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MPS-CAE SIMULATION ON DYNAMIC INTERACTION BETWEEN STEEL CASING AND EXISTING PILE WHEN PULLING OUT EXISTING PILES

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ABSTRACT: Many urban areas in Japan are located on soft ground and there are numerous buildings with pile foundations. Therefore, when dismantling a building, it is necessary to remove the piles (existing piles) remaining in the ground that are designated as industrial waste. One method of removing the existing piles consists of crushing and removing the piles, but there is a problem of vibrations and noise. Therefore, in many existing pile-drawing methods, the outer circumference of the pile is drilled by a steel casing, and the existing pile is pulled out by cutting the boundary between the pile and the surrounding ground. When pulling out an existing pile that exists diagonally, due to the pressure in the soil or an error in the construction, it has been confirmed that the steel casing follows the sloped pile when inserted into the ground. However, the dynamic mechanism of this phenomenon is unknown because the situation in the ground cannot be observed visually. In this study, therefore, an MPS-CAE simulation will be used to clarify visually and quantitatively the dynamic mechanism along an existing pile in which the steel casing is inclined when inserted into the ground, which occurs at actual sites.

Keywords: Dynamic interaction, Existing pile, MPS-CAE, Pulling out, Steel casing

1. INTRODUCTION

In Japan, accompanying periods of rapid economic growth came a great increase in the demand for offices and commercial facilities as well as for the construction of high-rise buildings that could effectively utilize narrow land. However, it is thought that the aging of those structures built in the same period will be concentrated, and that the demand to rebuild those structures will increase. In addition, disaster prevention awareness has been raised among people due to the Tohoku region Pacific offshore earthquake that occurred on March 11, 2011, in addition to a Tokyo metropolitan area earthquake, a Tokai earthquake, a Tonankai earthquake, and a Nankai earthquake that are said to have a high probability of occurrence. It is thought that this awareness is increasing the demand for the rebuilding of aging structures. Furthermore, the increase in the demand for rebuilding structures is accelerating not only because of deterioration, but also because the number of facilities are being reduced due to obsolescence and a decline in population.

Many urban areas in Japan are located on soft ground and there are numerous structures with pile foundations. Therefore, it is necessary to remove not only the existing structures, but also the existing piles that support the structures, in order to newly utilize the land. In addition, because existing piles are treated as industrial waste that is generated as a result of business activities and defined by the Waste Disposal Act, it is a problem to just leave the piles in the ground [1], [2], [3]. Furthermore, in land sale transactions and so on, the problem of a “hidden trap” has actually occurred. Thus, it can be said that the removal of existing piles is essential [1], [2], [3].

Among the methods for removing existing piles, one method consists of crushing and removing the piles with a rock auger. In this method, the friction between the pile and the surrounding ground is eliminated by a cylindrical steel casing [1], [2], [3]. However, vibrations and noise are generated during the construction work, which often create big problems. Furthermore, with these methods, there are cases when the pencil part and the flange at the tip of the pile cannot be removed, which means that industrial waste is left in the ground. Thus, it can be said that these methods pose problems for the environment.

Therefore, the pulling out of piles is now being adopted at many sites. At the beginning of the work for pulling out a pile, the outer periphery of the pile is drilled with a steel casing. At this time, however, the situation in the ground cannot be visually checked, so various examinations have to be carried out to confirm the inside situation. However, because many on-site surveys cannot be performed, due to time and money restraints, computer-based

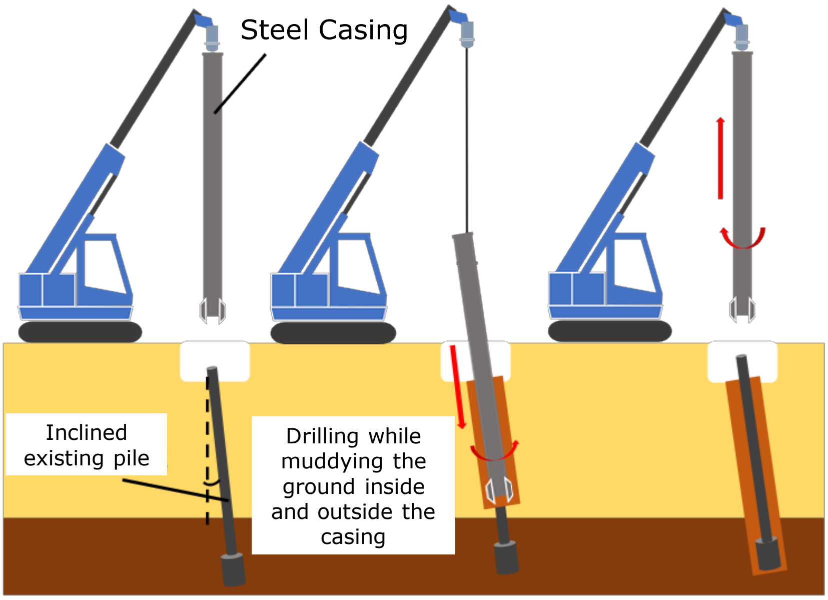

Fig. 1 State of muddy water on the ground

simulations are being used for visual and efficient evaluations.

