An Investigation of Effect of Distance and Shape of Pile on the Displacement of Gag Pile by 3D FEM Analysis

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ABSTRACT

Press-in 3D FEM analyses were carried out to examine the behavior of a buried gas pipe and the soil ground during the press-in installation of a sheet pile. The displacement of a buried gas pipe was set as the parameter to investigate the gas pipe behavior. In the first analytical model, both of the sheet pile and the gas pipe were modeled as rectangular solid structures and the horizontal distances between a sheet pile and a buried gas pipe were arranged in 100mm, 200mm, 500mm and 1000mm. In the second model, not only the rectangular shape but also a standardized shape (SP-3) based on the real model was made as a sheet pile. In addition, 6 series of modeling were prepared in terms of the setting direction of the SP-3 sheet pile and the horizontal direction between the sheet pile and the gas pipe. In order to clarify the behavior of the inside ground, strain contour diagrams were shown in addition to the displacement of the gas pipe. Through these two types of analyses, the effect of the press-in installation to underground structures was discussed.

Key words: *press-in method, SP-3 sheet pile, displacement of gas pipe, 3D FEM analysis*

1. Background

1.1. Place

The Press-in method enables construction in narrow space and it is widely used in urban areas, so the number of neighboring constructions is increasing. Threfore, it becomes important to understand the behavior during the press-in execution and evaluate the influence on the existing structures in the ground to avoid the damage of them.

A field experiment with a gas pipe has been conducted for the purpose of showing some conditions quantitatively which preserve the soundness of existing structures (Yamakawa, 2014; Giken *et al.*, 2014). The main subjects of this measurement were the horizontal and vertical deflections of a gas pipe under the different horizontal distances between the steel sheet pile and the gas pipe from 100mm to 1106mm when the steel sheet piles were pressed into the ground up to 1.5m in depth. **Fig. 1** shows the layout of this experiment. Press-in construction was done from the left to the right side of **Fig. 1**. The gas pipe made of polyethylene was laid underground 1.0m in depth from the ground level in advance and its both ends were fixed not to move horizontally except for the rotation (**Fig. 2**). Through this experiment, the maximum deflection was about 7mm and the maximum external force applied to the circumferential direction was about 50kPa when the horizontal distance between the steel sheet pile and the gas pipe was 100mm.

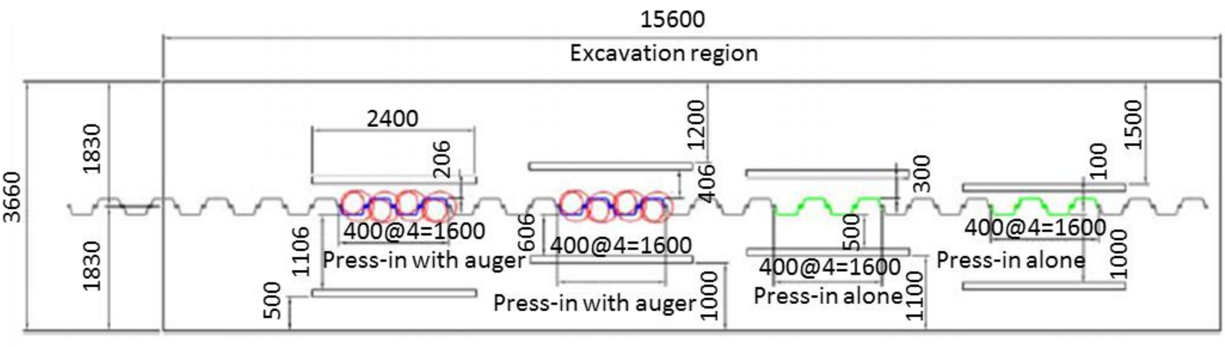


Fig. 1 Experimental layout (unit: mm)

