Study on the Control Effect of Pretreatment Measures on the Deformation of Subway Caused by the Excavation of Foundation Pit

Yahui Jia[1,2], Yanliang Shang[1,2], Jianhua Du[1,2], and Hongqian Dang[1(✉)]

[1] Department of Railway Engineering, Shijiazhuang Institute of Railway Technology, Shijiazhuang 050041, China
xrzhsh@sohu.com

[2] Application Technology R&D Center of Bridge and Tunnel Intelligent Construction of Hebei Colleges, Shijiazhuang, China

Abstract. At present, there are many control measures for the deformation of subway caused by the excavation of foundation pit. It is worthy of attention that pretreatment measures can effectively reduce the influence of deformation on the subway tunnel under different working conditions. Therefore, the finite element model is established by Midas/GTS to explore the reinforcement effect of two measures of pit bottom reinforcement and isolation pile reinforcement. The results show that: in the excavation of foundation pit, the two schemes have different effects on controlling the deformation of tunnel structure, and the inclination of diameter line is generally smaller. The deformation characteristics of each component structure of the diameter line after the pit bottom reinforcement are similar to those of the unreinforced condition, while the displacement changes of each structure after the isolation pile reinforcement become uniform and reasonable. Isolation pile reinforcement is better than pit bottom reinforcement, especially in reducing the vertical displacement of the structure. The reduction degree of the maximum horizontal displacement after the isolation pile reinforcement is about 24%–31%. Therefore, when selecting the pretreatment method, priority is given to the isolation pile reinforcement method.

Keywords: Foundation Pit Excavation · Displacement · Pit Bottom Reinforcement · Isolation Pile Reinforcement

1 Introduction

The excavation of foundation pits in cities inevitably causes disturbance to nearby subways. It is necessary to take corresponding reinforcement measures when encountering additional deformation caused by excavation of foundation pits in subway tunnels [1, 2]. Previous researchers have done sufficient work on the deformation control of corresponding tunnel structures. Isolation pile reinforcement is currently one of the most widely used reinforcement methods, playing an effective role in controlling building deformation [3]. Although there has been extensive research on reinforcement methods

G. Feng (Ed.): ICCE 2023, LNCE 526, pp. 683–690, 2024.
https://doi.org/10.1007/978-981-97-4355-1_67

by predecessors, there are few reports on the application of full pit bottom reinforcement and isolation pile reinforcement methods in the same project, and comparing their deformation control effects. This article will rely on the adjacent underground diameter line project of Tianjin Jiahai Deep Foundation Pit, adopting pre-treatment schemes of bottom grouting reinforcement and isolation pile reinforcement respectively. Based on the established finite element model, the control effect of reinforcement measures on diameter line deformation caused by foundation pit excavation will be analyzed. The analysis results can provide reference and reference for similar projects.

2 Project Overview

The south side of the Tianjin Jiahai Foundation Pit Project is the underground diameter line from Tianjin West Station to Tianjin Station. As this foundation pit belongs to a super large deep foundation pit, it is divided into three parts: the north, middle, and south. The excavation depth of the southern foundation pit is about 10.8 m, with a distance of 16–20 m from the diameter line and a parallel distance of about 250 m. Multiple construction methods are used for the underground diameter line. The tunnel is buried at a smaller depth and is constructed using the open excavation method. The section with a deeper burial depth in the middle is constructed using the shield tunneling method. The side of the foundation pit close to the diameter line adopts a support form of drilled cast-in-place piles + concrete internal support, while the west side of the foundation pit adopts double row cast-in-place piles + counter pressure soil. The enclosure structure of the open cut tunnel adopts the form of drilled pile + water stop curtain, and underground connecting wall structure (the deeper section of the foundation pit adopts underground connecting wall, and the shallower section adopts drilled pile + water stop curtain). Two pre-treatment methods are considered for reinforcement, and the pre-treatment scheme adopted for foundation pit construction is shown in Table 1.

Table 1. Foundation Pit Excavation pretreatment scheme

Scheme	Concrete content
Scheme 1	Strengthen the soil of 3 m below the pit bottom. The reinforcement area is the southern foundation pit with full reinforcement
Scheme 2	A separation wall (pile) is used to reinforce the soil between the southern foundation pit and the shield shaft. The reinforcement range is: the length range of the shield tunnel is extended by 20 m towards the open excavation section and the shield tunnel section, with a reinforcement width of 3 m and a depth of 30 m below the surface

3 Model Establishment

The dimensions of the 3D model are 250 m in length, 135 m in width, and 50 m in depth. In order to consider the above two working conditions in the same model, the geometric entities will be cut accordingly during modeling, and the entities in the grouting reinforcement area at the bottom of the pit and the reinforcement area of the separation wall (pile) will be cut in advance, so that the transformation of the two models can be easily realized by modifying the material properties. See Fig. 1 and Fig. 2 for the specific segmentation. The constitutive relationship between soil and structure is determined using the D-P model and the linear elastic constitutive model, respectively. The soil within a depth range of 50 m in the model is approximately divided into four layers. Simulation of the excavation process of foundation pits. CS1: Apply gravity and initial water head to form an initial stress field, and then clear the displacement to zero; CS2: The first step of excavation is completed, and the support and waist beam are completed; CS3: Excavate to the bottom of the pit.

