Optimization of construction parameters of Highway Tunnel CRD Method

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Abstract. For shallow buried tunnels with poor surrounding rock stability, reasonable construction parameters are of great significance for ensuring tunnel construction safety and controlling construction quality. Taking Huiqing a tunnel as an example, comprehensive analysis of the partition wall R=11.6∠520, R=5.76∠1060, R=5.46∠1040, R=∞∠1800 three different radii of curvature, using FLAC software for four calculations Numerical simulation of working conditions, analysis of plastic zone changes and surrounding rock deformation under different calculation conditions, and the radius of curvature of this project is proposed. The research results show that the middle partition wall adopts R=5.76 and the central angle=1060 can ensure the stability of surrounding rock and the minimum deformation of surrounding rock, which can provide a certain reference for the construction of such highway tunnels.

1. Introduction

In recent years, with the enhancement of people's knowledge about tunnel construction, people are not satisfied with the status quo of relying on experience to solve the problem of parameter quantification in tunnel construction. The current code does not specify the excavation sequence, excavation size and support angle, which requires tunnel designers and constructors to sum up the appropriate practices for this project based on their experience. However, this method can not effectively speed up the construction progress, ensure construction safety and save funds. Therefore, optimizing construction parameters plays a vital role in controlling settlement and ensuring construction safety [1-2].

For parameter optimization in tunnel construction, scholars at home and abroad have done the following research in tunnel excavation by using theory and numerical simulation: Chen Weitao used FLAC3D thermal field-stress field coupling method to set thermal expansion coefficient to simulate the process of water absorption and water loss in expansive soil layer. It was concluded that the net distance of double-hole metro tunnel should be greater than 1.5 times the diameter of tunnel and the distance of double-hole face should be greater than 40m [3].

Although the above parameters are optimized for the excavation distance and the setting of deformation joints under different surrounding rock conditions, there is no in-depth study on a construction method to better supplement and optimize the construction parameters [7]. Starting from the TJ4 tender section of Huizhou-Qingyuan section of Shantou-Zhanzhou Expressway, this paper analyses four different calculation conditions of curvature selection of the middle partition wall when a tunnel in Huiqing is selected by double-sided wall method. Combining with a series of on-site
monitoring and analysis in the construction process, the optimum parameters of the middle partition wall suitable for this kind of project are obtained. The research results can provide reference for tunnel construction under such surrounding rock conditions [5-7].

2. Brief Introduction of Engineering

2.1. General situation of engineering and mechanical parameters.
A tunnel in Huiqing passes through a low hilly geomorphic area with small spacing separated tunnel. The tunnel has a three-center circular shape with a span of 17.2m and a height of 11.8m. Considering the design reserved deformation of 15cm, the excavation span reaches 17.5m and the height is 12.1m. The Left-Line tunnel is 729m long with ZK70+656~ZK71+385. The entrance is end-wall type, the design elevation of the entrance is 361.85m, the exit is end-wall type, the design of the entrance is 367.83m, and the maximum buried depth of the tunnel is about 98.68m. The Right-Line tunnel is 620m long and has the mileage of K70+655~K71+275. There exists bias in the section of ZK70+645~ZK70+850 of a Huiqing tunnel. The local stress concentration of the tunnel is easy to occur, which may lead to the shear failure of the tunnel structure. It should be monitored emphatically.

According to the data of regional geological survey and investigation, the surrounding rock level at the tunnel is IV-V. The distribution of mechanical parameters of surrounding rock is shown in Table 1. C25 shotcrete with thickness of 30; I22b steel frame with spacing of 0.6; double-layer steel mesh with spacing of 20*20; D25 hollow grouting bolt with spacing of 1*0.6 (annular*longitudinal); C25 reinforced concrete secondary lining with thickness of 60. The spacing of grade IV surrounding rock section steel should be reduced appropriately.

| Surrounding rock boundary | Severe (kN/m³) | Deformation modulus E(GPa) | Poisson ratio μ | Internal friction angle ψ (°) | Cohesion c(MPa) |
|--------------------------|----------------|---------------------------|----------------|-----------------------------|----------------|
| IV                       | 22             | 2.4                       | 0.31           | 30                          | 0.3            |
| V                        | 20             | 1.3                       | 0.35           | 22                          | 0.12           |

2.2. Numerical model
The numerical analysis model in this paper is shown in Fig. 1, and is simulated by the numerical calculation software FLAC. In the simulation process, the Mohr-Coulomb constitutive model is adopted for surrounding rock, the elastic constitutive relation for support, shell element for initial support and solid element for second lining [12]. The total longitudinal length of the numerical simulation model along the tunnel is 100, and each width is about 35. The model has a free boundary at the top, a fixed constraint at the bottom and a displacement constraint around it.
3. Purpose and Program

Generally speaking, on the premise of meeting the safety requirements at the same time, there exists an optimal process and process flow related to the stress path in the sectional excavation method. The construction safety of partial excavation is closely related to the number of excavation sections, the size of the guide pit, the curvature and position of the vertical temporary support, and there is an optimization problem. However, the global optimization scheme is not representative for a single double-sided excavation project. Under local conditions, only a limited number of schemes can be accepted by the construction unit. Therefore, it is more representative to study the standardization process under the condition of local optimization.

