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Research Article

Demonstration and Analysis of Urban Traffic Tunnel Expansion Project Adjacent to Buildings

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Abstract: With the increasing number of urban underground construction projects, the evaluation of the influence of tunnel expansion on building foundation is one of the important factors to be considered in the project. In this paper, the deformation of the upper structure and the deformation pattern of the upper structure were analyzed, and the two-dimensional finite element model was built based on the case of Chongqing Jiefangbei Underground Ring Road Expansion Project Scheme. Comparative analysis of the deformation and changes in stress of the two tunnel expansion construction schemes of full-frame support and bolt suspension was performed, and the safety, rationality and feasibility of the bolt suspension scheme was confirmed through project safety analysis. It is hoped that this paper will serve as a reference for similar projects in the safety control technology of tunnel construction process.

Keywords: Proximity engineering; Deformation index; Jiefangbei Underground Ring Road; Engineering safety

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1 Foreword

The number of tunnel expansion projects has gradually increased, and the construction of tunnels adjacent to buildings is also becoming more common, but the expansion of existing tunnels adjacent to buildings is rare. Due to the complexity of rock engineering, the interaction mechanism between the building and the tunnel during the expansion of tunnel is still unclear. The selection of the right type of construction plan for the expansion is the primary problem faced by the projects. In various researches, there are mainly three methods, namely: numerical simulation, on-site monitoring and engineering analogy, among which numerical simulation has a dominant position in various research and engineering applications due to its convenience and predictability[1-4]. This paper takes the expansion of the Jiefangbei Underground Ring Road Project in Chongqing as an example; performed comparative analysis on the above two schemes through two methods of finite element analysis and engineering safety analysis, and derived a reasonable design and construction scheme.

2 Building resistance to deformation

When the building is subjected to deformation caused by tunnel excavation, the structure itself has different responses under different conditions, including: the stiffness of the foundation; the stiffness of the superstructure; the position of the subsidence trough where the structure is located; the width of the foundation; size and form, etc[5-6].

Large displacements during the construction of the tunnel may result in the loss of normal functions. Moreover, different structural forms are also crucial to resistance to deformation. The overall rigidity of box foundation and raft foundation is obviously better than that of independent foundation and strip foundation, and their ability to resist soil subsidence, differential subsidence, horizontal displacement, tension and compression strain, etc. are stronger, while the independent foundation is relatively weak[7-9].

According to the survey results, shear failures in masonry structures etc. usually include normal / \-shaped failure and \ /-shaped failure, as shown in Figure 1; common tensile failure is shown in Figure 2.

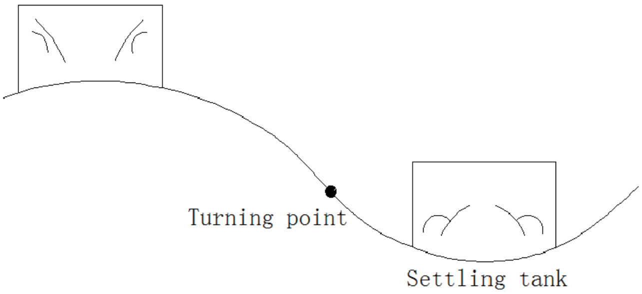

Figure 1. Crack development in the upper structure

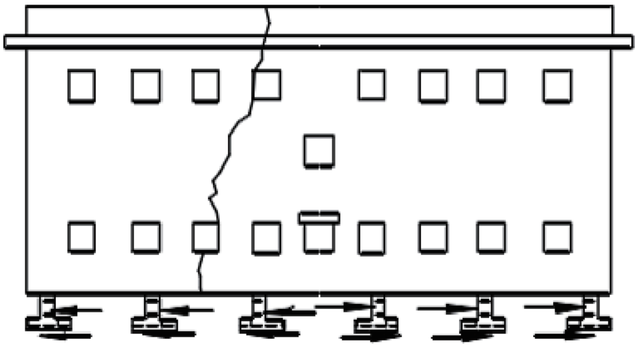

Figure 2. Illustration of tensile failure

3 Project overview

The first phase of the Jiefangbei Underground Ring Road Project was modified based on the original civil air-defense parking lot. Part of the main passage does not meet the fire protection requirements, therefore it is necessary to demolish the old lining structure of the original civil air-defense cavern K0+435~K0+444.5 and expand horizontally with different widths of 1.028~1.543m, see Figure 3 below.

