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<https://hdl.handle.net/2324/4743329>

出版情報 : Proceedings of International No-Dig 2018, 36th International Conference and Exhibition, pp.Paper Ref 095-, 2018-10-08. iSTT: International Society for trenchless technology

バージョン :

権利関係 :



Cape Town, South Africa
8-9 October 2018

Paper Ref 095

Behavior of Soil around Rectangular Pipe by Using New Type Excavation of Pipe Jacking

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DRAFT PAPER: In recent years, the effective utilization of the underground space using rectangular pipe such as underpass and barrier-free underground passageway is being promoted in urban areas. As an effective construction method in urban areas, the box culvert construction is being carried out these days. Additionally, it is required to apply the large section pipe jacking method of box culvert under the low earth covering because of the proximate structures and topographical conditions. However, the effects on surrounding ground and surface have to be considered with carefully when these structures are constructed in shallow depth. For mitigating these influences, application of the upper semi-section excavation method is expected. However, the influence of the construction method on the surrounding ground has not been clarified because there are few construction examples of the method. Therefore, three-dimensional finite element analysis was carried out to clarify the behavior of the surrounding ground during the construction of the upper semi-section excavation method. This study discusses the effects on the behavior of surrounding ground with the upper semi-section excavation method by means of numerical analysis.

1. INTRODUCTION

Pipe jacking is a technique used to install an underground pipeline through a bore created by a shield type drive machine, which is used hydraulically from a starting point. Underground structures using jacking methods are generally built in a circular construction because such a construction provides increased stability when the pipes are laid underground, and due to the ease of manufacture of jacking pipes. However, from the perspective of effective usage in underground space, the pipes with rectangular shape are more convenient than circular pipes. Due to this fact, the box culvert pipe jacking method was recently developed.

It is required to apply the large section pipe jacking method of box culvert under the shallow strata especially in the urban areas in Japan. However, the effects on surrounding ground and surface have to be considered with carefully when the construction with large section area in shallow strata. In order to mitigate the influences, application of the upper semi-section excavation method is suggested, but there are few construction examples using this method.

Given these factors, this paper discusses to evaluate the influences of the surrounding ground and surface when the upper semi-section excavation method is adopted. The finite element method is used for the prediction of deformation behavior of the surrounding ground and surface during the pipe jacking construction.

2. PIPE JACKING

In the pipe jacking method, 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 via, jacks located in the drive shaft push the pipe, and the jacking force is transmitted through a pipe-to-pipe interaction to the excavating face. The system is used as follows (Shimada *et al.*, 2004):

- 1) Install the pushing equipment in the starting pit, and then set the drivage machine.
- 2) Extend the rear-end pushing jack and push the drivage machine.
- 3) By repetition of the pushing process, if the rear-end driving after one concrete pipe length is driving in, connect another pipe.
- 4) After driving is completed, recover the drivage machine from the arrival pit.

The pipe jacking construction is best employed in stable, water free soil condition (Senda *et al.*, 2012). Unfortunately, with the demands on available space and the need to provide more services, it is not always possible to select stable strata. Recent technological developments have led to successful methods of stabilizing unstable strata by excluding water from the excavations by means of the mud slurry around the pipes. During the pushing processes, the mud slurry and lubricant are injected into the face and into the overcutting area, which is between the concrete box culvert and the soil, to prevent the ground from deformation due to stress release caused by formation of overcutting area in the ground. After the slurry fills the soil voids, the soil stabilizes due to the slurry pressure. To minimize ground deformation in the pushing process, it is necessary to maintain the slurry pressure that was kept on the ground water pressure.

3. UPPER SEMI-SECTION EXCAVATION METHOD

The upper semi-section excavation method has been applied as drilling method for mountain tunnels in Japan to minimize the ground surface subsidence and maintain stability of the working face. Therefore, it is expected that applying this method to the pipe jacking technology is also effective. In the upper semi-section excavation method, the excavating machine is divided by the upper half and the lower half. Figure 1 shows the cross sectional view of the drivage machine. In this method, it is expected that the effect of excavation in the lower half can be mitigated due to the gap between the upper and lower.

