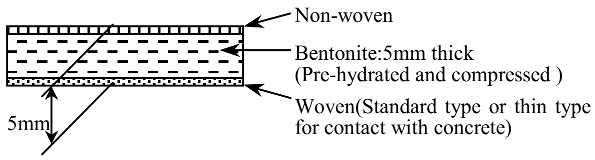


Figure 1. Schematic of PH-GCL

2.2 *Impermeability test*

Waterproof performance of PH-GCL under several conditions of surface contact were investigated using original apparatus. PH-GCL specimens were installed in containers with an O-ring at the bottom, and in which even small amounts of leakage could be measured by weight. The experimental set-up and conditions are outlined in Table 1. Figure 2 shows an apparatus of impermeability test that has many holes at the bottom.

Table 1 Condition of impermeability tests

Condition	Swelling Time	Water Pressure
Standard	1, 7 and 15 days	300, 600 and 900kPa
Overlapping	1, 7 and 15 days	50, 150 and 300kPa
Horizontal contact to concrete	15 days	300kPa(Const.)
Vertical contact to concrete	15 days	300kPa(Const.)

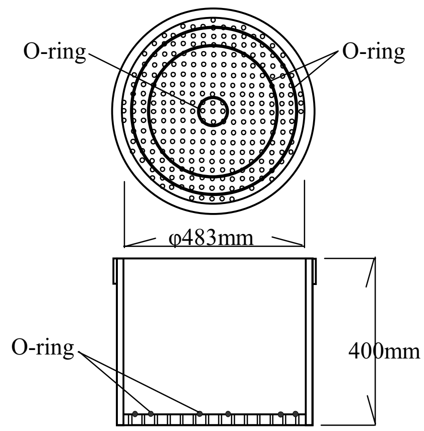
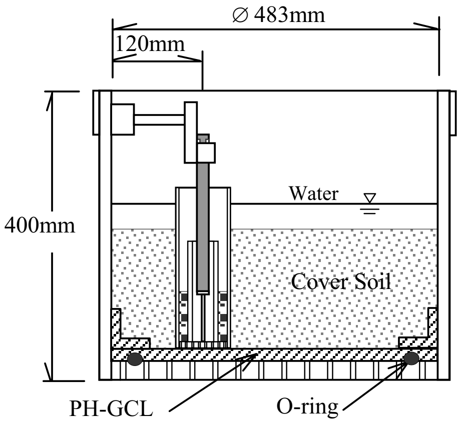
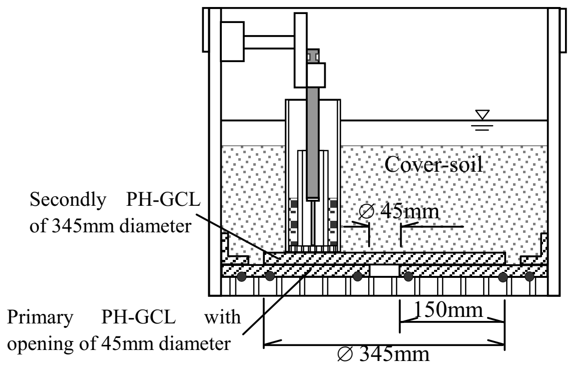


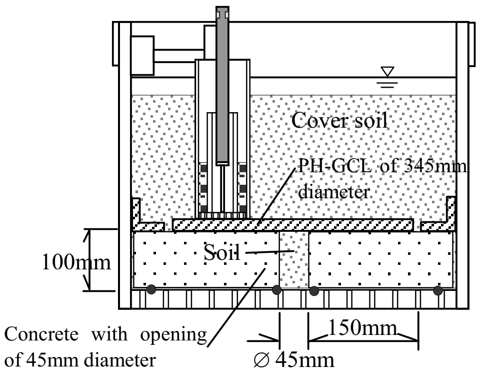
Figure 2. Apparatus of Impermeability test