In this study, the authors will clarify the mechanism of the behavior that occurs at an actual site, where the steel casing follows the existing pile when the steel casing is inserted into the ground, by verifying the behavior of the ground and the pressure distribution using MPS-CAE [4], [5].

2. ANALYSIS CONDITIONS IN MPS-CAE

2.1 Outline of MPS-CAE on Steel Casing Drilling

In the case of removing an existing pile, the inside of the steel casing and the surrounding ground become full of muddy water because water is discharged from the lower part of the steel casing while penetrating the steel casing (see Fig. 1).

In this analysis, the authors set the state of the existing pile area, up to the depth of 15,000 mm, to be filled with muddy water particles, and carried out the analysis to make the rotational penetration of the steel casing to the depth of 10,000 mm. In addition, the existing pile in this analysis has a foot protection part at a depth of 16,100 mm or deeper, and the steel casing is not penetrated to the foot protection part at the lower end of the existing pile. In this study, two patterns in which the inclination angle of the existing pile is inclined 0° and 2° from the vertical direction are analyzed.

2.2 Parameter Setting for Muddy Water Particles

Table 1 shows the material parameters of the muddy water particles in MPS-CAE. The parameter setting was performed with the muddy water to be

Table 1 Material parameters of muddy water particles

	Density (kg/m³)	Plastic viscosity (Pa·s)	Yield value (Pa)
Muddy water	1200	6.92	10

analyzed as the Bingham fluid. Regarding the density and the plastic viscosity, the density of the mud collected from the hole of the existing pile at the site of the removal of the existing pile was measured, and the plastic viscosity was set by measurement using a Brookfield's B-type viscometer. In addition, the yield value gave the measurement result of 10 Pa for the yield value of drilling the mud obtained by measurement with a double-cylinder type rotational viscometer from previous researches [1], [2], [3].

2.3 Modeling Method of Existing Piles and Steel Casing

The existing piles and steel casings were created according to the actual dimensions using 3D-CAD based on the shape of the steel casing used at a certain field site and the removed existing piles. From Figs. 2 and 3, the existing piles in this analysis were existing piles with a foot protection part, and the steel casing was cylindrical. In addition, the steel casing was set as the wall boundary, and the characteristics were determined not by the material parameters, but by the contact angle between the liquid and the wall boundary. According to previous researches, the contact angle between the water and the stainless steel was 45° to 58°, and the analysis results when the contact angle was set to 45° and