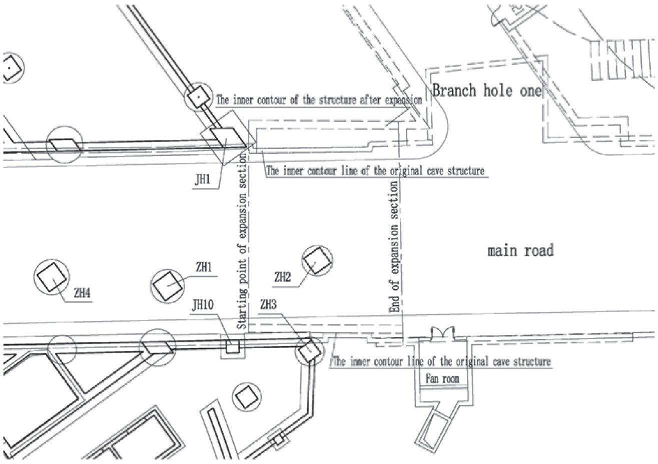

Figure 3. Project floor plan

After the expansion construction, the newly built tunnel lining is an asymmetric heterogeneous structure. The starting point of the expanded section K0+435 is in contact with the existing pile foundation of the World Trade Centre Chongqing (WTCC) at zero distance, and the end-point K0+444.5 is connected to the intersection of the main passage and the branch tunnel.

The WTCC Project is a frame-tube structure with 4 basements and 43 floors above ground, with a construction area of 31705m^2. The tower adopted a manually dug pile foundation, the core tube area has a raft foundation, and the podium has an independent column foundation. The foundation bearing layer is moderately weathered sandstone, and the pile is embedded in the bearing layer twice the pile diameter, and the pile diameter is 2300~1000mm. The pile foundation concrete strength grade is C35 or C30.

The foundation of the podium is an independent column foundation with a size of 2500×2500mm~1000×1000mm, and it is 1000~500mm embedded in the complete moderately weathered rock. The foundation plate reinforcement is Φ22-16, and the spacing is 140-130mm. The core tube raft foundation of the tower is 1800mm high, made of mass concrete, and the concrete strength grade is

C30. Among them, ZH stands for pile foundation and JH stands for column foundation.

The extension section uses 26cm thick C30 shotcrete, with 20b I-beam inside, and the secondary lining thickness is C30 reinforced concrete. The initial support of the ordinary section of the cable tunnel adopts 2.5m long φ22 mortar anchor rod and 20cm thick shotcrete with I-beam inside; the secondary lining adopts 30cm-thick C40 reinforced concrete, and a waterproof layer is laid between the initial support and the secondary lining. The tunnel lining section is shown in Figure 4 below.

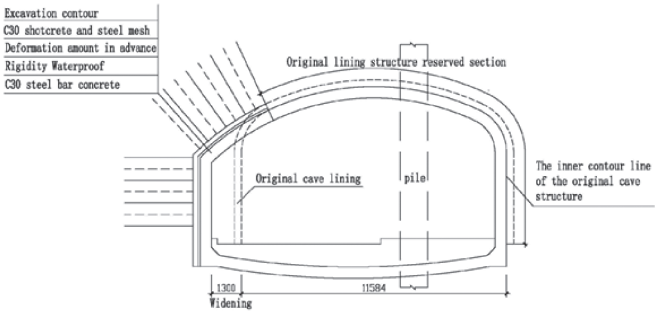

Figure 4. Cross section of tunnel lining

The designer proposed two construction schemes, namely full-frame support and bolt suspension, respectively as follows:

3.1 Full-frame support scheme

First, use full-house bracket to support, secondly, remove the partial lining of the existing manned shelter, and then implement mechanical expansion, overlap the new initial support with the existing initial support, and finally remove the full-house bracket and construct a secondary lining. See Figure 5 below for details.

