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Evaluation of soil confinement effect due to geosynthetics using X-ray CT

J.OTANI & J.HIRONAKA, Department of Civil and Environmental Engineering, Kumamoto University, Japan
T.HIRAI, Mistui Chemicals Industrial Products, LTD, Japan
Y.MIYATA, National Defense Academy, Japan

ABSTRACT: The objective of this paper is to evaluate the effect of soil confinement due to geosynthetics using Xray CT scanner. Here, the new pull-out testing apparatus for the use with X-ray CT scanner was developed and a series of pull-out test were conducted. 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 using a large number of cross sectional images in each test. Finally, the density change around the reinforcement in the soil was evaluated quantitatively 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 2-D cross section but also in three-dimension.

The objective of this paper is to evaluate the effect of soil confinement due to geosynthetics in the soil using industrial X-ray CT scanner. Here, a series of pull-out tests are conducted and the reinforced soil specimens are scanned during pull-out loading. In order to evaluate the effect of the shape of the reinforcing materials, different types such as geogrid and geomembraine are examined. Then, a number of cross sectional images for the density change around the reinforcement in the soil are obtained. Three dimensional images are also reconstructed by summing up all the images in each step. 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 the reinforcing material on that behavior is discussed.

2 X-RAY CT SCANNER

2.1 *Theory*

In ideal situations, projections are a set of measurements of the integrated values of some parameter of the specimen which is the integration being along straight lines through the specimen. When x-ray beam propagates through the one-dimensional homogeneous specimen, the intensity of the x-ray, I_0 in terms of the number of photons that enter the specimen changes to that value of I after the attenuation of x-ray in the specimen. This process is expressed by the following equation for the width of the specimen, W with the linear coefficient of absorption, f:

$$I = I_o exp\{-fW\}. \qquad (1)$$

Then, the projection, p is defined by

$$p = fW = \ln\{I_o/I\}. \qquad (2)$$

When the specimen is non-homogeneous in two dimension, Equation (2) is rewritten by following line integral form for the case shown in Fig.1:

$$p(r,\theta) = \ln(Io / I) = \int_{-\infty}^{\infty} f(x,y)dt \qquad (3)$$

in which $f(x,y)$ is the spatial distribution of the coefficient of absorption in two dimension and each line integral by the (r,θ) parameters which are shown in Fig.1. In the X-ray CT scanner, a large number of independent projections are measured by tomographic technique and finally the spatial distribution of the coefficient of absorption, $f(x,y)$ is obtained by the Filtered Back-Projection Method (Kak and Slaney (1987)). In the image processing analysis, following so called "CT-value" is used:

$$\text{CT-value} = (\mu_t - \mu_W)\, \kappa / \mu_W \qquad (4)$$

where μ_t: coefficient of absorption at scanning point; μ_W: coefficient of absorption for water; and κ: a constant. 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 the water is 0 from the definition of Equation (4). The CT images are presented with shaded gray or black color for low CT-value and light gray or white

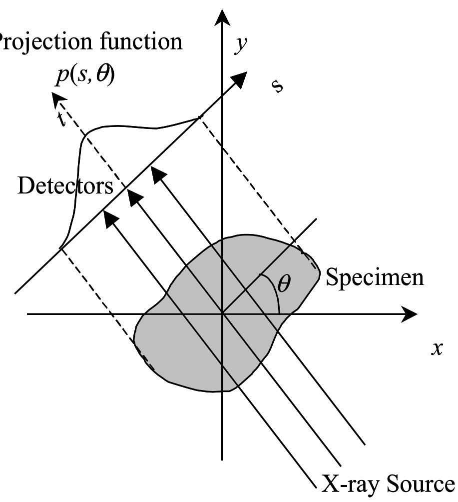

Figure 1. Principle of X-ray CT scanner.

color for high CT-value as all the subsequent black and white images. The total number of levels on these colors is 256. Figure 2 shows the relationship between CT-value and density of sand used in this study. Those results show a linear relation among all the results, so that the CT-value can be a parameter for evaluating the change of the density. Therefore, it is promised 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.

