Study on Optimization of Excavation Scheme of the Entrance Section of Hongjiaban Tunnel

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Abstract. The choice of excavation method is particularly important for small clear distance tunnel with short distance between two holes. The finite element software is used to simulate the excavation of Hongjiaban tunnel, which obtained a series of laws, such as the stress change of surrounding rock, the stress of supporting structure and the displacement of surrounding rock during the excavation of the tunnel with a small distance, which is helpful to better guide the construction. There are different excavation methods for tunnel excavation under different surrounding rocks. The rock mass of the entrance section of Hongjiaban tunnel is the Class V surrounding rock, and a variety of excavation methods can be used, such as full section method, reserved core soil method and CRD method. Through the numerical analysis of the above three methods, the advantages and disadvantages of each method are discussed, and the most suitable excavation method for Hongjiaban tunnel is optimized.

1. Introduction
With the development of science and technology, the application of modern information technology in tunnels is becoming more and more popular. BIM technology is gradually applied in the analysis and design of tunnels. Shield tunneling technology is becoming more and more mature in tunnel construction. In recent years, many achievements have been made in the research of tunnels [1-4]. Shi Lu [5] established a finite element model, simulated three excavation methods, namely, the upper and lower step method, the single-side wall guide pit method and the CD method, analyzed the distribution of settlement, displacement and stress, and optimized the excavation method. [6] study the appropriate excavation scheme of Changshao small clear distance tunnel, using the upper and lower steps method, reserved core earth method and CRD method to carry out numerical simulation calculation for the tunnel through finite element software, and it analyzed its plastic zone and surrounding rock deformation, and we concluded that the upper and lower steps method could effectively guarantee the stability of surrounding rock. Wang Qingbiao et al. [7] used finite element software to simulate the step method and the CRD method for the excavation of near overlapping tunnels, analyzing and comparing the stress-strain curve and plastic zone, and we found that the CRD method had the best control effect on surrounding rocks when excavating the lower new line tunnel. Chakeri et al. [8] summarized the deformation conditions and laws of surrounding rock during the excavation process of the tunnel with small clear distance by monitoring the middle rock of the tunnel with small clear distance in the actual site shield excavation. Sheng Hanyang [9] introduced the construction process of “CRD method” and “double-wall pit guide method”, and summarized the construction process of small clear distance tunnel.
2. Model Establishment of Different Excavation Methods

Model total height of the rear is 60 m, the length is 90 m and the width is 22 m. Mohr-Coulomb constitutive model was used for 3D solid units, elastic constitutive model was used for 2D entities, and linear elastic constitutive model was used for 1D solid units. We apply vertical constraints perpendicular to the surface of the rock mass on the front, left, and bottom of the model. The specific excavation scheme is shown in figure 1 below, and parameter values are shown in table 1.

| Name                        | Modulus of elasticity E/MPa | Poisson’s ratio μ | Bulk density γ/KN·m⁻³ | Cohesive force c/MPa | Friction Angle φ/° |
|-----------------------------|----------------------------|------------------|------------------------|----------------------|--------------------|
| Shotcrete                   | 15                         | 0.2              | 24                     | —                    | —                  |
| Anchor                      | 210                        | 0.3              | 78.5                   | —                    | —                  |
| Steel arch shelf            | 200                        | 0.3              | 78.5                   | —                    | —                  |
| The clay                    | 0.05                       | 0.27             | 19.1                   | 19.1                 | 27                 |
| Highly weathered phyllite   | 0.6                        | 0.32             | 21                     | 150                  | 28                 |
| Moderately weathered phyllite | 0.7                    | 0.31             | 20                     | 240                  | 32                 |

3. Analysis of Calculation Results

3.1 Analysis of Surrounding Rock Displacement under Different Excavation Methods

ZK14+589 was selected as the reference section. The horizontal displacement cloud map of the full section method, the reserved core soil step method and the CRD method is shown in figure 2.