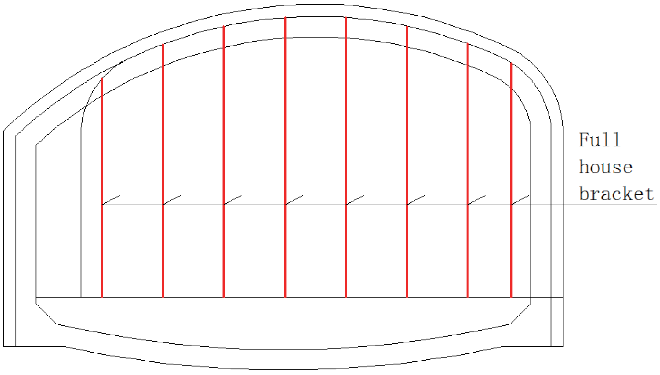

Figure 5. Full-frame support scheme

3.2 Bolt suspension scheme

The bolt suspension scheme adds anchor rods as a temporary reinforcement measure for the existing manned-tunnel lining. See Figure 6 below for details.

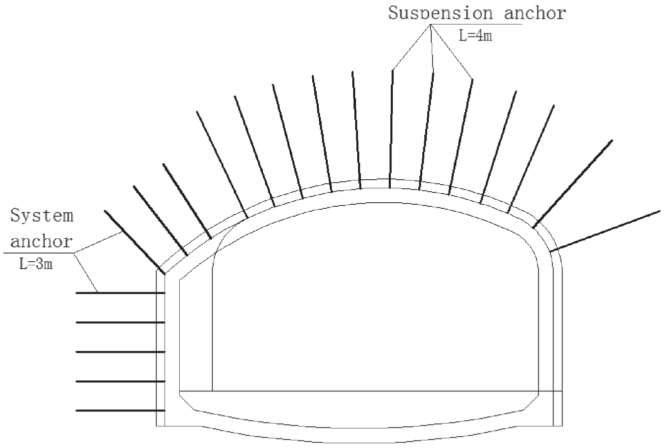

Figure 6. Bolt suspension scheme

3.3 Physical and mechanical parameters

The physical and mechanical parameters provided by the geological survey are as follows (Table 1).

Table 1. Physical and mechanical parameters of rock and soil table

Name of Rock Soil	Natural Density	Shear Strength		Elastic Modulus, Es	Poisson Ratio, μ	Tensile Strength (KPa)
		Internal Friction Angle, φ	Cohesion, c			
	kN/m^3	°	kPa	MPa (10^4)		
Plain Fill	21	30.0	0	0	0	0
Moderately Weathered Sandstone	25.3	27	700	1.3	0.35	240

3.4 Building foundation load

The WTCC has a large area, a large number of pile foundations, an extremely complex internal structure, and the expansion area is small. Therefore, only the pile foundations around the expanded tunnel were modeled and analyzed. The calculation adopted building foundation + upper load simulation, and the calculation of the upper load is as follows: ZH2 foundation N=28800KN; ZH1 foundation N=30400KN; ZH4 foundation N=31200KN; ZH3 foundation N=11200KN; JH1 foundation N=20000KN; JH10 foundation N=13200KN;

4 Calculation results

4.1 Full-frame support scheme

It can be seen from Figure 7 that the maximum subsidence of the surrounding rock after the expansion of the tunnel was 5.1mm, the increase in subsidence was 1.4mm, and the growth rate was 38%. The expansion of the tunnel had little effect on the subsidence of the surrounding rock of the vault.

