Application of Under-pinning Pipe Jacking on Tunnel Auxiliary Construction

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出版情報：IOP Conference Series: Earth and Environmental Science. 861 (3), pp.032038-, 2021-10-27. IOP Publishing
バージョン：

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Abstract. When a new structure is constructed in an overcrowded underground space, it is necessary to consider how to reduce the impact of the new structure on the surrounding existing structures and the surrounding ground, and one of the methods is the under-pinning method using pipe jacking. The under-pinning method is a general term for the method to reinforce the lower part of an existing structure with piles and pipes in advance to reduce the impact of new construction on the existing structure and surrounding ground. In this study, various numerical analyses were carried out assuming that the under-pinning method using pipe jacking was applied to the case where a new structure was to be installed underneath the existing structure. As a result of comparison with the under-pinning method, it was clarified that the under-pinning method with pipe jacking suppressed the influence on the existing structure and the surrounding ground by supporting the overburden pressure above the pipe over a wide area. In addition, it was found that the combination of the under-pinning method with the pipe-roof method, in which pipes are placed on top of the new structure, is more effective to suppress the deformation of the surrounding ground around the new structure than the under-pinning method alone.

1. Introduction

Overcrowding is increasing in urban areas due to population growth and economic development. In particular, there are many tunnels and pipes buried underground for railroads, gas, telecommunications, water, and sewage [1]. Therefore, adjacent constructions of underground structures are increasing in the underground space of urban areas. In adjoining constructions of such underground structures, it is a problem suspected that the influence on existing structures becomes particularly large when constructing new structures. As a solution to reduce the influences, the pre-treatment by adopting pile foundation and ground treatment with grouting are introduced as the under-pinning technologies in some cases. The under-pinning technologies with pile have been adopted for the subway construction [2], shield tunnel construction [3, 4], and modification of the extisting foundations under the soft clay [5]. The costruction combined with micropiles and jet-grouting have been also reported as the actual construction example of under-pinning method [6].

In this study, the under-pinning method using the pipe jacking method is discussed to be applied. The application of pipe jacking technologies as under-pinning method is few discussed while it is considered to be an effective method in urban areas because it can be constructed without excavating the ground surface. The pipe jacking is also utilized as the reinforcement of the ground before the excavation of underground space such as tunnel [7], subway station [8], mine entry [9], and adjacent construction [10]. However, there are few adopted examples of the under-pinning method using the pipe jacking method, meaning that little knowledge about the influence of the method on the surroundings has been obtained so far. Therefore, the effect of the change in the construction pattern of pipe on the surrounding ground is studied in the case of the under-pinning method using pipe

jacking. The purpose of this study is to clarify the differences of deformation in surrounding ground when the pile support and the pipe jacking method is applied in the urban area of Tokyo. The finite element method is used for the prediction of deformation behavior of the surrounding ground during the under-pinning construction.

2. Pipe jacking

Pipe jacking is a technique to install an underground pipeline created by a drivage machine, which is used hydraulically from a starting shaft. The procedure of pipe jacking is to install jacks in the shaft, press-fit the existing pipe into the soil, excavate the soil from inside the pipe, carry out the excavation and the removal of the soil from the pipe, and bury the pipeline by adding the pipe sequentially. In the pipe jacking method, a drivage machine is set at the head of the pipeline and the pipes are jacked forward with the hydraulic jack, located at the starting shaft. Pipe jacking operates with pushing pipes, and the jacking force is transmitted through a pipe-to-pipe interaction to the excavating face. In the past, pipe burying was done by open-cut excavation, but in recent years, pipe jacking without excavating the ground surface has been widely used in urban areas because of the high density of buildings above the ground. One of the advantages of this method is that it does not affect the traffic during construction and damage the environment because it is categorized as non-excavation technology. Only shafts are drilled, there is less pollution, and the construction period is shortened [11]. In this study, a rectangular pipe with a larger effective area is used.

3. Under-pinning method

The under-pinning method is a general term for the method to control the impact on the existing structures and the surrounding ground when new structures are constructed. In general, it is used when a new structure is constructed directly underneath or close to an existing structure. Besides, it is often used in urban areas for tunnel construction such as subways and roads [12]. In this study, the under-pinning method, in which the existing structure is indirectly supported by pipes laid by the pipe jacking method, is adopted.

