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Study on selection of excavation methods for ultra-shallow-buried short net distance tunnel under unsymmetrical pressure

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ABSRTACT: The design and construction of ultra-shallow-buried short net distance tunnel under unsymmetrical pressure is the key to underground engineering. Based on the analysis of the mechanical characteristics of rock and supporting structure of a ultra-shallow-buried short net distance tunnel under unsymmetrical pressure in Rongjiang Tunnel, the dynamic construction of ultra-shallow-buried short net distance tunnel under unsymmetrical pressure is simulated by numerical simulation method according to the specific working conditions and design requirements. The influence of three construction schemes, full face method、up and down short bench method and double sides heading method, on stress field, displacement field and displacement time history curve. The results show that the three excavation methods will lead to the stress concentration in the middle rock column and the right part of the left tunnel in the ultra-shallow-buried short net distance tunnel under unsymmetrical pressure, and the corresponding parts should be pre-supported and reinforced in the construction; The support time has a significant effect on the stress and stability of the structure, so the stress and displacement should be considered comprehensively to control the stress release ratio of surrounding rock; It is recommended that the double sides heading method be used in the case engineering.

Keywords: Ultra-shallow-buried and under unsymmetrical pressure; Short net distance tunnel; Stability of surrounding rock; Numerical simulation

Restricted by terrain and construction level, short net distance tunnel scheme is often used in tunnel route selection[1]. At this time, the structures of the tunnel are disturbed for many times during the construction process, and the mutual influence is significant. Under the ultra-shallow partial pressure, the mechanical behavior of surrounding rock and supporting structure is more complicated. As a result, the determination of tunnel excavation method is an urgent problem to be solved in this kind of tunnel[2].

For the optimization of construction scheme of small spacing tunnel section, He Han et al[3] proposed the construction method of bench core soil method for tunnel, based on fluid-solid coupling theory, by comparing the vertical displacement change of surrounding rock under different construction schemes, the horizontal displacement change of middle intercalated rock column, the change of stress field and the change of plastic zone of surrounding rock; Li Jianlin et al[4] analyzed the construction mechanics process of the short net distance section of surrounding rock of grade IV by using the CRD method, CD method and bench method by using numerical simulation method, and analyzed the deformation and stability of the supporting structure and surrounding rock by the three construction methods. Ling Tonghua et al[5] analyzed the stability of surrounding rock of short net distance tunnel under different construction sequence by simulation method. In reference [6-11], the evolution characteristics of surrounding rock pressure of short net distance tunnel are analyzed, the relationship between geological parameters and lateral pressure coefficient is studied, and the stability control method of surrounding rock of short net distance tunnel is established.Luo Zhenyan et al[12] analyzed the mechanical behavior characteristics of short net distance tunnel with the

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combination of various load sharing ratios, and the optimization of load sharing ratio of surrounding rock support in advance tunnel and rear tunnel is studiedby simulation method.But Mr. Lu[13], based on the reverse load method and a tunnel engineering, analyzedthe deformation of surrounding rock and surface settlement of shallow buried tunnel with different stress release rate by CRD construction scheme.

In summary, there is limited research on the construction scheme of ultra-shallow-buried short net distance tunnel under unsymmetrical pressure. As a result, the finite element method is used to analyze the influence of full face method、up and down short bench method and double sides heading method on the stress field, displacement field and displacement time curve of ultra-shallow-buried short net distance tunnel under unsymmetrical pressure, which provides reference for the design and construction of this kind of engineering.

I. PROFILE OF THE ENGINEERING

The tunnel is located at Ganzhou Rongjiang. TThe longitudinal slope from Rk_0 + 620 to rk0 + 717 on the north bank is 0.3%, from Rk_0 + 717 to Rk_1 + 468 on the north bank is - 5%, from Rk_1 + 468 to Rk_1 + 633 is 0.5%, from Rk_1 + 633 to Rk_2 + 462 on the south bank is 4.5%, and from Rk_2 + 462 to Rk_2 + 500 is - 0.3%. The tunnel adopts the parallel design of left and right lines, which is a short net distance tunnel under unsymmetrical pressure.

The key points of tunnel construction are as follows: (1) Ultra-shallow-buried tunnel under unsymmetrical pressure. The maximum depth from tunnel vault to ground is 13.1m.According to specifications, the tunnel is definitelythe ultra-shallow-buried tunnel under unsymmetrical pressure;(2) Short net distance. Thethickness of rock column is 4.7m, which is one fifth of the excavation width of a single tunnel;(3) Surrounding rock in gradeV with complex lithology. The surrounding rock is strongly - weakly weathered broken silty mudstone, the rock structure is crushed stone structure, and the bearing capacity of the middle rock column is low.4) Overlying important structures. There is a High Voltage Tower with 110kV high voltage on the surface of the tunnel, which is about 3.5m away from the vehicle tunnel.

II. MODEL ESTABLISHMENT

According to the field investigation data, a typical ultra-shallow-buried tunnel under unsymmetrical pressure is simulated. The proposed short net distance tunnel is directly under the slope of this section, and the slope angle is 11°. The buried depth of the tunnel is 13.1m, the width is 18.99m, the net height is 5.5m, and the tunnel spacing is 5.23m. The numerical model is established as shown in Fig.1.