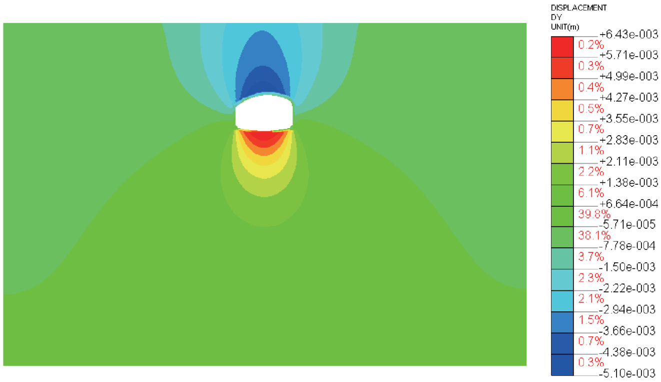

Figure 7. Vertical displacement cloud after tunnel expansion

It can be seen from Figures 8 and 9 that the maximum principal stress of the existing lining structure after the expansion is 230KPa, and the maximum principal stress of the structure after the initial support was connected to the existing lining structure is 591KPa, all located at the right arch; the minimum principal stress of the existing lining structure after expansion is -2.98 MPa, the minimum principal stress of the structure after the initial support was connected to the existing lining structure is -2.98 MPa, all located at the right arch waist.

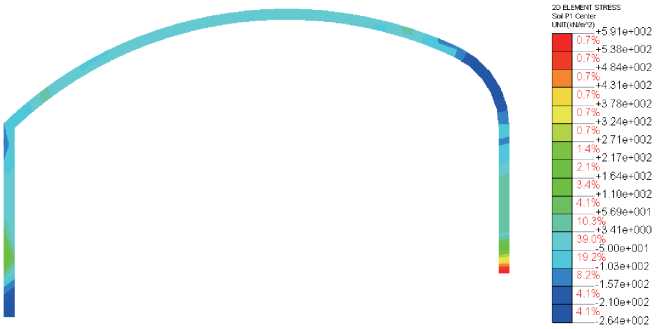

Figure 8. Plot of maximum principal stress of new initial support and existing lining after expansion

Figure 9. The minimum principal stress plots of new initial support and existing lining after expansion

It can be seen from Figures 10 and 11 that the maximum principal stress of the newly constructed secondary lining is 49.7KPa, and the minimum principal stress of the secondary lining is -94.4KPa, which is located at the arch waist on the right. All parameters are within the design strength of the structure and will not be damaged.

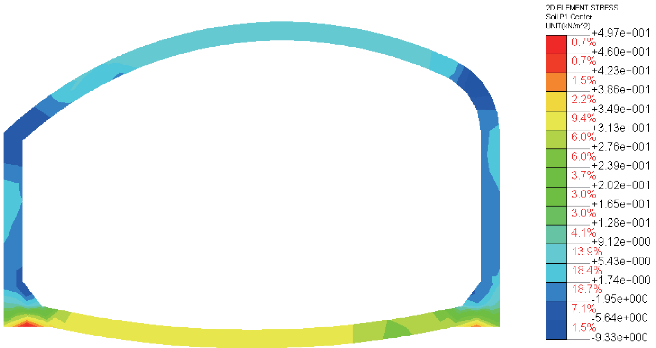

Figure 10. The maximum principal stress cloud pattern of the new secondary lining after expansion

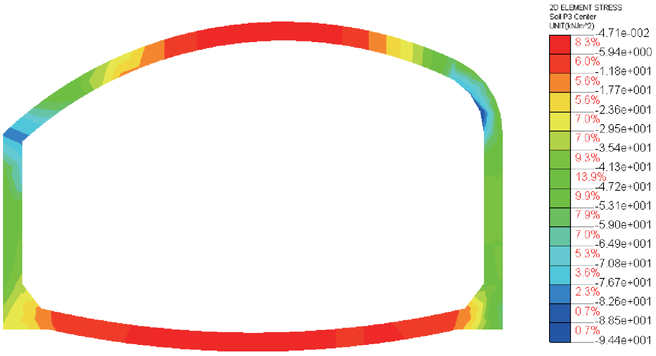

Figure 11. Minimum principal stress plots of secondary lining after new expansion

