EVALUATION OF CONSTRUCTION IMPACTS AND OPTIMIZATION OF CONTROL MEASURES FOR LARGE-SECTION METRO TUNNELS OVERPASSING EXISTING TUNNELS

by

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The development of urban rail transit has led to an increase in the number of large section subway tunnels crossing existing tunnels. This study combines the actual engineering of the Yanggongqiao Station Longzhuayan Station section tunnel of Chengdu Metro Line 17 Phase II project crossing the existing Line 7 shield tunnel, and uses on-site investigation, monitoring, and numerical simulation methods to evaluate the construction impact. Based on this, measures such as bench pile reinforcement, pre grouting, and parameter optimization are proposed. In practical applications, the comparison between monitoring and simulation results shows that these measures effectively control the deformation of existing tunnels, providing important references for similar projects.

Key words: *large section subway tunnel, upside construction, impact assessment, optimization of control measures, engineering application*

Introduction

In recent years, numerous scholars have conducted extensive research on reinforcement measures based on practical engineering cases. Qi [1] proposed a method combining theoretical analysis, numerical simulation, and on-site measurement to apply support trolleys and grouting reinforcement to existing tunnels when studying the construction of shield tunnel sthrough existing tunnels. At the same time, steel rail weights were placed inside the new tunnels to effectively control the uplift of the existing tunnels.Wang *et al.* [2] found that grouting and steel ingot placement can effectively suppress tunnel uplift in the study of urban comprehensive pipe gallery crossing existing subway tunnels. Liao *et al.* [3] combined the shield tunneling project of Shanghai Metro Line 11 and confirmed through numerical simulation that specific construction sequence and grouting reinforcement can reduce the deformation of existing tunnels. Zhao *et al.* [4] proposed reinforcement measures of steel support and arch grouting

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for the overpass of existing tunnels in the new entrance and exit sections of Nanchang Metro. Zhang *et al.* [5] proposed a plan to inject sleeve valve pipes around the existing tunnel before shield tunneling when simulating the crossing of Shenzhen Metro Line 11 over Line 1. Based on the Shenzhen Metro Line 5 project, Luo *et al.* [6] found that sleeve valve pipe grouting and rotary jet grouting pile reinforcement can reduce the deformation of existing tunnels. Bai *et al.* [7] compared different construction methods in the new super large section frame bridge and culvert overpass project in Beijing and proposed a reinforcement method combining isolation piles and grouting. Among them, the stress balance pushing method had a relatively small impact on the existing tunnel. Liu *et al.* [8] conducted engineering case studies to clarify that friction and grouting pressure during the crossing process of shield tunnel construction affect the deformation of the existing tunnel, and unloading additional stress after crossing plays a major role. They also proposed that ring support reinforcement can effectively control longitudinal deformation. Liu *et al.* [9] analyzed that sleeve valve pipe grouting mainly affects tunnel bending moment and shear force in the shield tunnel project of operating subway sections on large-diameter power tunnels, and has a greater impact on horizontal displacement than vertical direction.

At present, the deformation control and reinforcement measures for the construction of existing tunnels mainly focus on support reinforcement, soil grouting reinforcement, and internal pressure and weight of newly built tunnels. However, in practical engineering, when the clear distance between the upper and lower tunnels is small and the cross-section of the newly built tunnel is large, it is often difficult to achieve the desired effect of soil grouting reinforcement. In view of this, based on the principle of reinforcing isolation columns, a reinforcement measure of setting bench beams between newly built tunnels and existing tunnels is proposed. However, due to its complex construction process, the control effect on the deformation of existing tunnels is not yet clear. Therefore, based on the existing Line 7 shield tunnel spanning the Yanggongqiao Station Longzhuayan Station section of Chengdu Metro Line 17 Phase II project, this study conducts an in-depth analysis of the influence of parameters such as the diameter and length of manually excavated piles, the quantity of steel in the top pipe pressure beam, and the strength grade of concrete on the deformation of the existing tunnel in the bench beam reinforcement measures. Reasonable reinforcement parameters are determined to provide practical and feasible reference experience for similar subway tunnel spanning projects in the future.

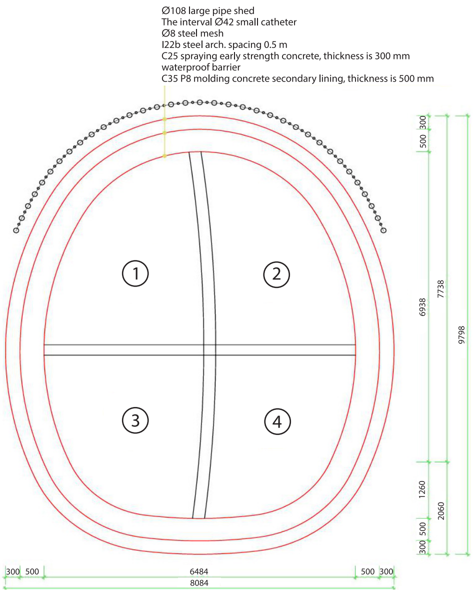

Figure 1. Schematic diagram of cross-section of newly constructed tunnel [mm]

