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Visualization of interaction behavior between soil and reinforcement using X-ray CT

J. Otani, K. Miyamoto & T. Mukunoki
Graduate School of Science and Technology, Kumamoto University, Japan

T. Hirai
Mitsui Petrochemical Industrial Products, LTD, Japan

ABSTRACT: The objective of this paper is to visualize the behavior of soil-reinforcement interaction using industrial X-ray CT scanner. Here, a new pull-out testing apparatus for the use in the system of X-ray CT scanner was developed and a series of pull-out tests was conducted for geogrid type of reinforcement. Then, the pull-out box was scanned at several steps of pull-out displacement. And a number of cross sectional images for the interaction behavior in each step were obtained. Three-dimensional images were also reconstructed by summing up all the images in each step. Here, the sheet type of the reinforcement was also examined in order to evaluate the effect of the reinforcement geometry on the soil behavior around the reinforcement. Based on those results, the change of the density in the soil around the reinforcement during pull-out displacement was observed and the effect of the shape of reinforcing material on that behavior was also discussed. Finally, the effectiveness of industrial X-ray CT-scanner to geotechnical engineering was confirmed based on those test results.

1 INTRODUCTION

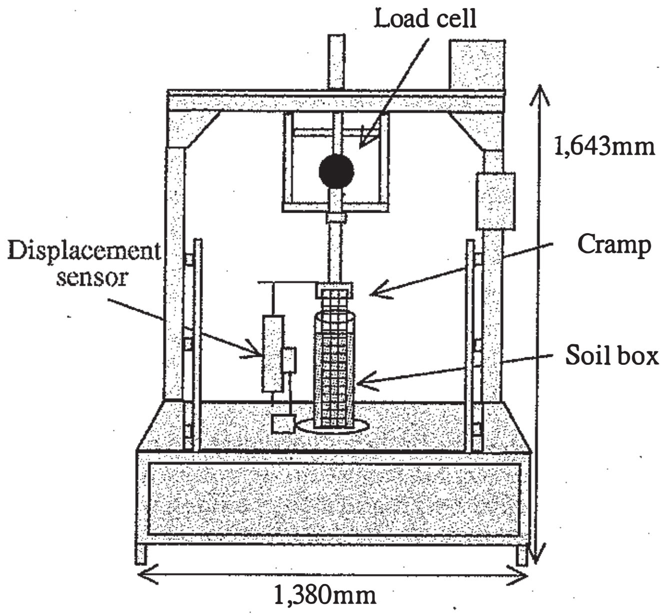
Earth reinforcement technique has been widely used around the world and so far, many research projects for both experimental and analytical aspects such as model testing and numerical analysis have been conducted. But the modeling of interaction between soil and reinforcement is still on going issues and its real behavior has not been observed precisely. Recently, an X-ray CT scanner became a useful tool even for geotechnical engineering as a nondestructive testing apparatus. It is known that the result from CT scanning can be realized as the change of the density in the material. This apparatus produces visual images for not only in cross section but also in three-dimension.

The objective of this paper is to visualize the behavior of soil-reinforcement interaction using industrial X-ray CT scanner. Here, a new pull-out testing apparatus for the use in the system of X-ray CT scanner is developed and a series of pull-out tests is conducted for grid type of reinforcement. Then, the pull-out box in the apparatus is scanned at several steps of pull-out displacement and a number of cross sectional images for the interaction behavior in each step are obtained. Three dimensional images are also reconstructed by summing up all the images in each step. Here, the sheet type of the reinforcement is also examined in order to evaluate the effect of the reinforcement geometry on the soil behavior around the reinforcement. Based on those results, the change of the density in the soil around the reinforcement materials during pull-out displacement is observed and the effect of the geometry of reinforcing material on that behavior is also discussed.

