Research on retaining the middle heading and spraying steel fiber concrete support method for large-span bifurcated tunnel

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Abstract. In order to solve the problem of surrounding rock deformation during the construction of large-span bifurcated tunnels, this article takes the Yangang East Interchange project as the engineering background, and combines with the existing construction design scheme of large-span bifurcated tunnels, establishes a construction method of retaining the middle heading and spraying steel fiber concrete. Firstly, the construction process of retaining the steel fiber reinforced concrete construction method for the middle guide pit was provided. Then, numerical models of B and C bifurcation tunnels were established based on universal finite element software. From the perspective of surrounding rock deformation, the advantages of this project's construction method over the original design construction method were analyzed. Research has shown that the construction method proposed in this article not only significantly controls arch crown settlement and inverted arch uplift, but also improves construction efficiency. This study can provide reference for the construction of urban bifurcated tunnels.

Keywords: Large span bifurcation; tunnel; stable construction; middle heading; steel fiber reinforced concrete; numerical simulation.

1 Introduction

With the increasing complexity of urban transportation networks, construction cases of adjacent existing tunnels are gradually increasing. During construction, the mechanical properties of the surrounding rock may change, which in turn affects the safety of the tunnel. If not controlled at this time, it may cause catastrophic consequences. In addition, the stress mode of the bifurcated tunnel is different from the construction of a single cavity in a semi-infinite body, due to the variability of its mechanical characteristics after the initial stress field is disturbed. Therefore, domestic and foreign scholars have conducted research on the construction of bifurcated tunnels [1-2]. However, in previous studies, the types of tunnels were relatively single, and the understanding of construction methods for large-span bifurcated tunnels was still insufficient, and there was no standard for design and construction to follow [3-5]. Therefore, conducting research on the deformation of surrounding rock during the construction process of bifurcated

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tunnels is of great significance for guiding the construction of bifurcated tunnels and ensuring their safety [6-7].

The deformation control of bifurcation section is the key to the construction of bifurcation tunnel engineering. Therefore, this article takes the Yangang East Interchange project as the engineering background, combined with the existing construction design scheme of large-span bifurcated tunnels, and proposes a construction method of retaining the large cross-section of the middle heading with sprayed steel fiber concrete. Based on universal finite element software, numerical models of B and C bifurcation tunnels were established, and the advantages and feasibility of the proposed construction method compared to the original design and construction method were compared and analyzed from the perspective of surrounding rock deformation.

2 Project profile

The supporting project of this project is the Yangang East Interchange Project, located on the north side of Donggang District, Yantian Port, Shenzhen. The length of the engineering tunnel section is 2022.727m, including LY tunnel, LZ tunnel, I-ramp, J-ramp, and G-ramp. Among them, the node range of B bifurcation with large span includes G ramp mileage of GK0+390~GK0+47, and J ramp mileage of JK0+090. 528~ JK0+110m; The node range of the C-branch large span includes the mileage of the LY tunnel from LYK1+090 to LYK1+227.720, and the mileage of the G-ramp from GK0+531.885 to GK0+554.318. The strata on the site of this project are composed of artificial accumulation layer, Quaternary alluvial-proluvial layer, and Yanshan granite from top to bottom, with an earthquake intensity of VII degrees. B. The design reference period for the C-bifurcation is 100 years, and the design loads are all city level A, and the structure is designed with a seismic fortification of 7 degrees.

3 Construction scheme of large-span bifurcated tunnel

3.1 Construction scheme from large section to small section

When constructing a bifurcated tunnel, connecting the widened section of the tunnel with the subsequent connecting line and main line tunnel in advance can greatly increase construction efficiency, accelerate construction progress, facilitate construction process conversion, and transport personnel and materials. For the B bifurcation tunnel, this article proposes a construction method of retaining the middle heading and spraying 3kg/m^3 steel fiber concrete in the middle heading for the large section to small section. The construction method of retaining the middle heading is based on the original design construction method. During the excavation process of the large cross-section section, the middle heading is retained, and after the widened section is connected to the bifurcation section, the middle heading is excavated. The construction sequence is shown in Fig.1. This method fully utilizes the bearing capacity of the rock walls in the tunnel, ensuring construction safety while improving construction efficiency. It can accelerate the convergence time with the bifurcation section to achieve the goal of rapid construction. To verify the safety of this construction method, the displacement of surrounding rock during the excavation process is analyzed to achieve the goal of improving construction efficiency while ensuring construction safety.