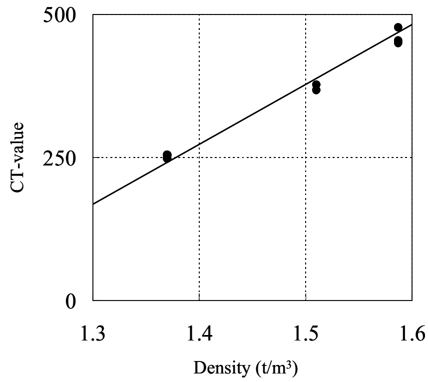

Figure 2. Relationship between CT-value and Density.

2.2 *System*

The system of the X-ray CT scanner used here is shown in Fig. 3 and this apparatus has been installed at the group of Rock Engineering, Kumamoto University, Japan(Sugawara et al.(1997) and Otani et al.(2000)). In this apparatus, the collimated x-ray is penetrated from all around the circumference of the specimen by rotating and translating the specimen table as shown in Fig.3. The detected data are assembled and the cross sectional images are reconstructed using image data processing device by means of the filtered back-projection method. Then, the image is expressed on the monitor of engineering workstation. By using all these cross sectional images around the circumference of the specimen, the three dimensional(3-D) images can be reconstructed. The contents of the specification on this X-ray CT scanner are shown in Table 1. The medical CT scanners are most commonly equipped with 140 kV x-ray tubes while the industrial ones used here is equipped with 300kV 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. As far as the previous studies on the application of X-ray CT scanner are concerned, the studies by Desrues et al.(1996) and Tani (1997) are pioneering works and recently, Alshibli et al.(2000) have used very powerful CT scanner in their study on the assessment of localized deformation in sand.

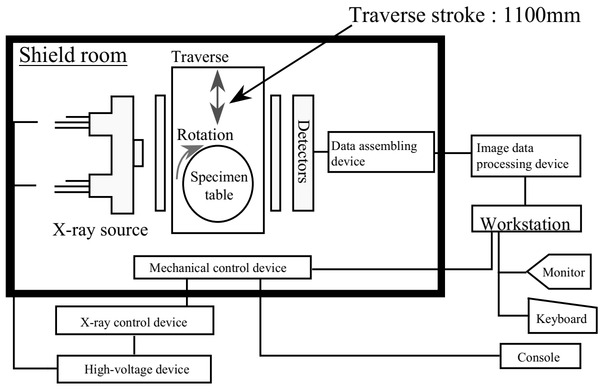

Figure 3. System of Industrial X-ray CT scanner.

Table 1. Specification of industrial X-ray CT scanner.

Contents	Specifications
Scann type	Traverse/Rotation
Power of X-ray	300 kV/ 200 kV
Number of detectors	176 channels
Maximum size of specimen	Diameter of 40cm x Height of 60cm
Thickness of X-ray beam	0.5, 1.0 and 2.0 mm
Spatial resolution	0.2mm (diameter of hole) for 20mm thickness of steel

3 PULL-OUT TEST

Figure 4 shows an apparatus of pull-out test which was newly developed by the authors. Figure 4(a) shows the total view of the apparatus with loading system while Fig.4(b) shows the close-up view of the soil box part, in which the size of the reinforcement and the area of scanning are described. Dry Toyoura sand was used in this test and its soil property is shown in Table 2. Two different types of reinforcing materials were used which are grid type and sheet type. Those are shown in Fig.5. In the test, following procedure was conducted:

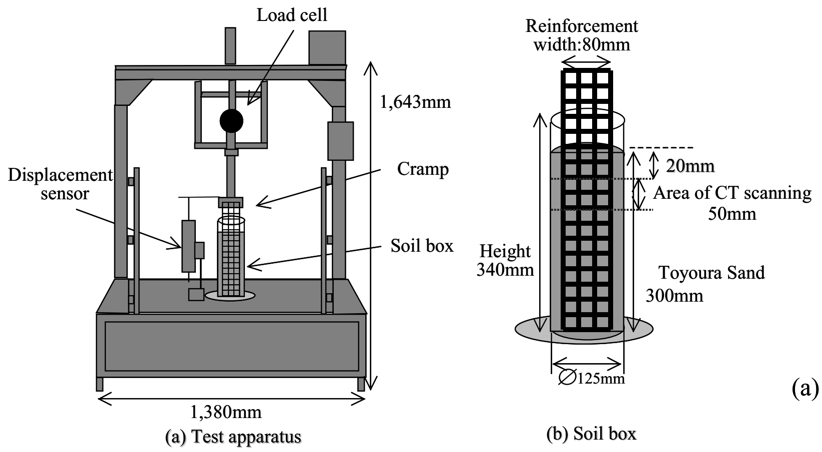

Figure 4. Pull-out test apparatus

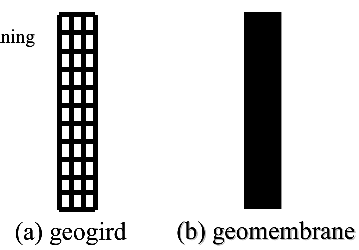

Figure 5. Reinforced materials.

