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DEFORMATION OF VERTICAL DRAIN MATERIALS UNDER CONSOLIDATION SETTLEMENT USING X-RAY CT

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ABSTRACT

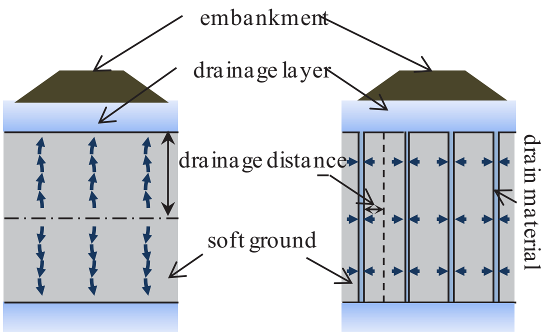
If the diameter of the drain materials in soft ground is too small compared to its length, drain materials are deformed due to large consolidation settlement. The objective of this paper is to study on the deformation process of vertical drain materials under consolidation settlement. Here, consolidation test with multiple loading steps was conducted for clayey soil where drain material has been installed vertically. And deformation behavior of the drain material in the soil was investigated using X-ray CT scanner at the end of each consolidation steps. The drain materials used in these tests were paper and PVD (Prefabricated Vertical Drain). PVD is a drain material with plastic core used at the site. In the results, deformation processes of drain material were visualized using X-ray CT and the difference of the deformation for both materials were observed. In case of using paper as a drain material, the paper was not deformed with simple behavior but with its complicated shape. On the other hand, in case of using PVD, it follows consolidation settlement by a firstly formed curve spreading in horizontal direction. Furthermore, the tests revealed that the deformation of drain materials gives an influence on the surrounding soil. According to all the results shown in this paper, it is concluded that the X-ray CT scanning is an effective tools and deformation process of the drain materials in the soil was firstly investigated in the world.

Keywords: Consolidation settlement, deformation of drain material, model test, vertical drain, X-ray CT scanner

INTRODUCTION

Vertical drain method is one of soft-ground stabilization methods. It consists in accelerating consolidation by installing a large amount of drain materials vertically which present higher permeability than that of soft ground only. Figure 1 shows basic principle of vertical drain method. The consolidation time is greatly influenced by the drainage distance of the pore water, so that the consolidation time is largely shortened using drain materials because drainage distance is governed by the pitch of drain materials.

In general, drain materials used in the vertical drain method are sand piles, paper and so on. If the diameter of the drain materials such as paper or other special drain materials is too small compared to its drain materials, those materials deform in the ground when a large consolidation settlement occurs. Figure 2 shows deformation of drain materials after



a) without drain   b) with drain

Fig. 1 Principle of vertical drain method

Fig. 2 Buckling of drain material due to large relative compression of the ground (Cortlever and Hansbo 2004)

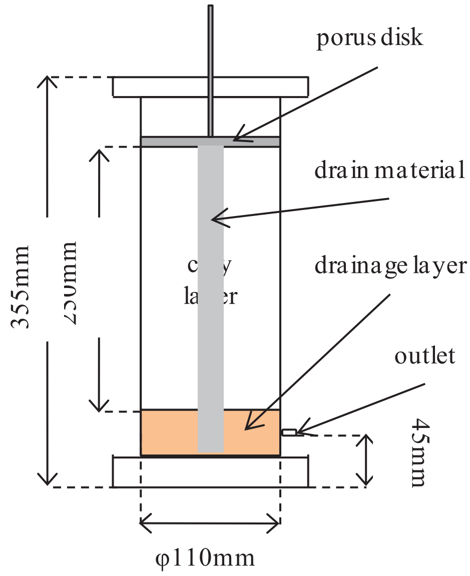


Fig. 3 Details of test apparatus

consolidation settlement. It was found that the shape of drain materials was changed by consolidation settlement (Aboshi et al., 2001) with different modes such as folding, crimping, bending, buckling or kinking. The deformation of drain materials may reduce its own permeability and disturb surrounding ground (Tran-Nguyen et al., 2010). As a result, the effectiveness of drain materials is decreased. In general, the shape of drain materials can be confirmed only after the end of consolidation process and this behavior is difficult to check because it is the behavior in the ground.