This paper combines the actual shape of a tunnel in Huiqing with the special geological conditions (shallow metamorphic sandstone and limestone) of Guangdong Province. It is of practical significance to seek local optimization to ensure that the standardized procedures obtained are "safe, reliable, technologically advanced and economically rational". In this paper, the large-scale geotechnical engineering software FLAC is used to carry out the standardized construction research of double-sided tunnel method under plane strain mode. Based on the shape and span of Guangle Road tunnel, the working conditions of four curvature radii are calculated, which are (1) R = 11.6m \angle 520, (2) R = 5.76m \angle 1060, (3) R = 5.46m \angle 1040, (4) R=+\infty \angle 1800, as shown in Figure 2. Among them, the calculation condition 1 corresponds to the scheduled excavation scheme of the construction drawing design, and the other three are used as the comparative calculation schemes. In the calculation, the shallow burial condition is set, the thickness of overburden is 15 meters, and the parameters of surrounding rock are selected according to V.

4. Analysis of calculation results

4.1. Analysis of Plastic Zone Results

The results of plastic zone analysis for different radius of curvature of the middle wall by bilateral wall method are shown in Fig. 2 below.
a) Calculated working condition 1 \((R=11.6 \angle 520)\)

b) Calculated working condition 2 \((R=5.76 \angle 1060)\)

c) Computational working condition 4 \((R=5.46 \angle 1040)\)

d) Computational working condition 3 \((R=+\infty \angle 1800)\)

After excavation of double-side d-wall method, the plastic zone mainly distributes in the waist and crown of the arch. From the scope of plastic zone, the plastic zone at the vault under calculation condition 2 and 3 has greater influence, and the plastic zone extends to the top of surrounding rock for about 15 m. The minimum plastic zone of arch extends only 5 m to the top of surrounding rock because the temporary middle wall of working condition 4 is arranged in a straight line and has strong supporting effect. In addition, the plastic zone of the four working conditions is basically the same, and the plastic zone extends about 4m to the side wall.

In summary, the two-sided wall method can control the deformation of surrounding rock better by setting the next wall according to the calculation condition 4, and the top of surrounding rock has better self-stabilization ability. The plastic zone of calculation condition 2, calculation condition 3 and calculation condition 1 is expanded to the surface, and the self-stabilization ability of surrounding rock is lost. Later, it must be satisfied by increasing the support ability.

4.2. Stress Result Analysis
The contrast table of support stress under four working conditions with different curvature radius of middle wall is shown in Table 2 below.
Table 2. Contrast Table of Support Stress under Four Working Conditions.

| Radius of curvature/central angle | Initial support stress /MPa | Temporary support stress /MPa |
|---------------------------------|-----------------------------|-----------------------------|
|                                 | Left hole | Right hole | Left hole | Right hole | Left hole | Right hole | Left hole | Right hole | Upper Hea | Heading | Heading | Upper Hea | Heading | Upper Hea | Heading | Upper Hea | Heading |
|                                 | top | In the wall | botto m | top | In the wall | botto m | Head ing | Head ing | Upper Hea | Heading | Heading | Upper Hea | Heading | Upper Hea | Heading | Upper Hea | Heading |
| $R=11.6m \angle 520$            | 2.1 | 4.1 | 2.8 | 1.3 | 3 | 1.5 | 2.1 | 5.1 | 1.4 | 3.6 |
| $R=5.76m \angle 1060$           | 3.2 | 4.3 | 2.2 | 3.1 | 3.4 | 1.9 | 2.1 | 2.7 | 1.6 | 2.1 |
| $R=5.46m \angle 1040$           | 3.0 | 4.3 | 2.1 | 2.8 | 3.5 | 1.8 | 2 | 2.9 | 1.6 | 2.3 |
| $R=+\infty \angle 1800$         | 1.0 | 2.9 | 1.4 | 0.93 | 1.6 | 0.91 | 6.4 | 6.5 | 2.8 | 3.1 |

