Investigation of Deformation Influence on Throat Area of Highway Tunnel across the railway station

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Abstract. In order to ensure that Baishiyi Tunnel, an control project passing through Zhongliang Mountain, successfully passes through the throat area of the North Railway Station, track deformation control standard is established (Vertical differential settlement≤3.5mm, subgrade settlement≤3.5mm). Based on survey data, engineering analogy and numerical simulation, the influence of different excavation procedures on the ground settlement and track structure deformation is analysed. The result shows the ground settlement and trend of the measurement points at the corresponding positions of the tunnel and track structure are basically the same. The maximum ground settlement above the left line tunnel is 7.0mm, and the minimum ground settlement is 2.4mm. The ground directly above the grain dedicated line is a key part to be paid attention to in settlement control.

1. INTRODUCTION

In recent years, the economy of central and western China has continued to develop rapidly, with more and more urban subways and highway tunnels, meeting the needs of urban space development and urban strategy and improving the needs of urban skeleton road networks crossing mountains and rivers[1]. The construction of urban tunnels is inevitably close to the above-existing structures such as tunnel, houses, railways, and bridges, which increases the hidden safety hazards of above-ground structures and also increases the risk of tunnel construction[2].

The analysis and research on the settlement and deformation of tunnels adjacent to existing structures have been paid much attention by many experts and scholars[1-5], and some research results have been obtained. Li Junjie[6] studied the structural and ground settlement deformation caused by the tunnel construction and proposed comprehensive control of the existing grouting to strengthen the soil, the advanced support of the newly built excavation section, strict control of the construction process, and feedback to the construction by monitoring and early warning measures. Li Jun[7] researched the construction control of shield tunnels passing through existing railways and proposed targeted construction control schemes including rotary jet grouting pile reinforcement. Zheng Yuchao[8], based on the subway tunnel crossing railway project, researched the close impact zoning discrimination criterion based on the settlement of the subgrade and the deviation of the track height. At the same time, it proved that the control of the track deviation is more stringent. Aiming at different impact zones, construction classification parameters were reasonably set up, and a "rail change" control method for safely crossing the railway on-site was proposed. Liu Ye et al.[9] Analyzed the influence of different shield parameters and support conditions on the force and deformation of the tunnel through the existing
viaduct group piles for a high-speed railway project under a subway in Beijing. The numerical simulation results reflect the actual excavation process and the final settlement was very close to the actual measurement results. Du Xiaoyu[10] studied the deformation rules of the existing railway facilities during the shield tunneling process. Based on numerical simulation, the deformation rules of the ground surface and roadbed are analyzed and discussed. There are more and more projects under the existing railway construction for urban highway tunnels. During the construction of the tunnel, it will affect roadbeds, rails, and other facilities, which will cause train safety problems, especially when the tunnel passes through the throat area of the railway station. The impact of the throat area of the adjacent railway is less studied. Based on the background of Chongqing Baishiyi Tunnel near the railway throat area, this paper analyzes and studies the impact of the urban tunnel near the railway throat area on the track settlement and structural safety.

2. PROJECT BACKGROUND

The Baishiyi Tunnel which length 10.6km starts at Shizikou Interchange crossing Baishiyi Airport and Liangtan River crosses Zhongliang Mountain and ends at Huayan Interchange on the Inner Ring Expressway. The main line of the project is designed as a 6-lane bidirectional road, designed according to the urban expressway 60 ~ 80km / h. The maximum longitudinal slope is 4.0%, and the tunnel uses a bidirectional herringbone slope of 0.6% and -0.6%. The west side of the Baishiyi Tunnel intersects with the Xingluo line of the Chongqing-Qianjiang Freight Railway and 10 railway turnouts. The Baishiyi Tunnel at the intersection includes two three-lane tunnels and an auxiliary road tunnel.