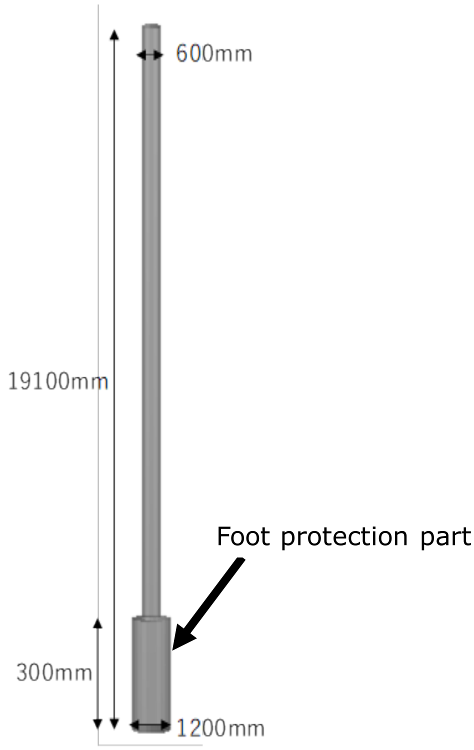

Fig. 2 Existing pile

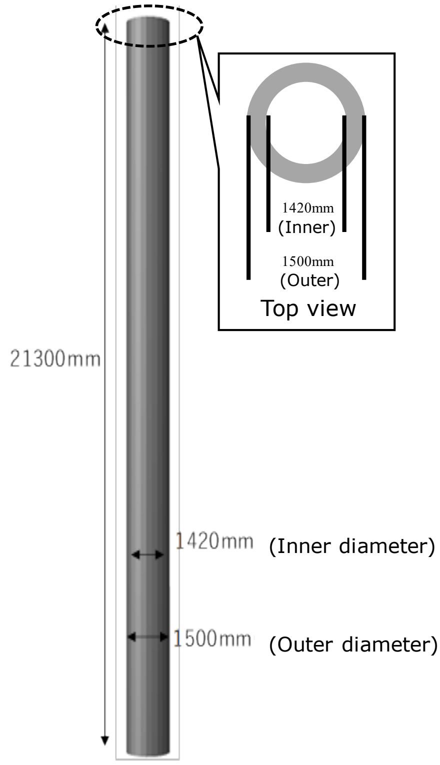

Fig. 3 Steel casing

58° did not show a large difference. The authors reproduced the steel casing as 50° [6], [7]. Table 2 shows the penetration speed and the rotational speed of the steel casing.

3. MPS-CAE SIMULATION FOR DRILLING OF STEEL CASING

3.1 Velocity of Muddy Water Particles According to Drilling Depth

The cross section, color-coded by the vertical velocity at depths of 5 and 8 m, is shown in Fig. 4. The particles close to red have velocity components in the vertical upward direction, and the particles close to blue have velocity components in the vertical downward direction. From Figs. 4 (a) and (c), in the case of an inclination angle of 0°, the particles with similar velocity components are evenly distributed, but from Figs. 4 (b) and (d), in the case of an inclination angle of 2°, the distribution of the velocity of the muddy water in the vertical direction was confirmed on both sides of the existing pile.

3.2 Pressure Gradient Acting Between Muddy Water Particles According to Drilling Depth

The cross section, color-coded by the pressure acting at depths of 5 and 8 m, is shown in Fig. 5. From Figs. 5 (a) and (c), when the inclination angle is 0°, almost the same pressure is received as a whole, and no pressure gradient is generated.

Table 2 Parameters of MPS-CAE steel casing

	Rotational speed (rpm)	Penetration speed (m/min)
Steel casing	15	0.5

However, according to Figs. 5 (b) and (d), when the steel casing is inserted into the existing sloped pile, the pressure increases in the process of narrowing the gap between the pile and the steel casing, and the pressure decreases in the process of widening the gap. This is the pressure gradient. It is thought that this pressure gradient is caused by the muddy water rotating together under the influence of the rotation of the steel casing.

Co-rotation is a phenomenon in which they (in this case, the steel casing and the muddy water) move together due to the frictional force generated between the steel casing and the muddy water. From Figs. 4 and 5, when the existing pile is inclined, the muddy water particles inside the steel casing show different behavior compared to the case of 0°. It has been confirmed that the muddy water particles have a vertical upward velocity at high pressure and a vertically downward velocity at low pressure, in addition to co-rotation by the rotational force of the steel casing. This is due to the fact that the muddy water particles subjected to high pressure try to

