

## Long-term transmissivity of geotextile confined in clay

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**ABSTRACT:** Transmissivity of geotextile ( $\theta_{GT}$ ) under clay confinement was investigated by large- and small-scale laboratory tests. Test results revealed that (a)  $\theta_{GT}$  reduced remarkably with increase of confine pressure; (b) under short-term condition, confined in clay values are comparable with reported confined in rubber membrane data and, (c) with clay confinement,  $\theta_{GT}$  reduced significantly with elapsed time, and the higher the confine pressure and the smaller the hydraulic gradient, the faster the reduction. It is suggested that long-term confined in clay  $\theta_{GT}$  value with an appropriate confine pressure should be used for design. Also, it is recommended that further development of geotextile composites to improve their long-term transmissivity is needed. Considering application of geotextile to embankment construction with clayey backfill, a simple method is proposed to predict pore pressure dissipation within embankment. The method takes into account the effect of geotextile transmissivity and is considered a useful tool for design.

### 1 INTRODUCTION

There are cases that require to use clayey soils as fill material for embankment construction, such as (a) areas lack granular fill materials and (b) the need of efficiently treating waste clayey soils from other construction sites. Using geotextile as drainage/reinforcement material is one of the methods to construct embankment with clayey fill material. In this case, the field long-term transmissivity of geotextile is a necessary design parameter. However, confined in clay long-term transmissivity of geotextile is not well understood yet. Practically, most designs were made by using data provided by manufacturers, which were tested under a condition different from that of the field.

In this paper, transmissivity of a geotextile has been investigated by both large- and small-scale confined in clay laboratory tests. Factors considered are (a) confining pressure, (b) hydraulic gradient and (c) elapsed time. Confined in clay test results are also compared with reported confined in rubber membrane data. Then, a method of predicting pore pressure within geotextile-reinforced embankment is proposed by considering the effect of transmissivity of geotextile.

### 2 TEST EQUIPMENTS AND MATERIALS

Two equipments for testing the transmissivity of geotextile with clay confinement had been developed. The set up of the equipments are illustrated in Figs. 1 (a) and (b). A large-scale one (Fig. 1 (a)) can test a geotextile sample with 0.2 m in width and 1.0 m in length under a lower confining pressures (about 10 kPa) and a small-scale one (Fig. 1 (b)) can test a geotextile sample of 88 mm in width and about 0.3 m in length with a confining pressure up to 500 kPa. For all tests, tap water was used and re-circulated by a micro-pump. Test procedure for the large-scale equipment is as follows:

- (1) Fill the remolded clay into the model up to the height of slots on the ends of the model box. The thickness of clay is about 90 mm. To ensure a leveled surface, the clay is compressed under 10 kPa pressure for one day.
- (2) Lay geotextile sample of 1.07 m in length and 0.2 m in width on the top of the clay. Put about 35 mm length geotextile sample into each slot (see Fig. 1 (a)) on the ends of the model box. Fix the gap between the sample and the slot by putty.
- (3) Put remolded clay on top of the geotextile sample with a thickness of about 150 mm. Set a wooden loading plate on top of the clay and apply 10 kPa pressure by dead load.

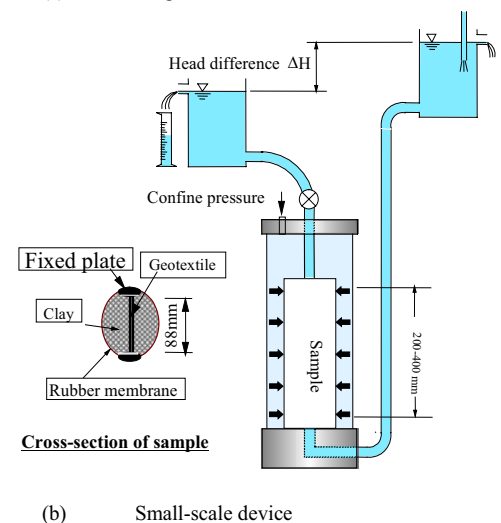
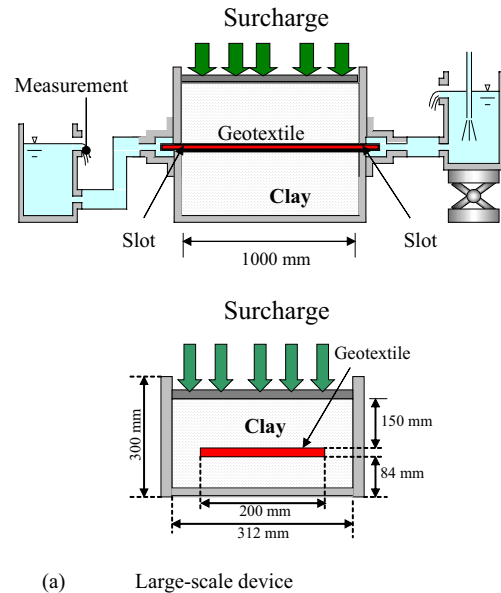


