Study on deformation law of double-line shield tunnel obliquely crossing underneath existing municipal tunnel

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Abstract: This paper mainly relies on the project of Hangzhou Metro Line 5 obliquely crossing underneath Zijingang Road Tunnel. The paper analyzes the influence of the shield position on the vertical displacement and torsion of the existing tunnel. Grouting pressure and stratum reinforcement conditions are also considered. And find the law of the influence of various construction technical parameters on deformation under different excavation stages. Then give corresponding advice for the project and provide guidance and reference for similar projects in the future.

1. Introduce
The previous literature has already studied the problem of shield tunnel crossing underneath existing structure. Li Donghai et al. studied the impact of tunnel crossing underneath existing stations [1-3]. Guo Jianning and others used numerical simulation software to study the tunnel adjacent to the existing tunnel [4-8] and Lai Hongpeng et al. optimized the construction parameters [9]. However, the following problems exist in these researches: (1) There are few studies of shield tunnel crossing underneath highway frame tunnels; (2) The research focuses on the influence of orthogonal crossing underneath the existing tunnel, but in reality it rarely exists; (3) For the different stages of the crossing underneath construction (before, during and after crossing), there are relatively few studies on the influence of technical parameters under different excavation stages. This paper studies the deformation law of the existing tunnel when the double-line shield tunnel obliquely crosses underneath the existing tunnel. Finally, the effects of grouting pressure and formation reinforcement measures on the tunnel are considered.

2. Engineering background
Zheda Zijingang Station to Sanba Village Station Section of Hangzhou Metro Line 5 obliquely crosses underneath the Zijingang Road Tunnel. The tunnel crown is about 4m away from the bottom of the Zijingang Road Tunnel. The Zijingang Road Tunnel is a municipal highway tunnel with a rectangular frame concrete structure. And shield transit conditions have been reserved. In order to reduce the impact of construction of the subway tunnel on Zijingang Road Tunnel, the bottom layer of the tunnel has been reinforced with 6m soil-cement pile mixed by three shafts, when building the Zijingang Road Tunnel.

J6-1~J6-6 are the monitoring points arranged along the center line of the left line on the existing tunnel structure. J1-1~J1-5 are the monitoring points arranged along the ramp structure. (as shown in
3. **Numerical modeling**

3.1. **Numerical model**

This chapter uses flac3d software for 3D modeling calculation. The depth of the subway tunnel is 19.1m. To Zijingang Road Tunnel, the depth of the roof is 3.3m, and the depth of the floor is 15.3m. The distance between the crown of the subway tunnel and the structural floor of the Zijingang Road Tunnel is about 3.8~4.0m, and the intersection angle between the center line of the subway tunnel and the center line of the Zijingang Road Tunnel is 51°. The 3D calculation model is shown in Fig. 3.

3.2. **Calculation parameters**

The mechanical parameters of each stratum and structure applicable to the Mohr-Coulomb model are determined as shown in Table 1. According to previous research results, the calculation of the elastic modulus is generally taken 2 to 5 times the compression modulus, the model takes 3.5 times. The overall stiffness reduction factor of the segment is 0.8.
Table 1. Mechanical parameters of stratum and structure

| No. | Stratum and structure name     | Density /g/cm³ | Compression modulus /MPa | Elastic modulus /GPa | Poisson's ratio μ | Cohesion /kPa | Friction angle /° |
|-----|--------------------------------|----------------|--------------------------|---------------------|------------------|---------------|------------------|
| 1   | Miscellaneous fill            | 1.93           | 3                        | /                   | 0.35             | 1             | 6                |
| 2   | Silty clay                    | 1.86           | 4                        | /                   | 0.31             | 24.6          | 14.7             |
| 3   | Sandy soil                    | 1.88           | 8.7                      | /                   | 0.21             | 4             | 25.1             |
| 4   | Clay                          | 1.96           | 8.8                      | /                   | 0.30             | 44.2          | 16.9             |
| 5   | Clay                          | 1.88           | 4.4                      | /                   | 0.31             | 28.9          | 11               |
| 6   | Fine sand                     | 1.99           | 8.6                      | /                   | 0.24             | 3             | 30               |
| 7   | Silty clay                    | 1.98           | 7.4                      | /                   | 0.30             | 42            | 17.6             |
| 8   | Medium sand                   | 2.00           | 18                       | /                   | 0.20             | 2             | 32               |
| 9   | Fully weathered tuff          | 2.00           | 11                       | /                   | 0.23             | 40            | 20               |
| 10  | Strongly weathered tuff       | 2.23           | 40                       | /                   | 0.28             | 60            | 28               |
| 11  | Municipal tunnel (C35)         | 2.50           | /                        | 31.5                | 0.2              | /             | /                |
| 12  | Shield segment (C50)          | 2.50           | /                        | 34.5                | 0.2              | /             | /                |
| 13  | Equal generation              | 2.40           | /                        | 0.10                | 0.3              | /             | /                |
| 14  | Reinforcement material        | 2.30           | /                        | 0.15                | 0.3              | /             | /                |

When the shield machine is excavated, the grouting pressure and the silo pressure are replaced by equivalent loads. Because the tunnel buried depth is unchanged in this study, the silo pressure (i.e., the equivalent equilibrium load on the face) remains unchanged at 0.2 MPa. Numerical model excavates 1.2m each time (i.e., 1 ring), the schematic diagram of the shield tunneling process is shown in Fig. 4.