It can be seen from Figure 12 that after part of the lining was removed, the maximum axial force of the rear full hall support is 8.45kN, the supporting structure is compressed, and the full-frame support is in a safe state.

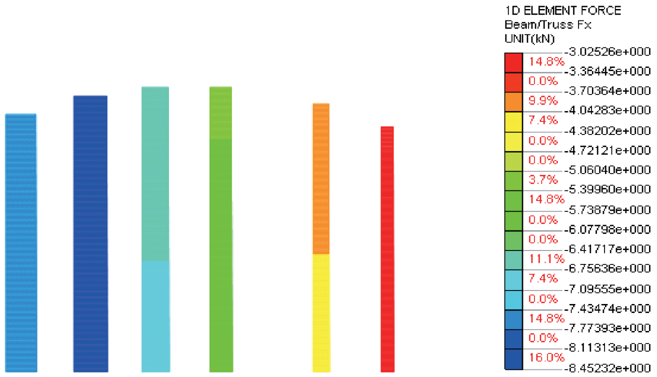

Figure 12. Full-frame support force cloud after the tunnel expansion

4.2 Bolt suspension scheme

It can be seen from Figure 13 that, as with the full-frame support plan, the maximum subsidence of the surrounding rock before the expansion of the tunnel was 3.7mm, and the maximum subsidence of the surrounding rock after the expansion of the tunnel is 5.1mm, the increase in subsidence is 1.4mm, and the growth rate is 38%. The expansion of the tunnel has little effect on the subsidence of the surrounding rock of the vault.

Figure 13. Vertical displacement cloud after tunnel expansion

It can be seen in Figure 14 and Figure 15 that the maximum principal stress of the existing lining structure before the expansion was 143KPa, which is located at the left side of the arch; after the expansion, the maximum principal stress of the existing lining structure is 232KPa, the maximum principal stress of the structure after the initial support was connected to the existing lining is 600KPa, all located at the right arch foot; the minimum principal stress of the existing lining structure before expansion was -2.90 MPa, located at the left arch waist; the minimum principal stress of the existing lining structure after expansion is -2.76MPa, the minimum principal stress of the structure after the initial support is connected with the existing lining structure is -2.98MPa, all located at the right arch foot.

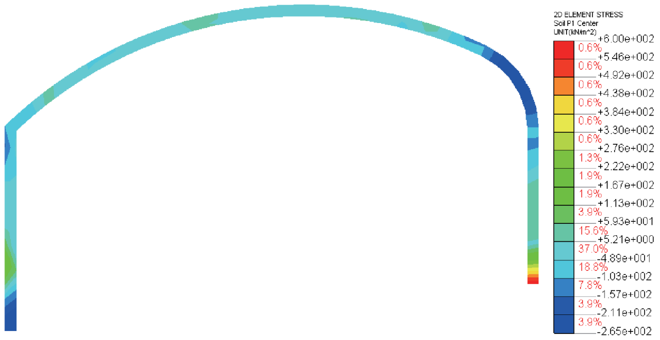

Figure14. Maximum principal stress cloud of new initial support and existing lining after expansion

Figure 15. Minimum principal stress cloud of new initial support and existing lining after expansion

As can be seen in Figure 16 and Figure 17, the maximum principal stress of the newly constructed secondary lining is 44.3KPa, and the minimum principal stress of the secondary lining is -102KPa. All are within the design strength range of the structure, and no damage will occur.