Fig. 2 State of gas pipes and press-in construction

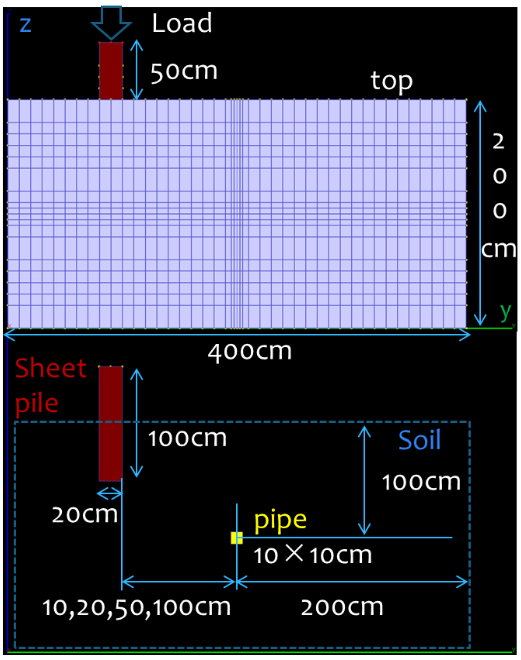


Fig. 3 Analysis model

If the concentrated load is applied to the center of this gas pipe, the breaking deflection is around 440mm. In this viewpoint the safety factor against deflection is about more than 60. Moreover, if the uniform distribution external force is applied to the circumferential direction, the breaking external force is around 200kPa. Here, the safety factor against the circumferential deformation is about more than 4. As a result of this experiment, the gas pipe is not damaged when the horizontal distance between the steel sheet pile and the gas pipe is more than 100mm (in cases of pressing-in individually) or 200mm (in cases of pressing-in with auger).

Though this experiment shows some clear numbers and evaluation, the general applicability is not enough because of its specific experimental qualifications. To understand the behavior in the ground more clearly, numerical simulation becomes a useful approach. In this study, therefore, the underground gas pipe displacement was set as the main subject to measure when the pile was pressed-in beside it. Then, the relationship between the gas pipe displacement and the horizontal distance between the steel sheet pile and the gas pipe, and the soil behavior under pressing-in several different types of steel sheet piles was investigated by using 3D FEM analysis (Maekawa *et al.*, 2003). Even though this study is based on the above field experiment, the aim is not to follow the experimental result on the analysis but to get qualitative tendency of the behaviors.

2. Effect to the horizontal distance between steel sheet pile and gas pile

2.1. Analysis model

Fig. 3 shows the analysis model from the view of X axis. Each of the three materials, soil, gas pipe and sheet pile, was modeled as a rectangular solid and both soil and gas pipe were modeled as elastic bodies, elastic 1 and elastic 3 (**Table 1**). Size of the each model is as follows;

Soil: (x,y,x)=(3000,4000,2000mm),

Gas Pipe: (x,y,z)=(2400,100,100mm),

Sheet Pile: (x,y,z)=(600,200,1000mm).

The bottom and side surfaces of the soil ground were fixed in every directions. The gas pipe was placed in the soil. 100mm displacement in the minus Z direction was given in 10 steps to the sheet pile which was already laid underground by 500mm in depth. Interfaces between the pile and soil emements are fixed and move together for the simplicity. The papameter of the analyses are the horizontal distances between the sheet pile and the center of gas pipe that are 100, 200, 500, and 1000 mm.

2.2. Results of analyses

Fig. 4 shows the maximum horizontal and vertical displacement of the gas pipe when the horizontal distance between the sheet pile and the gas pipe was changed from 100, 200, 500, and to 1000mm. The horizontal displacement increased from 100mm to 500mm in horizontal distance and the maximum horizontal displacement was about 6mm in 500mm. On the other hand, the vertical displacement showed that it became inversely proportional consistently from 100mm to 1000mm in the horizontal distance. In other words, the closer the distance between the sheet pile and the gas pipe was, the more the gas pipe was affected by the sheet pile in vertical direction. **Fig. 5** shows the relation between the horizontal and the vertical displacement of the gas pipe. If each point is connected to the origin, each line shows the displacement vector of the gas pipe. The bigger the distance between the sheet pile and the gas pipe was, the smaller both the slope and the length of the displacement vector were.

3. Effect of the shape of sheet pile

3.1. Analysis model

In order to examine the influence of the shape and the positional relation of the sheet pile, 6 types of analyses were carried out (**Fig. 6**). In **Fig. 6**, No.1 and

Table 1. Material properties for analysis

Material	Young’s modulus
Soil (elastic 1)	7.27 MPa
Soil (elastic 2)	7.27 MPa
Gas pile (elastic 3)	0.73 MPa
Gas pile (elastic 4)	750 MPa
Sheet pile (steel)	206 GPa

