Research on the Influence of Curved Shield Tunneling Construction on the Deformation of Existing Bridge Piles

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Abstract. The ABAQUS software was used to establish a finite element model of the existing bridge piles for curved shield tunneling, and the impact of each stage of curved shield tunneling construction on the upper surface and adjacent pile foundations was analyzed. Research has shown that the main settlement of shield tunneling occurs during the shield tunneling stage and the detachment stage of the shield tail, with the maximum surface settlement located on the inner side of the curved shield tunneling; The horizontal displacement deformation of the pile foundation is the largest within the scope of the shield tunnel; The maximum vertical deformation of the pile is located at the top of the pile, and the magnitude of the vertical settlement of the pile is related to the horizontal net distance between the pile and the shield tunnel. A smaller horizontal distance will result in larger vertical settlement.

Keywords: Curved shield tunneling; Deformation control measures.

1 Introduction

Simple straight tunnels can no longer meet the needs of shield tunnel construction. To meet practical needs, curved shield tunneling is indispensable. Especially when passing through important buildings, improper selection of shield tunnel parameters can cause unpredictable losses to surrounding buildings. Despite the difficulty and high construction risks of curved tunnels, as the urban environment becomes increasingly complex, the frequency of using curved shields will only increase to meet the linear requirements of shield tunneling. Ahrens[1]. evaluated the impact of shield tunneling on the stress and deformation of existing subway tunnels by conducting finite element simulations and comparing the model results with on-site measurement results. The results obtained from Lee[2].'s centrifuge model experiments and simulations indicate that tunnel excavation construction can lead to ground settlement, with an impact range of approximately twice the diameter of the excavation face of the shield cutter head.

This article is based on the shield tunneling section construction project of Xi'an Metro. The main strata crossed by the interval tunnel are medium sand and gravel sand strata, which have poor self stability and belong to typical weak strata. This article uses ABAQUS software to establish a finite element model of curved shield tunneling

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through existing bridge piles, and analyzes the impact of each stage of curved shield tunneling construction on the upper surface and adjacent pile foundations. The research results can serve as a reference for similar projects.

2 Project overview

The Xi'an Metro section curve (R=500m) shield tunneling project is based on a total length of 2825.07m. The section tunnel mainly passes through the strata of 2-5-3 medium sand and 2-7-3 gravel sand. The content of medium sand and gravel sand with particle size greater than 2mm accounts for 3.8% and 28.7%, respectively.

3 Model establishment and parameter settings

3.1 Modeling

Based on the influence range of shield excavation on the surrounding soil within 3-5 D (D is the tunnel excavation diameter) and the size of the curvature radius[3,8], the model dimensions are determined to be X=90m, Y=110m, and Z=50m. The distance between the left and right lines is 30m, and the depth of the tunnel arch is 20m. The pile foundation is 40m long, with a diameter of 1m. The upper load is about 3.4e3kN and acts on the top of the pile. Design and calculate the model using ABAQUS software as shown in Figure 1

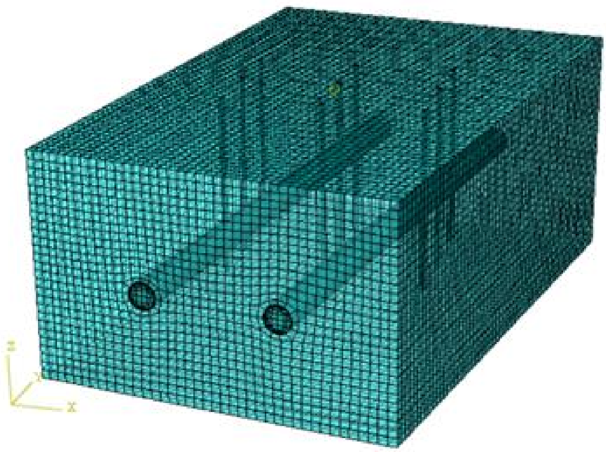


Fig. 1. 3D computational model diagram.

3.2 Parameter settings

(1) Stratigraphic parameters

According to the detailed geological survey report of the shield tunneling interval, the parameters in each layer model are shown in Table 1 and Table 2.