Figure 1 Illustrations of test set-up

(4) Adjust hydraulic gradient and let the clay sample consolidation for one day. Then measure the transmissivity of geotextile. It is aware that after one day, primary consolidation of clay sample may not finish, but after one day, the rate of water consolidated from clay is small and it will not give noticeable influence on rate of water flow measured.

The small-scale device is modified from a triaxial type discharge capacity test equipment. As shown in Fig. 1 (b), to provide a plane strain confinement to geotextile sample, two plates were fixed to pedestals to cut off pressure in the direction parallel to geotextile surface. Test procedure is similar as that of discharge capacity test of prefabricated vertical drain sample as reported by Miura & Chai (2000a).

Geotextile tested is a composite of non-woven and woven geotextiles, which consists two layers of non-woven geotextile sandwiched a layer of woven geotextile (Fig. 2). The unit weight is 510 g/m<sup>2</sup>, and thickness is 2.1 mm under 50 kPa confinement. The wide strip tensile strength is 40 kN/m under a strain rate of 1%/min (Public Works Research Institute, Japan 2000). Clay soil used was Ariake clay with a clay content (<5 m) of 57%, plastic limit of 42.8% and liquid limit of 105.0%.

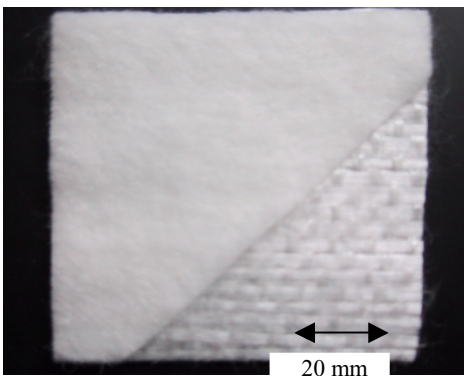


Figure 2 Picture of geotextile tested

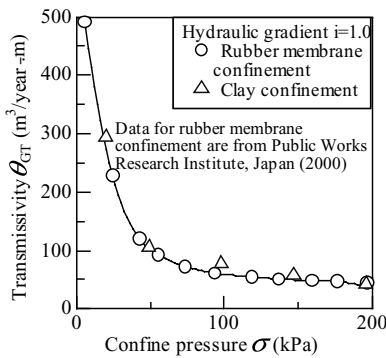


Figure 3 Effect of confining pressure

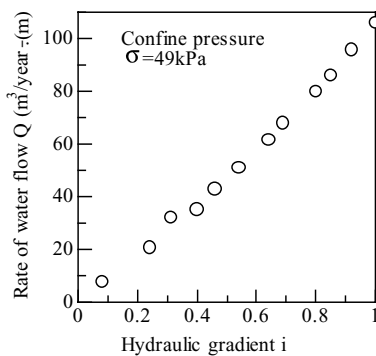


Figure 4 Effect of hydraulic conductivity

### 3 TEST RESULTS

#### 3.1 Short-term results

Effects of confine pressure and hydraulic gradient are first investigated by short-term tests using the small-scale device. In this case, after setting desired condition, waiting for 10 min., measurement was made. Figure 3 shows the results on the effect of confining pressure. For confine pressure less than 50 kPa, transmissivity reduced sharply with increase of confine pressure. Transmissivity under 50 kPa confinement was only about 20% of that under 5 kPa confinement. When the confine pressure is larger than 50 kPa, the effect of confine pressure on transmissivity became less significant. In the figure, test data reported by Public Works Research Institute, Japan (2000) for the same geotextile under rubber membrane confinement were included. It shows that the test data of clay confinement compare very well with the data under rubber membrane confinement, which indicates that for short-term value, the confine condition is not important.

The short-term rate of water flow ( $Q$ ) versus hydraulic gradient ( $i$ ) relation is given in Fig. 4. For tested range of  $i = 0.08$  to 1.0, the relation is almost linear. This shows that for short-term case, under  $i < 1.0$ ,  $i$  had no influence on the value of transmissivity.