4. Results

4.1. Construction impact law of shield tunnel crossing underneath existing municipal tunnel

Fig. 5 shows the tunnel excavates under the conditions of grouting pressure of 0.15 MPa and stratum reinforcement. As can be seen from Fig. 5, when the left line excavates, the settlement value of the monitoring point gradually increases with the advancement of the face. Maximum displacement of J6-1 is -0.78mm. When the face passes the monitoring point, the displacement begins to float and tends to be stable. The displacement tends to -0.38mm. When the right line excavates, the deformation of the monitoring point will continue as previous process. The deformation law is similar to that of the previous process. The maximum displacement of J6-1 is -0.61mm. And it tends to -0.23mm.

The vertical deformation of the J6-1~J6-2 is larger than that of the J6-3~J6-6. It shows that the resistance deformation ability of the main Zijingang Road Tunnel is larger than that of the ramp.

Fig. 6 shows the vertical displacement trend of the existing municipal tunnel. It can be seen from Fig. 6 that when the left line excavating, the settlement value of the J1-1~J1-5 monitoring points decreases as the horizontal distance from the center line of the left line increases. The shorter distance from the head surface, the earlier inflection point appearing. Maximum displacement of J1-2 is -0.72mm. After the face passes the monitoring point, the monitoring point begins to float and tends to be stable. The displacement tends to -0.32mm. When the right line excavating, the deformation value of the monitoring point continues to deform on the basis of the last process. The deformation law is similar to that of the previous process, and the final deformation is small. The maximum displacement
of J1-2 is -0.73mm. And it tends to -0.30mm.

Because the existing municipal tunnel structure’s overall stiffness is great, the deformation of the monitoring points on the existing tunnel structure is small.

4.2. Effect of grouting pressure on the structure of existing municipal tunnels

Fig. 7 shows the vertical displacement trend of J6-1 under different grouting pressure. The J6-1 monitoring point begins to sink when the tunnel begins to excavate. And the grouting pressure is 0.15MPa. The point starts to rise and tends to be stable after the face passes the monitoring point (26 rings), and the final deformation value is -0.25 mm. When the grouting pressure is 0.20MPa, the settlement is not as obvious as 0.15MPa. When the face passes the monitoring point, the monitoring point begins to float and tends to be stable, and final value is 0.4mm. Under the grouting pressure of 0.25MPa, J6-1 appears to be floating at the beginning. When the face passes the monitoring point, the increasing trend of the monitoring point becomes more obvious. Finally, it tends to be stable, and the deformation value is about 0.70 mm. Under the grouting pressure of 0.30 MPa, the deformation law of the J6-1 is similar to that of 0.25 MPa, and the final deformation value is 0.9 mm. When the right line excavates, the deformation value of the monitoring point continues on the basis of excavation of the left line. And the deformation law is similar to that of the last process.

4.3. Influence of stratum reinforcement on the structure of existing municipal tunnels

Fig. 8 shows the vertical displacement trend of J6-1 under the conditions of 0.15 MPa’s grouting pressure and stratum reinforcement or without reinforcement. It can be seen from Fig. 8 that the maximum deformation value of the J6-1 is -0.7mm and the final deformation value is -0.25mm under the condition of stratum reinforcement when the left line is excavating. Under the condition that the stratum is not strengthened, the maximum settlement value of the J6-1 is -0.9mm, and the final deformation value is -0.55mm, which is increased by 28.5% and 120% respectively compared with the deformation value under the stratum reinforcement condition. When the right line is excavating, the deformation value of the J6-1 continues to deform on the basis of the last process, which is increased by 58.3% and 225% respectively compared with the deformation value under the stratum.
reinforcement condition.

The existing municipal tunnel’s structure has undergone torsional deformation during the tunnel excavation process. The vertical deformation of the municipal tunnel’s structure under the condition of stratum reinforcement and stratum without reinforcement is shown in Fig. 9(a) and 9(b). For concrete structures, the torsional deformation of the structure will greatly affect the stress of the structure. Serious torsional deformation will cause cracking of the structure, affecting its normal use and durability. The Fig. 9 shows that after the reinforcement of the triaxial cement-soil mixing pile in the ground layer, the torsional deformation of the existing municipal tunnel structure is reduced. Under the condition of stratum reinforcement, the maximum torsional deformation is 0.72mm. The maximum torsional deformation is 0.87mm under the condition of stratum without reinforcement.

![Figure 9. The enlargement vertical deformation of the section structure of J6-1~6 monitoring point during the excavation of the left line(mm)](image)

5. Conclusion
The following conclusions are drawn:

(1) The vertical deformation value of the existing municipal tunnel is increasing with the shield tunnel excavating. When the face passes the monitoring point, the monitoring point starts to rise and eventually tends to be stable. Because the overall rigidity of the existing municipal tunnel structure is large, the deformation of the existing tunnel structure is small, and the vertical deformation of the ramp is larger than that of the Zijingang Road Tunnel.

(2) The vertical deformation value of the existing municipal tunnel will increase with the increase of grouting pressure. According to the calculation result, combined with the surface settlement value of the non-underpass section, it is recommended that the shield adopt 0.3MPa grouting pressure in the non-crossing section and adopt 0.15MPa in the crossing section.

(3) The vertical deformation value of the existing municipal tunnel will be reduced by the reinforcement measures of the triaxial cement-soil mixing pile at the bottom of the existing municipal tunnel. Using stratum reinforcement measures not only improves the bearing capacity of the foundation of the existing municipal tunnel, but also reduces the interaction between the shield tunnel and the existing municipal tunnel during construction and operation.

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