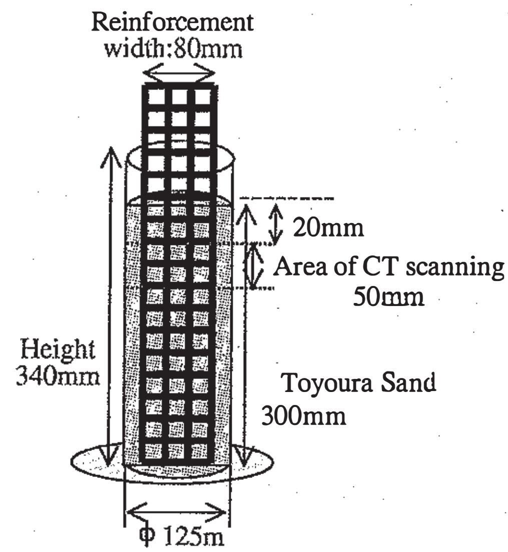
2 X-RAY CT SCANNER

An X-ray computed tomography(CT) method which is one of the nondestructive testing method has been used with the name of an apparatus commonly well-known by the medical diagnostic method which provides the cross sectional images based on the absorption of the x-ray beam through the materials. Recently, an industrial X-ray CT scanner (TOSCANER -23200min:TOSHIBA Corp.) has been installed at the group of Rock Engineering in Kumamoto University, Japan(Sugawara et al. 1997 and Otani et al. 1999). In the system of the X-ray CT scanner, the collimated x-ray is moved around the circumference of the specimen by rotating and translating the specimen table. The detected data are assembled and then, the cross-sectional images are reconstructed using engineering workstation. By using all these cross-sectional images around the circumference of the specimen, three-dimensional (3-D) image can be reconstructed. In order to evaluate these nondestructive test results quantitatively, following so-called "CT-value" is used:

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



(a) Test apparatus



(b) Soil box

Figure 1. Pull–out test apparatus.

where μ_t: coefficient of absorption at scanning point; μ_w: coefficient of absorption for water; and κ: constant called Hounsfield value. It is noted that the coefficient of absorption for air is zero. When the value of κ is set to be 1000, the CT-value of the air should be –1000. It is known that the CT-value has a linear relationship with the density of the specimen, so that the CT-value is a representative value for the density of the specimen. The CT images are presented with shaded darker or black for lower density region and light gray or white for high density one for all the subsequent black and white images. The total number of the gray level distribution is 256. Precise contents about CT scanner are shown in the reference by Otani et al. 2000.

3 PULL-OUT TEST AND CT SCANNING

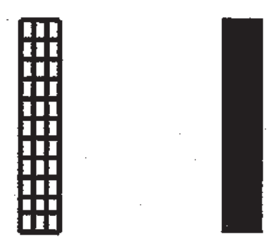
Figure 1 shows a pull-out testing apparatus which was newly developed by the authors. Figure 1(a) shows the total apparatus while Fig.1(b) shows the soil box part in which the size of the reinforcement and the area of scanning are denoted. Toyoura sand was used and its soil property is shown in Table 1. Two different types of reinforcing materials were used which are grid type and sheet type. Those are shown in Fig.2. In the test, following process was conducted:

1) After installing the reinforcement in the soil, a series of CT scanning are conducted as a initial condition.
2) Then the pull-out loading is applied at the head of the reinforcement under displacement control(1mm/min.). This loading is stopped at one pull-out displacement level (pre-peak condition) and start CT scanning with every 1mm thickness. The total number of scanning is 50.
3) After scanning the soil box, the loading is reapplied and same scanning is conducted at the next strain level (post-peak condition) which is the condition of relatively large displacement for the reinforcement.

Figure 3 shows the pull-out force - displacement relationship for the case of geogrid, in which the scanning points are indicated in the figure. It is noted here that stress relaxation was occurred as shown in this figure and this was caused by stopping the pull-out test during CT scanning.

Table 1. Soil property of Toyoura Sand.

Maximum dry density (t/m^3)		1.61
Minimum dry density (t/m^3)		1.35
Relative density	(%)	100



(a) geogird (b) geomembrane

Figure 2. Types of reinforcement.