2.1. Engineering Geology

The area where the project is located is staggered with mountains and basins. The terrain is generally undulating, high in the middle, and low in shape on both sides. The main exposed strata along the line are the Quaternary Holocene and Middle Jurassic Shaximiao Formation (J2s) and Xintiangou Formation (J2x). Quaternary strata are mainly composed of miscellaneous fill soil, silt, and silty clay. The lithology of the formation is mainly sandstone and mudstone with siltstone and shale. This stratum is dominated by soft thin-medium-thick layered mud, with poor mechanical properties of the rock mass and difficulty in cave formation. Drip or seepage can be seen in sandstone-like interlayers. The stratum is of soft to hard layered mudstone-sandstone type, and the rock mass has poor mechanical properties. This section is the tunnel body section. According to Appendix B of the DBJ50-174-2014 code, the surrounding rock grade of this section is V grade. The stratigraphic distribution of the profile shows in Fig.1.

![Fig. 1 Stratigraphic distribution of the profile](image)

2.2. Proximity of Rail Transit Line 5 to Existing Railway Tunnels

The Baishiyi tunnel passes through the railway turnout area in the form of three independent caves. The minimum clear distance between the left and right lines is about 7m, and the minimum clear distance between the right and white lines of the Baishiyi tunnel is about 12m. The left line of Baishiyi Tunnel and the Xingluo Line (down) are arranged diagonally, and the oblique angles are 75°. The intersection of the left line of Baishiyi Tunnel is ZK0 + 391.279 (ZK0 + 396.454) on Xingluo (Bottom) The mileage is K20 + 891.851 (K20 + 924.273). The left and right lines of Baishiyi Tunnel pass through the railway...
area according to a 2% longitudinal slope. The clear distance between the tunnel vault and the railway track top is about 12.2m (12.1m). Except for the Xingluo line, the left line of the Baishiyi Tunnel intersects with the railway line in the turnout area along the road forward direction. The tunnel vault and the minimum clear distance between the rail tops are about 11.4m. The intersection of Baishiyi Tunnel and Railway shows in Fig. 2. The Baishiyi Tunnel Location Relationship shows in Fig.3.

3. NUMERICAL MODELING
This article uses FLAC3D software, based on the stratum-structure model. Considering the spatial relationship between the Baishiyi tunnel and the turnout area, based on the stratigraphic distribution of the right section of the Baishiyi tunnel K0+310~K0+445(fractional mileage), a three-dimensional calculation model is established to simulate the construction process.

3.1. Description of the numerical model
The horizontal width of the 3D computing model is 169.5m (60m from the left line and the auxiliary B line centerline), the vertical length is 135m (the range of K0+310~K0+445), and it is taken vertically to 60m below the tunnel (shows in Fig.4). The buried depth of the tunnel is considered according to the actual buried depth, the stratum is considered according to the above distribution, and the tunnel spacing is considered according to the most disadvantage situation. The thickness of the rock sandwich between the mainline tunnel is 7m, and the thickness of the rock sandwich between the right line tunnel and the auxiliary ramp is 12m (shows in Fig.5). Consider 9 railway lines, including Xingluo line, down line and 7 railway forks. Railway lines such as the Xingluo Line are simulated by elastic solid elements. The solid material elements are used for railway trackbed and rock and soil. The Moore-Cullin yield criterion is adopted. The support structure is simulated by shell elements. The stress field is considered as the dead weight stress field.
3.2. Stratum and Structural parameter
The mechanical parameters of surrounding rocks, rails, and track beds were selected based on geological survey data, as shown in Table 1.

| Material type              | density | Elasticity modulus (Mpa) | Poisson ratio | Frictional angle | Cohesion (Kpa) |
|----------------------------|---------|--------------------------|---------------|------------------|---------------|
| Article fill               | 2000    | 1                        | 0.40          | 30.00            | 0             |
| Silty clay                 | 1960    | 15                       | 0.36          | 13.15            | 22.2          |
| Strongly weathered mudstone| 2470    | 400                      | 0.36          | 27.00            | 110           |
| Moderately weathered mudstone | 2500   | 1320                     | 0.33          | 31.52            | 433           |
| Strongly weathered sandstone | 2440   | 1310                     | 0.262         | 29.80            | 453           |
| Moderately weathered sandstone | 2470   | 4310                     | 0.24          | 34.79            | 1784          |
| Steel Rail                | 2397    | 210000                   | 0.3           | /                | /             |
| Ballast bed               | 2240    | 5800                     | 0.3           | 50               | 300           |
3.3. Evaluation criteria for deformation control of subway track structures

