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Visualization of load transfer mechanisms of reinforced soil on pile element using X-ray CT method

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ABSTRACT: Construction of embankment on soft ground often causes the differential settlement. Then, deep mixing method of soil stabilization and reinforcement techniques are used to reduce this settlement. This combined method offers the low improvement rate of soil stabilization by using geotextile, because the embankment load is transferred to the geotextile and the pile element. And it is considered that a search for the load transfer mechanism in nondestructive and three dimensions is important for the performance-based design. However, an interaction between geotextile and soil over the pile element heads is going issue and the real behavior has not been observed precisely. Besides this behavior itself appears in the ground so that it is difficult to check such behavior. 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. The objective of this paper is to visualize the load transfer mechanism over the pile element heads using industrial X-ray CT scanner. In this study, a series of model test for several geotextiles was conducted using a settlement test apparatus. Then, the behavior in the soil box was scanned after settlement using X-ray CT scanner. Based on these test results, the reinforcing effect by the geotextile and the soil arching effect over the pile heads is discussed precisely and those are done on 3-D with nondestructive condition because of the feature of X-ray CT scanner.

1 INTRODUCTION

Construction of embankment on soft ground often causes the differential settlement. Then, deep mixing method of soil stabilization and reinforcement techniques are used to reduce this settlement as shown in Figure 1. This combined method offers the low improvement rate of soil stabilization by using the geotextile, because the embankment load is transferred to the geotextile and the pile element. This load transfer results from an arching effect in the reinforced soil over the pile element heads and a membrane effect of geotextile. And it is considered that a search for the load transfer mechanism in nondestructive and three dimensions is important for the performance-based design. However, an interaction between geotextile and soil over the pile element heads is an ongoing issue and the real behavior has not been observed precisely. Besides this behavior itself appears in the ground so that it is difficult to check such behavior.

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. 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)).

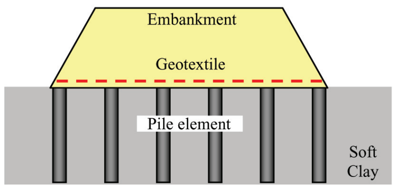

Figure 1. The outline of combined method.

The objective of this paper is to visualize the load transfer mechanism over the pile element heads using X-ray CT metod. First of all, a series of model test for several geotextiles was conducted using a settlement test apparatus. Then, the behavior in the soil box was scanned after settlement using X-ray CT scanner. Based on these test results, the reinforcing effect by the geotextile and the soil arching effect over the pile heads are discussed precisely and those are done on 3-D with nondestructive condition because of the feature of X-ray CT scanner. Finally, the effectiveness of the geotextile for the load transfer mechanisms is confirmed based on all the results in this study.

2 X-RAY CT METHOD

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 dimensional (3-D) image can be also reconstructed. It is noted that the scan area is 600 mm height with 400 mm diameter so that the specimen to be scanned on the specimen table has to be within that area. Medical CT scanners are most commonly equipped with 140 kV X-ray tubes while the industrial one used here is equipped with 300 kV X-ray tubes. Thus, it is easily realized that the capacity of scanning for the industrial use is much higher than that of medical one, so that the possibility of quantitative discussion may be expected. In the image processing analysis, the following so called "*CT-value*" is used:

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

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, this value for water is 0 from the definition of Eq. (1). The 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 images. 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. Figure 2 shows the relationship between CT-value and density of the soil. The results of Toyoura Sand are plotted in this figure and this result shows a linear relation, so that the *CT-value* can be a parameter for evaluating the density change due to the compression of the soils, and the distribution of the density change in soils could be evaluated quantitatively using X-ray CT scanner. It is noted that the precise contents of X-ray CT method can be obtained in the reference by Otani et al. (2000).

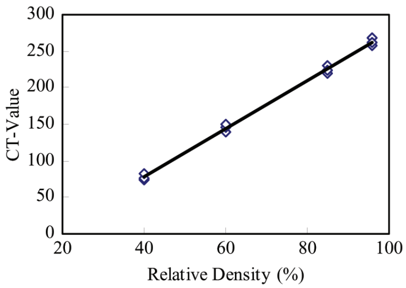

Figure 2. CT-value – Density relationship for Toyoura Sand.

