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Laboratory test on the performance of geogrid-reinforced and pile-supported embankment

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ABSTRACT: This paper investigates the behavior of geosynthetic-reinforced and pile-supported (GRPS) embankments through laboratory model tests. The model ground was made using reconstituted soft Ariake clay with thin sand layers. Model piles were made of timber. Geogrids were placed at the top of pile and under the embankment. Model embankment was sand and additional load was exerted on the embankment top. The test results show that the increase in the length of both pile and reinforcement or decrease in the piles improvement ratio creates an economical solution for GRPS embankment system.

1 INTRODUCTION

Geosynthetic-reinforced and pile-supported (GRPS) embankments have been emerged as an effective alternative successfully adopted worldwide to solve many geotechnical problems. In the GRPS embankment system, the geosynsthetic reinforcement carries the lateral thrust from the embankment, creates a stiffened fill platform to enhance the load transfer from the soil to the piles, and reduce the differential settlement between pile caps. As a result, the GRPS system does not require inclined piles, large pile caps, and close pile spacing. Therefore, the GRPS system creates a more cost-effective alternative. In the GRPS-supported embankment system, the piles carry most of the loads from the embankment and the soil is only subjected to small loads.

The GRPS embankment systems have been used for a number of applications worldwide, which include: bridge approaching embankments; retaining walls; roadway widening; storage tanks; low height embankment; and buildings, etc. There are a few methods available to design the GRPS embankment system. British Standard BS8006 (1995) proposed a relatively comprehensive design method. However, Li et al. (2002) concluded that current design methods could not well predict the performance of constructed GRPS systems. Therefore, there is a need for developing more rational design methods for this emerging technology. For this reason, the objective of this study is to reveal the load transfer mechanism through laboratory model test.

2 EXPERIMENTAL PROGRAM

2.1 *Setup of test apparatus*

The set-up of the model test is illustrated in Fig. 1. A model box made by transparent acrylic has an inner dimension of 1.5 m in length, 0.6 m in width, and 0.8 m in height. An acrylic plate was fixed at the middle of the box along length direction to form two separated sub-model chambers with a width of 0.3 m. Two layers of geotextiles were placed at the bottom and two end vertical boundaries as drainage layers.

2.2 *Model ground*

The model ground was formed by four clay layers sandwiched three thin sand layers. The thickness of each clay layer was about 122.5 mm and about 20 mm for each sand layer. The clay used was remolded Ariake clay, which was sampled from a ground depth of 1 to 3 m from Saga Airport site. The initial physical properties of the clay sample are: specific gravity $Gs = 2.62$, natural water content $w_n = 120 \sim 130\%$ (higher than its liquid limit with the value of about 105 to 110%). The plastic limit is about 40 to 50% and plasticity

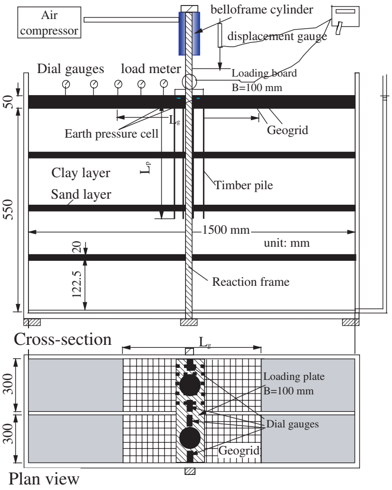

Figure 1. Set-up of the model test apparatus.

Table 1. Test cases with details of pile and geogrid.