Table 1. Physical and mechanical parameters of strata.

soil	thick-ness(m)	den-sity(kg/m^3)	Elastic modulus(MPa)	Pois-son's ratio	cohe-sion(kPa)	friction an-gle(°)
loessial soil	10	1874	9.42	0.16	13.87	21.0
Medium sand	25	2070	17.50	0.35	0.00	35.0
silty clay	15	2010	14.60	0.29	12.70	23.4

(2) Segment parameters

Table 2. Material parameters of shield tunneling machine and pile foundation.

material	Volume weight(kN/m^3)	Elastic modulus(MPa)	Poisson's ratio
Shield shell	75	210e3	0.20
Segment layer	25	3e4	0.25
pile foundation	25	3.5e4	0.20

4 Research on the Impact of Curved Shield Tunnel Construction on Surface Settlement

The vertical displacement cloud map of the strata after the completion of curved shield tunneling construction is shown in Figure 2.

To further understand the impact of curved shield tunneling on surface settlement, the main research focuses on the impact of shield tunneling at different stages on surface settlement, as well as the impact of left and right shield tunneling on surface settlement after completion[4].

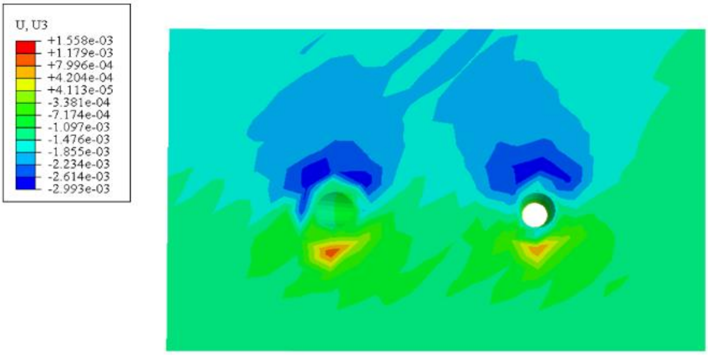


Fig. 2. Vertical displacement cloud map of strata after completion of dual line shield tunneling.

4.1 Research on the Influence of Different Stages of Curved Shield Tunneling on Surface Settlement

To study the influence of curved shield tunneling on surface settlement, a monitoring section is selected in the middle of the excavation direction of the model, arranged along the X-direction of the surface, and a measuring point is set every 5m. The monitoring point at a distance of 5m from the left side of the surface directly above the left shield tunneling arch in the X-direction is set as L, the monitoring point at the surface directly above the left shield tunneling arch is set as M, and the monitoring point at a distance of 5m outside the surface directly above the left shield tunneling arch is set as R[5]. The impact of the construction of the left shield tunneling on the surface settlement deformation of three monitoring points located at different positions on the curved shield tunneling surface in each stage of construction is obtained. The surface settlement curves of the three monitoring points at each stage of the left line shield tunneling crossing the monitoring section are shown in Figure 3.

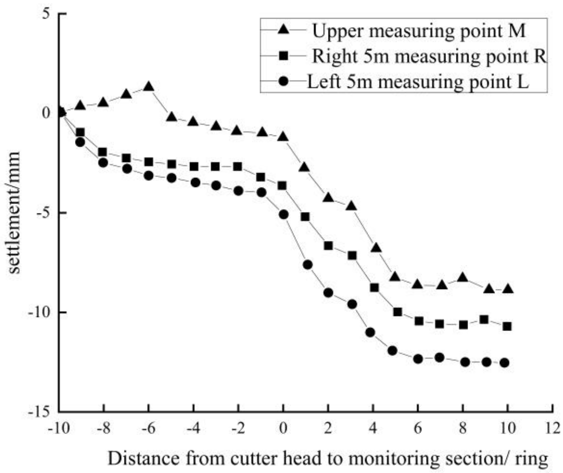


Fig. 3. Surface displacement and settlement curve of left shield tunneling at each stage.