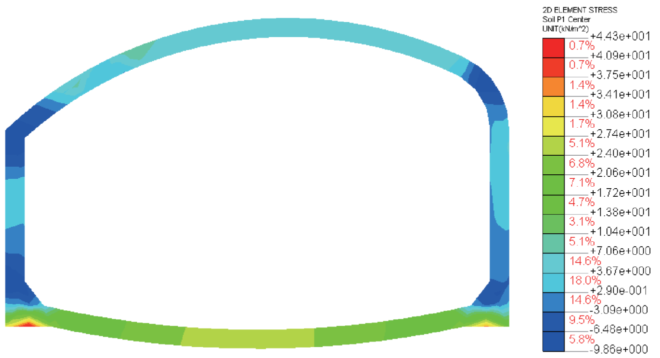

Figure 16. The Maximum principal stress of the secondary lining after the expansion

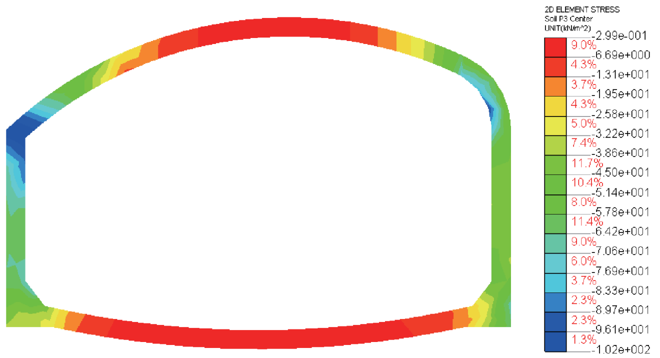

Figure 17. Diagram of minimum principal stress of new lining for secondary lining after expansion

It can be seen in Figure 18 that the maximum axial force of the suspension anchor rod before the tunnel expansion was 0.20kN, and the anchor rod structure was under tension; after the tunnel expansion, the maximum axial force of the suspension anchor rod is 8.49kN, and the anchor rod is tensioned, and the axial force increases 8.29kN, but its value is still within the safe range.

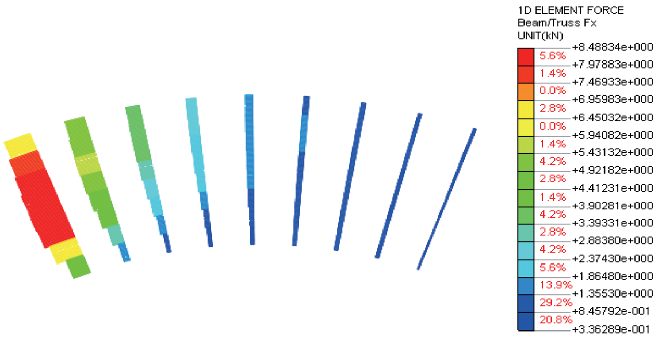

Figure 18. Diagram of axial force of suspended anchor rod after tunnel expansion

5 Project safety analysis

The expansion of the tunnel has zero-distance contact with the existing column foundation JH1. The existing column foundation JH1 has a rock-socketed depth of only 1m. If the inverted arch is excavated according to the design plan, as shown in Figure 19, the maximum excavation depth of the inverted arch will reach 1.9m, the excavation depth at the side wall is 1.3m, and the elevation of the tunnel base is lower than the base elevation of JH1, which will cause partial exposure of the column foundation JH1, and construction according to the design plan will have greater risks.