3.2 Construction scheme from small section to large section

For the *C*-branch tunnel, this project proposes a longitudinal gradient construction method from small section to large section, that is, the outer contour of the single side separated tunnel can gradually gradient along the longitudinal direction of the large section outer contour, and 35kg/m^3 steel fiber concrete is sprayed in the middle guide pit. As different longitudinal sections can be flexibly adjusted at any time, a gradual transformation construction method is used to form a normal large section through a long longitudinal distance. Then, the reverse expansion excavation method is adopted to ultimately form a bifurcated large section through reverse construction. After adjustment, both sides of the guide pit are used for advanced construction. By using reverse gradient construction, a smooth transition can be achieved. The construction sequence of *C*-bifurcation is shown in Fig.2.

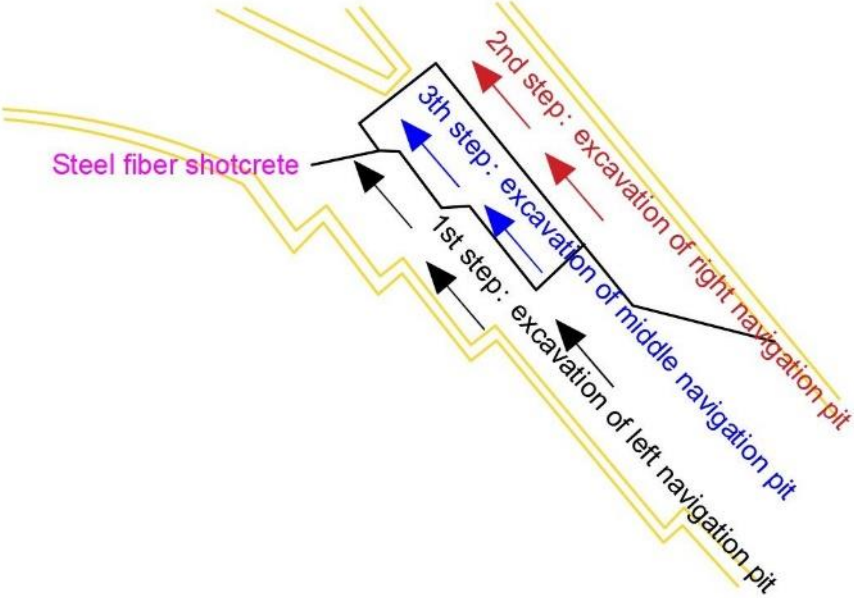


Fig. 1. B-Bifurcation Construction Method.

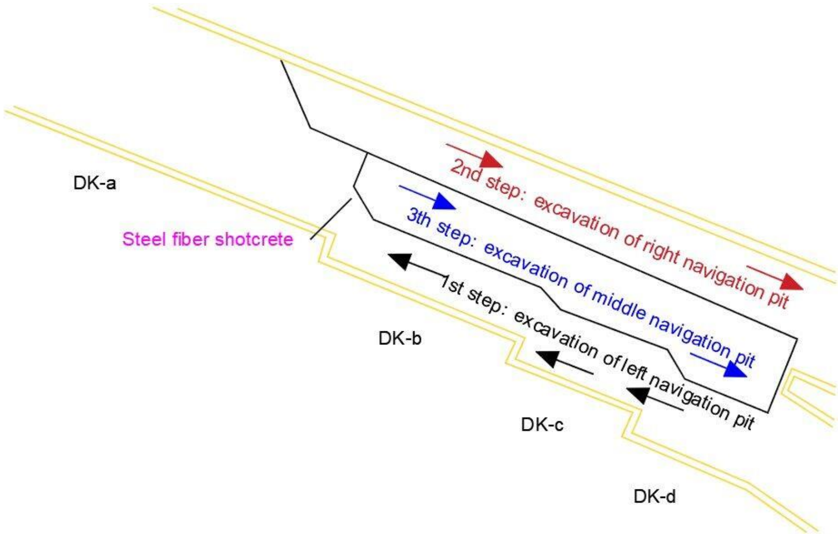


Fig. 2. C-Bifurcation Construction Method.