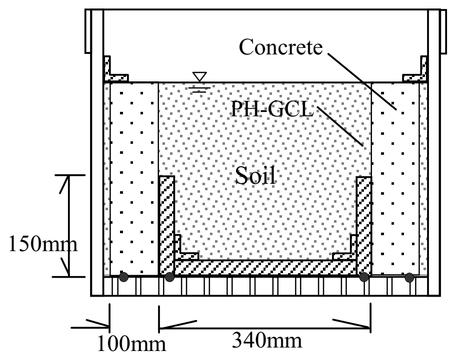
a. Standard



b. Overlapping



c. Horizontal contact to concrete



d. Vertical contact to concrete

Figure 3. Test conditions

For standard conditions, PH-GCL was laid on the whole bottom surface of the container and covered with soil 200-mm thick (Figure 3a). In the treatment with overlapping, a 345-mm-diameter piece of PH-GCL was overlaid on another piece of PH-GCL that had an opening of 45-mm diameter (Figure 3b). This specimen has an overlap of 150 mm. The permeability of overlapping layers was tested under two conditions: P-P, in which the textile layers were removed so that the bentonite of the two overlapping layers was in direct contact, and P-S, in which a thin layer of non-woven polypropylene was between two layers of bentonite. The impermeable performance of horizontal contact between PH-GCL and concrete was examined by setting a horizontal layer of PH-GCL, with thin non-woven polypropylene on the contact surface, over concrete that had a 45-mm-diameter opening (Figure 3c). The impermeable performance of vertical contact between PH-GCL and concrete was examined by lining a concrete cylinder with PH-GCL that had thin non-woven polypropylene on the contact surface (Figure 3d).

2.3 *Shear test*

Direct shear tests were performed using a 150-mm-diameter shear box to evaluate the stability of PH-GCL laid on a slope. Prior to installation in the shear box, the bentonite was covered with 200 mm of soil and soaked in water for 21 days until steady state of swelling. The shear strength of the slide surface was examined under different test conditions, in which different layers were placed in contact with each other and soaked in water (Table 2).

Table 2. Condition of impermeability tests

Case No.	Slide surface	Shear speed
1	Bentonite – Bentonite	0.015mm/min
2	Woven – Sandy soil	
3	Nonwoven – Sandy soil	
4	Woven – Cohesive soil	
5	Nonwoven – Cohesive soil	

3 RESULTS

3.1 *Impermeability*

3.1.1 *Standard condition*

The coefficient of permeability (k = q / (i ·A), A=1339.6 cm^2; following Darcy's law) of PH-GCL after swelling under standard conditions, was undetectable at water pressures of 300 kPa and 600 kPa (Table 3). Leakage tended to decrease with shortening of the time of swelling. The coefficient of permeability under standard conditions was less than 1×10^{-10} cm/sec in all cases in this research.

Table 3. Hydraulic conductivity of PH-GCL under standard conditions

Test No (Swell)	Water pres. (kPa)	Thick *t* (cm)	Unit leakage *q* (cm^3/day)	Hydraulic gradient *i*	Coeffi. of Permeability *k* (cm/sec)
1 (1day)	293	0.71	0.0	4,130	0.00
	597	0.77	0.0	7,750	0.00
	898	0.81	12.5	11,090	9.74×10^{-12}
2 (7days)	298	1.05	25.0	2,840	7.39×10^{-11}
	602	1.05	12.5	5,730	1.83×10^{-11}
	899	1.07	25.0	8,400	2.50×10^{-11}
3 (15days)	292	1.29	25.0	2,260	9.29×10^{-11}
	602	1.27	12.5	4,740	2.22×10^{-11}
	891	1.26	37.5	7,070	4.46×10^{-11}

3.1.2 *Overlapping*

A new coefficient of contacting flow, k_c, is proposed to evaluate impermeability through a contacting surface, based on Darcy's law as follows:

$$k_c = \frac{q}{L_k i} = \frac{qB_k}{L_k p} \quad (1)$$

where a hydraulic gradient, i, in k_c ((cm^3/sec)/cm=cm^2/sec)is estimated by the ratio of the width of the contacting surface B_k(cm), and the water pressure, p(kPa). L_k (cm)is the length that water can pass through from the contacting surface, and q (cm^3/sec)is the unit leakage. Figure 4 shows the overlap condition schematic.

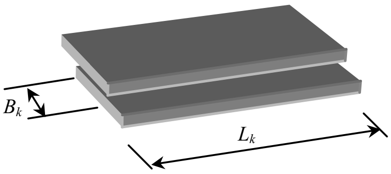


Figure 4. Overlapping condition schematic

Table 4 shows coefficients of contacting flow for treatments in which layers of bentonite contacted directly (P-P), or were separated by a thin layer of non-woven polypropylene (P-S), after periods of swelling of 1, 7, or 15 days. There was less leakage in the treatments with direct contact of bentonite (P-P) than in the treatments in which a layer of non-woven polypropylene was between bentonite layers (P-S). Moreover, there was no leakage at all after 1-day swelling in the P-P treatments, but leakage tended to increase with longer swelling time. The leakage values include leakage from overlapping layers, as well as water that passed vertically through the PH-GCL. The coefficient of contacting flow for the P-P treatments was less than 1 × 10^{-7} cm^2/sec but was more variable for the P-S treatments.