#### 3.2 Long-term results

Totally 4 long-term tests with a duration of more than 1 month were conducted, in which 2 by the large-scale device and 2 by the small-scale device, and results are shown in Figs. 5 and 6, respectively. Following points can be observed from the test results. (1) Transmissivity of the geotextile reduced significantly with elapsed time. At the times of terminating the tests, the geotextile samples were almost clogged. (2) The reduction is more serious for lower hydraulic gradient case. Arbitrarily consider the large-scale test results at 40 days of elapsed time, for  $i = 0.4$ , it is about 38%, and for  $i = 0.1$ , it is about 29% of corresponding initial values. This phenomenon is the same as the results of discharge capacity of prefabricated vertical drain (Miura & Chai 2000a). (3) Comparing Fig. 5 with Fig. 6 shows that the higher the confine pressure, the faster the reduction of transmissivity of the geotextile sample. When converting the rate of water flow of the large-scale tests (Fig. 5) to hydraulic gradient of 1.0, the initial values in Fig. 5 are comparable with those in Fig. 3 (the small-scale confined in clay tests). This indicates that the initial value is independent to the scale of device. However, head loss of equipments should be considered for interpreting test results (Miura & Chai 2000a).

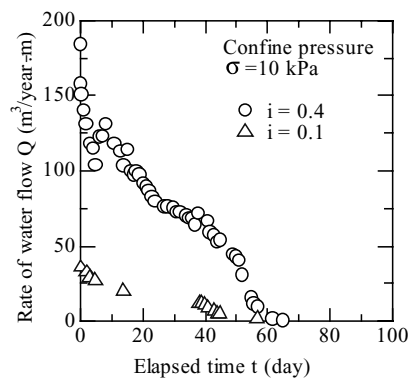


Figure 5 Long-term test results of large-scale device

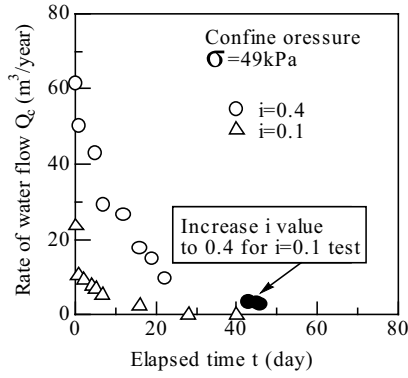
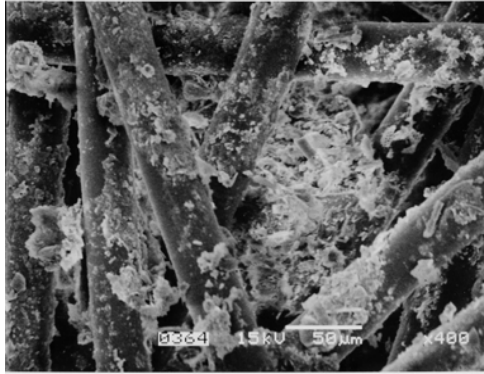
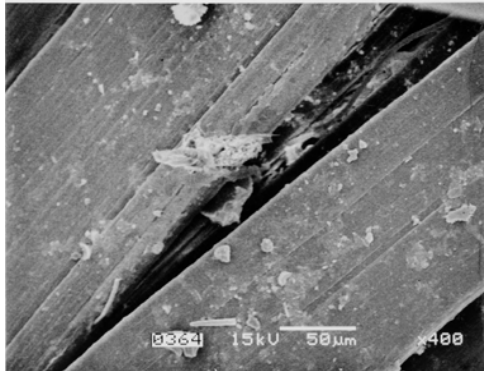


Figure 6 Long-term test results of small-scale device



(a) No-woven geotextile (two sides)



(b) Woven geotextile (core)

Figure 7 Microscopic pictures of geotextile

It is considered that one of the reasons for the transmissivity reduction is clogging. For the small-scale test, when the geotextile sample was clogged under  $i=0.1$ ,  $i$  value was increased to 0.4 and the transmissivity was partially recovered (Fig. 6). This is a direct indication of clogging. Figure 7 shows microscopic pictures of the geotextile sample after transmissivity test (confining pressure of 49 kPa). It can be seen that clay particles entered the openings of the geotextile sample. However, it may not take a long time for clay particles to enter the openings. One possible explanation is that clay particles can enter the geotextile openings with a short time, but repositioning of clay particles within the geotextile takes a long time, and it is the repositioning caused further reduction of transmissivity. Also, there may be some bio-films formed within the geotextile. Chai & Miura (1999) reported that there were bio-films formed on the filter of a prefabricated vertical drain after 5 months discharge capacity test.