Numerical simulation scheme

This project is a shield tunnel project for Chengdu Metro Line 17 Phase II, which spans over the existing Line 7 tunnel between Yanggongqiao Station and Longzhaoyan Station. Among them, the left line of Line 17 is 1126.202 m long, the right line is 1121.446 m long, and the upper span section is approximately orthogonal to the left and right lines of Line 7. The upper span length is about 45 m, and the minimum clear distance between the two is only about 1.21 m. According to relevant standards, it is judged as a special risk. The shield tunnel of Line 7 adopts C50 precast concrete lining segments, with an outer diameter of 6.0 m, an inner diameter of 5.4 m, a ring width of 1.5 m, a segment thickness of 300 mm, and a arch crown distance of about 17.2 m from the ground surface. The design section of the new tunnel is shown in fig. 1.

During the numerical simulation process, Midas GTS NX software was used to construct a 3--D model and simulate the construction of a new tunnel crossing an existing tunnel. The equivalent elastic modulus of the top pipe pressure beam composed of top pipe, section steel, and concrete can be calculated using the stiffness equivalent method [10], and simulated using beam elements. The specific parameters are shown in tab. 1.

Table 1. Physical and mechanical parameters of supporting structure and bench beam structure materials

Titles	Gravity [kNm^{-3}]	Elastic modulus [GPa]	Poisson ratio
Shield tunnel segment	25.0	30.0	0.2
Initial support	23.0	29.2	0.2
Temporary support	23.0	29.2	0.2
Secondary lining	25.0	31.5	0.2
Pipe jacking beam	27.5	40.2	0.22
Manual excavation pile	25.0	20.7	0.2

The construction simulation of the interval tunnel adopts the CRD method.

Engineering application and actual reinforcement effect analysis

After scheme comparison and demonstration, the new tunnel will be constructed using the CRD method. In order to ensure construction safety, the construction plan for the new tunnel in the upper span section has been optimized, and bench beam reinforcement measures have been taken above the existing tunnel, with pre grouting reinforcement applied to the surface. After optimizing the construction plan, the new tunnel adopts a composite lining structure of *initial support* + *secondary lining* + *tertiary lining*. [11]: the initial support adopts a combination of steel mesh, 22B steel frame, and C25 shotcrete support, with the shotcrete thickness adjusted to 0.35 m and the steel arch spacing reduced to 0.4 m. Three new linings (with a thickness of 0.35 m) are added, and a secondary lining (with a thickness of 0.25 m) is constructed before removing the temporary support to increase the self weight of the new tunnel and the stiffness of the support structure. Both the secondary and tertiary linings are made of C35 formwork concrete, and the length of each removal is reduced to 6.0 m. The bench beam consists of manually excavated piles and top pipe pressure beams: the diameter of the manually excavated piles is 1.5 m, the length of the piles is 10 m, and the concrete strength grade is C30. The top pipe beam is made of welded steel pipes with a diameter of 1.8 m, containing 4 I25b steel beams, and is poured with concrete with a strength grade of C30. The surface pre grouting reinforcement adopts cement slurry, with a reinforcement area of 46.26 m × 28.76 m. The grouting boundary is 3 m away from the outer edge of the initial support, and the grouting depth ranges from the ground to the upper guide tunnel area of the newly built tunnel, with a depth of 11.28 m. The schematic diagram of the optimized construction plan for the new tunnel is shown in fig. 2.

Bycomparing and analyzing numerical simulation results with on-site monitoring data, according to GB50911-2013 *Technical Specification for Monitoring of Urban Rail Transit Engineering* and CJJ/T 202-2013 *Technical Specification for Structural Safety Protection of Urban*

Rail Transit, combined with the working environment of existing subway tunnel monitoring, automatic monitoring methods are adopted to monitor local operating subway tunnels affected by external construction. Under the newly constructed tunnel, 15 monitoring sections are arranged on the left and right lines of the existing subway Line 7 section tunnel, as shown in fig. 3. Each monitoring section is equipped with 5 deformation monitoring points, as shown in fig. 4.

