# Observation of internal model ground around the spiral pile on vertical loading condition using X-ray CT scanner

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## ABSTRACT

The objective of this research is to elucidate the characteristics about the vertical bearing capacity of a spiral pile. In this study, the static penetration model tests were conducted on special boundary condition at the spiral pile head. It is the shaft rotate condition. It was confirmed that the shaft rotate condition have a significant impact for the penetration resistance and vertical bearing capacity of spiral pile. As other approach of grasp the mechanism of the bearing capacity of the pile, the internal alteration of model ground was observed using the X-ray CT scanner. A disturbed area of the model ground around the spiral pile was observed in visualized CT images.

## 1. INTRODUCTION

In recent years, a new shape steel bar was expected to use as a structural material in the field of rock and agricultural civil engineering. It is the spiral bar. The spiral bars are produced by twisting a flat steel bar. The shape of this structural material seems to have a high potential of reinforcement for the object if it was engaged well with them. In the field of geotechnical engineering, it has begun examining of the applicability of spiral bar as a structural material for the soil ground. There are some researches to use the spiral bar for soft ground and slope as a reinforce material and foundations (Hirata 2003). Spiral bar has experimentally been using as pile foundations called “spiral pile” on in-site. The spiral pile is displacement-pile, so that the installation of this pile is done under the condition of without digging the hole. So, the displacement due to installation work can be decreased because the quantity of removal soil is little. The advantage on vertical bearing capacity of spiral pile has been shown steadily on in-site loading test. However, the mechanism of bearing capacity of spiral pile on vertical load has not clarified yet. To spread this structural material for pile foundation in the future, it is necessary to prove pile’s superiority on bearing capacity. In this paper, to demonstrate the basic potential of bearing capacity of spiral pile, model test conducted on static penetration test. Three types of model piles, a plate pile, a tube pile and a spiral pile are used in this study to compare the bearing capacity. As other approach of grasp the mechanism of the bearing capacity of pile foundation, the internal alteration of model ground was observed using an industrial X-ray CT scanner. Because the shape of spiral pile is not axial symmetry, it is difficult to conduct the model test on 2-Dimensional condition. The X-ray CT scanner is a suitable apparatus to observe the alteration of internal ground on 3-Dimensional condition. There are many researches using X-ray CT scanner on observation of surrounding ground by different shape piles ( column, cone, tube, plate pile, etc.) on static penetration test (Otani 2004), (Taenaka 2007), (Kikuchi 2008). In this paper, the industrial X-ray CT scanner used to compare the soil density variation surrounded by the spiral pile with current study to grasp the qualitative character.

## 2. EXPERIMENTAL OUTLINE

Figure 1 shows model piles and details of spiral pile. Size of the aluminium plate pile is 20 mm width and 3 mm thickness. The spiral pile was made from plate bar. The plate bar was twisted in which 1 pitch is 65 mm and the twisted part is 140 mm. Size of the tube bar is 20 mm outer diameter and 1 mm thickness. The bottom area of all model pile is same (60 $mm^2$). The aluminium cylindrical soil box was used which has the following dimensions: 140 mm internal diameter and 430 mm height. Dry *Toyoura* sand ($D_{50}$=0.175 mm) was used for the model ground. Dry sand was packed in soil box by raining method as 80% relative density. The experiments were conducted on two phases of static penetration. The first phase as the pile foundation was installed into the ground. The second phase simulated that a force exerted on pile head as loading weight. The load and penetration depth were measured at the pile head. The velocity of penetration is 20 mm/min on installation phase and 3.6 mm/min on loading phase. Figure 2 shows summary of the test procedure. In this study, the static penetration tests were compared with the different shaft rotate condition at the pile head. The shaft rotate condition is below. 1) Locked rotate condition: The pile was fixed with shaft holder. 2) Free rotate condition: The spiral pile can rotate smoothly without shaft holder friction. 3) Forced rotate condition: The spiral pile was given the rotation by hand on some “rotate ratio”. The “100%-rotate ratio” means that during the installation every section of the spiral pile would go through the ground at the exact same position. Thus, the pile would turn one time (360°) during one-pitch installation. The test conditions on installation and loading phase will abbreviated like “Free-Free”. That means free rotate installation and free rotate loading condition. Figure 3 shows state of X-ray CT scanning of model ground. At first, CT scanning of model ground was done for check the initial condition. Then, spiral pile was installed in which the total depth of 140 mm. And then, scan it again for check the alteration of model ground after pile installation. The configuration

