Research on Influence of Pile-arch Conversion Structure on Existing Tunnel

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Abstract: Based on the actual project of Chongqing North Station project, this paper uses the software Flac3D to construct the excavation conditions of the foundation pit near the tunnel. A pile-arch conversion structure was applied above the tunnel. By examining the stress and axial force of the tunnel and calculating its safety factor, the advantages of the arch structure over the flat beam were explained, providing guidance and reference for similar projects in the future.

1. Introduction

The arch structure has excellent compressive properties. The previous papers [1-3] specifically addressed this issue. Compared with the bending-shear structure system, the arch structure has the advantages of large span, high bearing capacity, thin section and small deformation, and can save more building materials economically [4]. Arched structures have been widely used in underground engineering, and almost all tunnels use arched sections [5]. Arched structures are often used in long-span bridges and stadium structures, but they are less commonly used in high-rise buildings [6-7].

The Chongqing North Station of Yuli Railway and Chongqing North Railway Station Line 10 between Chongqing North Station South Square Station and North Square Station have an overlapping relationship. The urban corridor will be excavated by open-cut method, so that the buried section will be changed from a deep buried tunnel to a shallow buried tunnel. Therefore, it is necessary to study the impact of the reconstruction project on the safety of the underground tunnel. In the form of conversion structure, if the conversion method of straight beams and piles is adopted, the minimum distance between the beam bottom and the tunnel vault will be less than 1 meter (the maximum design of the conversion load is about 48000kN), and the support anchors for the section tunnels Removal of the rods poses a greater risk of construction. If the conversion arch and pile are used to cross the subway section, the minimum distance between the bottom of the conversion arch and the top of the subway section can be more than 2 meters, which will greatly reduce the impact of the reconstruction project on the section tunnel.

It can be seen from the above that the project has large conversion load, large deflection with straight beams, and large conversion system construction risk, but the conversion mechanism between the arch and the foundation using the conversion method of arch and pile is unknown, and the
deformation control between them is strict and many other features, so the interaction mechanism between the pile-arch conversion structure and the stratum was studied.

2. Research content and methods

2.1. Research content
In this paper, through the method of numerical simulation, using the finite difference software Flac3D, a finite difference calculation model based on stratum-structure is established for research, and whether the safety factor of the structure can meet the specifications is calculated through back stress calculation (bending moment and axial force) claim. The main research is to analyze the influence of the pile-arch conversion structure on the interval tunnel.

2.2. Research methods
The damage stage method is used to perform safety check on the conversion beam structure and the lining structure of the tunnel section.

(1) Check of compressive strength of plain concrete structure
The structural safety evaluation regards the concrete structure as a bending member, and the compressive safety factor is calculated according to formula (1):

\[
K = \frac{\varphi \alpha R \cdot bh}{N}
\]

(2) Check of tensile strength of plain concrete structure
Starting from the crack resistance requirements, the tensile safety factor of concrete eccentric compression members with rectangular section is calculated according to formula (2):

\[
K = \frac{1.75 \varphi R \cdot bh}{N(\frac{6}{h} - 1)}
\]

(3) Check of compressive strength of reinforced concrete structures
According to the "Code for Design of Railway Tunnels", the section strength of reinforced concrete rectangular sections with large eccentric compression shall be calculated as follows:

\[
KNe \leq R_g h_0 (h_0 - x / 2) + R_s A_s (h_0 - a)
\]

(4) Check of tensile strength of reinforced concrete structures
According to the "Tunnel Regulations", the section strength of small eccentric compression members (x > 0.55h_0) of rectangular section of reinforced concrete should be calculated as follows:

\[
KNe \leq 0.5 R_g h_0^2 + R_s A_s (h_0 - a)
\]

(5) Value of safety factor
For non-seismic areas or structural calculations that do not take into account the effects of seismic forces, the safety factor is obtained based on the main load.
According to the "Code for Design of Railway Tunnels", the strength safety factors of concrete and reinforced concrete structures are shown in Table 1 and Table 2.

### Table 1. Strength safety factor of concrete and masonry structures

| Cause of destruction | Concrete | Masonry |
|----------------------|----------|---------|
| Load combination     | Main load | Main load + additional load | Main load | Main load + additional load |
| Concrete or masonry reaches compressive ultimate strength | 2.4 | 2.0 | 2.7 | 2.3 |
| Concrete reaches tensile ultimate strength | 3.6 | 3.0 | — | — |

### Table 2. Strength safety factor of reinforced concrete structures

| Cause of destruction | Main load | Main load + additional load |
|----------------------|-----------|-----------------------------|
| Load combination     |           |                             |
| Rebar reaches calculated strength or concrete reaches compressive or shear ultimate strength | 2.0 | 1.7 |
| Concrete reaches tensile ultimate strength | 2.4 | 2.0 |

According to the above table, when the structure is checked, because the main load combination is used, if the concrete structure reaches the compressive ultimate strength (that is, the compressive strength control of the concrete), the calculated safety factor should be ≥2.4; if the concrete structure reaches the ultimate tensile strength (that is, the crack strength control of concrete), the calculated safety factor should be ≥3.6; if the reinforced concrete structure has reached the calculated strength or the concrete has reached the compressive or shear limit strength, the calculated safety factor should be ≥2.0; if the reinforced concrete structure has reached the tensile strength for the ultimate strength (that is, the crack strength control of concrete), the calculated safety factor should be ≥2.4.

### 3. Analysis of influence of construction pile-arch conversion structure on interval tunnel

When the pile-arch conversion structure is completed, the distribution laws of the vertical displacement, maximum principal stress of the surrounding rock around the tunnel, and the displacement, bending moment, and axial force of the section tunnel are shown in Figure 1.
Figure 1. Effect of construction of pile-arch conversion on section tunnels

As shown in Figure 1, when the pile-arch conversion structure is completed, it can be seen from Figure (a) that the maximum vertical uplift displacement of the section tunnel and surrounding surrounding rocks is 3.844mm; it can be seen from Figure (b) the maximum principal stress of the section tunnel and the surrounding surrounding rock is 0.182 MPa; it can be seen from Figure (c) that the displacement of the section arch is 3.549mm, and the displacement of the vault is 2.985mm.

When the pile-arch conversion structure is completed, the bending moments and axial force diagrams of the two linings of the left and right tunnels in the section are shown in Figure 2 and Figure 3, and then the safety check is performed according to the bending moment axial force.
It can be known from the calculation that the minimum safety factor of the second lining of the left tunnel of the section is 22.529, and the minimum safety factor of the second lining of the section right tunnel is 23.198, which are located at the connection between the foot of the wall and the inverted arch. Thick elements, but local strengthening has been made in actual engineering, so the safety factor here is too small to fully meet the requirements of the specification. The calculation results of other parts of the tunnel also meet the requirements of the code, so the effect of the pile-arch conversion structure on the tunnels is small.

4. Conclusion

The pile-arch conversion structure with excellent compressive performance of the arch structure can not only bear the load of the superstructure, but also release the load along the arch into the soil on both sides of the existing tunnel, effectively releasing the load of the superstructure. This ensures the safety and reliability of the existing tunnel.

Compared with the transmission flat beam, the arched curved beam in the conversion structure uses less steel bars and reduces the amount of engineering. The transition structure reduces the deflection in the mid-span and thereby reduces the impact of the superstructure load on the section tunnel. It takes full advantage of the arched structure to ensure the safety of the existing tunnel during operation. The pile-arch conversion structure can provide continuous settlement and deformation due to the superstructure load during the operation period of the tunnel, ensuring that the load above the tunnel can be effectively released, thereby ensuring the long-term safety of the tunnel structure.

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