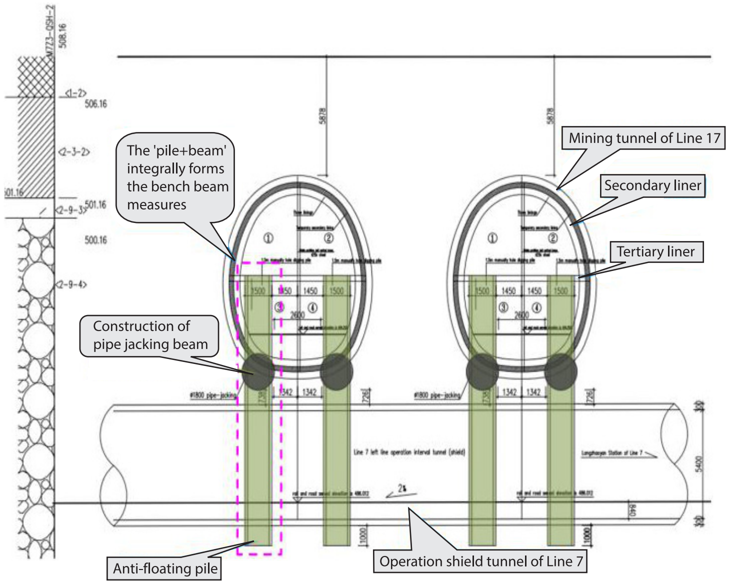

Figure 2. Schematic diagram of the new tunnel construction scheme

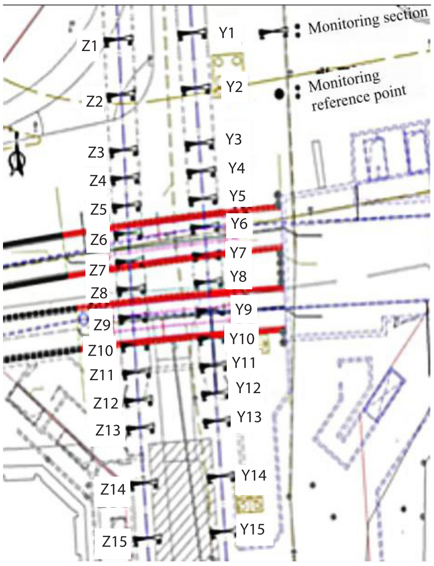

Figure 3. Schematic diagram of the lay-out of monitoring sections in existing tunnels

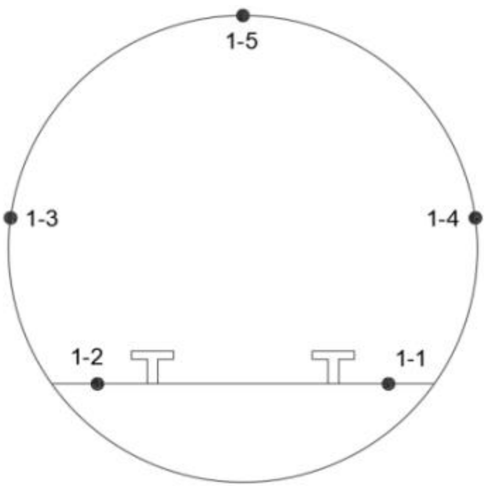

Figure 4. Schematic diagram of the lay-out of monitoring points in existing tunnels

Select the left and right arch monitoring points 5 of the existing tunnel monitoring section 7, and compare the on-site monitoring data with the numerical simulation results as shown in fig. 5.

As shown in fig. 5, with the progress of construction, the cumulative uplift value of the left and right tunnel arches continues to increase, but the uplift value of the left line is always greater than that of the right line. The reason for this is that the monitoring point Z7-5 of the left tunnel is located near the center of the new tunnel edge, while the monitoring point Y7-5 of the right tunnel is located at the edge of the new tunnel. Therefore, the monitoring point of the left tunnel is greatly affected by the excavation and unloading of the new tunnel, resulting in a slightly larger uplift value than the right tunnel. During the construction process, the cumulative maximum uplift values of the two monitoring points were 2.25 mm and 0.79 mm, respectively, and the on-site monitoring values were 1.94 mm and 0.95 mm, respectively. The final simulated uplift values were 1.11 mm and 0.50 mm, respectively, and the on-site monitoring values were 1.16 mm and 0.53 mm, respectively. The difference between the numerical simulation calculation and the on-site measurement was small, and the two were basically close, with the same trend of change. Numerical simulation can be used to analyze the construction process of the upper span, and the reinforcement measures of bench beams are effective.

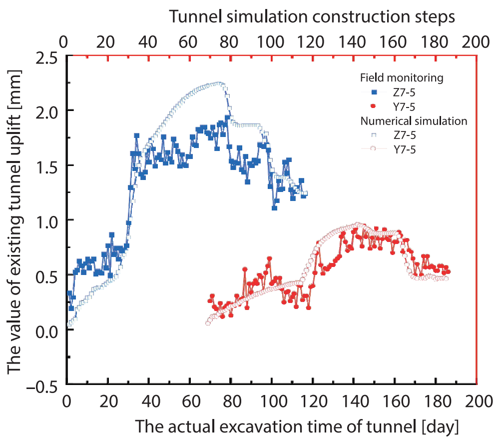

Figure 5. Comparison between numerical calculation and field measurement results of monitoring points

Conclusion

When using bench beam reinforcement measures to cross existing tunnels in a new tunnel mining method, the maximum uplift value of the existing tunnel decreases with the increase of the length and diameter of the manually excavated pile, the strength grade of the top pipe pressure beam concrete, and the number of steel sections. The excavation area of the new tunnel reaches 64.7 m^2. The setting of the bench beam can effectively control the uplift deformation of the existing tunnel. When constructing a new large section tunnel using the mining method with a small clear distance over an existing tunnel, the new tunnel section structure adopts a three lined structure, with bench beams set above the existing tunnel and reinforcement measures such as surface pre grouting. This can effectively control the uplift of the existing tunnel and ensure construction safety.

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