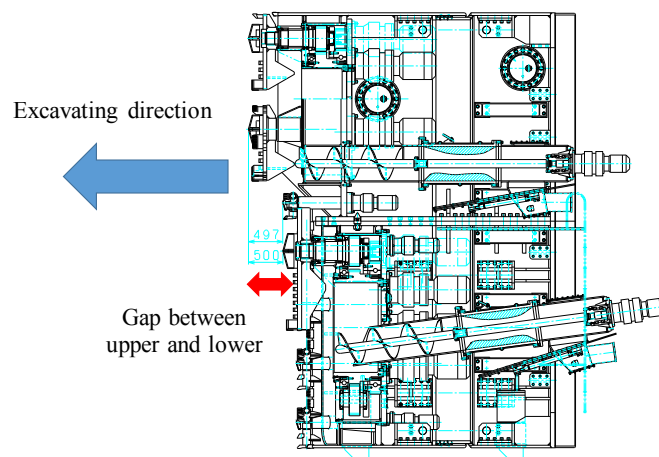


Figure 1. The cross sectional view of the drivage machine

4. NUMERICAL ANALYSIS

The boundary conditions of the ground, where the pipe jacking construction is made, are so complex and wide-ranging that in many cases 3-dimensional effect cannot be ignored when considering the design of the pipe jacking construction. Therefore, excavation elements are used to create a 3-dimensional finite element method considering the actual construction process of pipe jacking construction.

Figures 2 and 3 show a 3-dimensional finite element model used in this study. A half section model with a length of 50 m and a width of 50 m was used as the analysis range because both loading and structural systems were symmetrical.

As the initial conditions, the model of overburden depth is considered as 1.5 m. Overcutting area is set 50 mm around the culvert. The stresses release load and the appropriate slurry pressure of cutting face must be applied on the soil around the pipes. As the actual construction lubricant is injected into the tail-void to prevent the ground from deformation due to stress release caused by formation of the tail-void in the ground. To simulate this situation in the analysis, a nodal force equivalent to the injection pressure is applied to the soil element where the stress is released after the tail of the drivage machine passes by.

Table 1 shows the input parameters used for this analysis. Parameters of the clay is referred to soil modulus that are commonly used in finite element analysis. The parameter of the pipe is also determined based on the terms of the popular tube.

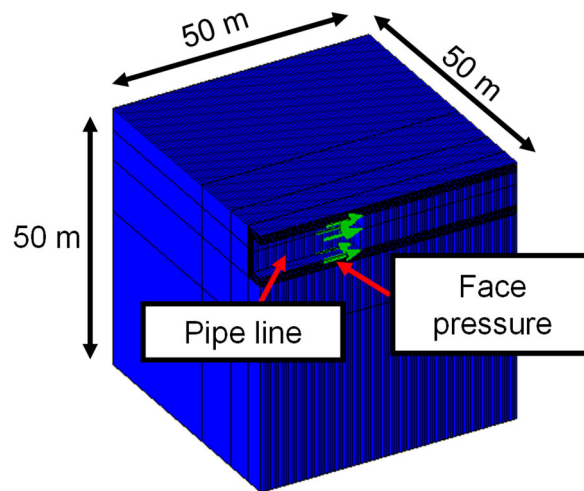


Figure 2. Analysis model (whole model)

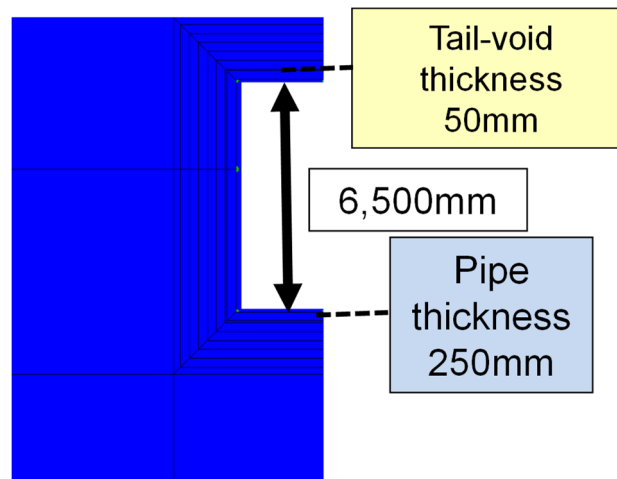


Figure 3. Analysis model (around box culvert)

Table 1. Input parameters used for this analysis

	Clay	Pipe	Lubricant
Young's modulus (MPa)	50	33,000	9.8×10^{-4}
Poisson's ratio (-)	0.26	0.17	0.45
Unit Weight (MN/m ³)	0.019	0.026	0.019

In order to understand the effect of design of drivage machine and operating conditions on the behavior of surrounding ground and surface, this study discusses the influence of gap between upper and lower, face pressure, and the height of upper drivage machine.

4.1. Influence of Different Gap between Upper and Lower

Figure 4 shows the schematic drawing of the analysis model. The analysis was conducted by changing the gap between upper and lower (0 m, 0.5 m, 1.0 m).