Table 4. Coefficients of contacting flow k_c of overlapping

Swelling time (Cntact)	Water pressure (kPa)	Leakage (cm^3)	Hydraulic gradient i	k_c(cm^2/sec)
1day	52	12.5	34.7	4.21E-8
(P-S)	168	Break	112.0	
	301	350.0	201.0	2.04E-7
7days	50	37.5	33.3	1.32E-7
(P-S)	146	100.0	97.3	1.20E-7
	295	75.0	197.0	4.46E-7
1day	51	0.0	34.0	0.00E+0
(P-P)	141	0.0	94.0	0.00E+0
	300	0.0	200.0	0.00E+0
7days	49	0.0	32.7	0.00E+0
(P-P)	145	12.5	96.7	1.51E-8
	283	37.5	189.0	2.32E-8
15days	49	0.0	32.7	0.00E+0
(P-P)	150	62.5	100.0	7.31E-8
	288	62.5	192.0	3.81E-8

3.1.3 *Contact to concrete*

There was no leakage observed in any of the experimental treatments in which PH-GCL was in horizontal contact with concrete and a maximum pressure of 300 kPa was applied for up to 15 days.

Table 5. Coefficients of contacting flow k_c of vertical contact with concrete

Swelling time & Water pressure	Total amount of leakage (cm^3)	In case PH-GCL k=1x10^{-10}cm/sec		In case PH-GCL k=1x10^{-11}cm/sec	
		Leakage from contact (cm^3)	k_c cm^2/sec	Leakage from contact (cm^3)	k_c cm^2/sec
15days	192	82.1	9.87^{-9}	181.1	2.18^{-8}
&	64			53.1	6.38^{-9}
300kPa	115	5.3	6.37^{-10}	104.3	1.25^{-8}

In contrast, leakage was observed in treatments in which PH-GCL was in vertical contact with concrete. The amount of leakage from the vertical contact was calculated by deducting the estimated leakage from the PH-GCL lining the bottom, based on assumed permeability coefficients of PH-GCL of 1 × 10^{-10} cm/sec and 1 × 10^{-11} cm/sec, from the total amount of leakage observed. The PH-GCL laid on the bottom was 1.29cm thick and covered an area of 907 cm^2. Coefficient of contacting flow k_c of vertical contact with concrete was calculated under the condition that the PH-GCL in vertical contact with the concrete was B_k=20cm wide and L_k=107cm long as Table 5.

3.2 *Shear strength*

The strength of each slide surface can be shown in Table 6 with the angle of internal friction (∅) and the cohesion (c) in the same way as the strength of the soil can be. And it can be emphasized that the shear strength of bentonite which is soaked in water for 21 days before shearing is not very strong (Figure 5).

Table 6. Shear strength

Boudary condition	Bentonite to Bentonite	Woven to Sandy soil	Nonwoven to Sandy soil	Woven to Cohesive soil	Nonwoven to Cohesive soil
∅ (deg.)	2.41	30.08	31.90	25.10	30.51
tan ∅	0.0421	0.5792	0.6224	0.4684	0.5892
c(kPa)	0.0151	0.0000	0.0000	0.0070	0.0083

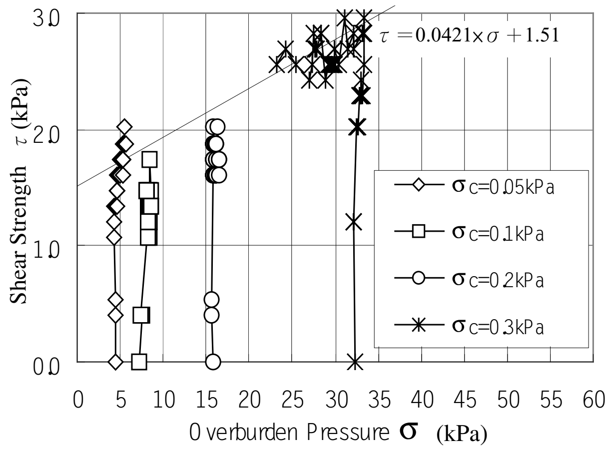


Figure 5. Relationship between shear strength and overburden pressure of bentonite-to-bentonite contact

4 TRIAL CALCULATION

4.1 *Impermeability including overlap*

The performance of GCL must be evaluated, particularly at the region of overlapping layers.