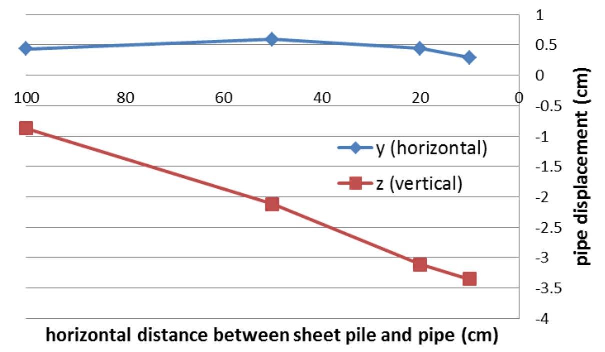


Fig. 4 Relationship between horizontal distance and pipe displacement

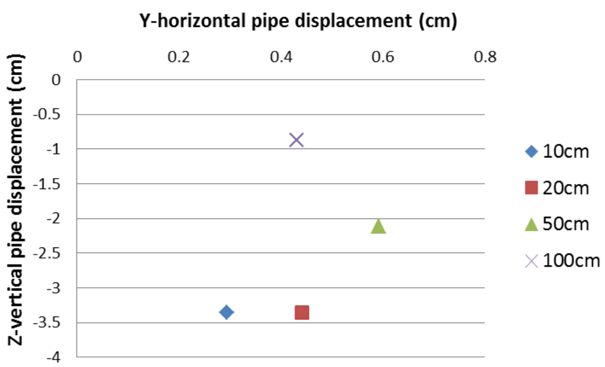


Fig. 5 Relation between horizontal and vertical pipe displacement

No.2 sheet piles were modeled as a rectangular solid, thickness t=13mm, length in the X axis direction L=300mm or 400mm, and the horizontal distance to the surface of the gas pipe d=200mm. The other No.3-No.6 sheet piles were modeled as steel sheet pile SP-3 shapes used at the actual site, L=400mm, t=13mm, h=125mm. The height of the sheet pile in the Z axis direction was 1000mm and its 500mm was already laid underground at first. Given the displacement of the sheet pile was 100mm in the minus Z axis direction and the press-in steps were 10. The size and restriction condition of the soil and pipe solid were the same as the second chapter, but the material properties of the soil and the gas pipe were changed to elastic 2 and elastic 4 to make the models close to the actual things (**Table 1**).

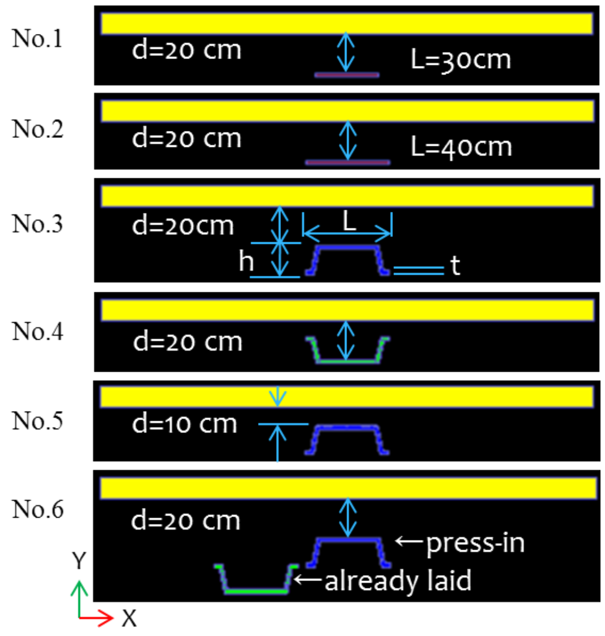


Fig. 6 Series of sheet pile modeling

3.2. Results and comparison

3.2.1. Rectangular shape and its length difference

Fig. 7(a) shows the comparison of the gas pipe displacement between No.1 and No.2 models. If the length of the sheet pile was bigger from 300mm to 400mm, both of the horizontal and vertical displacement became larger by 13% of No.1 displacement and the slope from the origin to two points corresponded to each other.

3.2.2. SP-3 shape and its direction difference

The difference of sheet pile shape between the rectangular (No.2) and SP-3 (No.3,4) is shown in **Fig. 7(b)**. In terms of the comparison between No.2 and No.3, the displacement of gas pipe of No.3 was bigger by 25% in horizontal displacement and 8% in vertical displacement than that of No.2. In regards to the comparison between No.2 and No.4, although the horizontal displacement decreased by 5%, the vertical displacement increased by 15% in No.4 compared to that of No.2. **Fig. 8** is a strain contour diagram of the YZ plane cut through the center of the sheet pile. Strains spread out on both sides of the sheet pile in No.2 model (**Fig. 8(a)**), however, strain spread mainly to the gas pipe side in No.3 model (**Fig. 8(b)**) or to the opposite side from the gas pipe in No.4 model (**Fig. 8(c)**). That is why the horizontal displacement of No.4 became smaller than that of No.2.