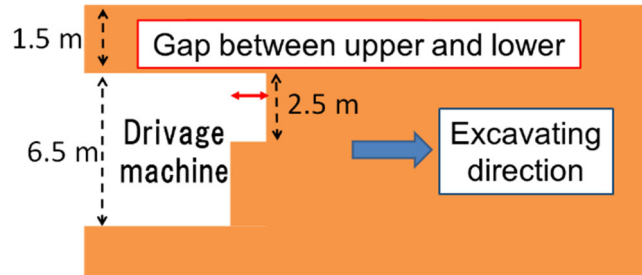


Figure 4. Influence of different gap between upper and lower

4.2. Influence of Different Face Pressure

In order to examine for impact of the face pressure under the shallow strata, the face pressure is changed in this study. The face pressure in the pipe jacking method is determined by the sum of groundwater pressure and active earth pressure, meaning that the face pressure is determined by the overburden depth. Therefore, the face pressure is constant when the overburden depth is constant above the water level. However, since the drivage machines are divided into two parts in the upper semi-section excavation method, the assumed overburden pressure is different in the upper half and the lower half. Furthermore, the constructions of the large section pipe jacking method in the shallow strata give the large influence. From the above reasons, the analysis was conducted by changing the face pressure described below.

- A: When the top of the pipe is used as the reference point of the overburden depth.
Face pressure = ground water pressure + active earth pressure + spare pressure = $0 + 1.5 \times 19 + 20 = 48.5$ kPa
- B: When the center of the pipe is used as the reference point of the overburden depth.
Face pressure = ground water pressure + active earth pressure + spare pressure = $0 + (6.5/2) \times 19 + 20 = 81.75$ kPa
- C: When the bottom of the pipe is used as the reference point of the overburden depth.
Face pressure = ground water pressure + active earth pressure + spare pressure = $0 + 6.5 \times 19 + 20 = 143.5$ kPa

4.3. Influence of Different Height of Upper Drivage Machine

Figure 5 shows the schematic drawing of the analysis model. The analysis was conducted by changing the gap between upper and lower (2.5 m, 4.0 m). In order to examine for influence of the height of upper drivage machine, comparison is done when the height is upside down.

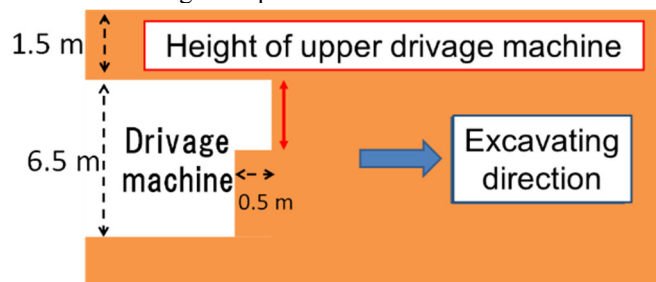


Figure 5. Influence of different height of upper drivage machine

5. RESULTS AND DISCUSSIONS

The following analysis results is discussed to focus on the deformation of the crown at the tail-void when the cutting face has reached the 20 m from the end face of the analysis model. Additionally, the starting point of the excavation is the position of vertical shaft.

5.1. Influence of Different Gap between Upper and Lower

Figure 6 shows the deformation of the crown at the tail-void during pipe jacking of 20 m. The pressure of the

cutting face is given against the front face of excavation. As the gap between upper and lower increases, the deformation of tail-void decreases from Figure 6. This means the effects on surrounding strata and surface can be mitigated with upper semi-section excavation method because the crown deformation is decreased with gap between upper and lower compared with conventional pipe jacking method.

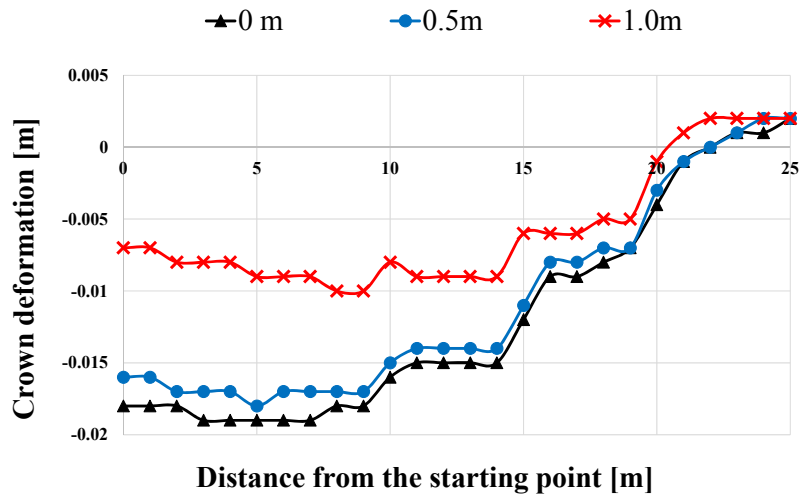


Figure 6. Effect on the deformation by differences of gap between upper and lower

5.2. Influence of Different Face Pressure

Figure 7 shows the deformation of the crown at the tail-void during pipe jacking of 20 m under the different cutting face pressure. The pressure of the cutting face is given against the front face of excavation. As the cutting face pressure increases, the deformation amount of tail-void decreases from Figure 7. Therefore, face pressure is considered to be an important factor for attenuating the impact of the construction in the large section pipe jacking under the shallow strata condition.