4. Numerical analysis

In order to investigate the applicability of the under-pinning method, numerical analysis is conducted using the three-dimensional finite element method. The analysis model is for constructing a new underground passageway directly under the existing structure as shown in Figure 1. The mechanical properties of soil and pipe used in this model listed in Table 1. The boundary conditions are as follows; the surface is free, the bottom is locked in vertical direction, and the side plane is locked in horizontal direction. For the analysis step, the new structure is constructed after the piles or pipes which played a role in under-pinning of the existing structure are constructed. In this study, the various parameters are investigated to evaluate the effectiveness of under-pinning method such as the amount of settlement, subsidence of the lower part of the existing structure, subsidence of the ground surface, and deformation of the surrounding ground of the existing structure.

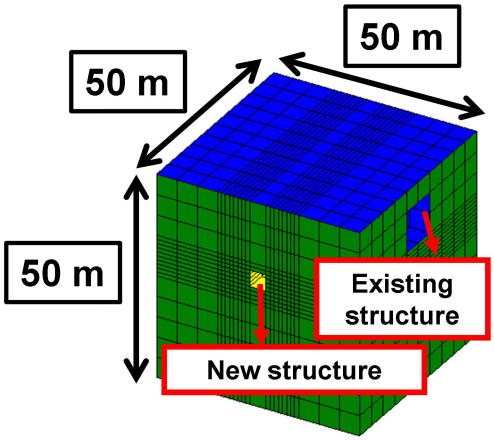


Figure 1. Analysis model (whole model)

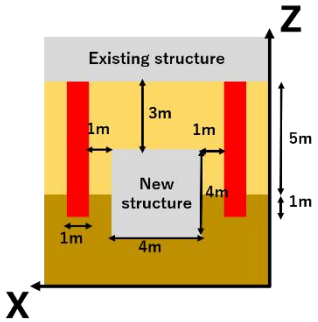
Table 1. Mechanical properties

	Soil	Pipe
Young's modulus (MPa)	20	23,500
Poisson's ratio (-)	0.4	0.2
Unit Weight (MN/m^3)	0.02	0.025

5. **Results and discussion**

5.1 Comparison of the pile and pile jacking

The effect of under-pinning method is discussed by using the model of the conventional under-pinning method and under-pinning method using pipe jacking. The outline of each model is shown in Figures 2 and 3.



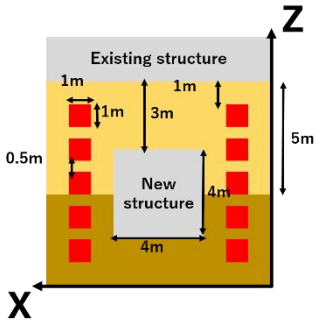


Figure 2. Piles support model (not using pipe jacking)

Figure 3. Pipe jacking model

Figure 4 shows the vertical deformation of the lower part of the existing structure. It can be seen that the vertical deformation of the two models is similar in the area between 20 and 30 m where the new structure is constructed. Therefore, the under-pinning method using pipe jacking is effective to reduce the deformation. Figure 5 shows the result of the deformation of the ground surface for both models. This figure shows that under-pinning with pipe jacking has a higher suppression effect than pile support because pipe jacking supports the ground surface more extensively than pile support.

Figures 6 and 7 show the vertical deformation of a vertical section in the center of the existing structure and 10 m away from the existing structure, respectively. From these figures, it can be seen that the under-pinning with pile support can reduce the deformation just below the existing structure while that of pipe jacking suppresses the settlement of the existing structure away from it.