The construction of the C-branch tunnel is carried out from a small clear distance to a large cross-section direction, starting with the construction of pilot tunnels 1 and 2, passing through three types of sections: DK-d, DK-c, and DK-b. After entering the DK-a section, the double-sided wall pilot tunnel method is changed to the CD method, forming a large cross-section; Afterwards, guide pits 3 and 4 were constructed from the large section to the small clear distance section. At this time, from the DK-a type to the DK-d type section, the CD method was used to expand the excavation, and then both sides of the wall were used to expand the excavation. Then, guide pits 5 and 6 were constructed. The cross-section of the large cross-section support is shown in Fig.3.

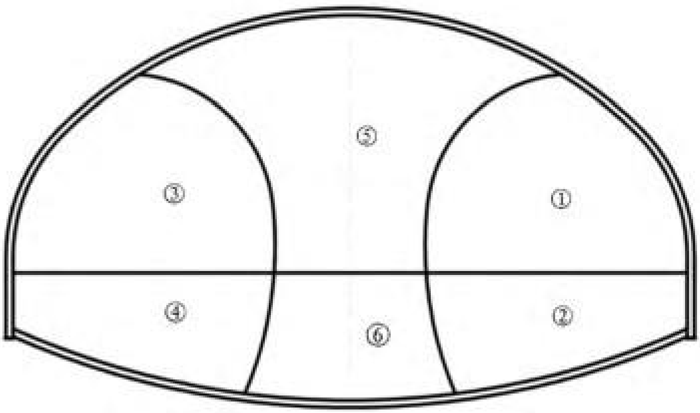


Fig. 3. Sketch of large cross-section support.

4 Numerical Analysis of Surrounding Rock Deformation in the Construction Method of Retaining Middle Heading and Spraying Steel Fiber Concrete

4.1 Numerical calculation model of large-span bifurcated tunnel

According to the Saint Venant principle, the left and right and lower boundaries of the numerical model are taken as 5 times the tunnel diameter, and the tunnel burial depth is based on the actual burial depth. The elastic-plastic model and Mohr Coulomb yield criterion are used. The horizontal displacement is constrained around the model, the vertical displacement is constrained at the bottom, and the top is a free boundary. The numerical models of *B*- and *C*-bifurcation are shown in Fig.4 and Fig.5, respectively.

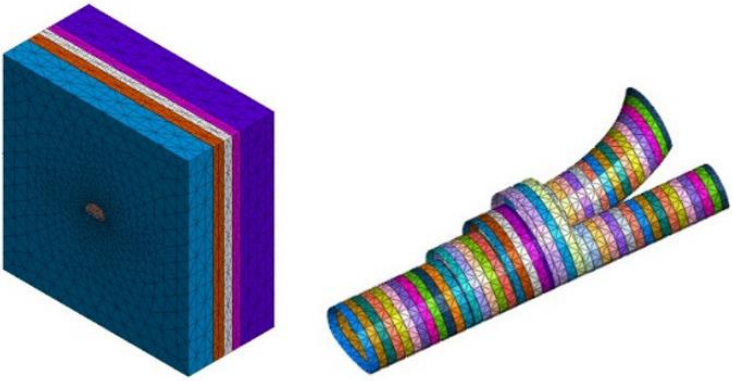


Fig. 4. B-bifurcation finite element model.

Fig. 5. C-bifurcation finite element model.

According to the design data and highway tunnel design specifications, the physical and mechanical parameters of the surrounding rock and support concrete in the numerical simulation process of this article refer to Table 1.

Table 1. Mechanical parameters of surrounding rock and support concrete.

Item	Weight (kN/m^3)	Elastic modulus (GPa)	Cohesion (KPa)	Internal friction angle (°)	Poisson's ratio
Grade II surrounding rock	26.5	25	1.8	55	0.225
Grade III surrounding rock	25.5	13	1.1	44.5	0.275
Grade IV surrounding rock	23.5	1.45	0.45	33	0.325
Grade V surrounding rock	20	1.30	0.125	23.5	0.4
C25 concrete	23	26	---	---	0.2
C35 concrete	24	30	---	---	0.2

4.2 Model calculation formula

The steel frame and sprayed concrete in this article are calculated using equivalent stiffness, as shown in the following equation

$$E = E_0 + \frac{S_g \times E_g}{S_c} \tag{1}$$

In the formula, E is the converted elastic modulus of sprayed concrete, E_0 is the elastic modulus of the original sprayed concrete, S_g is the cross-sectional area of the steel reinforcement of the steel frame, E_g is the elastic modulus of the steel frame, S_c is the cross-sectional area of sprayed concrete.