In this paper, a series of consolidation test are conducted and the deformation property of drain materials in soft soil during consolidation is investigated using X-ray CT scanner. Here, it is also conducted that the change of soil property in the surrounding ground near the drain materials is also evaluated.

EXPERIMENTAL STUDY

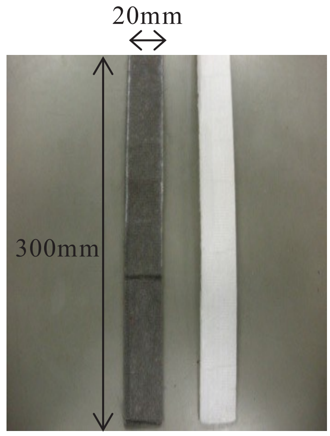
Test Procedure

Figure 3 shows the details of test apparatus. The soil box was made by acrylic cylinder which is 110mm inside diameter with 355mm height. The drainage condition at the bottom end is performed by putting sand layer using Toyoura sand. The load was applied by dead load at the top of the ground through porous disk and total of four consolidation steps of loadings were applied.

A model ground was prepared in the box after installing the drain material vertically at the center of the cylinder. The initial ground was made of a clay layer of the thickness of 250mm with a water content of 150%. Table 1 shows material properties

Table 1 Material property of Kaolinite

Specific gravity G_s	2.61
Coefficient of consolidation C_v (m^2/s)	11.6×10^{-8}
Coefficient of permeability k (m/s)	2×10^{-9}
Liquid limit w_L (%)	77.0
Plastic limit w_p (%)	28.2
Plasticity index I_p	48.8



a) filter paper b) PVD

Fig. 4 Drain materials

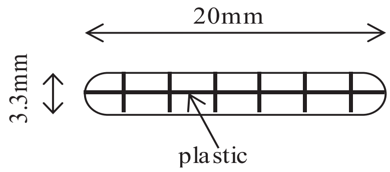


Fig. 5 Cross section of PVD

of Kaolinite which was used as the clayey model ground. As drain materials, filter paper as alternated drain materials and PVD used on site were tested in which PVD is a drain material with plastic core. Figure 4 shows drain materials used in this study and Fig. 5 shows cross section of the PVD. As for the size of drain materials, its width is 20mm with the thickness of 3.3mm. Table 2 shows initial condition of the ground in each drain material case.

Furthermore, X-ray CT scanner was used in order to scan the initial condition of the ground and those of after the consolidation of each loading step. CT scanning starts from the bottom end of the clay layer and scanning was conducted at every 5mm distance towards the top of the ground. Here, the total height of the scanning in each case was set to get total view of the drain materials.

Table 2 Initial condition of the ground

drain material	water content w (%)	degree of saturation S_r (%)	void ratio e	wet density ρ_t (t/m^3)
filter paper	154.0	98.3	4.25	1.31
PVD	155.2	97.7	4.30	1.30

X-ray CT

Industrial X-ray CT scanner is the device used for nondestructive testing apparatus. It can investigate density change in the test specimen. Figure 6 shows industrial X-ray CT scanner used in this study. Cross sectional images of the test specimen can be obtained with this apparatus. The image is comprised of the values called CT-values which are in correlation of density of the material. The CT-value is defined by the following equation:

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

where μ_t : coefficient of absorption at scanning point; μ_w :coefficient of absorption for water; and K: constant in which this constant is fixed to a value of 1000. Based on this equation, CT-value of air is -1000, and that of water is zero. It was found that the X-ray coefficient of absorption is affected by various conditions such as power of X-ray, scanning area, testing materials and the size of test specimen (Otani, 2004). Thus, it is necessary to conduct calibration in order to determine proper test conditions. Figure 7 shows the relationship between CT-value and its material density including water, air, and clay of wet condition. Thus, it can be seen that increase and decrease of the CT-value is well correlated with its density change. Table 3 shows the specification of the X-ray CT scanner used in this study.