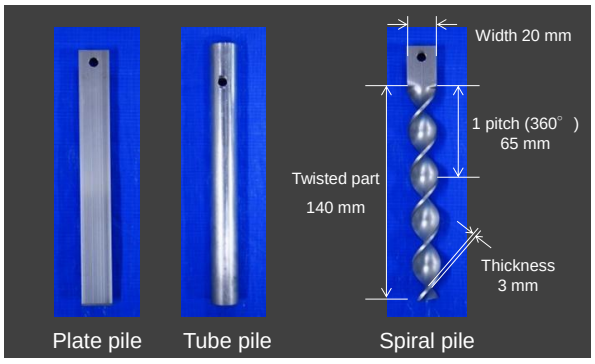


Figure 1: Model piles and details of spiral pile

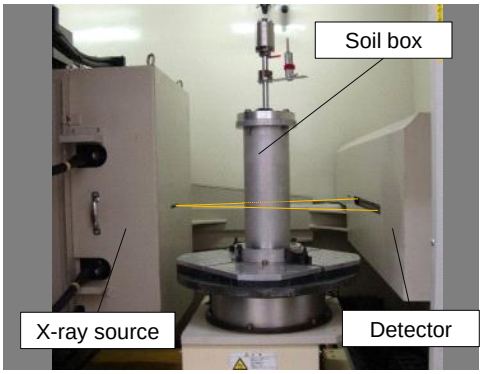


Figure 3: State of X-ray CT scanning

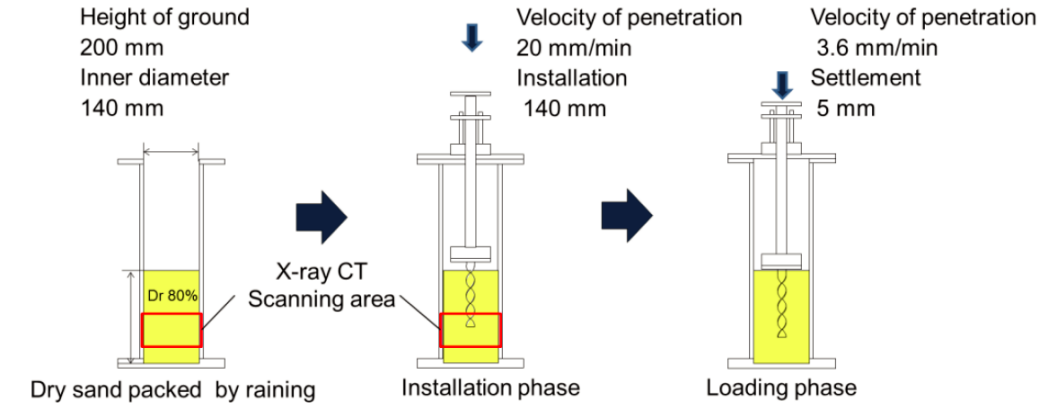


Figure 2: Summary of the test procedure

of X-ray CT scanning was 200 kV of voltage, 3 mA of current, 2 mm thickness of X-ray beam and a resolution of 2048 ×2048 voxels in each slice image.

## 3. RESULTS AND DISCUSSION

### 3.1. Loading test results

The relationship between pile head load and penetration depth is shown in Figure 4. At the phase of installation of model pile, plate pile generated smallest penetration resistance. Tube pile and spiral pile on locked-rotate condition generated largest resistance. The spiral pile on free-rotate condition and 100%-rotate ratio condition generated small resistance compare with tube pile. Especially, 100%-Rot condition generated resistance lower than half of tube pile at the 140 mm depth. On the other hand, at the loading phase, the increasing rate of head load becomes larger and larger in order of rotate condition of spiral pile, Locked-Locked, Free-Locked, 100%-Rot-Locked. It has been surprisingly found that 100%-Rot-Locked spiral pile generated resistance larger than tube pile at the 3 mm settlement on loading phase. The 100%-Rot condition was inhibited penetration resistance and generated large bearing capacity more than historical increasing rate of penetration resistance. There is a good chance of the spiral pile will be an “Easy installation and have large bearing capacity” foundation, if the shaft has been given the optimal rotate on installation of pile and the shaft rotation has been locked on loading phase.

### 3.2. X-ray CT images

As mentioned previously, CT image is constructed by a large amount spatial distribution of the CT values. Figure 5 shows vertical cross sectional CT image around the spiral pile that was penetrated on free-rotate condition. From this image, a low density area exists around the piles, and it is confirmed that the size of low density area is not equal along the pile longitudinal direction. Although free-rotate condition on install phase, it was not occurred enough rotation such as 100%-rotation in this case. It is reasonable to think that the disturbed area were arose surrounding pile because of the relative displacement of the pile between soil. Figure 6 shows comparison of disturbed area around the pile on different rotate condition. Very low density area is continuously existed as column shape around the spiral pile on 50%-Rot and 200%-Rot condition. In contrast, there is a little low density (disturbed) area along the pile surface on the 100%-Rot condition. It seems that these low density area strongly associate with the vertical bearing capacity as the pile foundation.