1) The reinforcement is set in the soil box;.
2) Toyoura sand is poured using multiple sieve;
3) A series of CT scanning are conducted as a initial condition;

4) The pull-out loading is applied at the head of the reinforcement using special chuck under displacement control with the velocity of 1mm/min;
5) This loading is stopped at some pull-out displacement level (pre-peak condition) and start CT scanning with every 1mm thickness. The total number of scanning is 50; and
6) 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 level of the reinforcement.

Table 2. Soil property of Toyoura Sand

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

4 TEST RESULTS AND DISCUSSION

Figure 6 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 observed as realized in this figure and this can be considered as a result of stopping the pull-out test during CT scanning. Figure 7 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 8 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.8(c) although there is not much change between initial and pre-peak strain levels. Figure 9 shows the same images as Fig.8 for the case of sheet type of reinforcement under the same pull-out test. There is no density change around the reinforcement in the ground, so that the geometry of the reinforcement makes the interaction behavior different. Figure 10 shows three-dimensional reconstruction images for those three strain levels in which the subtraction images between two images which are shown in Figs.10(d) and (e) are 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 11 shows the same figure as Fig.10 for the case of sheet type of the reinforcement. As clearly shown in Fig.11(d) and (e), there is no change of the density around the reinforcement under pull-out force and again, it is concluded that the effect of horizontal lib is essential for the pull-out behavior. Figure 12 shows special three-dimensional images for the case of grid type of reinforcement, 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.

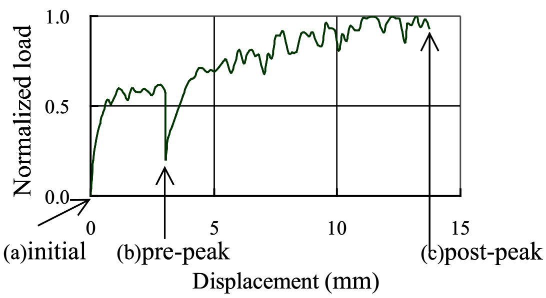

Figure 6.Force-displacement relationship for the case of geogrid.

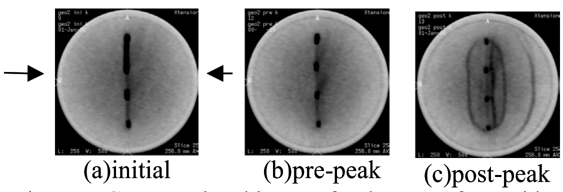

Figure 7. Cross sectional images for the case of geogrid.

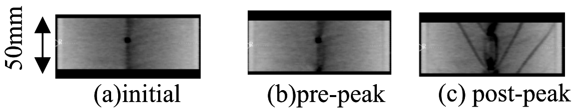

Figure 8. Vertical images for the case of geogrid.

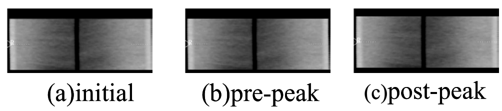

Figure 9. Vertical images for the case of geomembrane.

