New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Load transfer mechanism in reinforced embankment on pile elements

J. Hironaka & T. Hirai
Mitsui Chemicals Industrial Products, LTD, Saitama, Japan

J. Otani & Y. Watanabe
GeoX CT Center, Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan

ABSTRACT: When the embankment is constructed on soft ground, any kinds of geotechnical solutions, for example, pile foundation and deep mixing method, have been used for the purpose of reducing differential settlement. This paper deals with a combined method of pile elements with earth reinforcement technology using geogrids. This type of the combined method offers decrease of load concentration on pile elements due to the reinforcing effect by geogrids. And it is considered that a search for the load transfer mechanism in three dimensions is important for the performance-based design of this method. Recently, an industrial X-ray CT (Computed Tomography) scanner which is one of the nondestructive testing method has been developed and the inside behavior of material could investigate without any destructions in three dimensions. The objective of this paper is to visualize the load transfer mechanism over the pile element heads using industrial X-ray CT scanner. A series of model test were conducted. Then, the behavior in the soil was scanned during the settlement of the ground using X-ray CT scanner. Based on these results, the reinforcing effect by the geogrids and soil arching effect over the pile element heads were discussed precisely. And finally, the evaluation of load transfer mechanism of this system was examined, quantitatively.

1 GENERAL INSTRUCTION

Construction of embankment on soft ground often causes the differential settlement. Pile elements with earth reinforcement technology are used in order to reduce this settlement as shown in Fig-1. This combined method offers the reduction of the loading at the pile element head by using geogrid, because the embankment load is transferred with arching effect in the reinforced soil above the pile element heads and membrane effect of geogrid. And it is considered that a search on the load transfer mechanism under this system is important for the performance-based design of this method.

Recently, an industrial X-ray CT (Computed Tomography) scanner which is one of the nondestructive testing method has been used in geotechnical engineering field and the inside behavior of soils can be investigated without any destructions. Authors have conducted a series of studies on the application of industrial X-ray CT scanner to geotechnical engineering such as characterization of soil failure (Otani et al., 2000) and visualization of the failure in mixed soil with air foams (Otani et al., 2002) and others (Otani and Obara (2003) and Otani et al.(2005)).

The objective of this paper is to visualize the load transfer mechanism over the pile element heads using industrial X-ray CT scanner. A series of model test are conducted. Then, the behavior in the soil is scanned after the settlement of the ground using X-ray CT scanner. Based on these results, the reinforcing effect by the geogrids and soil arching effect over the pile element heads are discussed precisely. And finally, the evaluation of load transfer mechanism of this system is examined, quantitatively.

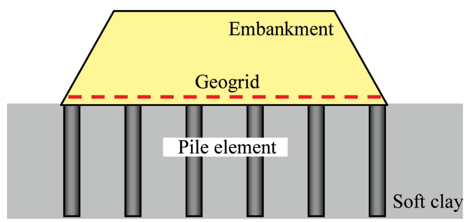

Figure 1. The outline of combined method.

2 X-RAY CT

The detected data are assembled and the cross sectional images are reconstructed using an image data processing device by means of the filtered back-projection method. By using all these cross sectional images around the circumference of the specimen, three

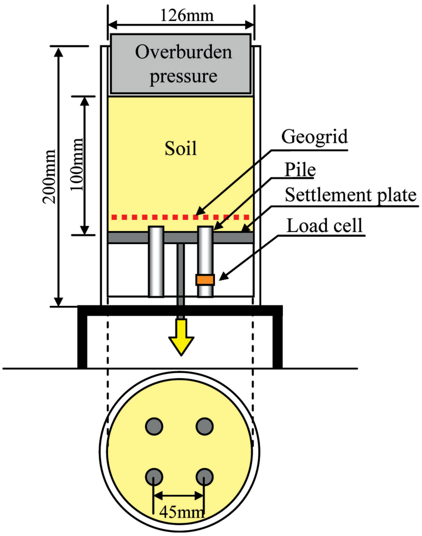

Figure 2. Settlement test apparatus.