Considering that the steel pipe needs grouting, an equivalent method can be used to consider it, and its equivalent elastic modulus can be expressed as follows:

$$E_{eq} = E_{01} + \frac{S_{g1} \times E_{g1}}{S_{c1}} \tag{2}$$

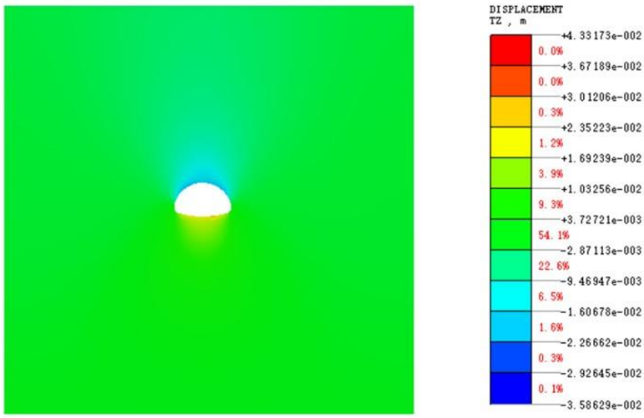
In the equation, E_{eq} is the equivalent elastic modulus after conversion, E_{01} is the elastic modulus of the filling material inside the pipe, S_{g1} is the cross-sectional area of the steel pipe, E_{g1} is the elastic modulus of the steel pipe, S_{c1} is the cross-sectional area of the steel pipe. Improving the cohesion and internal friction angle of the surrounding rock can simulate the effect of the anchor rod, but due to the small change in friction coefficient, only the change in cohesion c is considered.

$$c = c_0 \left[1 + \frac{\varphi}{9.8} \frac{TA_m}{ab} \times 10^4\right] \tag{3}$$

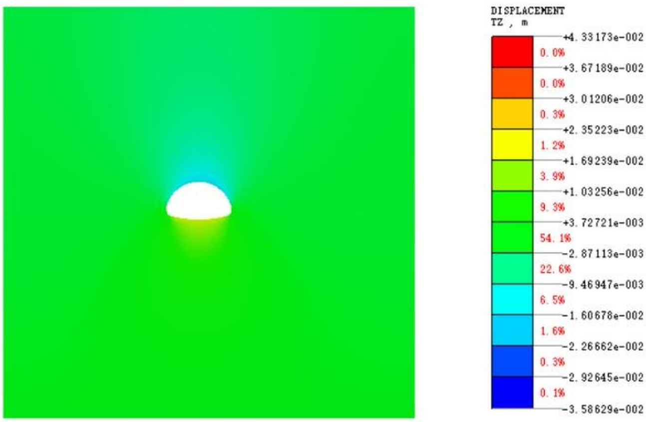
In the formula, c_0 is the cohesive force of the surrounding rock without anchor rods, T is the shear strength of the anchor rods, A_m is the cross-sectional area of the anchor rods, and a and b are the longitudinal and transverse spacing of the anchor rods, respectively, φ Is the empirical coefficient, taken as 2-5.

4.3 Model calculation analysis

In order to further analyze the advantages of retaining the construction method of steel fiber reinforced concrete in the middle heading compared to the original design construction method, the deformation size of tunnel surrounding rock was studied based on the established B and C bifurcation finite element model methods. For this purpose, Fig.6 and Fig.7 respectively provide displacement cloud maps of monitoring sections 3 and 4 of the B bifurcation tunnel under the original design construction method and the retained middle heading spray steel fiber concrete construction method. At the same time, Fig.8 and Fig.9 respectively provide displacement cloud maps of monitoring sections 3 and 4 of the C bifurcation tunnel under the original design construction method and the retained middle heading spray steel fiber concrete construction method.

