Boundary shear strength characteristic between surface soil and geosynthetic clay liner and its stability analysis in interface of irrigation pond

Atsushi Koyama i), Motoyuki Suzuki ii), Yoshifumi Kochi iii), Tomoko Urabe iv) and Jun Ito v)

i) MS Student, Graduate School of Science and Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube, 755-8611, Japan.
ii) Associate Professor, Graduate School of Science and Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube, 755-8611, Japan.
iii) Dr. Eng., K’s Lab. Co., 3533-4, Osaba, Yamaguchi, Yamaguchi 753-1212, Japan.
iv) MS, VOLCLAY JAPAN, 3-1-9, Shimbashi, Minato-ku, Tokyo 105-0004, Japan.
v) MS Student, Graduate School of Science and Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube, 755-8611, Japan.

ABSTRACT

Geosynthetic clay liner (GCL) is an impervious liner for the construction of a dam body. It consists of bentonite encapsulated between woven and non-woven geotextiles, which are needle-punched. This method constructs a widening of an embankment to a precast embankment that was laid with a GCL. However, its detailed construction, the internal shear strength of the GCL, and the shear strength between the GCL and the dam body soil have not been reported. In this study, a direct box shear test was carried out to clarify the shear strength of bentonite, the boundary between the bentonite and geotextiles, and the boundary between the dam body soil and geotextiles. In this study, the dam body soil was decomposed granite soil. In addition, this study was carried out to evaluate the stability state of the dam body that employs a GCL. The main conclusions are as follows: 1) a bentonite that swelled uniformly and a bentonite laminated sealing sheet had almost the same shear strength; 2) the shear strength characteristic between soil and geotextiles varies by the type of soil or water content; and 3) the maximum safety factor is the boundary between the decomposed granite soil and GCL, and the minimum safety factor is the boundary between the bentonite and the geotextiles.

Keywords: irrigation pond, GCL bentonite, safety factor

1 INTRODUCTION

There are approximately 210,000 irrigation ponds in Japan, and some of these ponds have deteriorated. Where water has leaked or deformation of the embankment has occurred, the stability of the dam body may be diminished and compromised. It is essential to prevent the failure of irrigation ponds and to repair problematic parts caused by the deterioration.

Generally, a repair technique using high-quality clay is used for water barriers in irrigation ponds. However, the surface soil in the embankment erodes, and it has sometimes been difficult to replace it in recent years. Consequently, a method that involves widening a new embankment over a constructed embankment laid with a geosynthetic clay liner (GCL) has been developed 9) (Fig. 1). The GCL consists of bentonite encapsulated between woven and non-woven geotextiles. It can prevent leaks in irrigation ponds caused by the infiltration of water and due to the bentonite swelling 2) However, to the best of our knowledge, the details of this type of construction method, the internal shear strength of the GCL, and the shear strength between the GCL and the dam body soil have not yet been clarified. Therefore, this study aimed to elucidate the shear strength characteristics of the internal GCL and the boundary between the GCL and soil. The soil samples used for the study are decomposed granite (Masado) and bentonite in the GCL by means of a consolidated constant-pressure direct box shear test. Both field tests and direct box shear tests were carried out to clarify the shear strength of the bentonite and the boundary between the bentonite or dam body soil and geotextiles. We also evaluated the stability of dam bodies that employ a GCL based on the test results.

2 FIELD TESTS AND MEASUREMENTS

We constructed three dam bodies made of decomposed granite and with angles of inclination of $\beta = 34^\circ$, $40^\circ$, and $45^\circ$ in Yamaguchi, Japan. After 6 months of submergence, field shear tests and measurements of the water content of the dam body and bentonite in the GCL were conducted. Photo 1 shows the site of the dam body construction, and Table 1 shows the water content of the dam body and GCL that were submerged for 6 months.
The natural water content of bentonite in the GCL was 15.0%; however, after 6 months, it increased to approximately 150–180%. The natural water content of the dam body was 13.0%; after 6 months, it increased to 20–24%. There was no sliding failure or slipping of the GCL due to changes in the water content of bentonite during construction or submersion.