During the process of curved shield tunneling, the maximum settlement occurs not at the arch position of the shield tunnel, but on the left side (inner side) of the curved shield tunnel; Before the arrival of the shield, the impact on surface settlement is relatively small, mainly occurring during the shield excavation stage and the detachment stage of the shield tail; After the detachment of the shield tail, due to the gap between the pipe itself and the soil, as well as its own stiffness, it will lead to further increase in surface settlement. During the left shield tunneling process, the maximum settlement occurs after the detachment of the shield tail, with a maximum settlement value of 12.36mm.

4.2 Analysis of the Impact of Curved Shield Tunnel Construction on Surface Settlement

The surface settlement curve after the completion of dual line shield tunneling at the same monitoring section is shown in Figure 4.

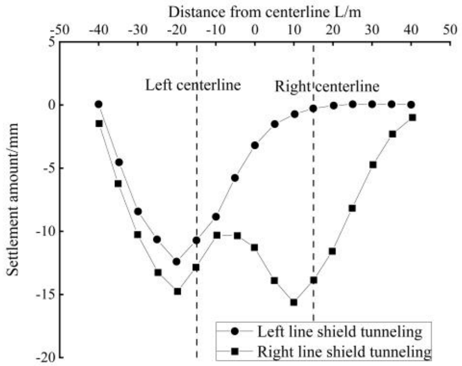


Fig. 4. Surface settlement curve during the penetration of dual line shield tunneling.

As shown in the figure, the surface settlement distribution of the monitoring section after the completion of the double line shield tunneling is in a "W" shape settlement groove[6]. The peak settlement of the left and right line shield tunneling occurs on the surface directly above the left (inner) 5m distance from the center axis of the curved tunnel. The maximum surface settlement above the left and right lines is 14.82mm and 15.67mm, respectively. From this, it can be seen that the maximum settlement of curved shield tunneling does not occur directly above the arch, but on the inner side of the curved shield tunneling. This is because curved shield tunneling will over excavate the soil on the inner side and compress the soil on the outer side, resulting in the maximum surface settlement occurring on the inner side of the curved shield tunneling.

5 Research on the influence of curved shield tunneling construction on pile foundation deformation

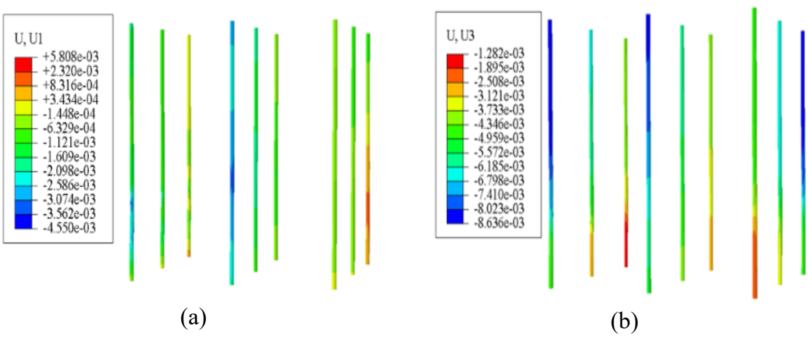


Fig. 5. Cloud map of final displacement and deformation of pile body.

The geological losses caused by curved shield tunneling construction can act on adjacent pile foundations through the surrounding soil layer as a medium, causing displacement and deformation of the pile foundation[7]. In severe cases, it can affect the normal operation of the existing line above. This mainly explores the influence of curved shield tunneling construction on the displacement and deformation of pile foundations. The final lateral displacement cloud map and vertical displacement cloud map of the pile foundation are shown in Figure 5.

5.1 Research on the influence of curved shield tunneling on the vertical displacement of pile foundation

The displacement deformation diagram of adjacent pile foundations caused by the construction of curved shield tunnels is shown in Figure 6, and the maximum displacement of each pile foundation top during the excavation of curved shield tunnels is shown in Table 3

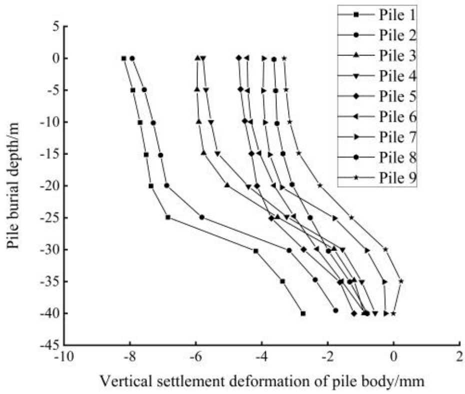


Fig. 6. Displacement deformation diagram of adjacent pile foundation vertical settlement caused by excavation of curved shield tunnel.