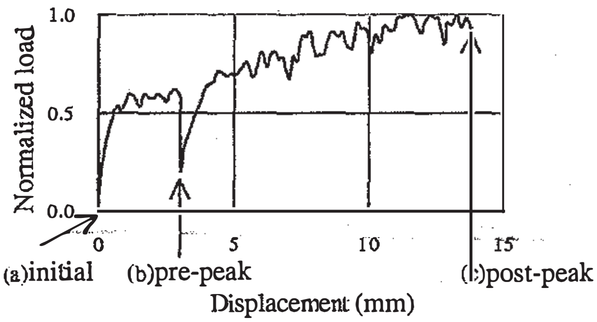


Figure 3.Pull–out force–displacement relationship for the case of geogrid.

4 RESULTS AND DISCUSSION

Figure 4 shows one of cross sectional image at the depth of 35mm from the surface of the ground for three different strain levels and the change of the density is shown by gray level distribution. As easily realized from those figures, the reinforcement makes the soil density variable even from the initial condition. Figure 5 shows the vertical cross sectional images for those three cases for total depth of 50mm from 20mm below the surface. These are reconstructed using all the horizontal cross sectional images and the clear shear zones can be observed at the large strain level as shown in Fig.5(c) in which there is not much change between initial and pre-peak strain levels. Figure 6 shows the same images as Fig.5 for the case of sheet type of reinforcement under the same pull-out test. There is no change of the density around the reinforcement in the ground, so that the geometry of the reinforcement makes the interaction behavior different. Figure 7 shows three-dimensional reconstruction images for those three strain levels in which the subtraction image between two images is also shown in this figure. As realized from these figures, the shear banding due to pull-out loadings is clearly occurred around the reinforcement with not single zone but multiple ones in three-dimension. Figure 8 shows special three-dimensional images which are reconstructed in order to emphasize the area of shear banding. This is enable to visualizing the inside behavior of the ground. Thus, it is confirmed that the industrial X-ray CT scanner has a possibility of characterizing the effect of the reinforcement in the soil and it may produce the valuable information about modeling of interaction between soil and reinforcement.

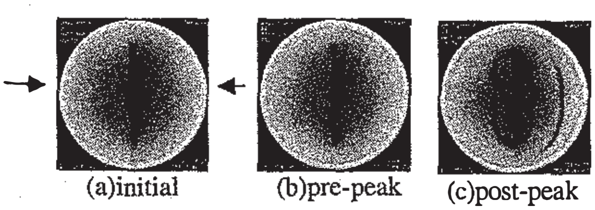


Figure 4. Cross sectional images for the case of geogrid.

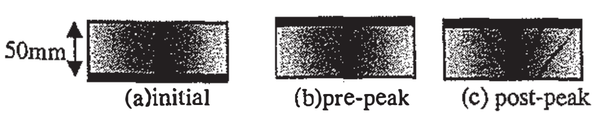


Figure 5. Vertical cross sectional images for the case of geogrid.

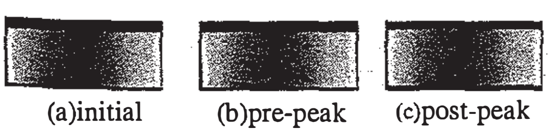


Figure 6. Vertical cross sectional images for the case of geomembrane.

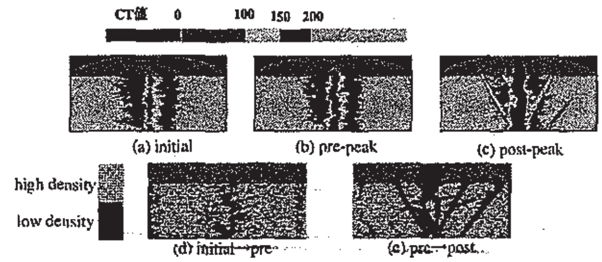


Figure 7. 3-D reconstruction images with subtraction images.

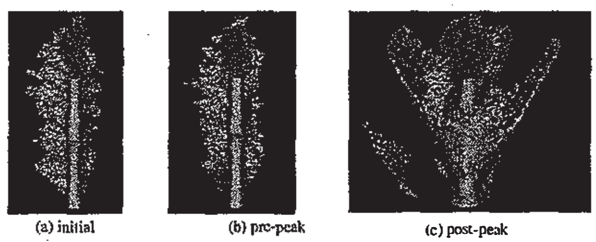


Figure 8. 3-D reconstruction images for the shear zone in the soil.