3 MATERIALS AND METHODS

3.1 Consolidated constant-pressure direct box shear test

The present consolidated constant-pressure direct box shear test examined the shear strength characteristics of the following cases:

1) Decomposed granite alone;
2) The boundary between decomposed granite and geotextiles (woven or non-woven);
3) Bentonite alone; and
4) The boundary between bentonite and geotextiles (woven or non-woven).

3.2 Test samples

A decomposed granite collected in Yamaguchi, Japan, with a particle size of ≤9.5 mm was used in the present study. Its physical properties are shown in Table 2. We also used a GCL consisting of bentonite encapsulated between woven and non-woven needle-punched geotextiles.

The physical properties of the bentonite are shown in Table 2. The particle sizes of the bentonite were determined by sedimentation analysis. Bentonite specimens were subjected to the same conditions as the GCL in the dam body. The specimens had a dry density of 1.248 g/cm³, and the GCL water content was 15.0%. Bentonite specimens were submerged and swelled in a direct box shear apparatus.

As illustrated in Fig. 2, geotextiles were attached to a steel plate for the shear test for the boundary soil and geotextiles.

3.3 Test apparatus

3.3.1 Test procedure for decomposed granite and decomposed granite with geotextiles

Decomposed granite was passed through a sieve size of 0.85 mm. First, the passed sample of decomposed granite was compacted at the optimum moisture content (\(w_{\text{opt}} = 13.0\%\)) determined by the compaction test. The specimens for the direct shear box test were cut from this compacted granite. The specimens were 6 cm in diameter and 2 cm in height.
For the shear test for specimens of decomposed granite constructed with geotextiles, decomposed granite was compacted in the shear box. The soil specimen was 1 cm in height and had a degree of compaction of 90%.

Three types of specimen (decomposed granite alone and decomposed granite with woven and non-woven geotextiles) were consolidated for 30 min under six different consolidation pressures ($\sigma_c = 10, 20, 30, 50, 75,$ and 100 kPa). After consolidation, shearing was conducted under the conditions of drainage and a shear velocity of $\delta = 0.2 \text{ mm/min}$. The specimen was put under water during the shear test.

### 3.3.2 Test procedure for bentonite and bentonite with geotextiles

The water content of the bentonite used in the present experiments ranged from natural water content to a GCL water content of 15.0%. All bentonite specimens were compacted in the shear box. The dry density of the specimen was 1.248 g/cm$^3$, which corresponded to that of the bentonite inside the GCL. The specimens of bentonite alone were 6 cm in diameter and 2 cm in height; the specimens of bentonite with geotextiles were 1 cm in height.

The aforementioned specimens were consolidated by an initial consolidation pressure of $\sigma_{c0} = 10$ kPa for 30 min and submerged for 7 days. After 7 days, the specimens were consolidated again using five consolidation pressures ($\sigma_c = 20, 30, 50, 75,$ and 100 kPa) for 24 h. Shear started with drainage and a shear velocity of $\delta = 0.02 \text{ mm/min}$ after 24 h.

The shear test was also carried out under $\sigma_{c0} = 10$ kPa. In this test case, specimens were consolidated by $\sigma_{c0} = 10$ kPa for 30 min and submerged for 7 days, after which they were sheared.
4 TEST RESULTS

4.1 Decomposed granite

Fig. 3 shows three failure envelopes: decomposed granite alone and decomposed granite with woven and non-woven geotextiles. Compared to the results of the decomposed granite, the boundary between the decomposed granite and the geotextiles showed a lower internal friction angle $\phi_d$ and higher cohesion $c_d$.

The difference in $\phi_d$ was not affected by woven or non-woven geotextiles. In contrast, the $c_d$ of the decomposed granite specimens with non-woven geotextiles was lower than that of the specimens with woven geotextiles. The difference in strength was due to whether the material of the geotextiles was woven or non-woven. Voids in the fibres of non-woven geotextiles are larger than those in woven geotextiles; as a result, it is easy for soil particles to enter.