The track structure deformation control standard involves factors such as the existing subway line conditions, operating speed, fastener types, and maintenance and repair conditions. Projects for deformation control of track structure mainly include settlement or uplift amount, settlement or uplift rate. This article uses the amount of settlement or uplift as the control standard, which is according to Railway Repair Rules (tieyun [2006] No. 146).

| Item(mm)          | $v_{\text{max}} > 160 \text{km/h}$ | $160 \text{km/h} \geq v_{\text{max}} > 120 \text{km/h}$ | $v_{\text{max}} \leq 120 \text{km/h}$ |
|-------------------|----------------------------------|----------------------------------|----------------------------------|
|                   | A  | B  | C  | A  | B  | C  | A  | B  | C  | A  | B  | C  | A  | B  | C  |
| Rail spacing      | +2 | +4 | +6 | +4 | +6 | +8 | +6 | +7 | +9 |
| Horizon difference| 3  | 5  | 8  | 4  | 6  | 8  | 4  | 6  | 10 |
| Vertical difference| 3  | 5  | 8  | 4  | 6  | 8  | 4  | 6  | 10 |
| Rail orbital      | 3  | 4  | 7  | 4  | 6  | 8  | 4  | 6  | 10 |

Note: A means acceptance of railway operation  
      B means regular routine maintenance  
      C means the temporary repair

In order to leave room for the actual project implementation, this plan determines the control standards for railway subgrade and track as follows: Vertical differential settlement $\leq 3.5 \text{mm}$, subgrade settlement $\leq 3.5 \text{mm}$.

3.4. Construction process

According to the proposed construction method-double sidewall guide pit method with reserved core soil, the excavation simulation of the left and right lines of the main tunnel is carried out, and the step method is adopted for the auxiliary line B tunnel. Along with the long-distance of the line, the three-dimensional overall stability analysis is in the order of "left tunnel line-right tunnel line-auxiliary tunnel line B" (from left to right). For a single tunnel, the lengthways spacing of each excavation face is 10m. It reserves 3 times of tunnel diameter on the longitudinal excavation (i.e.45m). The 3D excavation effect is shown in Fig. 6.

![Fig.6 3D excavation effect](image)

The scope of tunnel construction belongs to the Turnout Zone. Considering the spatial position relationship of each railway and tunnel, a total of 9 railway lines are simulated in the three-dimensional model, including the Xingluo down-line and 7 railway turnouts (shows in Fig.7). In addition, all railways in the turnout area are full of trains. In reality, from the perspective of partial safety, it is assumed that there are 6 railway stop trains in the turnout area (that is, trainloads are applied to 6 railways).
4. RESULTS AND DISCUSSION

From the perspective of geological conditions, the thickness of the tunnel cover rock (medium weathered rock layer) below the grain dedicated line is small and the geological conditions are poor. Therefore, the stability and deformation of the tunnel under the grain dedicated line is analyzed.

4.1. Excavation below the grain line

![Fig.8 Settlement of ground surface around the grain line with excavation](image8)

![Fig.9 Settlement of track directly above each tunnel with excavation](image9)

As can be seen from Fig.8, the maximum surface settlement above the left-line tunnel is 6.3mm, the maximum surface settlement above the right-line tunnel is 5.8mm, and the maximum surface subsidence of the auxiliary ramp is 1.6mm, indicating that the surface of the tunnel has a large deformation. The zero points on the horizontal axis correspond to the middle guide upper step of the double-sided guide pit of the corresponding tunnel of each curve, which is excavated directly below the grain dedicated line. The maximum track settlement directly above the left line tunnel is 6.7mm, the maximum track settlement directly above the right line tunnel is 6.2mm, and the maximum track settlement directly above the auxiliary ramp is 1.7mm, indicating that the track after tunnel excavation (shows in Fig.9). Taking the grain dedicated line track directly above each tunnel as the monitoring point, the differential settlement of the corresponding track measurement points directly above the left and right line tunnels is analyzed as the left line palm face advances. The right-line palm face advancement changes.