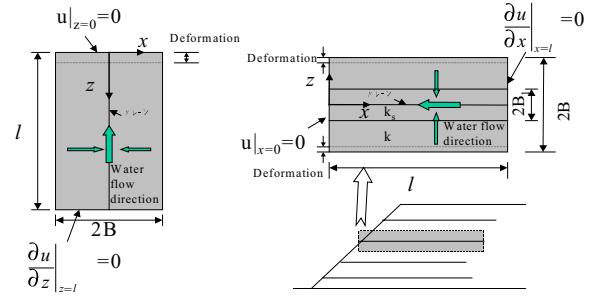
The test results indicate that in the case of using geotextile as drainage material, transmissivity reduction with time should be considered. On design, long-term confined in clay test value with an appropriate confining pressure should be used. For the geotex-

tile tested, its drainage function can only be expected for about 1 to 2 months period. For prefabricated vertical drain, it has been reported that reducing the apparent opening size of the filter increased long-term discharge capacity considerably (Miura & Chai 2000b). Therefore, further research on the effect of apparent opening size of side geotextile to the transmissivity of geotextile composites under clay confinement is needed.

#### 4 A SIMPLE METHOD FOR PREDICT PORE PRESSURE WITHIN EMBANKMENT

##### 4.1 Proposed method

For geotextile used for embankment construction with clayey backfill, its transmissivity will influence the pore pressure dissipation within embankment, and therefore the shear strength of fill material. A simple method is proposed to predict pore pressure within embankment by considering the effect of transmissivity of geotextile.



(a) Plane strain vertical drain unit cell (b) Plane strain horizontal drain unit cell

Figure 8 Plane strain unit cells

Hird et al. (1992) extended Hansbo's solution (1981) for vertical drain consolidation to plane strain condition. This solution has been slightly modified to predict the average degree of consolidation of clayey soil between geotextiles. Figs. 8 (a) and (b) show unit cells of plane strain vertical drain and horizontal drain, respectively. Although the deformation patterns in Figs. 8 (a) and (b) are different, both of them satisfy equal strain assumption, a basic assumption of Hansbo's solution. Therefore, equations derived for Fig. 8 (a) case can be used for Fig. 8 (b) case by considering corresponding notations used. Equations derived by Hird et al. did not include the smear effect, for completeness, considering smear effect and with the notation in Fig. 8 (b), average degree of consolidation at a distance of  $x$  from drainage surface is as follows:

$$U = 1 - \exp\left(\frac{-8T}{\mu}\right) \quad (1)$$

The expressions for  $T$  and  $\mu$  are as follows:

$$T = \frac{C \cdot t}{4B^2} \quad (2)$$

$$\mu = \frac{2}{3} + \frac{2k}{B \cdot Q_w} (2 \cdot l \cdot x - x^2) + 2 \cdot \left(\frac{k}{k_s} - 1\right) (b_s - b_s^2 + \frac{b_s^3}{3}) \quad (3)$$

where:  $C$  is coefficient of consolidation of clayey soil,  $t$  is time,  $B$  is half width of plane strain unit cell,  $k$  and  $k_s$  are hydraulic conductivities of clayey soil and smear zone, respectively,  $Q_w$  is transmissivity of geotextile per unit width,  $l$  is drainage length,  $x$  is the distance from drainage surface, and  $b_s = B/B_l$  ( $B_l$  is half width of smear zone).

During embankment construction, load is gradually applied. To predict pore pressure variation during embankment construction by Equations 1 to 3, following assumptions are made.

- (1) Approximate the linear loading process by stepwise loads (Fig. 9).
- (2) Take total load at  $i$  step as  $p_i$ , degree of consolidation at time  $t_i$  as  $U_i$ . At  $t_i$ , incremental load of  $j$  step  $\Delta p_j$  is applied, then for total load  $p_j = p_i + \Delta p_j$ , degree of consolidation ( $U_{j0}$ ) at  $t_i$  can be calculated as:

$$U_{j0} = \frac{U_i \cdot p_i}{p_i + \Delta p_j} \quad \times | \quad (4)$$

Imaginable time corresponding to  $U_{j0}$  (under load  $p_j$ ) is:

$$t_{j0} = - \frac{B^2}{2 \cdot C} \mu \cdot \ln(1 - U_{j0}) \quad (5)$$

Use the moment ( $t_i$ ) of applying  $\Delta p_j$  as a new origin for time. If time from the new origin is  $t_j$ , (see Fig. 9) then, time for calculating degree of consolidation at time  $t_j$  will be  $(t_{j0} + t_j)$ .