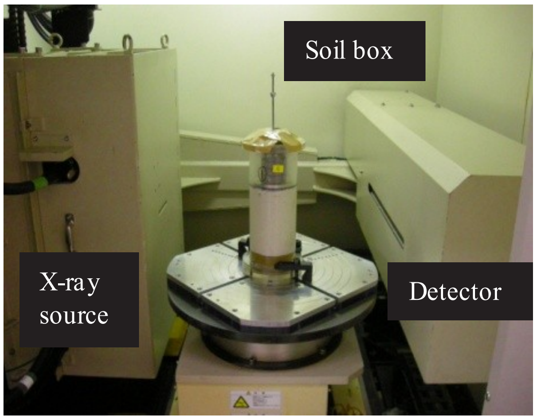


Fig. 6 Industrial X-ray CT scanner

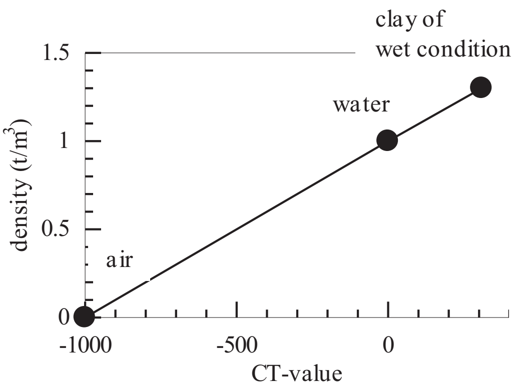


Fig. 7 Relationship between material density and CT-value

Table 3 Specification of X-ray CT scanner

voltage (kV)	200
current (mA)	3.0
irradiation thickness	1.0
scan range (mm)	φ150
matrix size (voxel)	2048×2048
data addition mode	Full (360°)

RESULTS AND DISCUSSIONS

Results of Consolidation Test

Figures 8 and 9 show consolidation settlement curves for the cases of both filter paper and PVD, respectively. On those figures, red circle shows the positions where CT scanning was carried out. In this study, CT scanning was conducted at initial condition, step 1, 2, and 4 during the process of consolidation. No significant difference was observed between those two consolidation settlement curves. It is thought that this is because the size of test specimen may be small enough. Tables 4 and 5 show the results of consolidation test. Void ratio and wet density were calculated from the amount of consolidation settlement and those are realized as an average value for the total model ground.

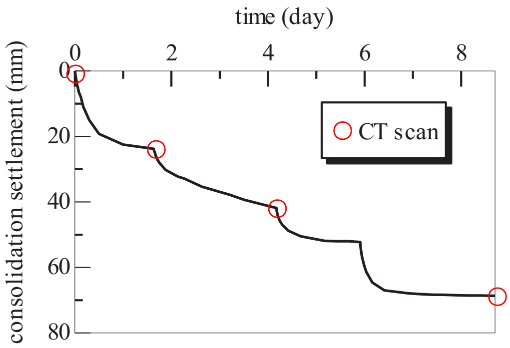


Fig. 8 Time-consolidation settlement curve for the case of filter paper

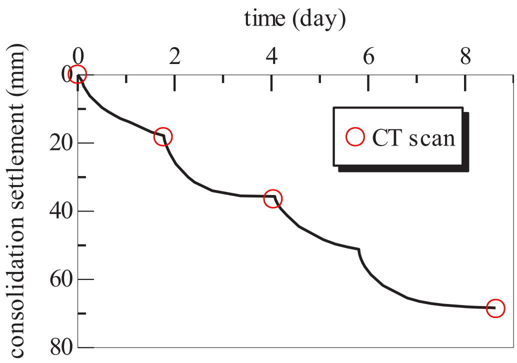


Fig. 9 Time-consolidation settlement curve for the case of PVD

Table 4 Results of consolidation test for filter paper

	pressure P (kN/m^2)	settlement s (mm)	void ratio e	wet density P_t (t/m^3)
step 1	0.41	17.8	3.87	1.34
step 2	4.12	35.5	3.50	1.36
step 3	8.25	51.0	3.18	1.39
step 4	16.50	68.3	2.81	1.43