We calculated the impermeability of PH-GCL, including at the region of overlapping layers, under the following conditions: a) thickness, t, of PH-GCL was 1.2 cm, b) permeability, k, of PH-GCL under the standard condition (Figure 3a) was 1 × 10^{-10} cm/sec, c) coefficient of contacting flow k_c at the region of overlap was 1 × 10^{-7} cm^2/sec, d) size of the PH-GCL used was 200 × 3000 cm and the width of overlap, B_k, was 15 cm (Figure6). An apparent coefficient of permeability, k_a, in the area of the reality, A_r, was calculated as follows

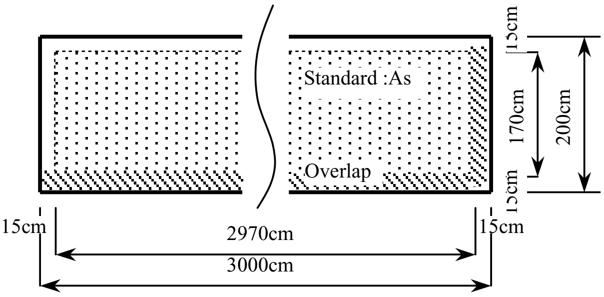


Figure 6. PH-GCL product including overlap

$$k_a = \frac{kA_s + k_c t \, L_k / B_k}{A_r} \qquad (2)$$

where A_s is the standard area(Not overlap area).

The amount of leakage from the overlap accounted for approximately 40% of the total, and k_a was 1.4×10^{-10} cm/sec.

4.2 *Slope stability*

A safety factor can be calculated for a scenario in which PH-GCL is installed on a slope as in Figure 7, based on the following equation from Koerner (1994):

$$Fs = \frac{T_r}{T_s} = \frac{c + \gamma Z \cos^2\beta \tan\phi}{\gamma Z \cos\beta \sin\beta} \qquad (3)$$

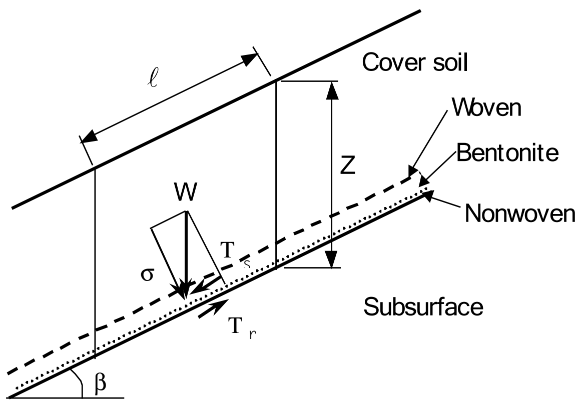


Figure 7. Slope schematic

The values of shear strength of each slide surface (Table 6) were applied to equation (3). Figure 8 shows the safety factor of slope stability of installed PH-GCL. Based on the strength of bentonite, a safety factor of 1 may be achieved for a slope of approximately 25°. However, safety factors exceeding 3 are recommended for stability of PH-GCL installed on slopes. In addition, an anchor trench that prevents slipping is required.

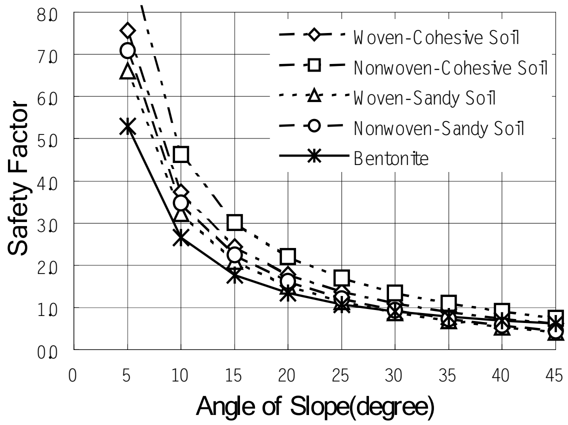


Figure 8. Relationship between the angle of slope and the safety factor

5 CONCLUSIONS

We evaluated the new knowledge that are useful for the actual site of PH-GCL and proposed a new coefficient of contacting flow, k_c , in this research. Moreover the apparent coefficient of permeability (k_a) of PH-GCL that included overlapping was less than 1×10^{-9} cm/sec at least. In order to satisfy a safety factor of 3, PH-GCL covered by approximately 20cm soil, could be installed on slopes of less than 10 °. The slope stability of installed PH-GCL must be examined in consideration of not only slope angle but also the slope length, the thickness of the cover soil and the strength of the textiles.

REFERENCES

Natsuka, I., Toyoda, H., Konami, T. & Horita, N. 1998. Permeability at contact face of Geosynthetic Clay Liner, Trans. of JSIDRE, No.193:111-118 ·

Koerner, R.M. 1994. Designing with Geosynthetics: 545-549:Prentice Hall