3 TEST PROCEDURE

A series of model tests for several types of geotextile was conducted using a settlement test apparatus as shown in Figure 3. It is noted that the soil box in the apparatus made by an acrylic molding, which is the size of 200 mm height with 126 mm diameter, was set in the CT scanning room. The model pile which is the size of 15 mm diameter, was set on the bottom of the soil box assuming the bearing pile. And, Four piles were set at intervals of 45 mm. The settlement plate which can penetrate through the piles using a jack, was set the bottom of the soil. The method of pulling down this settlement plate at constant speed assumes a consolidation settlement of soft ground under embankment. Soil used in this test was Toyoura Sand. In this test, the dry density was fixed to the relative density = 80% and the overburden pressure of 3.2 kPa was applied by dead-load in order to conduct relatively large confining pressure as the condition under embankment. The settlement plate was pulled down under displacement control and the test was stopped at the settlement of 5 mm. For the CT scanning, initial and the stage at after 5 mm settlement were scanned with 1mm thickness for maximum height of 40 mm above the settlement plate. Figure 4 shows geotextiles used in this test. Figure 5 shows tensile force – strain relationship for Grid-A and Grid-B. Grid-A is a geogrid with horizontal and vertical rib interval of 2 mm. Grid-B is a geogrid with horizontal

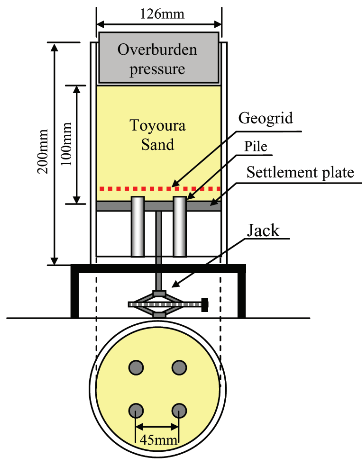

Figure 3. Settlement test apparatus.

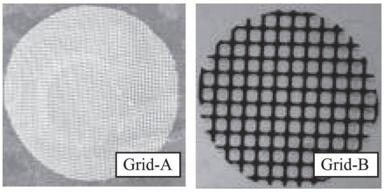

Figure 4. Geotextiles.

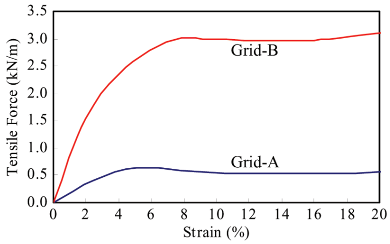

Figure 5. Tensile force – Strain relationship.

and vertical rib interval of 9 mm. These geogrids were installed above 5 mm height from the pile head into the soil. The test cases are three cases. CASE 1 is the basic condition without geogrid. CASE 2 is the condition of installing Grid-A. CASE 3 is the condition of installing Grid-B.

4 RESULTS AND DISCUSSION

Figure 6 shows the cross sectional images for after 5 mm settlement at the height of 2 mm intervals for three cases. As easily realized, the density around the circumference of the pile head is decreased as the settlement plate is pulled down, which is the appearance of the area of ring shape with black color in the image of CASE 1. This low density area is interfered above 10 mm height from the settlement plate. The density change of CASE 2 is similar to CASE 1. But the low density area around Grid-A is quadrangle shape. This shape is influenced the shape of the geogrid. But the density change of CASE 3 is not observed the low density area of quadrangle shape like CASE 2. This difference is influenced the rigidity and the shape of the geogrid. Since the large number of cross sectional images are obtained for each case, three dimensional image can be also reconstructed. Figure 7 shows the vertical reconstruction images for three cases. These images reconstructed by the density change using the colors of black and white gradation in the image. It is more clearly shown that the area of high density right above the pile head is surrounded by the banded area of low density for CASE 1 and CASE 2. It may be considered that those banded areas of low density are the areas of strain localization. The angle of density change from piles for CASE 1 is observed $\theta = 38°$. It is considered that this behavior is the soil arching effect. For CASE 2, the density change area extends horizontally by installing geogrid. The angle of density change from piles is observed $\theta_1 = 28°$, and this angle changes from the surrounding of Grid-A transformed by the settlement into $\theta_2 = 60°$. For CASE 3, more complicated high density area is not observed above the pile head. The angle of density change is observed $\theta = 25°$. And this density change area is observed between the piles and the geogrid. It is considered that this behavior is influenced the rigidity of the geogrid. Here, if it is assumed that the transmission of the overburden pressure according to the settlement influences the density change over the pile head, the piles support load widely according to the angle of density change is small. In addition to the soil arching effect, the membrane effect is demonstrated by installing the geogrid. In addition to the soil arching