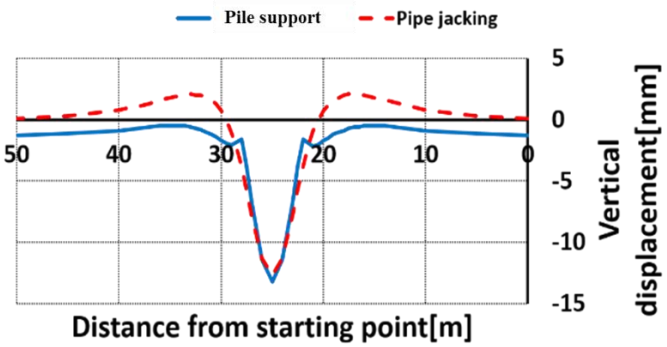


Figure 4. Deformation of the lower part of the existing structure (comparison of using piles support and pipe jacking)

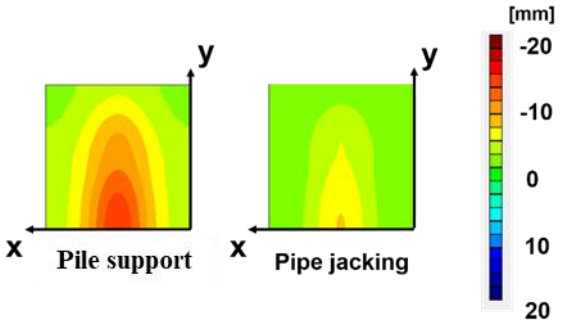


Figure 5. Deformation of the ground surface (comparison of using pile support and pipe jacking)

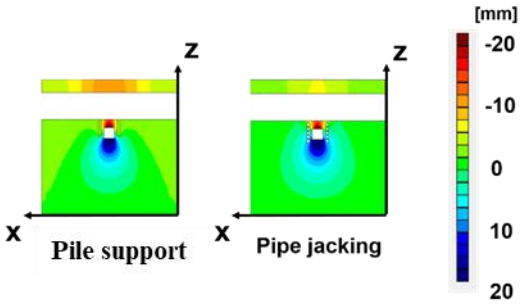


Figure 6. Vertical deformation of a vertical section near the center of the existing structure (comparison of using pile support and pipe jacking)

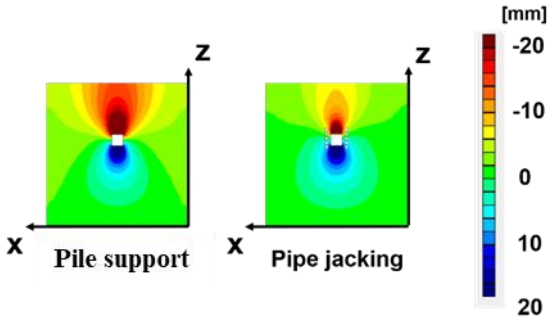
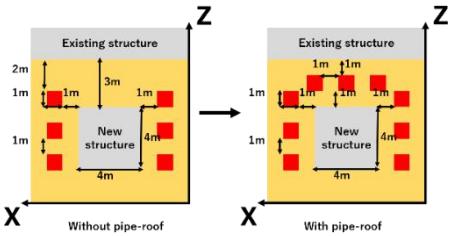


Figure 7. Vertical deformation of a vertical section near 10 m away from the existing structure (comparison of using pile support and pipe jacking)

5.2 Application of pipe-roof method

In addition to the under-pinning method using pipe jacking, the pipe-roof method is assumed to be used to further reduce the deformation. The pipe-roof method is to construct the new pipes between the existing structure and the new structure like a roof as shown in Figure 8 [13].



F**igure 8.** Application of pipe-roof method

Figure 9 shows the vertical deformation of the lower part of the existing structure. According to this result, there is no significant difference with/without pipe-roof. This is because the concrete structure of the lower part of the existing structure already acts as a pipe roof.

On the other hand, as shown in Figure 10, a wide range of subsidence control is observed in the case of the pipe-roof. In addition, as shown in Figure 11, the vertical deformation of the vertical section settlement at a distance of 10 m from the existing structure with the pipe-roof has a large effect on settlement control in the upper part of the ground surface where the pipe-roof is installed. Therefore, it is shown that the pipe-roof can further reduce the deformation.

