Evaluation of 3-D load transfer effect on deep mixing method combined with earth reinforcement technology

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ABSTRACT: When the embankment is constructed on soft ground, any kinds of soil improvement techniques such as deep mixing method have been used for the purpose of reducing differential settlement. This paper deals with the combined method of this deep mixing method with earth reinforcement technology using geogrids. This type of the combined method offers low improvement rate of soil stabilization 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, X-ray CT (Computed Tomography) scanner which is one of nondestructive testing methods has been applied to engineering field. Using this apparatus, the inside three dimensional behavior of materials could be investigated without any destructions. A series of model test were conducted. Then, the behavior in the soil was scanned after settlement using X-ray CT scanner. In addition, numerical analysis was conducted using 3-D FEM. Based on these results, the reinforcing effect by the geogrid and the soil arching effect over the pile heads were discussed precisely. And finally, the evaluation of failure mechanism of this system was examined, quantitatively.

1. INTRODUCTION

Construction of embankment on soft ground often causes the differential settlement. A deep mixing method of soil stabilization and earth reinforcement technology are used in order to reduce this settlement. This combined method offers the low improvement rate of soil stabilization by using geogrids and pile elements. It is usually considered that the embankment load can be transferred with arching effect in the reinforced soil above the head of pile elements and membrane effect of geogrids. And 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 methods has been applied to engineering fields. Using this apparatus, the inside three dimensional behavior of the materials could be investigated without any destructions. In particular, an industrial X-ray CT has much higher resolution because of high power of the x-rays. So far, authors have conducted a series of studies on the application of industrial X-ray CT scanner to geotechnical engineering. (Otani et al., 2000) and(Otani, 2003)

The objective of this paper is to visualize the load transfer and failure mechanism in three dimensions over the system of earth reinforcement method pile foundation using industrial X-ray CT scanner. In addition, numerical analysis is conducted using 3-D finite element method. In the analysis, elasto-plastic constitutive law called "t_{ij} model" (Nakai, 2007) is used. Based on these results, the reinforcing effect by geogrids and the soil arching effect over the pile heads are discussed precisely. And finally, the evaluation of load transfer mechanism of this system is examined, quantitatively.

2. TEST PROCEDURE (Hironaka et al., 2006)

Figure 1 shows the developed test apparatus. The soil box is 200mm in height with the diameter of 126mm. A model pile, which was the size of 15mm diameter, was set on the bottom of the soil box. And total of four piles were set at intervals of 45mm between each two piles. The settlement plate, which can penetrate through the piles, was set. The method of pulling down this settlement plate at constant speed was assumed for the simulation of consolidation settlement of soft ground due to embankment. Soil used in this test was Toyoura sand. Table 1 shows its material properties. In this test, a series of model tests for two types of geogrids were conducted. Figure 2 shows the materials of geogrids used in this test. Figure 3 shows tensile force – strain relationship for two geogrids. Grid-A is a geogrid with its spacing of 2mm while Grid-B is a geogrid with that of 9mm. In this test, dry density was fixed to be the relative density of 80% and the overburden pressure of 3.2kPa was applied by dead-load in order to conduct relatively large confining pressure as the condition under embankment. The settlement plate was pulled down at the loading speed of 1mm/min for the simulation of consolidation settlement under displacement control and the test was stopped at the settlement of 5mm. These geogrids were installed at 5mm height above the pile head in the soil. For the CT scanning, the model grounds at initial and after 5mm settlement were scanned with 1mm thickness until the total height of 40mm above the settlement plate. Total of three cases were examined, in which CASE1 is the case of without reinforcement, CASE2 is the case of using Grid-A and CASE3 is the case of using Grid-B.

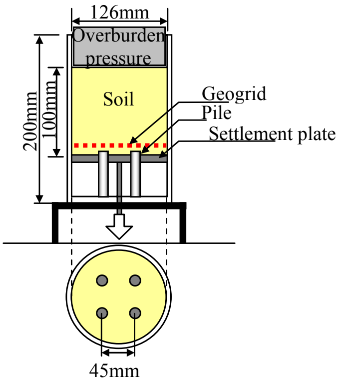
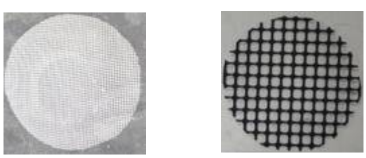


Figure 1. Settlement test apparatus.

Table 1. Material properties.

Mean grain size D_{50} (mm)	0.19
Uniformity coefficient	1.56


(a)Grid-A (b) Grid-B
Figure 2. Geogrids.