dimensional (3-D) image can also be reconstructed. CT images are constructed by the spatial distribution of so called "*CT-value*" and this is defined as:

$$CT - value = (\mu_t - \mu_w)\kappa / \mu_w \quad (1)$$

where μ_t :coefficient of absorption at scanning point; μ_w: coefficient of absorption for water; and κ: constant (Hounsfield value). Here, it is noted that this constant is fixed to a value of 1000. Thus, the *CT-value* of air should be –1000 because the coefficient of absorption for air is zero. Likewise, *CT-value* for water is 0 from the definition of Eq. (1). CT images are presented with shaded gray or black color for low *CT-value* and light gray or white color for high *CT-value* in all the subsequent black and white colors. The total number of levels on these colors is 256. It is well known that this *CT-value* is linearly related to the material density. It is noted that the precise contents of X-ray CT method can be obtained in the reference by Otani et al. (2000).

3 TEST PROCEDURE

A series of model tests for different types of geogrids were conducted using newly developed test apparatus as shown in Fig-2. The case without reinforcement was also conduced in order to discuss the soil arching effect with pile elements. The soil box in the apparatus made by an acrylic mold, which is the size of 200 mm with the height of 126 mm diameter, was set in the CT room. A model pile, which was the size of 15 mm diameter, was set on the bottom of the soil box. And, total of four piles were installed at intervals of 45 mm between every adjacent two piles. The settlement plate, which can penetrate through the piles using automatic settlement plate apparatus, was set at the bottom of the ground. The method of pulling down this settlement plate at constant speed was assumed to be the consolidation settlement of the ground due to embankment load. In order to discuss the effect of different soils on the load transfer mechanism, Toyoura sand, Silica sands (No.7 and No.8) and Dry clay powder were used. The material properties of all the soils are shown in Table. 1. In this test, the density was fixed to be the relative density of 80% for all the soils and the overburden pressure of 3.2 kPa was applied by dead-load in order to apply relatively large confining pressure. Fig-3 shows tensile force – strain relationship of geogrids as the reinforcing materials used in this test, in which Grid-A is a geogrid with its spacing of 2 mm while Grid-B is a geogrid with that of 9 mm. In order to discuss the effect of different geogrids on the load transfer mechanism, Grid-A and Grid-B were used. These geogrids were installed at 5 mm height above the pile head in the soil. The settlement plate was pulled down with the loading speed of 1 mm/min under displacement control and the loading was stopped at the settlement of 5 mm. And the pile load that acted on the pile elements was measured using the load cell. For the CT scanning, the model grounds at initial and after 5 mm settlement were scanned with 1mm thickness until the height of 40 mm above the settlement plate. The test cases are listed in Table. 2, in which CASE1, CASE2, CASE3, and CASE4 are the cases with different types

Table 1. Material properties.

	Effective particle size D_{50} (mm)	Uniformity coefficient U_C	Internal frictional angle φ (deg)
Toyoura sand	0.19	1.56	39.4
Silica sand No.7	0.15	1.63	36.0
Silica sand No.8	0.12	1.86	33.9
Dry clay powder	0.0026	10	25.9

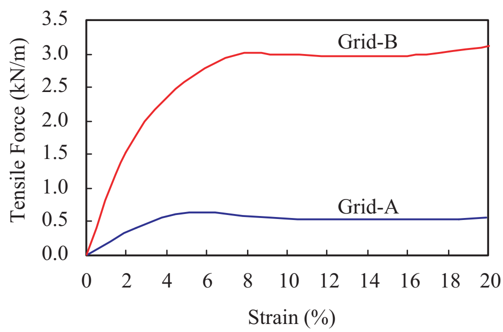

Figure 3. Tensile Force – Strain relationship.

Table 2. Test cases.