Table 3. Table of maximum displacement at the top of each pile foundation during excavation of curved shield tunnel.

Pile number /m	1	2	3	4	5	6	7	8	9
deformation /mm	-3.98	-5.86	-8.16	-4.69	-3.66	-4.49	-7.96	-5.78	3.32

The maximum vertical deformation of each pile body occurs at the top of the pile, and the maximum vertical settlement value occurs at the top of pile foundation 3. The maximum settlement value of the pile body is 8.16mm. From the figure, it can also be observed that the vertical settlement of pile 3 and pile 7 is greater than that of other piles, indicating that the magnitude of vertical settlement of the pile is related to the horizontal net distance between the pile and the shield tunnel. A smaller horizontal distance will result in larger vertical settlement.

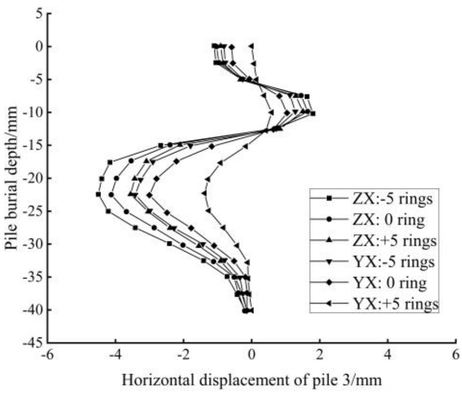
5.2 Research on the influence of curved shield tunneling on the lateral horizontal displacement of pile foundation

In order to better analyze the impact of curved tunnel lateral crossing on pile foundation deformation, the closest pile foundation to the left tunnel, the closest pile foundation to the right tunnel, and the middle pile foundation between the left and right lines were selected as the objects of pile foundation stress and deformation analysis. The lateral horizontal displacement deformation diagram of piles 3, 6, and 7 at each stage is shown in Figure 7. The positive value on the horizontal axis in the figure indicates deformation in the positive direction of the X-axis (on the right side of the shield tunneling direction).

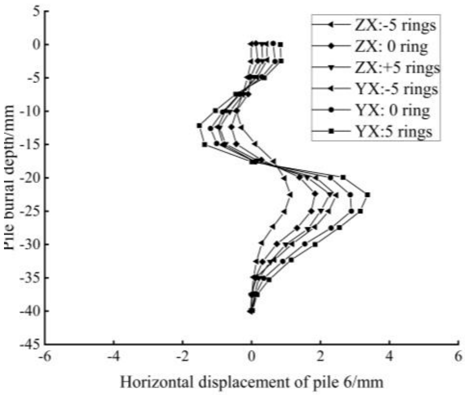
From Figure 7 (a), it can be seen that before the arrival of the shield tunnel, due to the compression effect of the shield machine on the soil ahead, the pile near the shield tunnel area undergoes displacement deformation in the negative X-axis direction. However, compared to the stage when the shield tunnel reaches the vicinity of the pile foundation and the stage when the shield tail detaches, the influence of the shield tunnel on the displacement deformation of the pile before arrival is relatively small.

From Figure 7 (b), it can be seen that overall, the horizontal deformation of pile foundation 6 is smaller than that of pile foundation 3 and 7. On the one hand, this is because pile foundation 6 is located in the middle row of the pile group, and the surrounding soil is constrained by the left and right rows of pile foundations, which is less disturbed by shield tunneling. As a result, the deformation of pile foundation 6 is less affected by shield tunneling at each stage of construction.