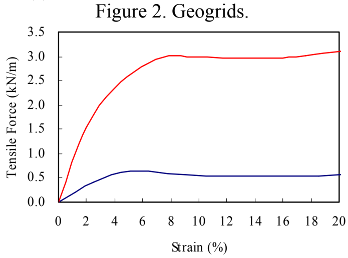


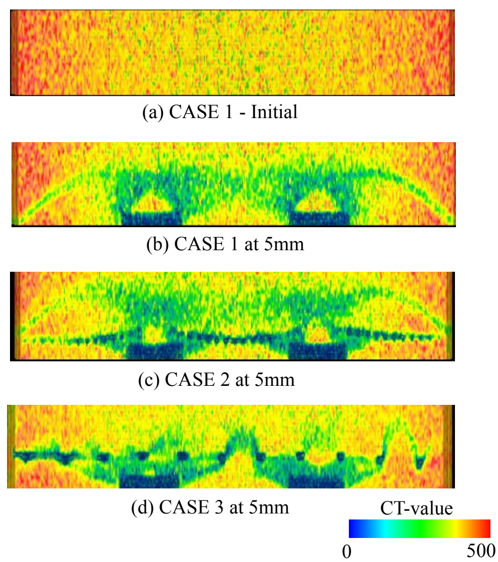
Figure 3. Tensile Force-Strain relationship.

3. TEST RESULTS

Figure 4 shows the vertical cross sectional images of initial and after 5mm settlement for three cases. These images were reconstructed by the density change using 7 different colors as shown in Figure 4. 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 CASE1 and CASE2. It is considered that this behavior is caused by the effect of soil arching. For CASE2, the area of density change extends to horizontally due to the existence of geogrid. Thus, the density change for CASE2 is decreased due to the effect of Grid-A. For CASE3, the area of changing density is not as large as that of CASE2 and it seems that the stress concentration is rather smooth. And this density change area is 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-D FINITE ELEMENT ANALYSIS

3-D finite element program (t_{ij}) which was developed by Nakai was used in this study. In the analysis, Toyoura sand was modeled as elasto-plastic material,



(a) CASE 1 - Initial
(b) CASE 1 at 5mm
(c) CASE 2 at 5mm
(d) CASE 3 at 5mm
Figure 4. Vertical images from CT scanning.

piles and geogrid were modeled as liner elastic materials. Table 2 shows the material parameters for sand. And Table 3 also shows the parameters for piles and geogrids. Figure 5 shows three dimensional finite element mesh which was used in this analysis, in which all the sizes were determined as those sizes of the model tests(total number of nodes: 8916 and total number of elements: 7564). More precise contents of this analysis can be referred in the reference by Fujimoto (2008).
All the loading conditions were set as the test conditions such as the overburden pressure of 3.2kPa and displacement of 5mm at the bottom of the ground. The analysis cases are the same as the model tests, which are CASE1, CASE2 and CASE3.

5. ANALYSIS RESULTS

Figure 6 shows the 3-D distributions of mean effective stress for CASE1. The stress concentration at the pile head is obvious and it is confirmed that the soil arching effect over the pile heads can be realized, easily. Figure 7 shows 3-D distribution of volumetric strain at one of the vertical cross section of the spe-

Table 2. Material parameters of soil.

λ	0.0700
κ	0.0045
R_{cs}	3.2
β	2.0

Table 3. Material parameters.

	E(kPa)	ν
Pile	50000	0.4
Grid-A	25000	0.3
Grid-B	1280000	0.3

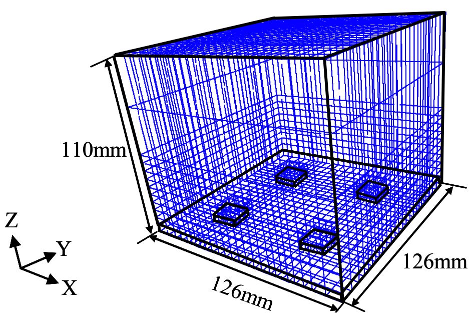


Figure 5. 3D FEM mesh.