	Ground materials	Reinforcement
CASE1	Toyoura sand	Without
CASE2	Silica sand No.7	Without
CASE3	Silica sand No.8	Without
CASE4	Dry clay powder	Without
CASE5	Toyoura sand	Grid-A
CASE6	Toyoura sand	Grid-B
CASE7	Silica sand No.7	Grid-B
CASE8	Silica sand No.8	Grid-B
CASE9	Dry clay powder	Grid-B

of soils in order to discuss the soil arching effect without reinforcement, CASE5 and CASE6 are the cases with different types of geogrids in order to discuss the reinforcing effect, and CASE6, CASE7, CASE8, and CASE9 are the cases with different types of soils using a geogrid in order to discuss the load transfer effect of reinforcement. The load transfer effect is examined with CASE1 to CASE4 and CASE6 to CASE9.

4 RESULTS AND DISCUSSION

4.1 *Effect of soil arching*

Figure 4 shows the results of CT scanning which is the vertical cross sectional images for CASE1, CASE2, CASE3 and CASE4 at the end of the test. It is observed that there is the area of high density with cone shape at the pile head. And as easily realized, the density around the circumference of the pile head is decreased due to the settlement, which is the appearance of the area of ring shape in CASE1. These low density areas are interrupted in each other for the adjacent two piles at the area of within 10 mm height above the settlement plate. The angle, θ between these interrupted areas which is shown with dotted line in the image was about 38 degree for the CASE1. Although the behaviour of the density changes for CASE2 and CASE3 were almost the same as CASE1, the angle, θ was 48 degree and 55 degree, respectively. For CASE4, it is totally different from all other results and this angle was almost 90 degree. Based on these results, it is concluded that the smaller the angle, θ is, the wider the load transfer is and this angle becomes larger when the soil strength is smaller. Fig-5 shows 3-D extraction images of the interrupted areas for CASE1. This 3-D area is considered to be the area where some part of embankment load is applied except that applied on the pile heads. Fig-6 shows the model of the embankment load that acts on the ground between the pile elements at existing design method (Public Work Research Center (2000)). In this design, it is conducted the settlement calculation of the embankment using this proposed model. As easily realized, Fig-5 and Fig-6 are similar very well.

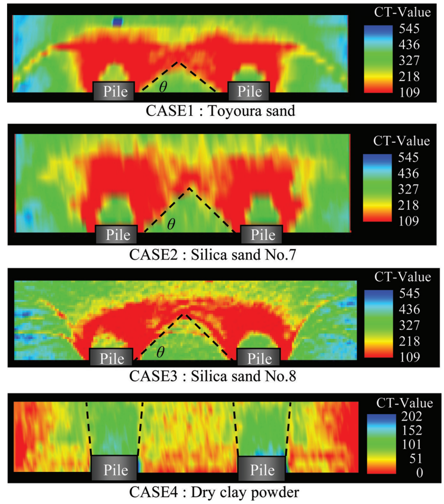

Figure 4. Vertical cross sectional images without reinforcement.

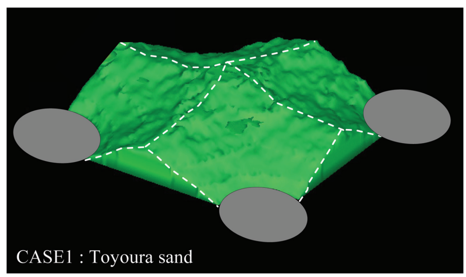

Figure 5. 3-D extraction image.

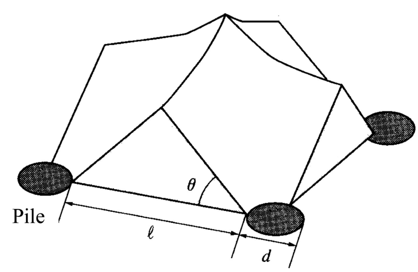

Figure 6. The proposed model of the embankment load that acts on the ground between the piles at existing design method (PWRC(2000)).