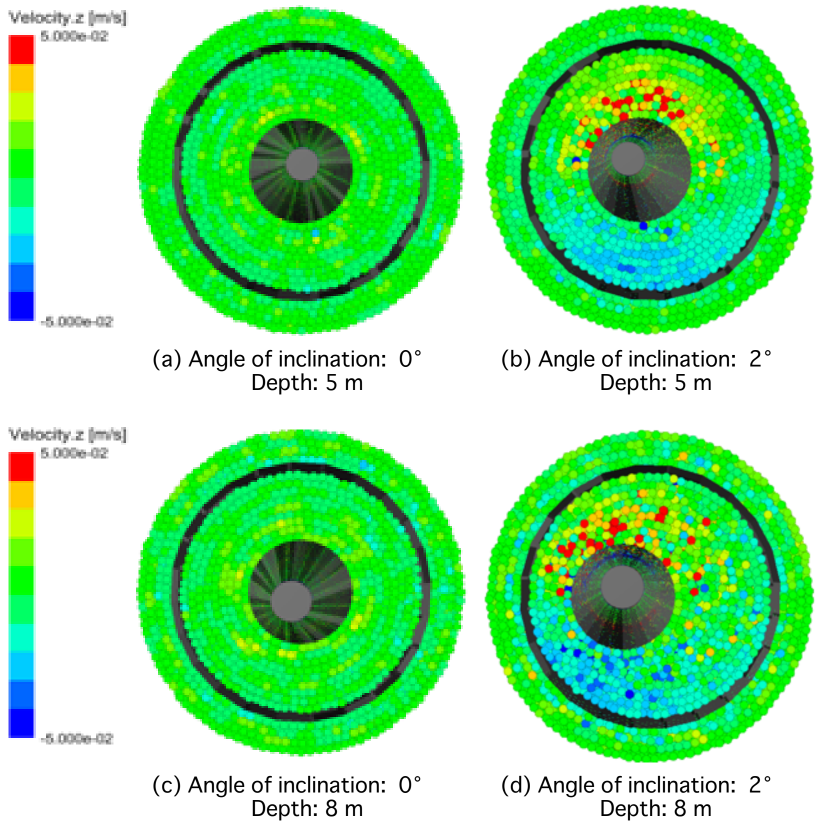

Fig. 4 Velocity of muddy water particles (vertical direction)

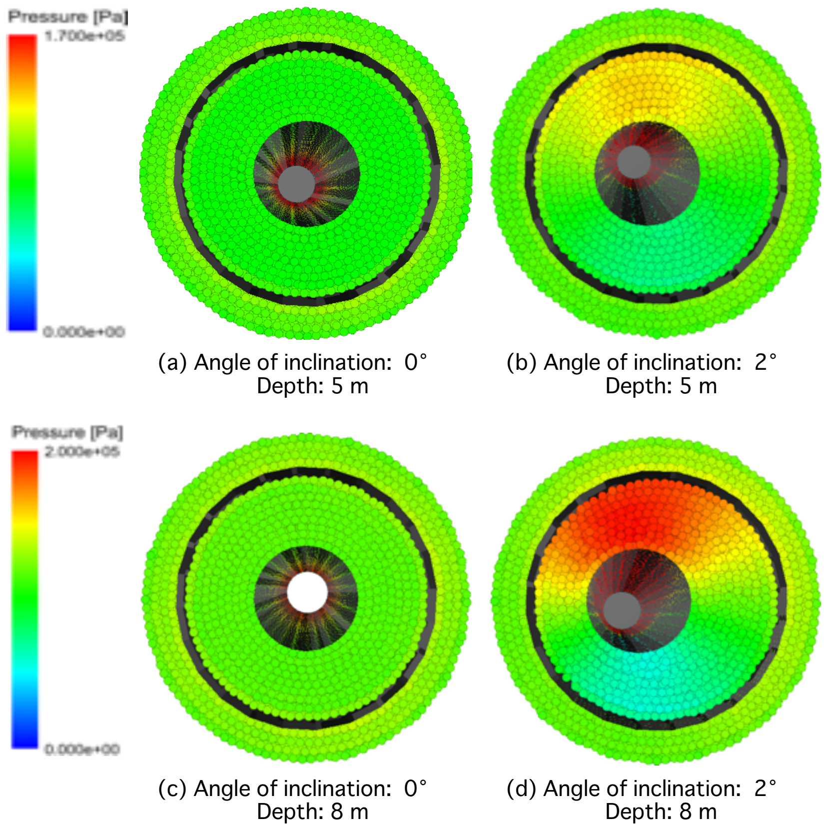

Fig. 5 Pressure gradient of muddy water particles

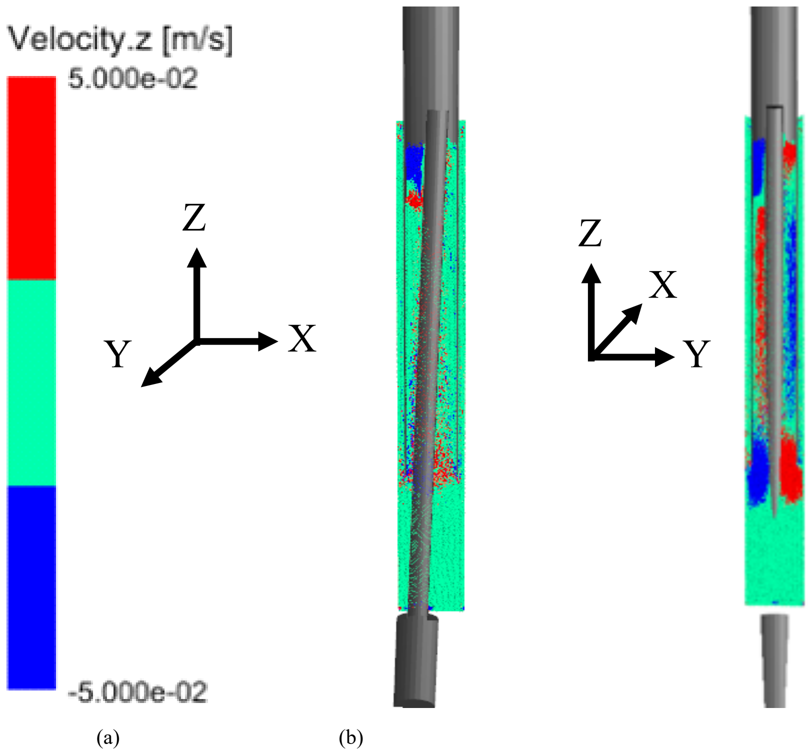

Fig. 6 Vertical velocity of muddy water particles (vertical cross section)