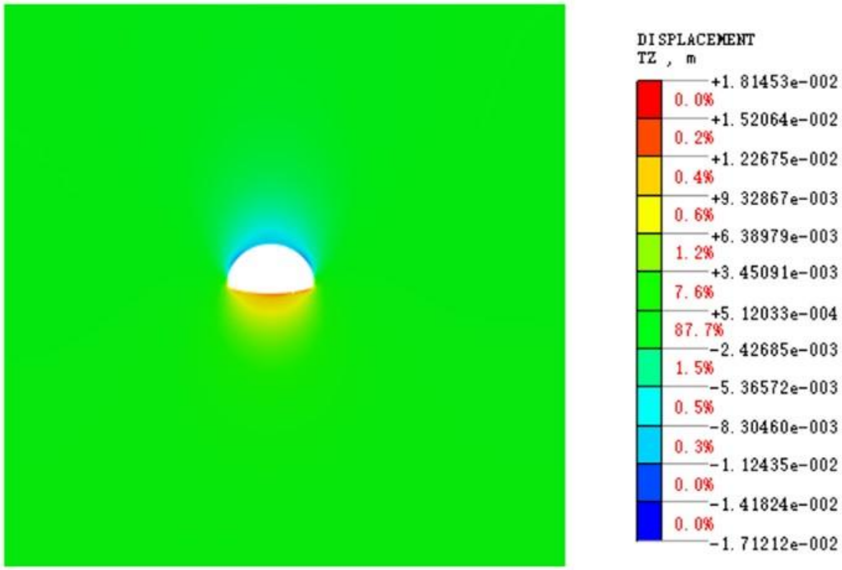


(a)Section 3

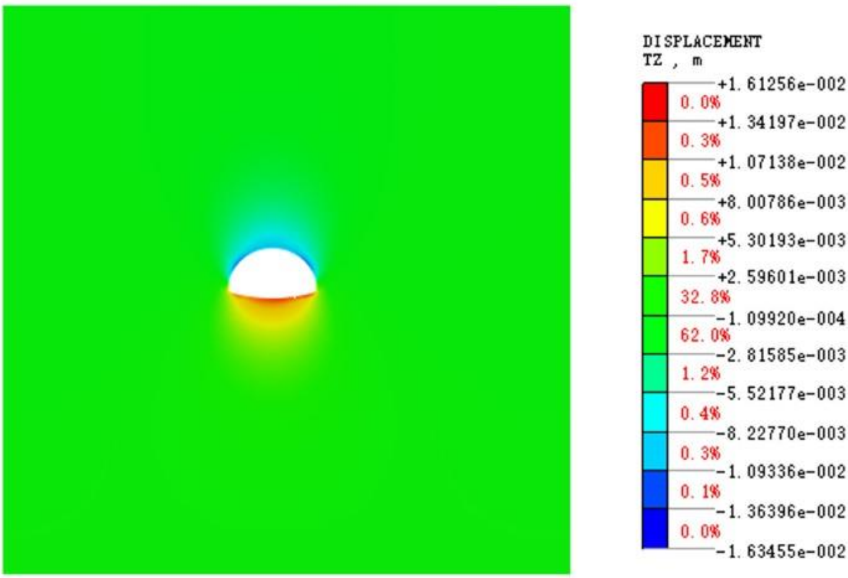


(b)Section 4

Fig. 6. Displacement distribution of different sections of B bifurcation tunnel under the construction method of original design.