Case label	Pile Length	Pile Rows	Geogrid Length
0H0B	0	0	0
0H0N6B	0	0	600 mm (6B)*
3H2N5B	165 mm (0.3H)**	2	500 mm (5B)
3H4N2B	165 mm (0.3H)	4	200 mm (2B)
3H4N3B	165 mm (0.3H)	4	300 mm (3B)
5H2N3B	275 mm (0.5H)	2	300 mm (3B)
5H4N0B	275 mm (0.5H)	4	0
5H4N2B	275 mm (0.5H)	4	200 mm (2B)
5H4N3B	275 mm (0.5H)	4	300 mm (3B)
7H2N3B	385 mm (0.7H)	2	300 mm (3B)
7H2N5B	385 mm (0.7H)	2	500 mm (5B)

*B = width of loading plate (0.1m); **H = thickness of model ground (0.55m).

index $I_p = 60$–70. The grain diameter of the sand is greater than 420 μm and less than 5 mm with specific gravity of 2.62, maximum density of 16.1 kN/m^3 and minimum density of 12.8 kN/m^3.

Before making the model ground, clay samples were completely remolded to the paste state using a hand controlling electric mixer by adding water to the water content of twice its liquid limit. The clay milk was put into the container in four layers with the thickness of about 175 mm. Among the clay layers sand was pulverized to a thickness of about 20 mm. After that a polywood board was placed over the soil. Then, a 10 kPa vertical consolidation pressure was applied to the soil for about 2 months. After the primary consolidation was finished, the consolidation load was removed. The thickness of the model ground was 550 mm and water content after consolidation was reduced to 77 ~ 80%.

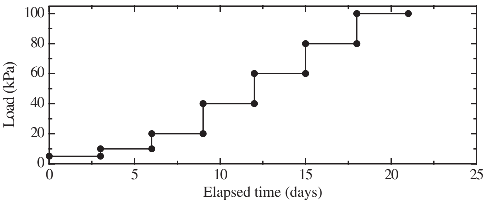

Figure 2. Embankment loading applied in the study.

The soil was sampled for strength and oedometer test. The test results indicate that the model ground had a compression index (C_c) of about 0.8, void ratio (e) of about 3.0, and undrained shear strength (S_u) of 4.5 kPa to 6.5 kPa (laboratory vane shear test).

2.3 *Test procedure*

Pile was made of timber with a diameter of 10 mm. Piles were inserted into model ground using a specific machine with the penetration rate of 10 mm/min. Model embankments (sand mat) with a height of 50 mm were compacted in three layers with the thickness of 15 mm, 20 mm, and 15 mm, respectively. At the bottom and top of the middle sand layer, two layers of geogrid in the sand mat were placed. The geogrid used was made of polyester and has a grid size of 6 mm by 6 mm, tensile strength of 5.2 kN/m (strain rate 1%/min). The stiffness is about 300 kN/m for less than 1% tensile strain condition. Due to the size of the model is about 1/20 to 1/30 of the prototype, the reinforcement was very strong and it can be regarded as “fully reinforced” (Jewell 1988). The second geogrid layer was connected with the top of pile. On top of the model embankment, a 100 mm wide loading plate was placed at the center. The load was applied stepwise by air pressure though a bello-frame cylinder with an pressure of 5, 10, 20, 40, 60, 80, and 100 kPa, respectively and the loading duration for each stage was about three days, as illustrated in Fig. 2. The same loading condition was maintained for both sub-models.

3 RESULTS AND ANALYSIS

3.1 *Effect of pile and geogrid*

The effect of pile and geogrid on the settlement and bearing capacity were investigated. Figure 3 show the results of three test cases: i) the unimproved case – no pile and geogrid were applied; ii) subsoil was improved by four rows of piles with length of about 275 mm (0.5H); iii) in the third case, sand mat was reinforced by two layers of geogrid with the length of 600 mm (6B). The bearing capacity of unimproved subsoil is very

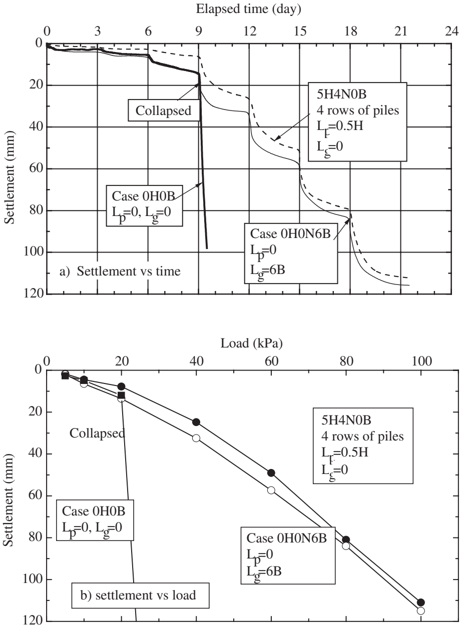

Figure 3. Effect of pile and geogrids on the settlement: a) settlement vs time, b) settlement vs load.