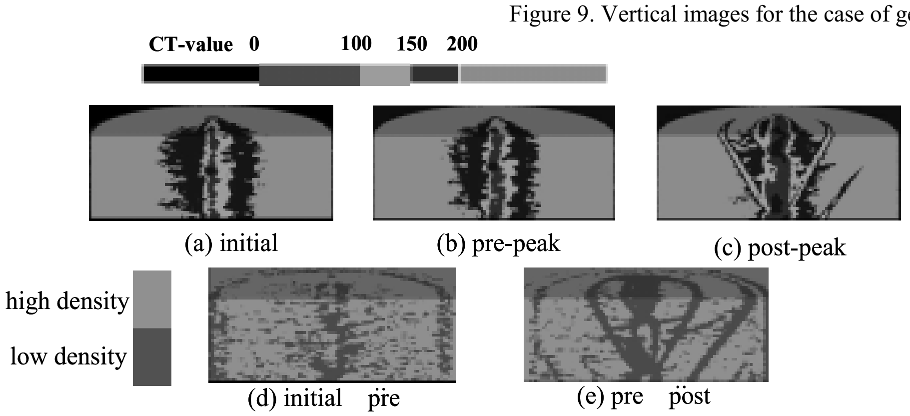

Figure 10. Three dimensional and subtraction images for the case of geogrid.

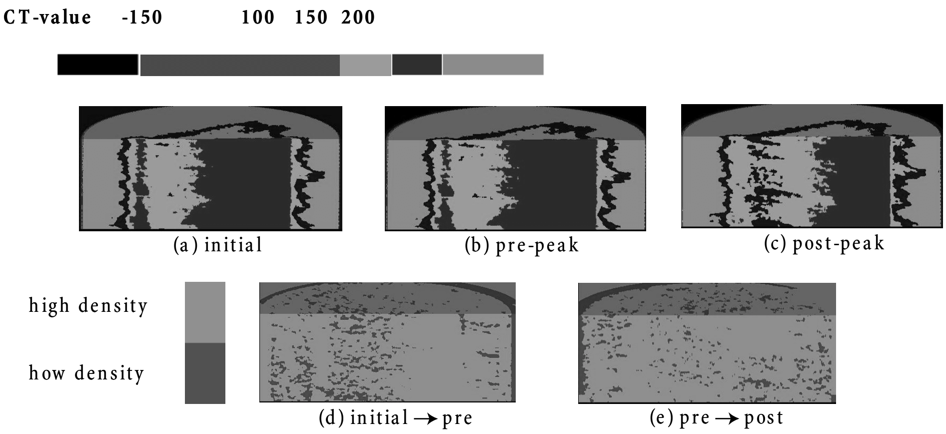

Figure 11. Three dimensional and subtraction images for the case of geomembrane.

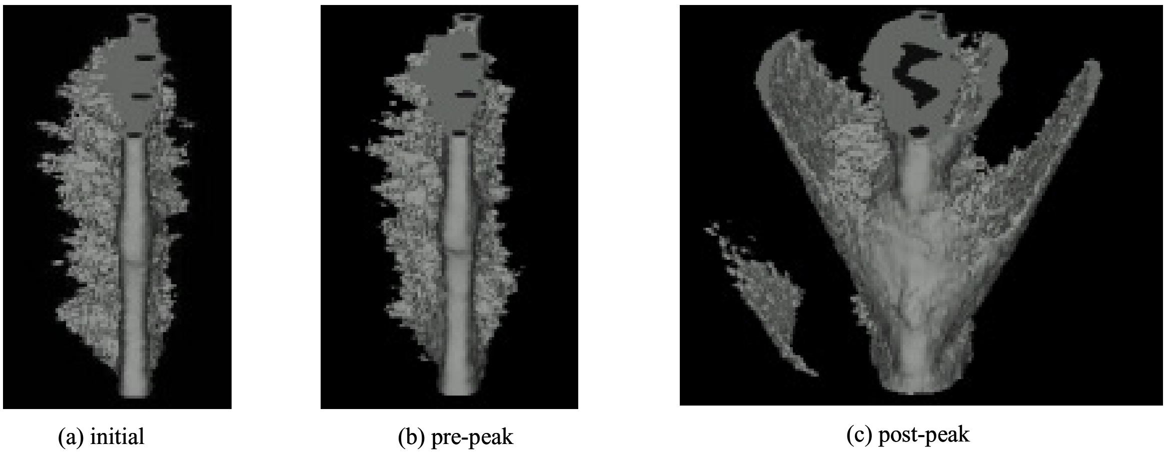

Figure 12. Reconstruction of three dimensional shear band in the soil.

5 CONCLUSIONS

A series of pull-out test was conducted for different 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. Based on the test results, the effect of the horizontal lib of the reinforcement on the interaction behavior was clearly observed. But, the modification of the pull-out test apparatus will be highly expected in order to obtain more reliable results.

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