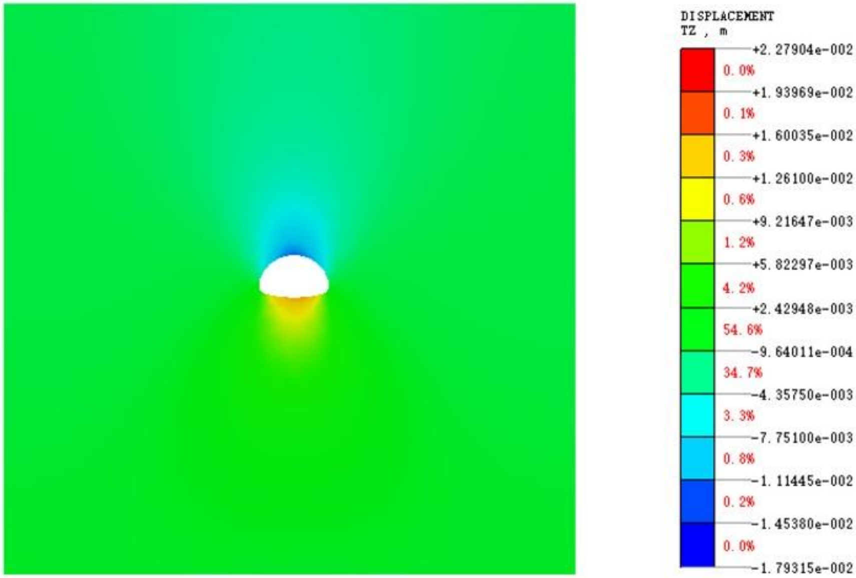


(a)Section 3

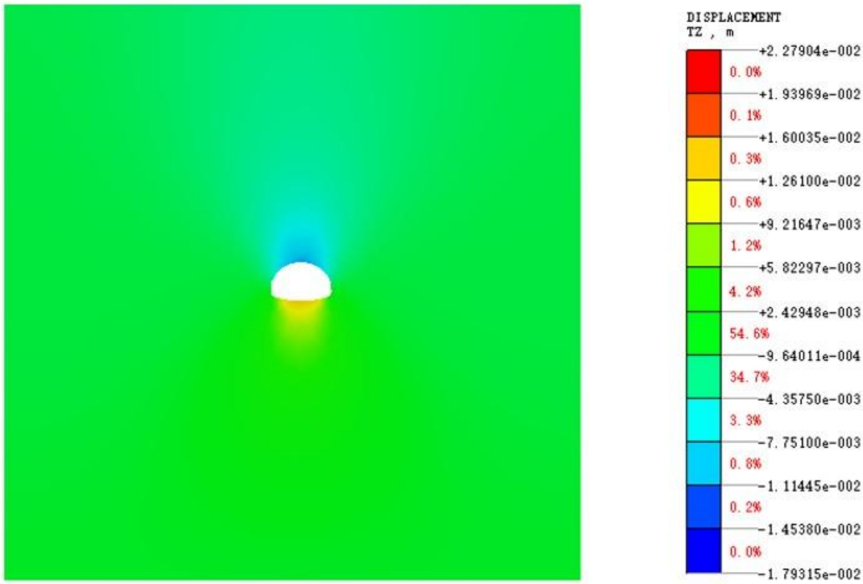


(b)Section 4

Fig. 7. Displacement distribution of different sections of B bifurcation tunnel under the construction method of retaining the middle heading and spraying steel fiber concrete.

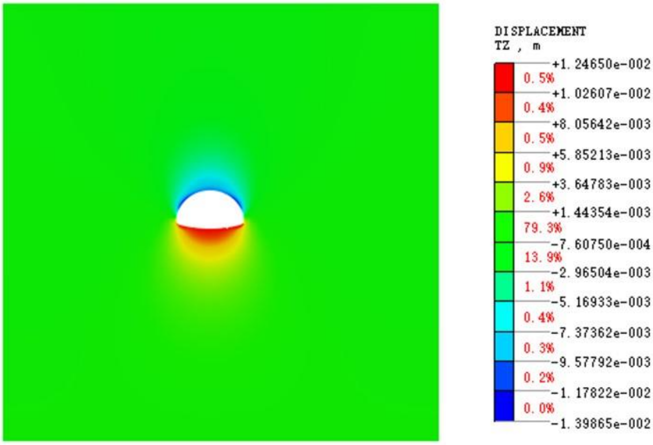


(a)Section 3

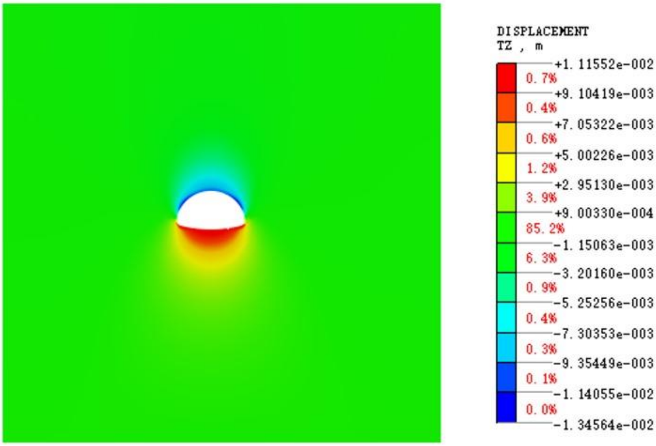


(b)Section 4

Fig. 8. Displacement distribution of different sections of C bifurcation tunnel under the construction method of original design.



(a)Section 3



(b)Section 4

Fig. 9. Displacement distribution of different sections of C bifurcation tunnel under the construction method of retaining the middle heading and spraying steel fiber concrete.