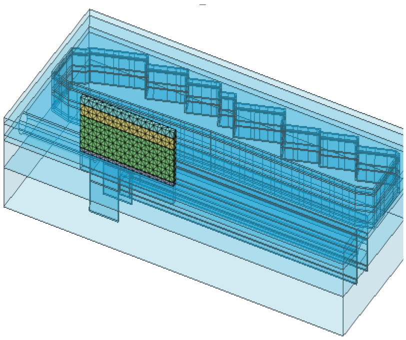


Fig. 1. Pit bottom reinforcement

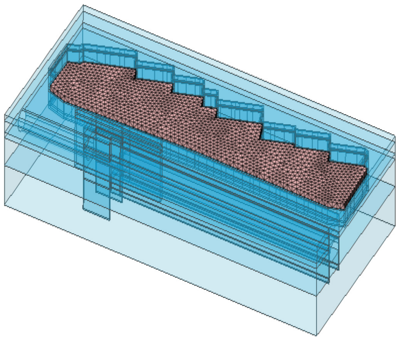


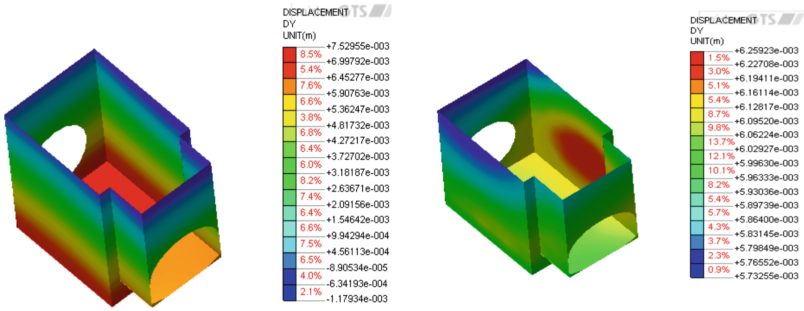
Fig. 2. Isolation pile reinforcement

4 Analysis of Reinforcement Measures

Select the CS3 (excavation to the bottom of the pit) process for analysis, and the model specifies that the horizontal direction is towards the side of the pit as the positive direction, and the vertical direction is upwards as the positive direction.

4.1 Displacement of Shield Shaft

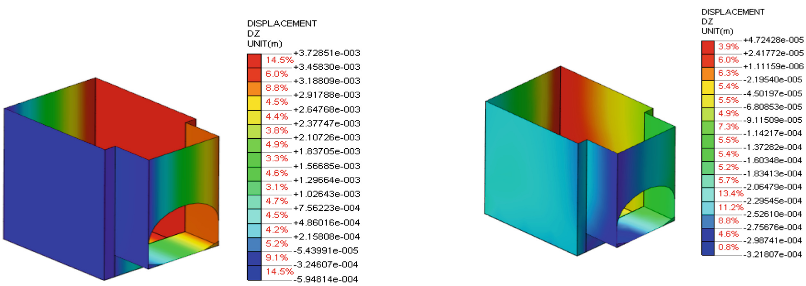
The horizontal displacement of the shield shaft for two preprocessing schemes is shown in Fig. 3. From the figure, it can be concluded that both schemes are effective in reducing the absolute displacement of the shield shaft bottom plate. However, after using bottom grouting reinforcement, a reverse displacement of 1.18 mm occurred at the top of the shield shaft (i.e. moving away from the foundation pit), resulting in a relative displacement of 8.72 mm. Compared to the relative displacement before reinforcement, the value increased, resulting in a more pronounced inclination of the shield shaft. After adopting the isolation pile reinforcement scheme, the horizontal displacement of the shield shaft varies uniformly along the height, resulting in a maximum horizontal displacement of 6.26 mm, which occurs in the middle of the side wall near the foundation pit. The minimum displacement at the top is 5.73 mm, resulting in a relative displacement value of only 0.53 mm for the shield shaft. This reinforcement method reduces relative displacement, which means that the inclination of the shield shaft is also reduced.