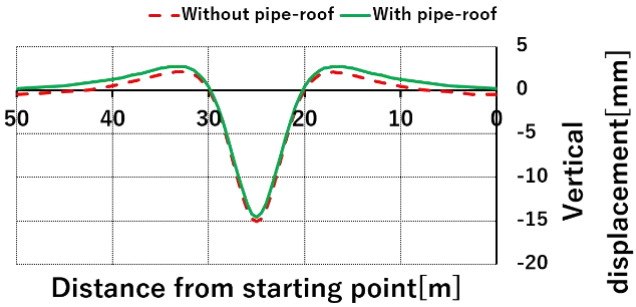
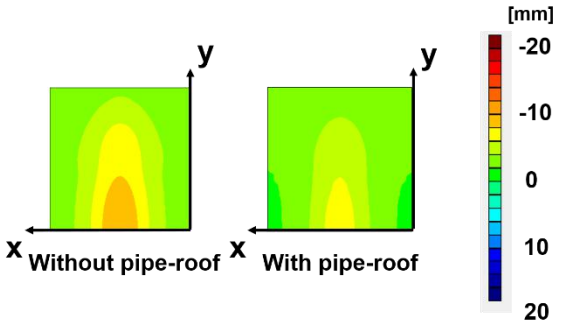
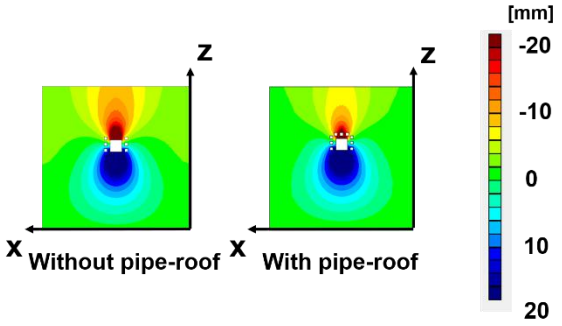


Figure 9. Deformation of the existing structure (application of pipe-roof method)



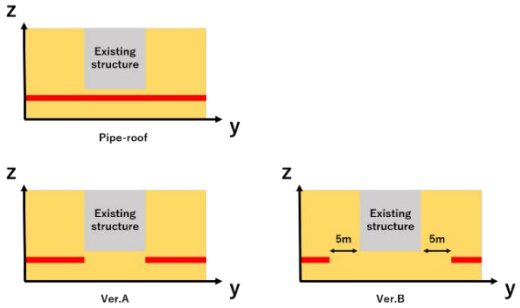
F**igure 10.** Deformation of the ground surface (application of pipe-roof method)



F**igure 11.** Vertical deformation of a vertical section near 10 m away from the existing structure (application of pipe-roof method)

5.3 Influence of pipe length

Since the ground surface of the upper part of the existing structure is already indirectly supported by the existing structure, the construction method of pipe length at the bottom of the existing structure is examined as shown in Figure 12.



F**igure 12.** Influence of pipe length

Figure 13 shows the results for each pattern. In all cases, the displacement increases with distance from the existing structure, indicating that the existing structure partially contributes to reducing the displacement of the ground surface.

The deformation of the ground surface rises with shortened the pipe. In the ver. B, the deformation increases in the vertical direction widely whereas the influence of surface deformation is minimized in the ver. A. Therefore, it can be said that ver. A has a certain suppression effect on the ground surface. If a conventional pipe-roof cannot be installed due to the presence of water/gas pipes and piles directly underneath the existing structure, ver. A can be an option to reduce the influence of surrounding ground.

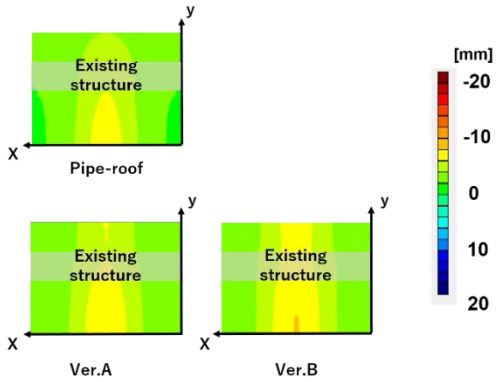


Figure 13. Deformation of the ground surface (influence of shorting pipe)

6. Conclusion

In this study, various numerical analyses were carried out to investigate the effects of the under-pinning method with pipe jacking on the existing structures and surrounding ground. As a result, it is found that the under-pinning method with pipe jacking has a wide range suppression effect by supporting the overburden pressure above the pipes. In addition, the pipe-roof method is expected to have a further suppression effect, even when the pipe-roof is shortened.

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