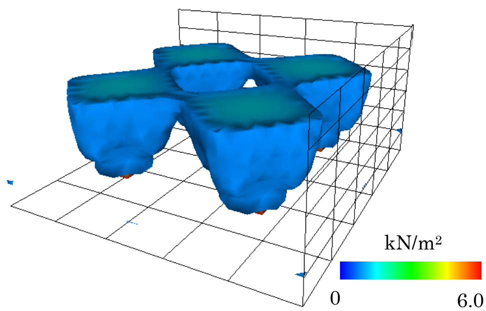
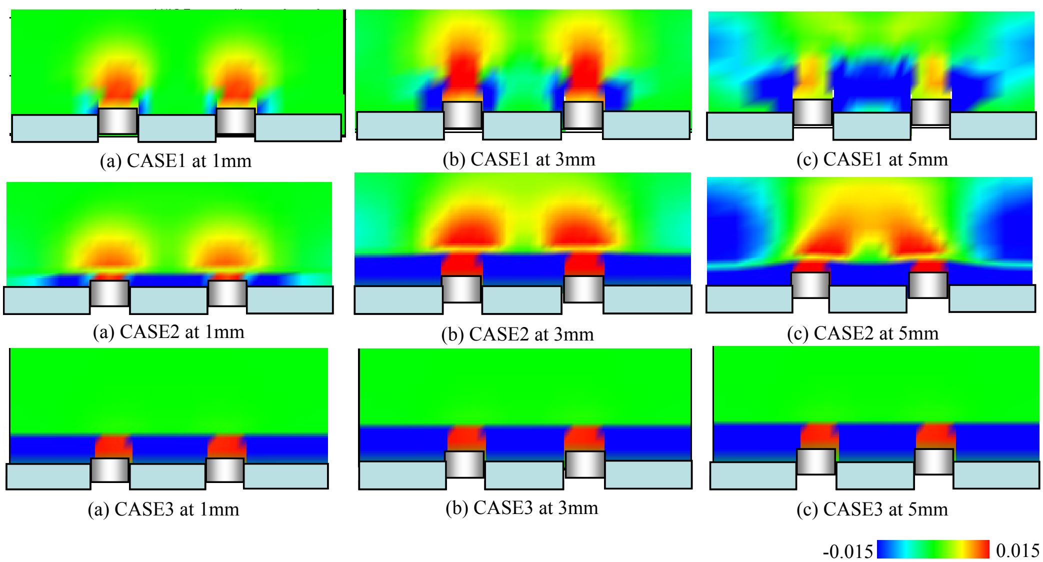


Figure 6. 3-D distribution of mean effective. stress.



(Compression) (Dilation)

Figure 7. Distribution of volumetric strain.

cimen. The images at the settlement of 1, 3 and 5mm for CASE1, CASE2 and CASE3 are shown. For CASE1, a compressive strain appears at the area of over the pile head and this area is extended as the increase of the settlement. And, this area decreases and there is an extension area around the pile head at 5mm settlement. For the case of low stiffness reinforcement (CASE2), the area of compressive strain becomes larger as the settlement increases and besides, the arching shape with this compressive strain is formed at 5mm settlement although the compression area above the pile head is stopped by geogrids of relatively high stiffness for CASE3. According to those results. Figure 8 shows the distributions of mean effective stress at one of the vertical cross section of the specimen. For the case of without reinforcement (CASE1), the stress concentration at the pile head is confirmed and for the case of relatively low stiffness of the geogird (CASE2), this concentration becomes less than that of CASE1. And for the case of high stiffness of the geogrid (CASE3), this decrease becomes larger and the stress due to embankment load can be spread in the ground. Finally, it can be said from all those results that the reinforcement can make the stress concentration disperse and some amount of the reinforcement stiffness is needed in order to make this effect, clearly.

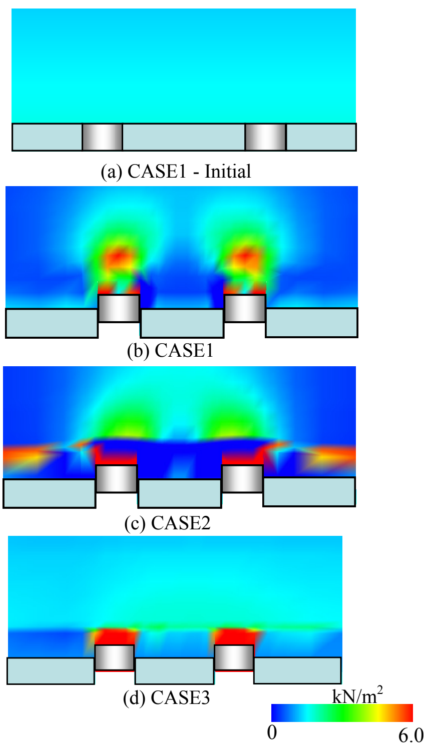


Figure 8. Distribution of mean effective stress at 5mm settlement.

6. CONCLUSIONS

The following conclusions are drawn from this study:

(1) The effectiveness of the reinforcement technology was confirmed by X-ray CT results which shows the density change;
(2) The effectiveness of the reinforcement technology was also checked with the results of FEM; and finally; and
(3) It may be said that an earth reinforcement is effective with the use of deep mixing method for the purpose of subsidence of the ground due to embankment.

It should be said that more quantitative numerical analysis have to be done in order to clarify this effectiveness, quantitatively.

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