Analysis of Construction Settlement of Shield Tunnel Crossing Metro Operating Tunnel

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Abstract. Based on the background of the Suzhou Metro Line 3 crossing the Line 1 operating tunnel, the finite element software MIDAS/GTS was used to perform 3D model and simulate the construction of the shield tunnel. The influence of shield tunnel penetration before and after strengthening on operating tunnels is studied. The research results show that the maximum settlement of the operating tunnel caused by underpass construction without reinforcement is 11.64mm, which exceeds the control value of 10mm, and deformation control measures must be taken. After reinforcement, the maximum settlement of the soil around Line 3 is only 5.65mm, the reduction of settlement about 50%, and the settlement control effect is obvious, which shows that it is feasible to take deformation control measures for pre-reinforcement of the soil around the tunnel.

1. Introduction

With the further densification of subway networks in major cities, subway construction will inevitably encounter a large number of underground buildings, bridges and railways. In recent years, with the increasing construction scale of subways, municipalities and other underground projects, the crisscross phenomenon of lines is becoming more and more common. Due to the characteristics of subway tunnel engineering construction and uncertain factors such as engineering geology and hydrogeology, there are safety risks in the construction of tunnel projects. Therefore, certain control measures need to be taken during the construction of the lower tunnel.

Comprehensively adopting strata reinforcement for soil layer improvement, compensating grouting, automatic real-time monitoring, theoretical analysis and other comprehensive technical measures and management methods can effectively reduce the settlement of existing tunnels after completion of construction [1-3]. Taking the intersection of the existing subway and the underpass tunnel as the axis, the local 2D scope of the existing subway tunnel and the soil layer between the two tunnels can be partially reinforced to prevent the longitudinal deformation of the existing subway tunnel caused by the new tunnel excavation [4]. In the case where the vertical clear distance between the upper and lower tunnels is only 1.079 m, the shallow buried subsurface excavation construction technology with a
rectangular section close to the upper tunnel floor is combined with measures such as full-section sleeve valve pipe grouting and monitoring to effectively control Settlement of wired structures [5]. The Midas / GTS software was used to simulate the impact of shield construction on the existing shield section under the condition that the shield tunnel in a certain section passes through the existing line and is not reinforced and the soil between the tunnels is grouted [6]. To sum up, the control of settlement when the shield subway passes through an existing building is the key. Controlling the settlement through the reinforcement of the soil layer and the real-time monitoring of the construction is a common method.

2. General situation of Engineering
The corresponding mileage of the Suzhou Metro Line 3 passing through the existing Line 1 operating tunnel is: the section is on the left DK30 + 850.879 ~ DK30 + 871.699, corresponding to the 845th ring to 864th ring, the left line is 21m from the south end of Door of East Station; the section is on the right DK30+847.749 ~ DK30 + 868.539, corresponding to 21st ring to 40th ring. The right line is 24.1m south of Door of East Station, as shown in Figure 1. The minimum clear distance between the upper and lower tunnels is 2.3m.

The soil cover of the tunnel operating under Line 1 between Jinjihu West Station and Door of East Station is

- ① Mixed filling layer,
- ② Plain filling layer,
- ③ Silty clay layer,
- ④ Silty sand and
- ⑤ Silty clay layer.

The Suzhou Metro Line 3 crosses the Line 1 operating tunnel, mainly through

- ④ Silty soil with silt,
- ⑤ Silty clay layer.

The concrete strength of the shield tunnel segment is C50, the impermeability level is P10, the inner diameter of the circular tunnel is 5500mm, the outer diameter is 6200mm, the lining width is 1200mm, and the lining thickness is 350mm.