4.2 Bentonite

Fig. 4 shows the shearing behaviour at 7 days of submersion for bentonite alone and for bentonite with woven and non-woven geotextiles. $\tau$ monotonically increased in an early stage of shearing and then switched to a steady state in all specimens. However, with regards to $\Delta H$, the specimen of bentonite with woven geotextiles constricted in the case of $\sigma_n = 10$ kPa. In contrast, the bentonite specimen with non-woven geotextiles dilated.

It seems that the boundary between the bentonite and non-woven geotextiles had more adhesion than the boundary between the bentonite and woven geotextiles. Therefore, dilatancy (dilation) occurred.

Fig. 5 shows the rupture envelopes of bentonite with geotextiles submerged for 7 days. These strength parameters were lower than those of decomposed granite. The bentonite particles in all specimens softened and swelled with the absorption of water after being submerged for 7 days. It is suspected that the internal friction angle decreased and the shear plane smoothed out. The $\phi_d$ of bentonite alone is consistent with that reported by Kamai and Miyata (1993), who reported the results of a direct box shear test for bentonite. In addition, the $\phi_d$ of bentonite alone was lower and the $c_d$ was higher than for bentonite with geotextiles because the specimens were sheared at the boundary between the bentonite and geotextiles.
5 STABILITY ANALYSIS FOR DAM BODIES USING GCL

As illustrated in Fig. 1, the safety factors for sliding failure were calculated under four conditions: 1) the inside of decomposed granite; 2) the boundary between decomposed granite and geotextiles; 3) the inside of bentonite; and 4) the boundary between bentonite and geotextiles.

The calculation used the strength parameters obtained from the direct box shear test. We also used the thickness of the widened embankment $H = 1.0$ m; the angle of inclination $\beta = 34^\circ$, $40^\circ$, and $45^\circ$; and the submerged unit weight of decomposed granite $\gamma' = 11$ kN/m$^3$. Pore water pressure and the thickness and weight of the GCL were neglected in the calculation. The safety factor was deduced from the following equation:

$$F_s = \frac{c_d + \gamma H \cos^2 \beta \tan \phi_d}{\gamma H \cos \beta \sin \beta}$$

(1)

Fig.s 6(a) and 6(b) show the safety factors of decomposed granite and bentonite after 7 days of submersion for sliding failure. $F_s$ was more than 1 in all cases. $c_d$ was the highest in the boundary between decomposed granite and woven geotextiles; therefore, $F_s$ was greater than 4. In contrast, $F_s$ in the boundary between bentonite and woven geotextiles at $\beta = 45^\circ$ was the lowest with $F_s = 1.9$.

6 CONCLUSIONS

The main results of the present study are summarized as follows:

1) Shear strengths in the boundary between decomposed granite and woven or non-woven geotextiles were lower than those in decomposed granite alone. Moreover, cohesion differed depending on whether the geotextiles were woven or non-woven.

2) After 7 days of submersion, the shear strengths of bentonite alone and the boundary between bentonite and geotextiles decreased. Furthermore, in the specimens of bentonite alone, $\phi_d$ was lower and $c_d$ was higher than in specimens with geotextiles.

3) The maximum safety factor was found at the boundary between decomposed granite and woven geotextiles, and the minimum safety factor was found at the boundary between bentonite and woven geotextiles.

ACKNOWLEDGEMENTS

This study was financially supported by the Ministry of Agriculture, Forestry and Fisheries. We wish to offer our sincere thanks.

REFERENCE

1) Hara, T., Sakota, K., Fujita, M., Kochi. Y: Efficacy of Inner Bentonite Matting for Controlling Seepage in Irrigation Tank Embankment, Journal of Irrigation, Drainage and Rural Engineering, Vol. 77, No. 2, pp. 124-125, 2009 (in Japanese).

2) Onigata, M: Characteristics and Application of Bentonite, Journal of the Clay Science Society of Japan, Vol. 46, No. 2, pp. 131-138, 2007 (in Japanese).

3) Kamai, T., Miyata. Y: Failure Propagation Process in Landslide Cohesive Soil Subjected to Direct Shear, Landslides, Vol. 29, No. 4, pp. 9-17, 1993 (in Japanese).