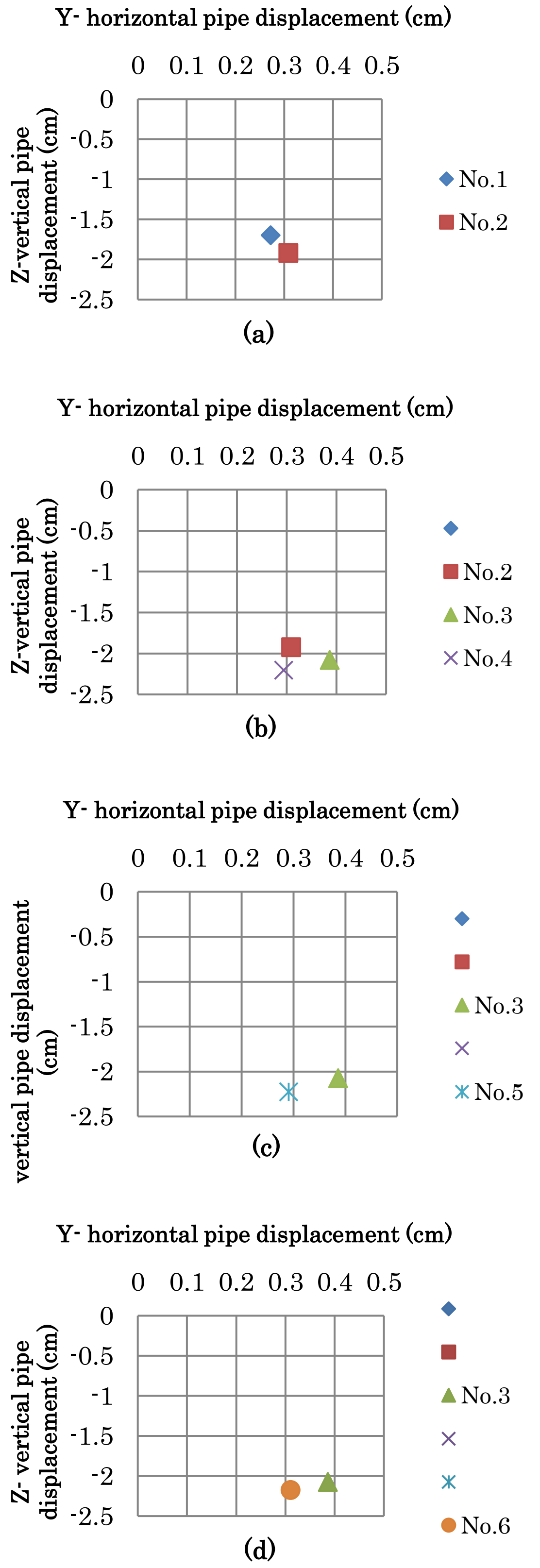
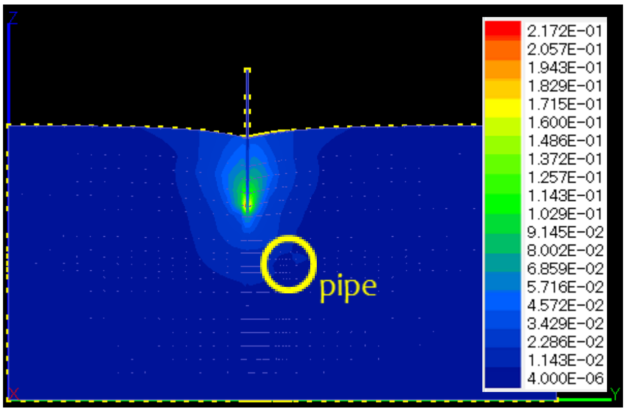
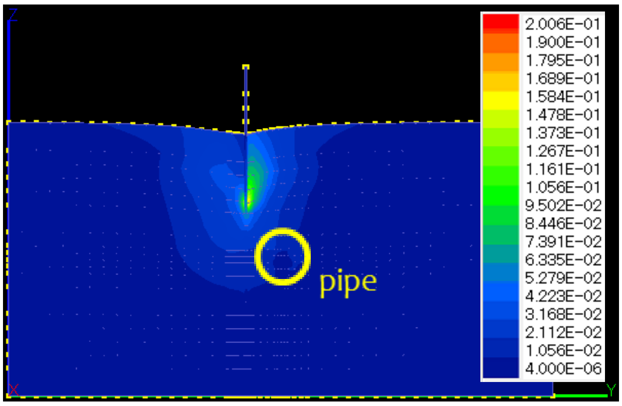