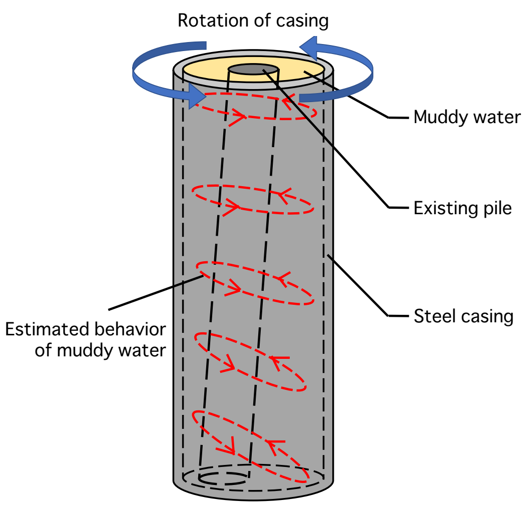

Fig. 7 Estimated behavior of muddy water particles

move in a spiral trajectory toward the released ground surface (upward direction) so that the pressure gradient disappears.

4. MECHANISM OF STEEL CASING FOLLOWING INCLINED EXISTING PILE

The vertical cross section obtained by cutting the analysis target in the X-Z plane is shown in Fig. 6 (a), and the vertical cross section obtained by cutting in the YZ plane is shown in Fig. 6 (b). The red particles have vertically upward velocity components, and the blue particles have vertically downward velocity components. From Fig. 6 (b), it can be understood that the vertical velocity of the muddy water is different on the two sides of the existing pile. First, due to the rotation of the steel casing, the muddy water inside rotates together. When the existing pile is inclined, the gap between the steel casing and the pile changes as the penetration depth of the steel casing gets deeper, and the pressure gradient shown in Figs. 5 (b) and (d) occurs. That is, in addition to the rotational speed of the steel casing, due to the co-rotation of the steel casing, it has a vertically upward velocity at high pressure and a vertically downward velocity at low pressure, resulting in the pressure gradient of the mud in the steel casing shown in the figure. As shown in Fig. 7, spiral co-rotation occurs. In addition, the steel casing is considered to be along an inclined pile so that the pressure gradient is eliminated.

5. CONCLUSIONS

The aim of this study was to clarify the mechanism of the behavior of a steel casing along an existing inclined pile confirmed in the field by performing an MPS-CAE analysis. The MPS-CAE analysis was performed by inserting a steel casing into the ground to an inclined existing pile, and then the behavior and the pressure gradient of the muddy water mainly in the casing were visually represented. It was possible to deduce the mechanism of the behavior of the casing along the pile, which has not been elucidated yet, by separating and examining the behavior of the mud particles and the pressure gradient at each depth.

Up to now, the co-rotation phenomenon of muddy water has been viewed in a negative manner as something to be avoided in construction works related to the ground. There are many cases where existing piles remain in an unhealthy condition, as shown in Fig. 2. If cracks and joints are not properly joined, penetration can occur while rotating the casing, which may cause further damage to the piles. That is, at the time of the casing penetration, the lower part of the existing pile is not yet cut off. It is fixed to the surrounding ground. However, the upper part is forced by the rotation of the casing due to the co-rotation of the muddy water, resulting in the existing pile being in a twisted condition and prone to breakage. In this research, however, it is concluded that the phenomenon whereby the casing follows the sloped existing pile cannot occur because there is no pressure gradient if the muddy water does not rotate together and if the muddy water does not move vertically due to it.

(1) By using MPS-CAE to visually represent the behavior and pressure gradient of the muddy water particles in the steel casing, it is possible to simulate the drilling of the steel casing in existing pile drawing-out work.
(2) The phenomenon along an existing pile, by which the steel casing is inclined, causes spiral co-rotation due to the influence of the pressure gradient of the muddy water in the steel casing, and the steel casing is gradually inclined along the pile in which the pressure gradient disappears.

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