(a) Grouting reinforcement plan at the bottom of the pit (b) Isolation pile reinforcement plan

Fig. 3. Horizontal displacement of shield shaft

The vertical displacement of the shield shaft in Scheme 1 and Scheme 2 is shown in Fig. 4. The grouting reinforcement scheme at the bottom of the pit resulted in the side wall (inner side) of the shield tunnel near the foundation pit floating upwards and the outer side wall sinking. After using isolation piles for reinforcement, the overall structure tends to sink, with a maximum vertical displacement of 0.32 mm and a downward direction.

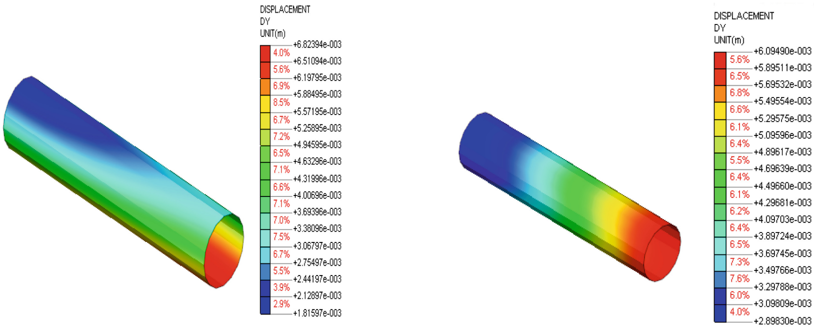


(a) Grouting reinforcement plan at the bottom of the pit (b) Isolation pile reinforcement plan

Fig. 4. Vertical displacement of shield shaft

4.2 Displacement of Shield Tunnel Segments

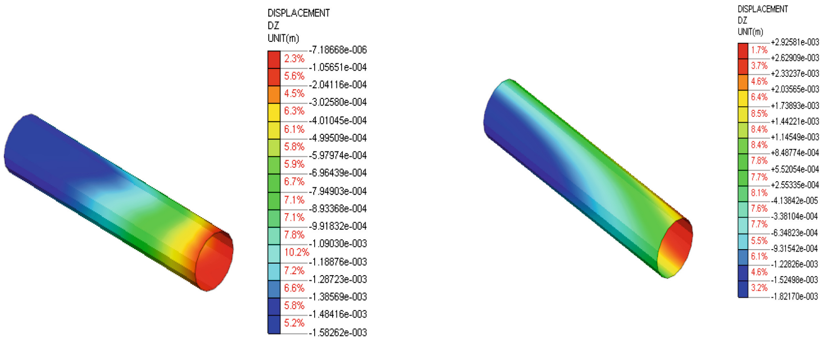
The horizontal displacement of the reinforced shield tunnel segment is shown in Fig. 5. The horizontal displacement variation of the shield tunnel segment after grouting reinforcement at the bottom of the pit is similar to that of the unreinforced scheme. The maximum horizontal displacement occurs at the bottom of the segment near the shield shaft, and the minimum displacement occurs at the top of the segment far from the shield shaft end. After the reinforcement of the isolation pile, the horizontal displacement trend of the shield tunnel segment changes, and the displacement of the segment is relatively uniform along the cross-sectional direction. The horizontal displacement of the segment near the shield shaft is the largest, and gradually decreases along the longitudinal direction of the segment.



（a）Grouting reinforcement plan at the bottom of the pit （b）Isolation pile reinforcement plan

Fig. 5. Horizontal displacement of shield segment

The vertical displacement of the reinforced shield tunnel segment is shown in Fig. 6. After grouting reinforcement at the bottom of the pit, the maximum vertical displacement occurs at the "arch waist" position near the shield shaft and closer to the foundation pit, with the displacement direction being upward. The minimum displacement occurs at the "arch waist" position on the side far from the shield shaft and the foundation pit, with a downward displacement direction. After using isolation piles for reinforcement, the vertical displacement change law generated by the shield tunnel segment is similar to the horizontal displacement change law, that is, the displacement is evenly distributed along the cross-sectional direction, which also indicates that the existence of isolation piles makes the segment more evenly stressed during the excavation process of the foundation pit.