4.2 *Effect of reinforcement*

Figure 7 shows the vertical reconstruction images for the cases with geogrids. These images were reconstructed by the density change using different colours. For CASE5, the area of density change extends to horizontally due to the existence of geogrid. Thus, the angle of density change for CASE5 is

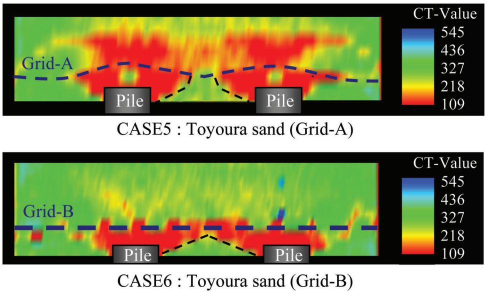

Figure 7. Vertical cross sectional images with reinforcement.

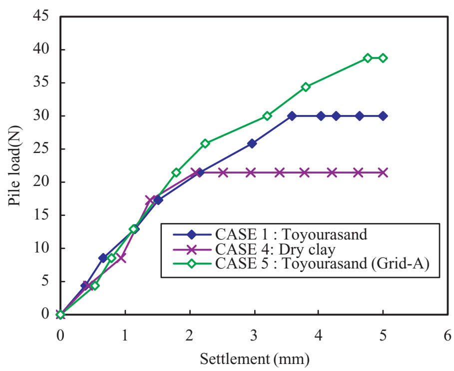

Figure 8. Pile load – settlement relationship.

decreased due to the effect of Grid-A. For CASE6, the area of changing density was not as large as that of CASE5 and it seems that the stress concentration is rather smooth. And the area of density change was observed between the piles and the geogrid. Here, if it is assumed that the transmission of the overburden pressure due to the settlement influences the density change over the pile head, it can be considered that the smaller the angle of this density change is, the wider the load distribution in the ground is. And this can be also considered to be the effect of soil arching and at the same time, the membrane effect due to existing of geogrid.

4.3 *Effect of load transfer*

Figure 8 shows some of the examples of pile load – settlement relationship of four piles measured by the load cell for CASE1, CASE4 and CASE5. For CASE4, the pile load is smaller than CASE1, because soil strength is small. For CASE5, the pile load is larger than CASE1, because of existing of geogrid. Fig-9 shows the relationship of the angle: θ of density change area between the piles by X-ray CT image – the internal friction angle: φ of soils by box shear test. For the cases without reinforcement, the relation between

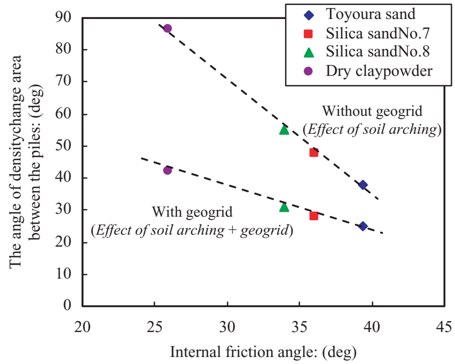

Figure 9. The angle: θ–Internal friction angle: φ relationship.

θ and φ is shown in a negative correlation. Thus, this relation is the effect of soil arching. And for the cases with reinforcement, the relation between θ and φ is shown in a negative correlation. Thus, this relation is the effect of soil arching effect and reinforcement due to existing geogrid.

5 CONCLUSIONS

The following conclusions are drawn from this study:

1) The load transfer mechanism in embankment beyond pile elements due to the settlement was observed using X-ray CT scanner; and
2) It may be said that earth reinforcement is effective with the use of pile elements for the purpose of stress re-distribution in the soil.

Finally, it is evident from all the discussion here that the industrial X-ray CT scanner promises to be a powerful tool even for the geotechnical engineering field.

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