Table 5 Results of consolidation test for PVD

	pressure P (kN/m^2)	settlement s (mm)	void ratio e	wet density P_t (t/m^3)
step 1	1.17	23.8	3.80	1.34
step 2	4.26	41.9	3.42	1.36
step 3	8.39	52.2	3.20	1.38
step 4	16.64	68.7	2.85	1.42

Results of CT Scanning

Cross-sectional CT image

Figure 10 shows horizontal cross sectional images of six different depths from the bottom end of the ground for the case of PVD. These images were extracted from the raw images at 75mm in diameter from the center of the ground with smoothing process. The block area at the center of the image corresponds to the location of drain material. The deformation of drain material can be obtained as the change of its location from the CT images.

It is found that high density area is formed in the bending direction of drain material because the ground is compressed by drain material being displaced horizontally. In addition, it is found that low density area inside the bending arc is formed on the other side of the bending direction at step 2. It is thought that the ground cannot follow the horizontal

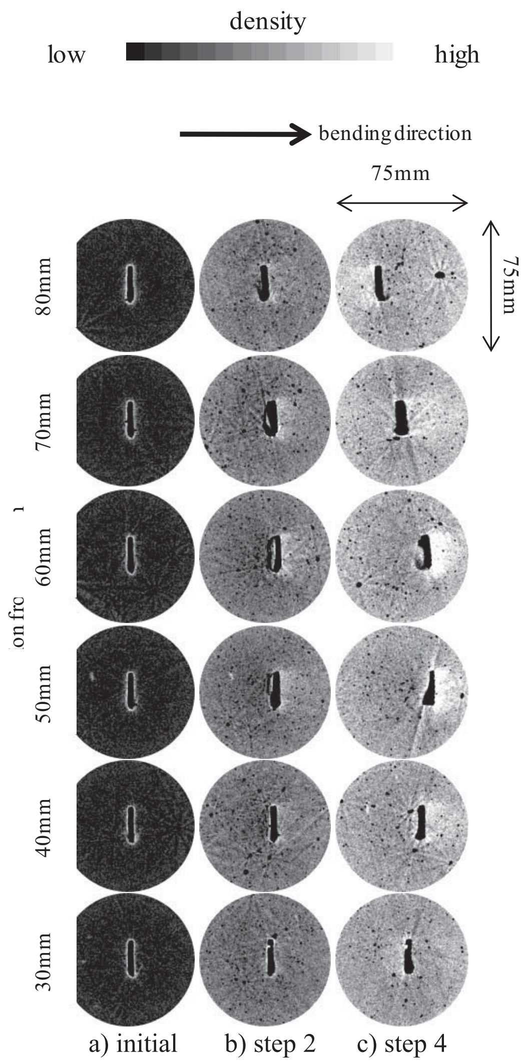


Fig. 10 Cross sectional CT images for PVD

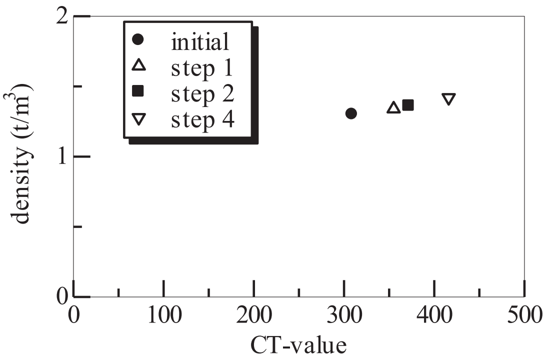


Fig. 11 Relationship between wet density and CT-value

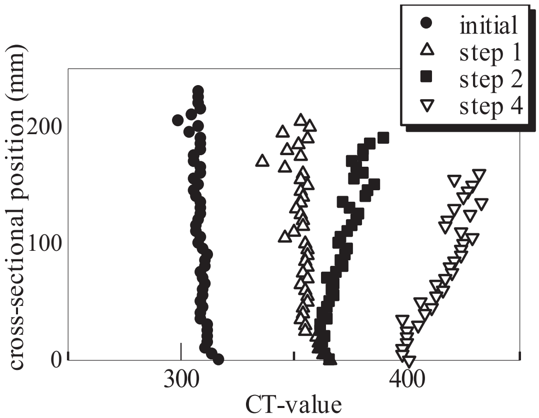


Fig. 12 Variability of CT-value in each cross section of each loading stage for PVD

displacement of the drain material.