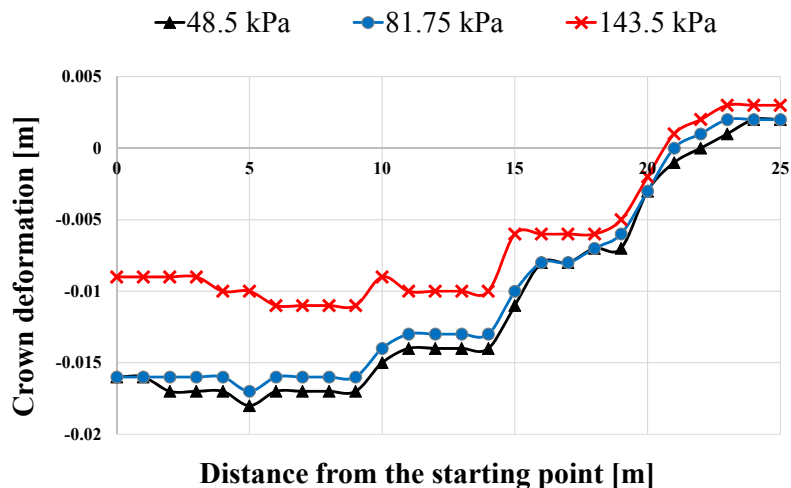


Figure 7. Effect on the deformation by differences of cutting face pressure

5.3. Influence of Different Height of Upper Drivage Machine

Figure 8 shows the deformation of the crown at the tail-void during pipe jacking of 20 m under the different height of upper drivage machine. The pressure of the cutting face is given against the front face of excavation. It can be seen that as the height of upper drivage machine increases, the deformation of tail-void decreases. This means the height of upper drivage machine clearly influences the deformation of the crown at the tail-void. Only two cases of 2.5 m and 4 m is compared in this study. Therefore, the more detailed studies about the impact of the height of upper drivage machine to the surrounding soil have to be conducted.

6. CONCLUSION

In this study, application of the upper semi-section excavation method under the shallow strata is discussed in order to clarify the effect on the surrounding ground and surface by means of numerical analysis. Based on the analytical results, it was found that the application of the upper semi-section excavation method can reduce the deformation of the crown at the tail-void during the large section pipe jacking project under the shallow strata condition. Furthermore, the differences of cutting face pressure and the height of upper drive machine are also important parameter to mitigate the deformation of surrounding ground and surface. Therefore, the effect of cutting face pressure and height of upper drive machine on the surrounding ground and surface is not negligible. In addition, not only the study of deformation of the crown at the tail-void during pipe jacking construction but also the surface deformation and stress conditions around drive machine have to be discussed.

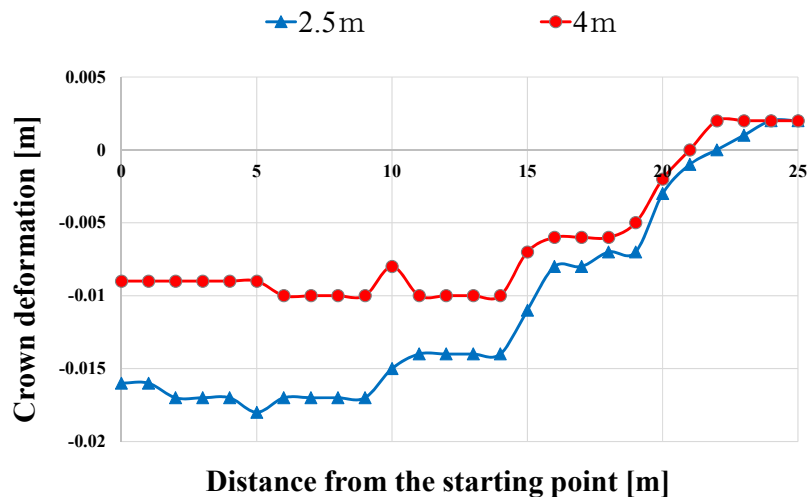


Figure 8. Effect on the deformation by differences of the height of upper drive machine

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