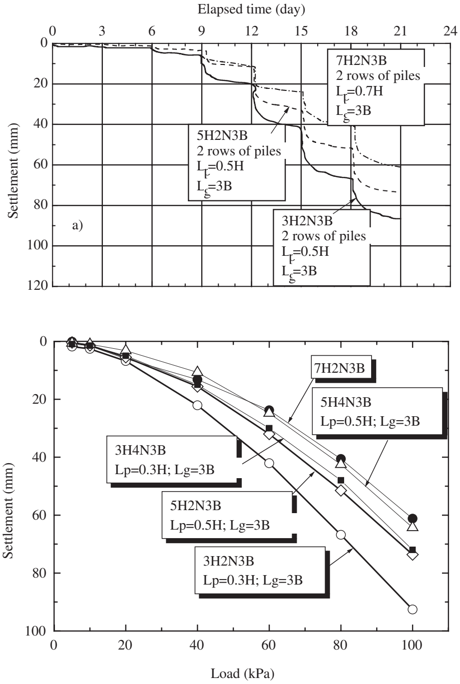

Figure 4. Effect of length and rows of pile on the settlement.

low with the collapsed load of only about 20 kPa. With piles or geogrids reinforcement, the bearing capacity of the subsoil was increased greatly. For the two improved cases with pile or geogrid, no collapse was found. It is clearly shown that pile and geogrid significantly reduced the settlement and increased the bearing capacity of the soft subsoil. In this test study, it is found that the reinforcement effect of two layers of geotextiles with length of 600 mm is similar to that of 4 rows of piles with the length of 275 mm. However, in the initial lower load (till to 20 kPa), geogrid reinforced case behaved in the same way as the unimproved case (see Fig. 3a). Moreover, when the load is less than 80 kPa, the settlement of geogrid improved case is greater than the pile improved case and after 80 kPa, difference of settlement between two case 0H0N6B and case 5H4N0B became smaller. The reason may be owing to the increased inward friction force at the interface between the geogrid and the soil with the increase of settlement, which might have played controlling role in reducing the settlement.

3.2 *Effect of pile length and rows*

Figure 4 shows the effect of length and rows of pile on the behavior of settlement. Increase in the length and rows of pile is very effectively in reducing settlement. If the length of pile increases from 0.3H (165 mm) to 0.7H (365 mm), at the load of 100 kPa, the settlement decreased up to about 30%. If the number of pile rows increased from 2 to 4, at the load of 100 kPa, the settlement decreased to about 20% for the case of 0.3H length pile and 15% for the case of 0.5H length of pile. Thus, the increase of pile length is much effective than the increase of pile row in settlement control. Two rows of 0.7H (365 mm) pile behaved in the same manner with 4 rows of 0.5H (275 mm) pile. Analogically, two rows of 0.5H (275 mm) pile behaved in the same manner with 4 rows of 0.3H (165 mm) pile.

3.3 *Effect of geogrid length*

Figure 5 shows the effect of length of geogrid on the behavior of settlement. Increase in the length of geogrid has the significantly effect on the reduction of settlement and the increase of bearing capacity. For the case of 0.3H pile length, if the length of geogrid increases from 2B (200 mm) to 3B (300 mm), at the load of 100 kPa, the settlement decreased to about 65%. Similarly, for the case of 0.7H pile length, if the length of geogrid increases from 3B (300 mm) to 5B (500 mm), at the load of 100 kPa, the settlement decreased to about 50%. Thus, the increase of georid length is much more effective for longer pile than that for the shorter pile in settlement control. Geogrid with 200 mm length over 4 rows of 0.5H pile behaves in the