Figure 11 shows the relationship between density calculated from the results of consolidation test and the average CT-value for total cross-sectional CT images. It can be thought that there is a linear relationship for those results. Figure 12 shows average CT-value at each cross-sectional depth in each loading stage. It is found that the ground is homogeneous because CT-values are almost unique for each cross-sectional position at initial and step 1. However, there is variation in this relation in step 2 and step 3 and the density at the top of the ground seems bigger than those of the bottom. From here, it is thought that consolidation of vertical drain is not uniform.

Shape of drain material in the ground

Figures 13 and 14 show the shape of drain material at the initial condition and after the end of consolidation. These images were made from CT images obtained from CT scanning. It is found that a small curved shape at the end of consolidation of first step was observed for the case of filter paper and during consolidation progresses, it is also found that the height of drain material became lower by forming a new curve with conservation of the first curve. On the other hand, it is found that a gentle curve at the end of consolidation with the first step was observed for PVD. And as consolidation progresses, the gentle curve becomes a sharp curve by spreading in the horizontal direction. It is thought that the cause of the difference in deformation of two drain materials is the influences of quality of drain materials on one hand and the change of confining stress from the clayey soil on the other hand. Because the filter paper has low stiffness, it is affected by confining stress from clayey soil and does not spread through the horizontal direction, but it can spread through the horizontal direction with high confining stiffness.

CONCLUSIONS

In this study, deformation process of drain materials and surrounding ground were visualized using X-ray CT scanner during consolidation tests. According to all the results shown in this paper, it is concluded that the X-ray CT scanner is an effective tools in this study and deformation process of the drain materials in the ground was firstly investigated in the world. The following conclusions are drawn:

1) High density and low density areas were found in the bending direction and in the opposite direction, respectively on each side of the deformed drain materials.

2) According to the results of CT scanning, the density of the ground is not uniform using vertical drain method.

3) In case of using filter paper as drain material, the drain material does deform with one single curve at the beginning and it follows the shape of sinusoidal with the consolidation settlement.

4) In case of using PVD as drain material, the shape at beginning of consolidation continue with changing those amount due to consolidation settlement.

In this study, the accuracy of consolidation test seems not enough to confirm all the results, especially those at the beginning of the deformation curve of drain material. An improvement of the test accuracy is next step of this study.