4.2. Excavation below Xingluo Line

Using the ground surface near the Xingluo line as a monitoring point, the curve of the change of the ground surface with the advancement of the palm is drawn, as shown in Fig. 10. It can be seen that the maximum surface settlement above the left line tunnel is 3.9mm, the maximum surface settlement above the right line tunnel is 3.6mm, and the maximum surface settlement above the auxiliary ramp is 1.3mm. The surface deformation after tunnel excavation is not large. The settlement of track directly above each tunnel with excavation shows in Fig.11.

![Fig.10 ground surface settlement around the Xingluo Line with excavation](image10)

![Fig.11 Settlement of track directly above each tunnel with excavation](image11)

4.3. Excavation of the left line tunnel is completed

At this time, the left line tunnel was fully excavated, the right line tunnel was excavated on the left side, the upper step of the middle guide has been excavated to 120m in the longitudinal direction, and the
auxiliary step of the auxiliary line B tunnel has been excavated to 95m in the longitudinal direction. After the excavation of the left line tunnel, the vertical displacement cloud diagram is shown in Fig.12, the ground settlement directly above the tunnel is shown in Fig.13, and the track settlement above the tunnel is shown in Fig.14, the maximum ground settlement above the left line tunnel is 7.0mm, and the minimum ground settlement is 2.4mm. The ground directly above the grain dedicated line is a key part to be paid attention to in settlement control. The settlement of each track after the excavation of the left line tunnel is shown in Fig.14. It can be seen that after the excavation of the left line tunnel, the upper track significantly settles. The maximum track settlement is 6.8mm, which is located on track line 1 and track line 2, that is, the special line for grain and its forks. It is thin, the stability of surrounding rock is poor, and the track settlement exceeds the limit after the tunnel is excavated.

Corresponding support measures must be taken during construction and monitoring must be strengthened. In addition, because the left-line tunnel and the right-line tunnel are only 7m in length, they are close to the tunnel. After the excavation of the left-line tunnel has caused the railway above the right-line tunnel to settle on the side of the left-line tunnel, the right-line excavation process is also the same. Attention needs to be paid to reducing construction disturbances.

Note: Track numbers 1 to 9, in turn, represent the railway lines from small to large along the mileage of the tunnel, which are the grain-only line fork, the grain-only line, the 2 Xingjing line forks, the Xingying line, the downline, and the other 3 Xingying lines Fork
5. CONCLUSION

(1) The geological conditions of the project are good, the state of the bare tunnel is sufficiently stable, and the initial risk of the adjacent project is low.

(2) The deformation control of the railway turnout area is strict. The settlement in the state of bare holes exceeds the control value. During the construction of the tunnel, it is necessary to do a good job of controlling the settlement to avoid or mitigate the impact on the existing railway. The overall risk is moderate.

(3) The left and right guide pits of the double sidewall guide pit method can be 5m wide. It is recommended to construct the method by the first middle and then two sides (right line, then excavation of left line and auxiliary line at the same time).

(4) During the entire construction process, the existing track structure first rises as a whole, and then the overall settlement does not exceed the control value. The settlement and trend of the measurement points at the corresponding positions of the tunnel and track structure are basically the same. It is 7.0mm, and the minimum value of ground settlement is 2.4mm. The ground directly above the grain dedicated line is a key part to be paid attention to in settlement control.

(5) Grain special line and its branch road, where the overlying rock layer is thin, the stability of surrounding rock is poor, and the track settlement exceeds the limit after the tunnel is excavated. During the construction process, corresponding support measures must be taken and the monitoring must be strengthened.

ACKNOWLEDGMENTS

The author would like to thank for the support from the Key R&D Program (project number 2017YFC0806006).

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