With Equations 1 to 5, continuity of average effective stress is satisfied, but there are errors on pore pressure distribution within the unit cell and variation of degree of consolidation.

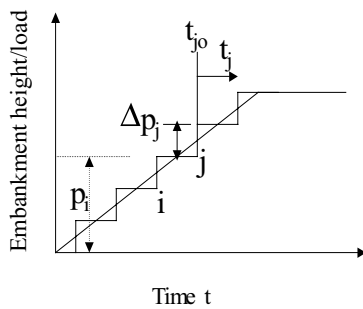


Figure 9 Assumed loading procedure

#### 4.2 Comparing with FEM analysis results and the effect of $\theta_{GT}$

Since there is no rigorous solution for step loading problem, results of the proposed method are compared with FEM analysis results under following conditions.

- (1) Total load is 50 kPa and load increment is 10 kPa.
- (2) Time between load increments is 10 days.
- (3) Parameters for clayey soil are: Young's modulus  $E=1000$  kPa, Poisson's ratio  $\nu=0.3$ , and hydraulic conductivity  $k=10^{-9}$  m/s.
- (4) Transmissivity of geotextile  $\theta_{GT} = 2, 10$  m<sup>3</sup>/year/m (two cases), half width  $B=0.4$  m, and  $l = 8.0$  m.

Model for FEM analysis is given in Fig. 10. Figure 11 shows the comparison of simulated average pore pressure. When  $\theta_{GT}$  value becomes smaller (2 m<sup>3</sup>/year), the proposed method tends to result in a slightly larger pore pressure than FEM result. However, the difference is very small and can be ignored for practical application. It is considered that the proposed method is a useful tool for design geotextile reinforced embankment with clayey backfill.

Also, the effect of  $\theta_{GT}$  on pore pressure dissipation is investigated. For the conditions assumed when  $\theta_{GT}$  reduced from 10 m<sup>3</sup>/year to 2 m<sup>3</sup>/year, pore pressure at the end of construction increased from about 3.5 kPa to about 11 kPa. Therefore, using an appropriate value of  $\theta_{GT}$  in design is important.

## 5 CONCLUSIONS

Considering the application of geotextile in embankment construction with clayey backfill, transmissivity of a geotextile is investigated by confined in clay laboratory tests. Following conclusions can be drawn from the test results.

- (1) Transmissivity reduced remarkably with the increase of confine pressure, especially for confine pressure less than 50 kPa.

- (2) For short-term case, confined in clay results are comparable with reported confined in rubber membrane data.
- (3) With clay confinement, transmissivity reduced significantly with elapsed time. The higher the confine pressure and the smaller the hydraulic gradient, the faster the reduction will be. It is suggested that long-term confined in clay test data with an appropriate confine pressure should be used for design.
- (4) Further research on the effect of apparent opening size of geotextile to the long-term transmissivity of geotextile composites under clay confinement is needed.

A simple method is proposed to predict pore pressure within geotextile-reinforced embankment with clayey backfill. The method takes into account the effect of transmissivity of geotextile, and is considered a useful design tool.

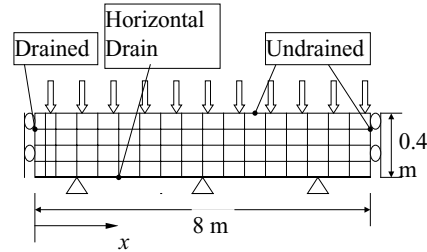


Figure 10 Finite element mesh and boundary conditions

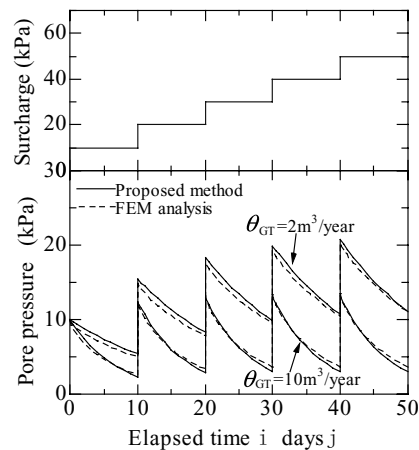


Figure 11 Comparison of predicted pore pressure

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