By comparing the deformation calculation results of the surrounding rock of the B and C bifurcated tunnels under the original design construction method and the new construction method of retaining the steel fiber reinforced concrete in the middle guide pit proposed in this article, it can be found that after adopting the new construction scheme, the settlement of the arch crown of section 3 of the B bifurcated monitoring section is reduced from 21.75mm to 16.45mm, and the uplift of the inverted arch is reduced from 20.72mm to 17.29mm; The settlement of arch crown in section 4 of bifurcation monitoring section B decreased from 19.71mm to 15.09mm, and the uplift of inverted arch decreased from 17.16mm to 15.43mm; C-bifurcation monitoring section 3 reduces the settlement of the arch crown from 15.49mm to 12.95mm, and the uplift of the inverted arch from 12.79mm to 11.91mm; The settlement of arch crown in section 4 of C-bifurcation monitoring decreased from 14.13mm to 12.51mm, and the uplift of inverted arch decreased from 11.63mm to 10.54mm. Therefore, under the new construction method of retaining the steel fiber reinforced concrete in the middle guide pit, the deformation of the surrounding rock is smaller than the original design method, and the control effect of the arch settlement is better than that of the inverted arch uplift.

5 Implementation

Relying on the project B section and C section, the construction method of retaining the middle guide pit sprayed steel fiber concrete after the demonstration of this paper is adopted, and the whole process monitoring and measurement of the tunnel is carried out during the construction process. Fig.10 shows the data comparison between the actual monitoring and the calculation model.

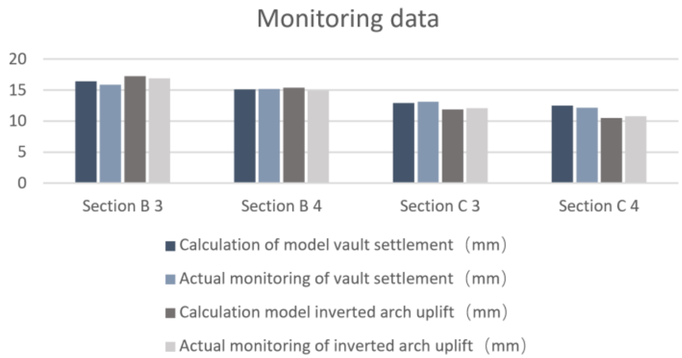


Fig. 10. The calculation model is compared with the actual monitoring data of each section.

Combined with the actual monitoring data in the construction process of the project, it can be found that the construction method of retaining the middle guide pit sprayed steel fiber concrete is beneficial to improve the construction safety of the large-span bifurcated tunnel. Compared with the model analysis data, the actual monitoring data is not much different from the model analysis data, and the overall development trend is consistent.

6 CONCLUSION

(1) To solve the problem of tunnel bifurcation deformation, a construction method of retaining the large section of the middle heading by spraying steel fiber concrete is proposed, which means that the outer contour of a single side separated tunnel can gradually gradient along the longitudinal direction of the large section outer contour, and 35kg/m^3 steel fiber concrete is sprayed in the middle heading.

(2) The use of retaining the middle guide pit and spraying steel fiber concrete effectively controlled the settlement of the arch crown. At this time, the settlement of the

arch crown of section 3 and section 4 of bifurcation B decreased by 24.4% and 23.4% respectively compared to the original design construction method, while the settlement of the arch crown of section 3 and section 4 of bifurcation C decreased by 16.4% and 11.5% respectively compared to the original design construction method.

(3) When using the method of retaining the middle guide pit and spraying steel fiber concrete, the inverted arch protrusion of section 3 and section 4 of bifurcation B is reduced by 16.6% and 10.1% compared to the original design construction method, respectively. The inverted arch protrusion of section 3 and section 4 of bifurcation C is reduced by 6.9% and 9.4% compared to the original design construction method, respectively. The control of inverted arch protrusion can also have a certain effect, but it is lower than the control effect of arch crown settlement.

(4) After comparing the model analysis data with the actual monitoring data, the construction method of retaining the steel fiber reinforced concrete in the middle pilot pit is beneficial to improve the construction safety of the long-span bifurcation tunnel. The actual monitoring data is not much different from the model analysis data, and the overall development trend is consistent.

(5) The application effect of this method is good under the conditions of surrounding rock, hydrology and surrounding environment. However, for other similar projects, due to the difference of external conditions, it should be combined with theoretical analysis and real-time adjustment of monitoring data.

This paper does not take into account the influence of environmental loads such as temperature when analyzing the deformation of surrounding rock when retaining the steel fiber reinforced concrete support method for the pilot tunnel in the bifurcation tunnel. Subsequent research needs to focus on the deformation law of surrounding rock under the coupling of environment load, in order to provide a basis for the optimization and promotion of this method.

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