Through the figure 2, we analyze the whole section method, the reserve core soil step method, the CRD method of the horizontal displacement, no matter what kind of excavation method, the horizontal displacement are mainly distributed in the tunnel, the arch foot displacement is maximum, the excavation will disturbed the rock, and the biggest span in tunnel is at arch feet, for lacking of lateral constraint, it may be more vulnerable. In the horizontal direction, the construction method causing the maximum displacement is the CRD method, which is 23.876 mm. The second is the construction with full section method, which is 19.641 mm. However, the displacement caused by reserved core soil step method is the smallest, which is 17.661 mm. It can be found that the horizontal displacement value can
be effectively controlled by reserving core soil step method due to the existence of steps, while the CRD method has more excavation steps than the other two methods due to the tedious excavation process, and it has more times of surrounding rock disturbance, so the horizontal displacement is relatively large. From the above data, it can be seen that from the horizontal displacement changes, the reserved core soil step method is superior to the full-section method and the CRD method.

Figure 3 shows the variation curves of the settlement displacement of the arch roof at section ZK14+589 by the full-section method, the reserved core soil step method and the CRD method.

As can be seen from the figure 3, among the three excavation methods, the final settlement displacement of the arch roof excavated by the full-section method is the largest, 22.704 mm. There is few difference between the vault settlement of reserved core soil step excavation and that of full section excavation, for 22.646 mm. The settlement displacement of vault caused by CRD excavation is the smallest among the three methods, which is 18.822 mm. Among the three excavation methods, only the CRD method can form the middle wall during excavation, which can restrain the deformation of surrounding rock in the vertical direction of the tunnel and effectively reduce the arch settlement caused by tunnel excavation. From the perspective of vertical displacement variation, CRD method is superior to the other three methods.

3.2. Stress Analysis of Surrounding Rock under Different Excavation Methods

When the tunnel is dug, the original balance of surrounding rock stress will be broken, and with the excavation, the surrounding rock stress has been changing. As shown in figures 4-5, it showed the cloud map of surrounding rock stress changes of these three excavation methods.

It can be seen from the figure 4 that the final horizontal stress caused by the reserved core soil step excavation is the largest among the three excavation methods, which is 1936.34 kPa. The total section method was 1706.83 KPa. The maximum value of horizontal stress in CRD method is the lowest, which is 1492.01 kPa. Due to the existence of steps in the excavation of reserved core earth method, the stress release is not complete and stress concentration occurs, which leads to greater horizontal stress.
Figure 5. Vertical stress nephogram of three excavation modes.

It can be seen from the vertical stress cloud map that among the three excavation methods, the maximum vertical stress is 2028.46 kPa after the excavation of the core soil step method. The total section method is 1733.96 KPa. The final vertical stress value of CRD method is the lowest, which is 1671.86 KPa. The CRD method is superior to the other two methods in terms of stress variation.

4. Conclusion
(1) Due to the existence of steps, the horizontal displacement control effect of core earth excavation method is the best, which is obviously better than the full section method and the CRD method. In terms of vertical displacement control, the CRD method will form the middle wall, which can effectively control the vault sinking drop; compared with the other two methods, the vertical displacement control has a better performance, and the surrounding rock stress is relatively small. After the completion of excavation by CRD method, the surrounding rock stress is smaller than that of the full section method and the reserved core soil method.

(2) CRD method has some disadvantages, such as complex construction process, many excavation steps, slow progress, high cost, and the need to remove temporary support in the later period. Compared with the CRD method, the reserved core earth method is more excellent in horizontal displacement control, it can greatly shorten the construction period and reduce the project budget, and it is more suitable for the construction and excavation of Hongjiaban tunnel.

Acknowledgments
This project was funded by the National Natural Science Foundation of China (Project No. 52068053), the Nanchang Science and Technology Innovation Team Project of Jiangxi Province (Project No. 2017CXTD012), Jiangxi Province graduate student innovation special Fund project (Project No. YC2019-5431) and the Science and Technology Project of Jiangxi Provincial Department of Education (Project No. GJ161101).

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