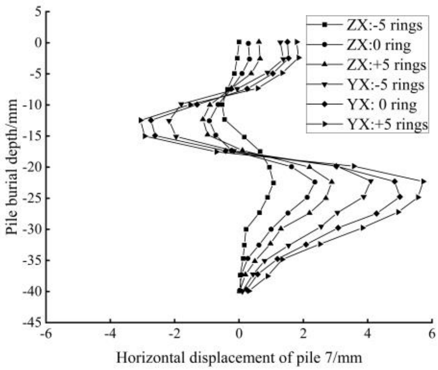
From Figure 7 (c), it can be seen that during each stage of shield tunnel construction, the pile body of pile No. 7 located near the shield tunnel area is subjected to displacement in the positive X-axis direction. After the detachment of the right shield tail, the pile body reaches its maximum horizontal deformation, with a maximum horizontal displacement value of 5.74mm; Due to the reinforcement effect of the pile foundation on the soil, the impact of the left line shield on the right side of the No. 7 pile foundation is also relatively small.



(a)



(b)



(c)

Fig. 7. Diagram of lateral displacement and deformation of pile body

In summary, the main stages that affect the horizontal deformation of pile foundations are the shield tunneling stage and the shield tail detachment stage. The maximum deformation position of the pile foundation occurs at the pile body near the shield tunnel area. At the same time, the overall horizontal deformation of the pile foundation on the inner side of the curved shield is smaller than that on the outer side of the curved shield, and due to the reinforcement effect of the pile group on the soil, the disturbance of the excavation of the left shield on the right pile foundation is relatively small.

6 Conclusion

Establish a finite element simulation of the pile foundation of a high-speed bridge passing through a curved shield tunnel in a sandy formation, and calculate and analyze the effects of curved shield tunneling on surface settlement, horizontal displacement of pile foundation, and vertical displacement deformation of pile foundation. The conclusions drawn are as follows:

(1) In the process of curved shield tunneling, the impact on surface settlement is relatively small before the shield arrives, and the main settlement occurs during the shield tunneling stage and the detachment stage of the shield tail. The maximum surface settlement occurs at a distance of 5m above the inner axis of the curved shield tunnel, rather than directly above the arch.

(2) During the excavation process of curved shield tunneling, the overall horizontal deformation of the pile foundation on the inner side of the curved shield tunneling is smaller than that on the outer side of the curved shield tunneling. Moreover, due to the reinforcement effect of the pile group on the soil, the disturbance of the left side shield tunneling to the right side pile foundation is relatively small.

(3) The maximum vertical deformation of each pile is located at the top of the pile, and the maximum vertical settlement value occurs at the top of pile 3, with a maximum settlement value of 8.16mm. The magnitude of vertical settlement of the pile is related to the horizontal clearance between the pile and the shield tunnel, and a smaller horizontal clearance will result in larger vertical settlement.

References

1. Ahrens E S A H. Two- and three-dimensional analysis of closely spaced double-tube tunnels[J]. Tunnelling and Underground Space Technology, 2013.
2. Lee GTK, Ng CW W. Effects of Advancing Open Face Tunneling on an Existing Loaded Pile[J]. Journal of Geotechnical & Geoenvironmental Engineering, 2005, 131(2):193-201.
3. Suling Ni. Analysis of the Impact of Subway Shield Tunnel Crossing on the Pile Foundation of Commercial Complex [J] Guangdong Building Materials, 2012, (8): 60-62.
4. Yong Wang. Risk analysis of shield tunnel passing through highway viaduct piles at close range [J] Shanxi Architecture, 2016, 42 (16): 192-194.
5. Shuai Peng , Nan Tao Song, etc Analysis of Key Technologies for Design and Construction of Small Curve Metro Shield Tunnels in Reclamation Areas [J] Urban Rail Transit, 2023, (03): 30-36.
6. Ding Jia, Ke Yuan Cheng, etc Analysis of deformation effects of curved shield tunnels penetrating existing tunnels over long distances [J] Modern Urban Rail Transit, 2023, (04): 63-68.
7. Zhao ran Xiao, Yang Zhang. Impact of Shield Tunneling on Nearby High Speed Railway Bridge Piles in Silty Soil Strata. Journal of Henan University of Technology (Natural Science Edition), 2020, 39 (01): 141-148.
8. Xiao Luo. Numerical simulation study on the disturbance mechanism of shield tunneling through pile foundations in soft soil areas [D] Hangzhou: Zhejiang University, 2017.