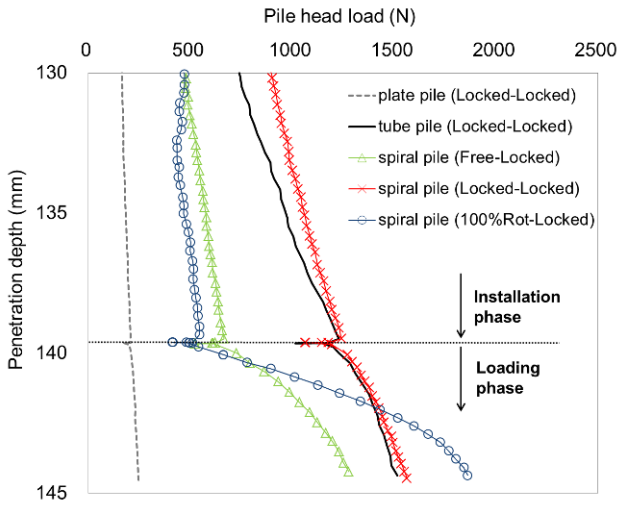


Figure 4: Relationship between pile head load and penetration depth

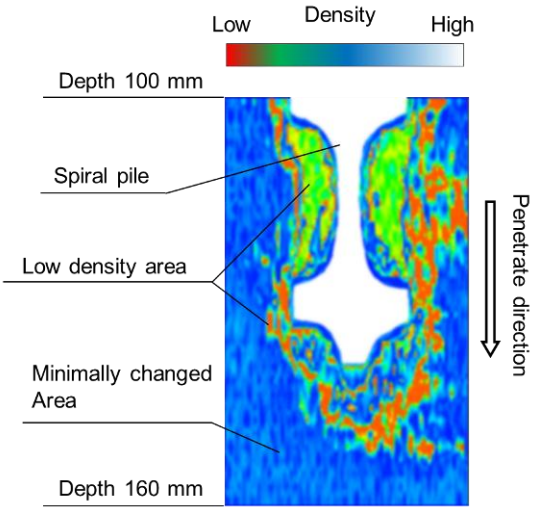


Figure 5: Vertical cross-sectional CT image (free rotate penetration)

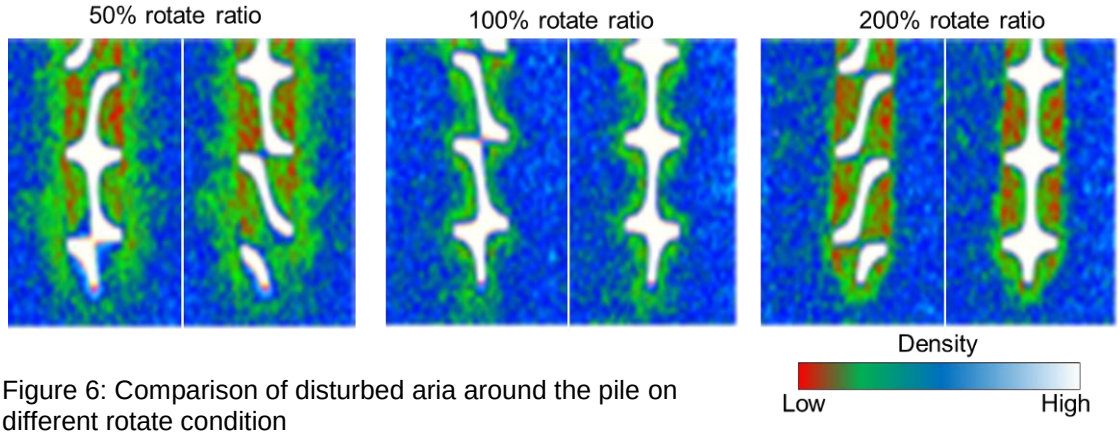


Figure 6: Comparison of disturbed aria around the pile on different rotate condition

## 4. CONCLUSIONS

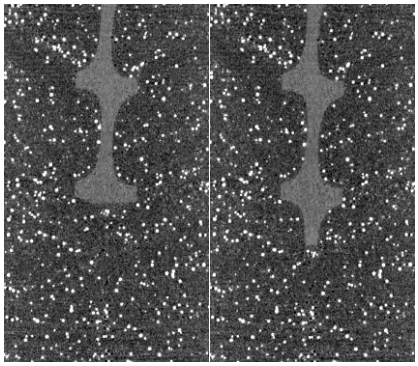

Figure 7: Observation of particle displacement on stepwise pile penetration test using Micro-focus X-ray CT image

These results obtained in this paper are summarized as follows: 1) Shaft rotate condition has a significant impact for the penetration resistance and vertical bearing capacity of spiral pile. The condition of optimal rotate inhibit penetration resistance and generate large bearing capacity more than historical penetration resistance with a few settlement on load. 2) The X-ray CT scanner is a powerful and effective apparatus as observation the internal ground alteration on penetration test of peculiarity shape pile such as spiral pile. The disturbance area of the surrounding ground at the model pile could be observed on CT images.

Future research, relationship between bearing capacity and rotation ratio will be particularly examined on controlled (the pile intrusion and rotation rate) model test. For investigate the mechanisms of the bearing capacity of the spiral pile, we will use the high-resolution Micro-focus X-ray CT Scanner in these experiments. It makes possible to distinct the individual sand particles in the model ground. Figure 7 shows the preparative experimental CT images on stepwise pile penetration test. The model ground deformation will be analysed from these images.

## 5. REFERENCES

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