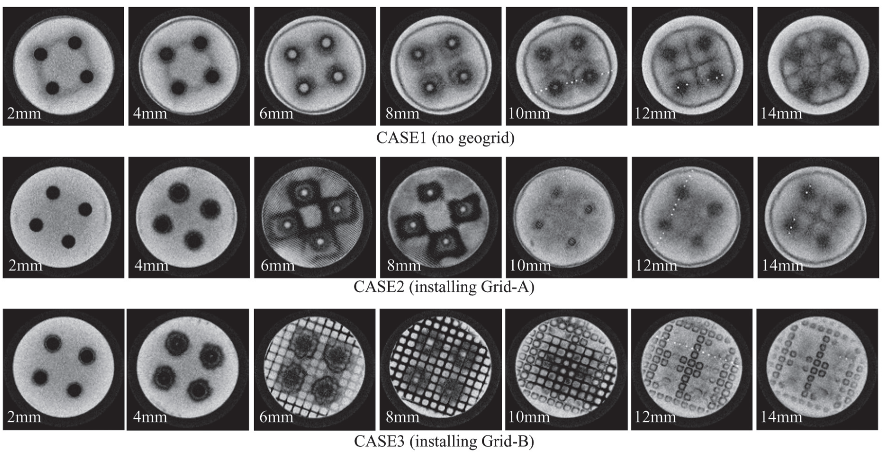

Figure 6. Horizontal cross sectional images.

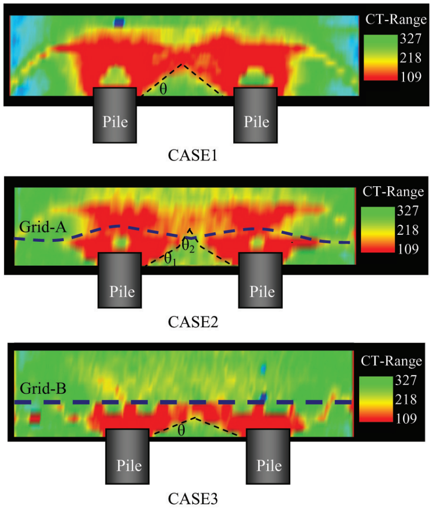

Figure 7. Vertical reconstruction images.

effect, the membrane effect is demonstrated by installing the geogrid. And the piles support the embankment load widely. Figure 8 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. Figure 9 shows the reconstruction images in three dimension for CASE 1. This image is extracted an area alone without the density change between the piles. As easily

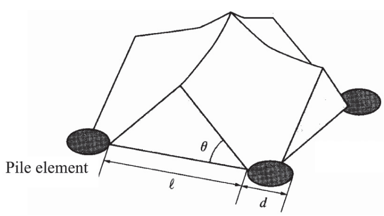

Figure 8. The proposed model of the embankment load that acts on the ground between the piles at existing design method (PWRC (2000)).

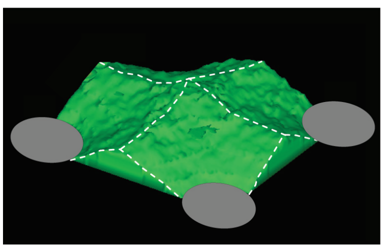

Figure 9. Three dimensional image that extracts an area alone without the density change between the piles (CASE 1).

realized, Figure 8 and Figure 9 are similar very well. It is confirmed that the transmission of the overburden pressure according to the settlement influences the density change over the pile head. By the same method, Figure 10 shows the three dimension image for CASE 3. This area is ragged shape according to the influence of the geogrid. However, the total volume decreases by installing the geogrid. Therefore, it is confirmed that the embankment load that acts on the ground between the piles decreases by installing the geogrid.

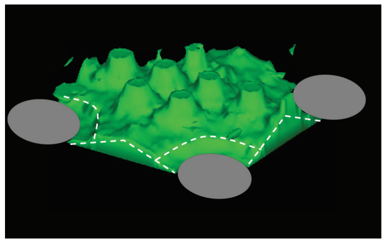

Figure 10. Three dimensional image that extracts an area alone without the density change between the piles (CASE 3).

5 CONCLUSIONS

The following conclusions are drawn from this study:

(1) The transmission of the overburden pressure according to the settlement influences the angle of density change over the pile head.
(2) And the piles support load widely according to the change angle of density from piles is small.
(3) In addition to the soil arching effect, the membrane effect is demonstrated by installing the geogrid.
(4) And the piles support the membankment load widely.
(5) However, this effect influences the characteristic of the geogrid.

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