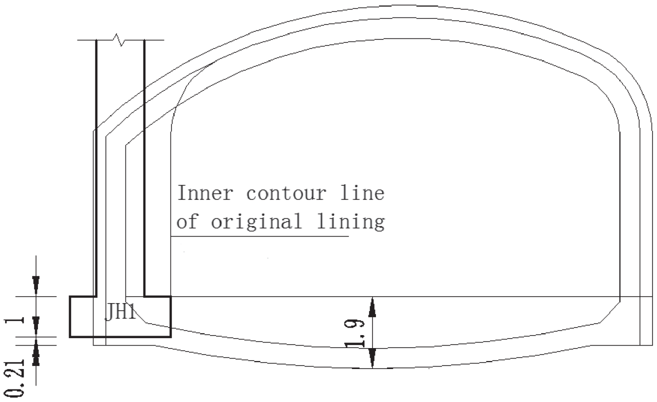

Figure 19. JH1 foundation and the location of the tunnel section diagram

ZH2 and ZH3 adjacent to the expansion section are pile foundations with rock-socketed depths of 4.75m and 4.5m, as shown in Figure 20. According to the design plan, the elevation of the tunnel base during the expansion was higher than that of the pile foundation ZH2 and ZH3. However, due to the inverted arch excavation, the rock-socketed depth of ZH2 is only 2.85m, and the rock-socketed depth of ZH3 is only 3.2m. The rock depth is greatly reduced, and construction according to the design plan will have greater risks.

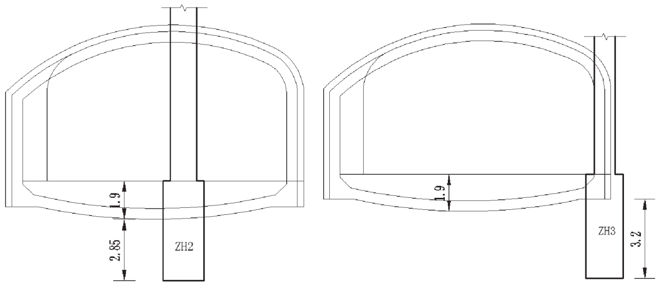

Figure 20. ZH2, ZH3 Foundation and the Location of the Tunnel Section Diagram

6 Conclusion

As the expanding tunnel is adjacent to the building foundation, the construction of the new tunnel will have a certain impact on the adjacent buildings. This paper takes Chongqing Jiefangbei Underground Ring Road Project as an example, built a two-dimensional finite element model, and compared and analyzed the two expansion support construction schemes of full-frame support and bolt suspension, and the following conclusions were obtained:

(1) The tunnel expansion of this project has zero-distance contact with the existing column foundation JH1. The existing column foundation JH1 has a rock-socket depth of only 1m. If the excavation is carried out according to the design plan, the maximum excavation depth of the inverted arch will reach 1.9m. The excavation depth at the wall is 1.3m, and the elevation of the tunnel base is lower than the elevation of the JH1 foundation, which will cause the column foundation JH1 to be exposed and fail to meet the original design safety requirements. To ensure that the rock-socketed depth of the pile foundation of the WTCC meets the requirements, a lining structure without inverted arch should be adopted.

(2) ZH2 and ZH3 adjacent to the expansion section are pile foundations with rock-socketed depths of 4.75m and 4.5m. According to the design plan, the elevation of the tunnel base during the expansion was higher than that of the pile foundation ZH2 and ZH3. However, due to the inverted arch excavation, the rock-socketed depth of ZH2 is only 2.85m, and the rock-socketed depth of ZH3 is only 3.2m. The rock depth is greatly reduced, which does not meet the safety requirements of the original design.

(3) The current scheme adopts the destruction of the partial civil air-defense cavern lining, and adopts the anchor and shotcrete support, and the internal I-beam is connected with the unbroken lining to jointly take on the surrounding rock pressure. The existing manned-cavern lining is a plain concrete structure, and it is difficult to connect the initial support to it, and its reliability after the temporary support is removed and before the second lining is constructed cannot be effectively guaranteed.

(4) By comparing and analyzing the two schemes of using full-frame to provide temporary support and using anchor rods to suspend the unbroken part of the lining, both options can ensure the safety of tunnel lining removal and replacement. However, using full-frame as temporary supports will result in no working face for the tunnel expansion construction, therefore it is not feasible. The bolt suspension scheme is more feasible.

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