5 CONCLUSIONS

A series of pull-out test was conducted for geogrid type of reinforcement. And a number of cross sectional images for the interaction behavior in each loading step were obtained using industrial X-ray CT scanner during pull-out forces. The same pull-out test for sheet type of the reinforcement was also examined and the effect of the geometry of the reinforcement on the interaction behavior between soil and reinforcement was discussed.

Finally, it is concluded that the progressive failure in the soil could be precisely discussed without any destruction using industrial X-ray CT scanner. It is also confirmed that the possibility of the other applications of this apparatus would be highly expected.

6 ACKNOWLEDGEMENT

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Laboratory testing of long-term performance of clay-geogrid interaction

A. Pamuk
Department of Civil Engineering, Rensselaer Polytechnic Institute, USA

D. Leshchinsky & V.N. Kaliakin
Department of Civil and Environmental Engineering, University of Delaware, USA

H.I. Ling
Department of Civil Engineering and Engineering Mechanics, Columbia University, USA

ABSTRACT: Pullout tests are often conducted to evaluate soil-to-geogrid interaction properties in design. Most of these tests have used static loads with cohesionless soils to assess stress distribution along the soil-geogrid interface as well as pullout resistance. In this work, laboratory pullout tests were carried out to study the long-term performance of a polymeric geogrid embedded in a cohesive soil. Incremental long-term static or cyclic tensile pulling loads were applied to the embedded geogrid under various confining pressures. Some in-isolation creep tests were conducted to compare the long-term effects of confinement. Under dynamic loading conditions, different frequencies of tensile load were applied. Strain progress and creep development were measured. The testing method and results are presented and discussed in details.

1 INTRODUCTION

A limited number of reinforced earth structures constructed with cohesive soils has performed well, showing that they can be used in place of granular soils and thus, reduce the cost of construction. The results from both laboratory and full-scale field tests backfilled with cohesive soil demonstrated that both the short-term and long-term shear strength of cohesive soil might be increased by grid reinforcement (Jewell and Jones, 1981). Bergado et al. (1993) reported that cohesive soils compacted to 95% of standard Proctor's density on the dry side of optimum moisture content could generate pullout capacities comparable to those of the good quality granular soils. Accordingly, there has been great demand on using locally available cohesive soil in mechanically stabilized earth structures, especially in places where good quality granular soil is not readily available.

A variety of geogrids has been used for soil reinforcement to provide short-term and long-term stability under static and dynamic loads. Appropriate testing methods are needed to evaluate the long-term stress-strain properties of confined geogrids subjected to pulling loads. Laboratory and field pullout tests are often conducted to evaluate the properties of soil-to-geogrid interaction. Field tests are less common because of the high cost in constructing full-scale structures, but may be more representative. Laboratory pullout tests are often conducted because they offer more controlled testing environment with less cost. On the other hand, boundary effects (e.g., side wall friction, rigid front face etc.) increase due to various limitations in the size as well as various configurations of pullout apparatus geometries used (Juran et al. 1988; Juran and Christopher, 1989; Abremento and Whittle 1995; Farrag et al. 1993). These variations make it difficult to consistently compare the performance of geosynthetics in different soils (Farrag and Griffin, 1993; Abremento and Whittle 1995).

Most of the tests reported in the literature have used monotonically increasing loads with granular backfill materials to assess stress distribution along the soil-geogrid interface as well as pullout resistance. The related testing procedures (e.g., Christopher et. al., 1990) were developed for both short and long-term.

This paper presents the results from laboratory pullout tests that were conducted to study the long-term performance of a polymeric geogrid embedded in kaolin clay. The incremental static or cyclic tensile pulling loads were applied to the embedded geogrid under various confining pressures. Strain gages were used to monitor strain distribution and creep development in the geogrid reinforcement subjected to incremental tensile loads. Some in-isolation creep tests were conducted to compare the long-term effects of confinement on the geogrid reinforcement. Under cyclic loading conditions, and in-isolation, different frequencies of tensile load were applied. The testing method and results are presented and discussed in details.