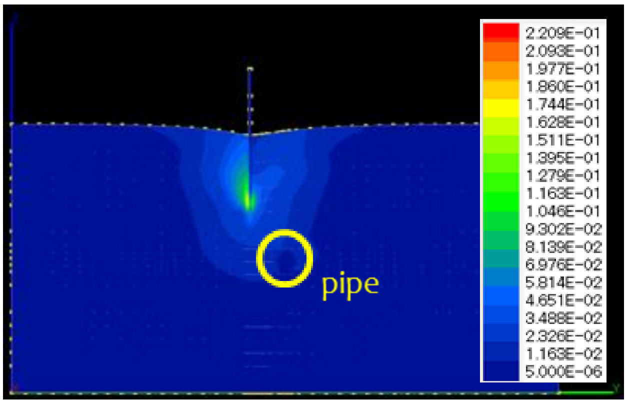
Fig. 7 Relation between horizontal and vertical pipe displacement



(a) No.2 model



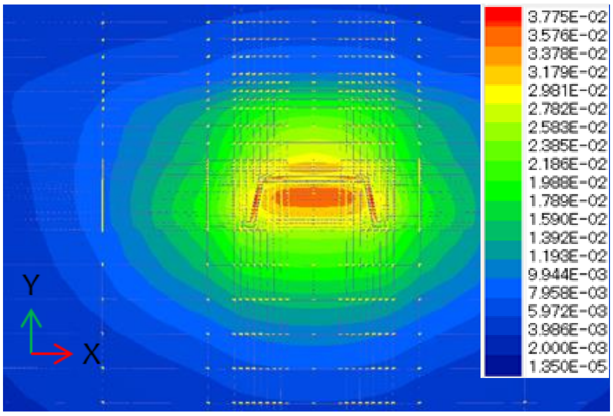
(b) No.3 model



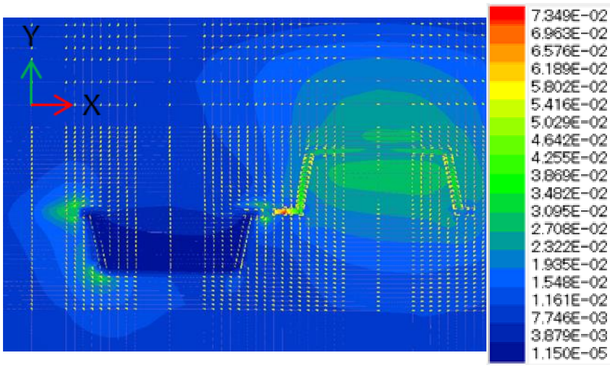
(c) No.4 model

Fig. 8 Strain contour disgram

It is possible to say that the wing parts of SP-3 sheet pile contribute to generating the horizontal displacement of gas pipe in No.3 or the vertical displacement of gas pipe in No.4 when the minimum horizontal distance between the wing parts and the gas pipe is taken into account.



(a) No.3 model



(b) No.6 model

Fig. 9 Strain contour diagram just under the bottom of sheet pile

3.2.3. Influence of the minimum horizontal distance and an existing sheet pile

The comparison between No.3 and No.5 according to the horizontal distance is shown in **Fig. 7(c)**. The results of No.5 was quite similar to the results of No.4. One possible reason is the similarity of the minimum horizontal distance between the sheet pile and the gas pipe.

Fig. 7(d) also shows that the results of No.6 was roughly the same with the results of No.4 and No.5. In No.6 model, the left sheet pile whose height was more than 1.5m had been laid underground 1.5m in depth before pressing-in the right sheet pile. **Fig. 9** are strain contour diagrams of the XY plane cut just under the bottom of the sheet pile after pressing-in. The way of the spread of soil strain of No.6 (**Fig. 9(b)**) was different from that of No.3 (**Fig. 9(a)**) due to the exsisting sheet pile.

4. Conclusions

The gas pipe displacement was measured when the steel sheet pile was pressed-in by 100mm from 500mm to 600mm in depth beside the gas pipe laid underground 1.0m in the depth by using 3D FEM analysis. In the first analysis that the horizontal distance between the sheet pile and the gas pipe was changed from 100mm, 200mm, 500mm and to1000mm, the smaller the horizontal distance was, the bigger the pipe displacement became. Besides, the horizontal pipe displacement reached the maximum value at the 500mm in horizontal distance. In the second analysis that the shape of the sheet pile and its direction were changed in several cases, the SP-3 shape sheet pile made the pipe displacement bigger than the rectangular shape in any case. Moreover, the lateral part of SP-3 shape produced strain spreads of soil ground toward the opposite side from the wing parts. So, in the case of SP-3 shape, the way of propagation of strain in soil ground was different from that of the rectangular shape.

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