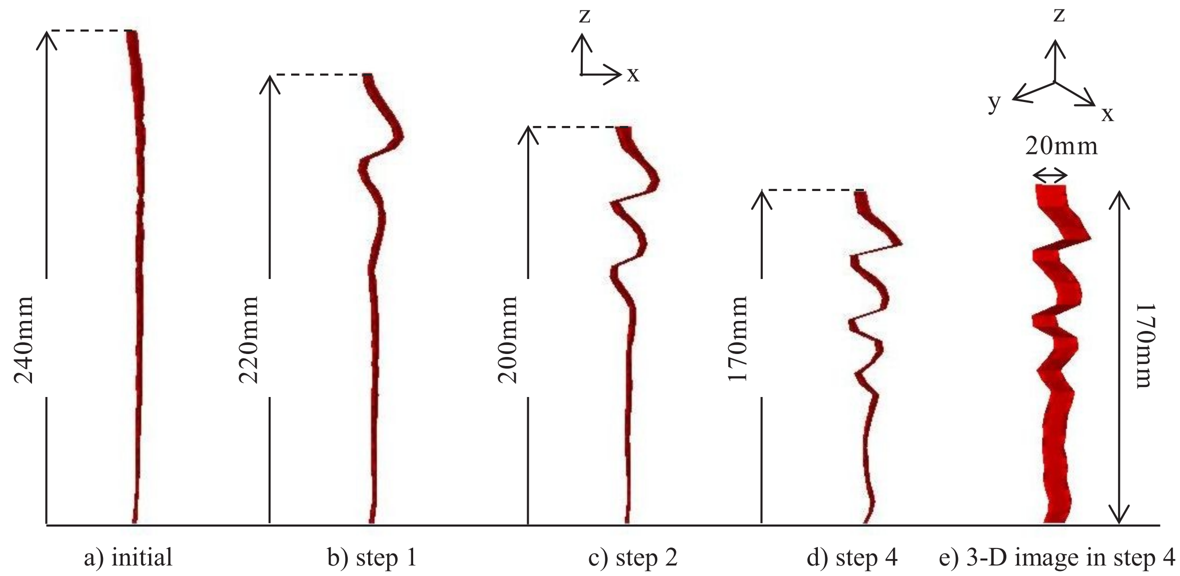


Fig. 13 Shape of drain material in each loading stage for the case of filter paper

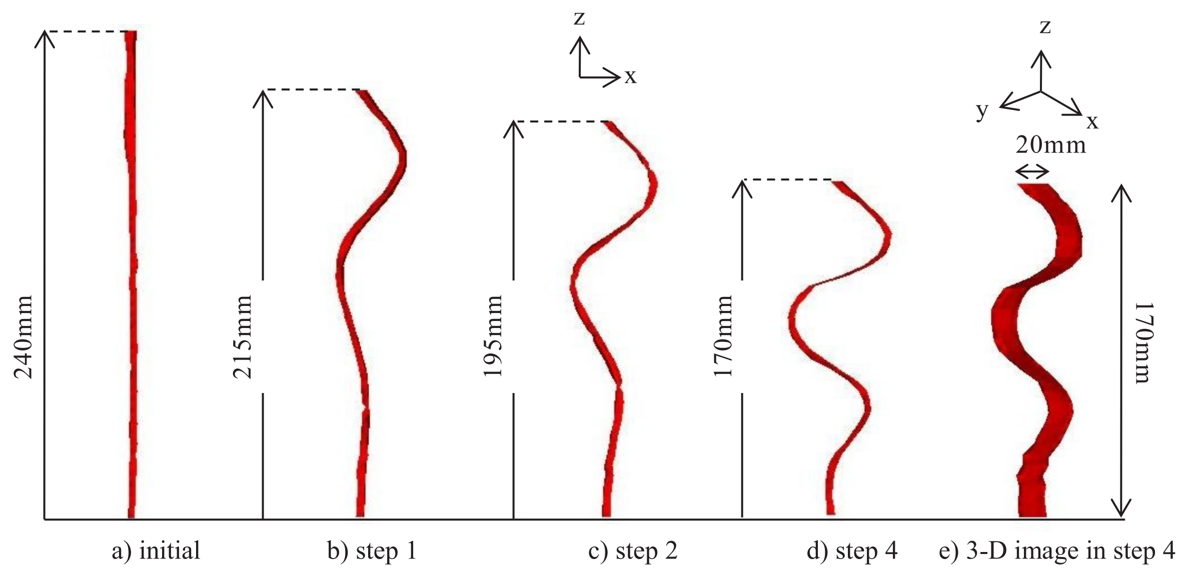


Fig. 14 Shape of drain material in each loading stage for the case of PVD

REFERENCES

Aboshi H., Sutoh Y., Inoue T. and Shimizu Y. (2001). Kinking deformation of PVD under consolidation settlement of surrounding clay. Soils and Foundations. 41(5): 25-32.

Cortlever N. and Hansbo S. (2004). Aspects of vertical drain quality and action. Proc. EuroGeo 3 Conference. Munchen. B2-01: 335-340.

Otani J. (2004). State of the Art Report on Geotechnical X-ray CT Research at Kumaoto University. X-ray CT for Geomaterials. Soils. Concrete. Rocks: 43-76.

Tran-Nguyen H.H., Edil T.B. and Schneider J.A. (2010). Effect of deformation of prefabricated vertical drains on discharge capacity. Geosynthetics International. 17(6): 431-442.