![Figure 1. Suzhou Rail Transit Line 3 goes through Line 1](image)

3. Model building
The finite element software MIDAS / GTS was used for modeling, simulation of shield excavation, and numerical calculation. As shown in Figure 2, the model takes an underground space of 62m × 72m × 60m (length × width × depth), and the minimum clear distance between the upper and lower tunnels is 2.3m. The overall model constrains the X direction to the left and right, the Y direction to the front and back, and the Z direction to the bottom. The model is modeled using 3D solid elements, with a total of 72765 divided cells. The soil layer uses a modified Mohr-Coulomb model. The concrete strength of the shield tunnel segment is C50 and the impermeability level is P10. Considering that the assembly of the segment will affect the overall structural strength of the shield tunnel, the elastic modulus of the segment is reduced by 40%. As shown in Figure 3, the excavation of Line 3 is carried out first by excavating the left line, and the back shield is turned by excavating the right line.
4. Calculation results and analysis

4.1. Analysis of unreinforced settlement of soil layer

The four tunnels of Suzhou Rail Line 3 and Line 1 have the same size, and the final diameter of the designed tunnel is \( D = 6.2 \text{m} \). After the excavation of the left line of Line 3, the shield machine turned around and excavated the left line. As shown in Figure 4 (a), subway Line 1 has settled due to the excavation of the lower tunnel. The maximum settlement is located at the overlap of the upper and lower tunnels. The control standard for the deformation of the operating tunnel is: the control value of the settlement amount is 10mm; the control value of the uplift amount is 5mm. As shown in Figure 4 (b), the settlement caused by the longitudinal displacement of Line 1 and the settlement of both left and right lines is greater than 10mm, and the maximum settlement is about 11.64mm, which exceeds the control requirements for the safe operation of the subway operation tunnel. Soil layer needs to be reinforced before construction.

Figure 2. Overall model

Figure 3. Location layout diagram

Figure 4. Vertical displacement of unreinforced soil line 1
4.2. Analysis of soil reinforcement effect

Before tunnel shield excavation of Line 3 or so, pre-grouting reinforcement is applied to the soil in the excavation area through the upper tunnel. The reinforcement range is 10.2m × 10.2m, and the reinforcement width is 10m across the upper tunnel, as shown in the figure. In addition, during the process of grouting during tunneling, the soil is reinforced twice to ensure the effective range and strength of the reinforcement. After reinforcement, the elastic modulus of the soil is 300 MPa, the Poisson's ratio is 0.25, and the bulk density is 25 kN / m³.

Figure 5. Soil reinforcement diagram

It can be seen from the displacement cloud diagram and trend diagram after reinforcement in Fig. 6 that the overall displacement trend is the same as that without reinforcement. The maximum displacement still appears in the overlapping area of the upper and lower tunnels. The maximum settlement value is 5.65mm, and the settlement is reduced by nearly 50%. It can be seen that the reinforcement of the surrounding area of the lower tunnel can effectively control the settlement.

Figure 6. Vertical displacement of line 1 after soil reinforcement
5. Conclusion
For the construction of the shield tunnel through the operating tunnel, the settlement control of the upper tunnel is related to the operation safety of the subway, and the research on the settlement control is very important. Relying on the construction of the Suzhou Metro Line 3 shield tunnel passing through the Metro Line 1 operating tunnel, MIDAS / GTS was used to simulate the analysis and calculation of the shield tunnel crossing the operating tunnel construction, and obtained: Before the reinforcement, the maximum settlement of the tunnel around Line 1 is 11.85mm, which exceeds the control value of the settlement of the operating tunnel by 10mm, and soil reinforcement is required. After the excavation area of Line 3 of the upper and lower tunnels was reinforced, the maximum settlement was 6.04mm, a reduction of about 50%, and the settlement was effectively controlled.

Therefore, under the condition of soft soil, the construction of a short-range shield tunnel through an operating tunnel requires reinforcement of the soil body to ensure the safety of the operating tunnel. Through simulation, it can be known that the excavation area of the overlapped part of the upper and lower tunnels is reinforced with grouting in advance to improve the parameters of the soil layer, which can effectively control the settlement of the upper tunnel, and reduce the tensile stress on the upper tunnel to ensure construction safety.

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