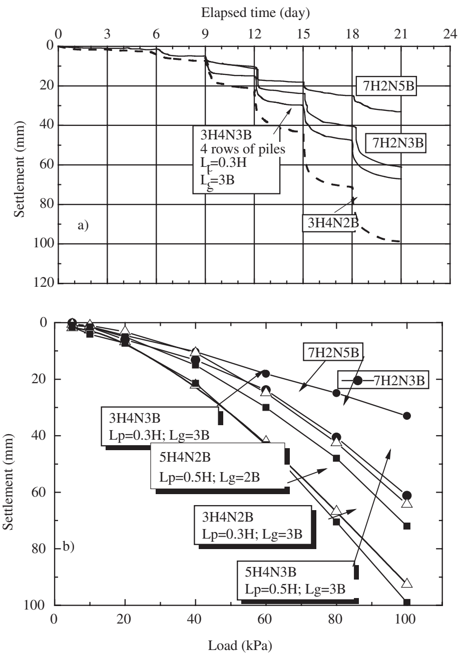

Figure 5. Effect of length and rows of pile on the settlement.

same manner with the 300 mm geogrid over 4 rows of 0.3H (165 mm) pile.

3.4 *Soil arching effect*

The degree of soil arching was defined as follows (as proposed by McNulty 1956):

$$\rho = \frac{p_b}{\gamma H + q_0} \tag{1}$$

where $\rho = $ soil arching ratio; $\rho = 0$ represents the complete soil arching while $\rho = 1$ represents no soil arching; $p_b = $ applied pressure on the top of the trapdoor in Terzaghi or McNulty's studies (geosynthetic for this study); $\gamma = $ unit weight of the embankment fill; $H = $ height of embankment; and $q_0 = $ uniform surcharge on the embankment.

Figure 6 depicts the variation of soil arching ratio with the applied load. The test result shows that in the initial two load stages, the soil arching ratio decreases with an increase in the applied embankment load, which is in agreement with the experimental findings by McNulty (1965) and the numerical analysis results (Han and Gabr, 2002). However, in the later loading stages, the soil arching ratio increases with the increase of the applied load, which is contradict with the findings by other researchers. Moreover, the value of the soil arching ratio is lower than the results by Han and Gabr (2002), which means that there is a very strong soil arching effect in the present study. The reasons of these discrepancies are: i) stiffness of the loading plate is much higher than the sand soil; ii) the sand mat covered the earth pressure meter is too thin. The strong arching effect is due to the loading plate. The sand mat is too thin to form the arching. Most of the load is directly transferred to adjoining supporting piles from loading plate (TTN: WM3 1989; Schmertmann (1999)). Arching effect also influenced by the pile length. From Fig. 6, the longer the pile, the stronger the arching effect. This is because for the shorter pile case, under the same load, the relative movement between the soil and pile is smaller so that the vertical pressure on the reinforcement is larger.

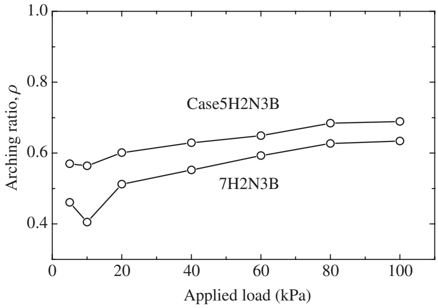

Figure 6. Variation of arching ratio with load.

4 CONCLUSION

From the test studies, the following conclusions can be drawn:

1) Two layers of geogrids with length of 600 mm is equivalent to four rows of piles with length of 175 mm in terms of settlement behavior.
2) In settlement control, increase in the length of geogrid is more effective than the increase in the length of piles.
3) Increase in pile length is more effective than the increase in pile rows.
4) Further, numerical analysis should be conducted to investigate the optimum values of pile lengths, pile rows, the length and layers of geogrid, and the combination of pile and geogrid.

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