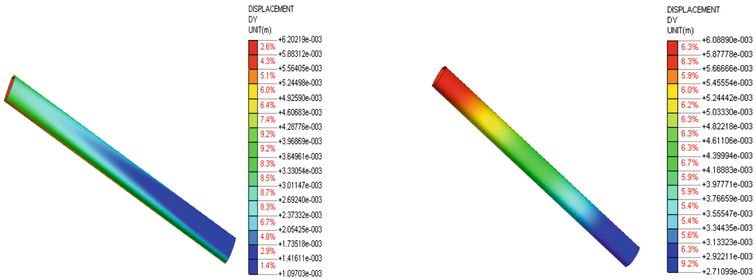


(a) Grouting reinforcement plan at the bottom of the pit (b)Isolation pile reinforcement plan

Fig. 6. Vertical displacement of shield segment

4.3 Displacement of the Main Structure of Open Excavation

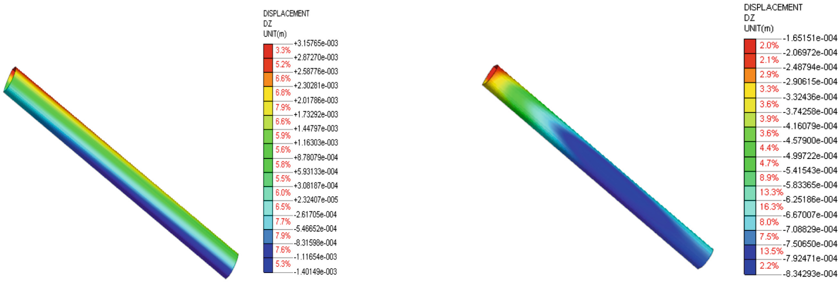
The horizontal displacement of the reinforced open cut main structure is shown in Fig. 7. After using bottom grouting reinforcement, the maximum horizontal displacement of the main structure of the open excavation occurs at the bottom plate near the shield shaft, and the minimum horizontal displacement occurs at the arch far from the shield shaft end, similar to the pattern in the unreinforced situation. After using isolation piles for reinforcement, the displacement variation pattern of the open excavation section is consistent with that of the shield tunnel section using the same reinforcement method. The displacement near the shield shaft is the largest, and there is a clear uniform decreasing trend along the longitudinal direction of the structure.



（a）Grouting reinforcement plan at the bottom of the pit （b）Isolation pile reinforcement plan

Fig. 7. Horizontal displacement of open-cut main structure

The vertical displacement of the reinforced open cut main structure is shown in Fig. 8. After adopting Scheme 1 for reinforcement, the maximum and minimum vertical displacement of the main structure of the open excavation is similar to that of the shield tunnel segment. After adopting Scheme 2 reinforcement, the displacement of the main structure of the open excavation is similar to that of the shield tunnel segment, with the maximum vertical displacement occurring near the shield shaft.



（a）Grouting reinforcement plan at the bottom of the pit（b）Isolation pile reinforcement plan

Fig. 8. Vertical displacement of open-cut main structure

5 Conclusion

(1) Both pre-treatment schemes have played an effective role in controlling the deformation of the diameter line, and the overall inclination of the diameter line structure is reduced.
(2) The control effect of isolation pile reinforcement on deformation is better than that of grouting reinforcement at the bottom of the pit. After the reinforcement of the isolation pile, the deformation of each structure shows a uniform trend, and the stress situation becomes reasonable compared to the unreinforced one; The decrease in absolute and relative displacement of the structure after adopting the isolation pile reinforcement scheme is greater than that of the pit bottom grouting reinforcement scheme.
(3) When selecting the pre-treatment method, priority can be given to the reinforcement method of isolation piles.

Acknowledgments. This study was founded by Science Research Project of Hebei Education Department (Grant No. ZD2022027), the Hebei Province Construction Science and Technology Research Guidance Plan Project (Grant No. 2022-2021), and the Science and Technology Project of Hebei Province (Grant No. 16215408D). These financial supports are gratefully acknowledged.

References

1. Wang Weidong, W., Jiangbin, W.Q.: Numerical simulation of the impact of excavation and unloading of foundation pits on subway section tunnels. Geotech. Mech. **S2**, 251–255 (2004)
2. Hongwei, H., Huang, X., Helmut, S.F.: Numerical simulation study on the influence of foundation pit excavation on the operation of shield tunnels under the ground. J. Civ. Eng. **45**(03), 182–189 (2012)

3. Lei, Y.: Research on protection measures for the underpass City Wall and bell tower of Xi'an metro line 2. Geotech. Mech. **31**(01), 223–228+236 (2010)
4. Gang, W., Jing, L., Haili, X., Dong Lizheng, X., Yongyong, Z.S.: Experimental analysis of the impact of large-scale deep foundation pit excavation on nearby subway shield tunnels. J. Railw. Sci. Eng. **15**(03), 718–726 (2018)
5. Hongwei, Y., Tao, L., Yongwen, Y., Xinyu, X.: Analysis of the effectiveness and engineering application of deep foundation pit partition walls for protecting adjacent buildings. J. Geotech. Eng. **33**(07), 1123–1128 (2011)