From the point of view of the circumferential initial support force, the support stress under the four working conditions is not large, and the value is close, which meets the safety requirements. From the view of the temporary support force of the next wall, the support stress of working condition 4 is larger, and it is more significant than the initial support force of circumferential direction. In the later stage of bracing removal, the main bearing capacity of the bearing system is transformed from the middle-wall support to the ring-to-initial support. Because of the large span of the three-lane highway tunnel, the ring-to-initial support is relatively flexible. If the transformation load of the middle-wall support is large, the deformation and stress risk of the ring-to-initial support will be increased. If the follow-up distance of the secondary lining is relatively close when the temporary support is removed, the quality problems such as cracking of the secondary lining will be easily caused by the disassembly of the support. In addition, in the area with large vertical low pressure, the buckling of compression bar is easy to occur on the air side because of the vertical arrangement of working condition 4 without bending curvature. The bending side of the other three working conditions is the core soil, which can provide better elastic resistance of stratum and restrain the radial displacement of the middle wall support, so the effect is better.

4.3. Displacement Result Analysis

Deformation comparison table of surrounding rock under four working conditions of different curvature radius of middle wall in bilateral wall construction method is shown in Table 3 below.

Table 3. Contrast Table of Surrounding Rock Deformation under Four Working Conditions.

| Radius of curvature/central angle | Vault settlement /mm | Horizontal Displacement of Side Wall /mm | Plastic Zone Range /m |
|---------------------------------|----------------------|----------------------------------------|----------------------|
|                                 | Left hole | Middle hole | Right hole | Left hole | Right hole | Left hole | Right hole | Vault Sidewall |
| $R=11.6m \angle 520$            | 6.7 | 13.4 | 9.2 | 6.1 | 7.8 | 4.8 | 6.1 | 15 | 5 |
| $R=5.76m \angle 1060$           | 5.7 | 15.7 | 7.9 | 5.3 | 6.9 | 4.3 | 5.6 | 15 | 4 |
| $R=5.46m \angle 1040$           | 4.5 | 15.9 | 6.3 | 5.4 | 6.7 | 3.9 | 4.5 | 15 | 4 |
| $R=+\infty \angle 1800$         | 6.7 | 9.6 | 9.2 | 6.8 | 8.8 | 5.5 | 6.7 | 3 | 5 |
From Table 3, it can be seen that the left and right holes are excavated first in the construction of bilateral wall method, and the middle holes are equivalent to the reserved core soil, so the settlement of the vault roof is the largest in the excavation of the middle holes, of which the settlement of calculation condition 2 and calculation condition 3 are the largest, accounting for 67.4% and 59.6% of the total settlement of the vaults respectively. During the excavation of the left and right guide tunnels, the horizontal displacement of the side walls of the right excavation accounts for the largest proportion of the total horizontal displacement, and the horizontal displacement values of the calculated working conditions 1 and 4 are the largest, accounting for 56% and 55.8% respectively, while the total horizontal displacement values of the remaining working conditions are smaller. Generally speaking, according to the key indexes such as vault settlement and lateral wall horizontal displacement, the working conditions 2 and 3 are the smallest and the scheme is the best.

In conclusion, when determining the curvature radius of the middle adjacent wall of the double-sided guide pit method, considering the mechanical effect, working condition 2 (R = 5.76 1060) and 3 (R = 5.46 1040) are the best, but in working condition 3, the excavation volume of the upper step of the guide hole increases by 103 per extension meter, and the slag yield is too large, and it is located on the upper step, which is not convenient to clean up. Considering the convenience of construction and slag discharge, it is recommended that the curvature radius of the middle wall determined by working condition 2, namely R=5.76 and center angle=1060, should be adopted.

5. Conclusion
Based on the above, a three-dimensional model of a tunnel in Huiqing is established, and the excavation method of double-sided wall is used to carry out numerical simulation. The deformation of surrounding rock and surface monitoring subsidence under different working conditions are compared and analyzed, and the following conclusions are drawn:

(1) During the excavation of double-sided tunnel, the settlement of vault roof is the largest, which is the superposition of the settlement of vault roof caused by the excavation of left and right guide tunnels. The middle guide tunnels play an important role in controlling the settlement of left and right vault roofs. Therefore, monitoring should be strengthened in the construction process, early support should be done under the condition of satisfying the self-stabilization ability of surrounding rock. In addition, the excavation scale and cyclic footage of the upper and lower steps of the pilot tunnel should be controlled to ensure the construction progress.

(2) For different excavation sequence of left and right tunnels, the relative increase of vault settlement is as much as 30%-40% during the excavation of right tunnels, and the relative increase of lateral displacement of side walls in the excavation of right tunnels is as much as 20%-30%. The displacement value of excavation behind the tunnels is larger than that of excavation before, so the construction monitoring of right tunnels should be strengthened. In this project, the curvature radius of the adjacent wall is chosen as R=5.76m, and the central angle is 1060. This value is the optimal value selected under the 4 middle working conditions, which is in line with the actual conditions of this project. It has reference significance for this kind of project.

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