The displacement boundary condition is adopted, the ground surface is a free surface and not constrained; The left boundary, the right boundary and the lower boundary are all constrained by normal displacement.

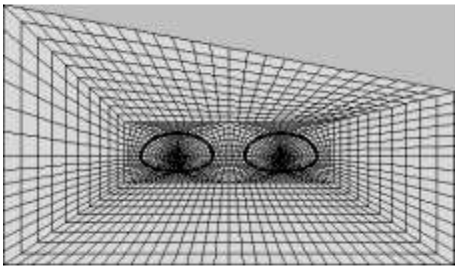


Figure 1 Calculation Model Grid

2.1 Calculation parameters

According to the relevant specifications and combined with the geological conditions, hydrological conditions and field measured data of the construction site, the mechanical parameters of surrounding rock and structure are shown in Table 1 and Table 2.

Table 1 Mechanical parameters of surrounding rock

Rock strata	Thickness/ m	Lithology	Severe/(kN/m^3)	C/kpa	φ/°	E/MPa	Poisson's ratio
1	10	Clay clay	18	20	15	7.0	0.4

2	15	Fully weathered strata	19.1	20.2	21.8	9.5	0.34
3	35	Strong weathered rock	21	14.8	24.6	295	0.25

Table 2 Structural Mechanical Parameters

Structure	Materials	Strength grade	Thickness/ cm	Severe/(kN/m^3)	E (Gpa)	Poisson's ratio
Initial support	Plain concrete	C20	25	23	28.1	0.2
Secondary lining	Reinforced concrete	C25	50	25	29.5	0.2

2.2 Numerical simulation

Referring to the design code and similar engineering examples, full face method、up and down short bench method and double sides heading method are selected for the construction schemes. This paper analyzes and compares the changes of stress field and displacement field caused by those three excavation methods, and studies the advantages and disadvantages of different excavation methods and the applicable conditions.

2.2.1 Full Face Method

1) Condition of not supporting in time after excavation: after excavation in full face method, support construction should be carried out at specific intervals. (The specific time is the same as that of the second lining in the supporting process. Below is as the same);

2)Condition of timely support after excavation: after construction in full face method, temporary structure is adopted for support, and secondary lining is constructed at last.

2.2.2 Up and Down Short Bench Method

1)Condition of not supporting in time after excavation: The upper step of the tunnel face is excavated, after which the lower step of the palm face is excavated, andthe secondary lining is appliedin a specific time interval.

2)Condition of timely support after excavation: The upper step of the tunnel face is excavated, after which the initial support construction is applied, and finally the lower step of the palm face is excavated, with the initial support and the secondary lining constructed.

2.2.3 Double Sides Heading Method

This excavation method is also known as the middle column method. When this method is used to excavate the tunnel with small clear distance, the stress concentration is easy to occur at the middle rock column. Therefore, when this method is adopted, the intermediate rock column should be formed finally, and the specific process is as follows:

1) Condition of not supporting in time after excavation: after the excavation of the left guide pit of the left tunnel and the right guide pit of the right tunnel, the remaining guide pit is excavated, and the supporting structure is applied in a specific time interval;

2)Condition of timely support after excavation: after excavation of the left guide pit of the left tunnel and the right guide hole of the right tunnel of the tunnel, the excavation profile is sprayed with concrete, and the remaining part is excavated and supported.

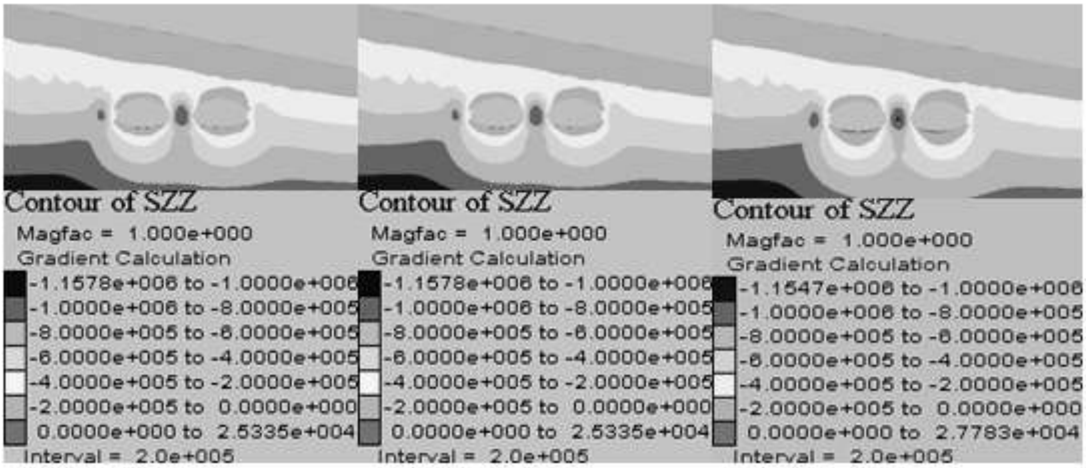
III. ANALYSIS OF CALCULATION RESULTS

3.1 Distribution of stress fields

As a result that the tunnel is mainly subjected to vertical compressive stress (third principal stress), the third principal stress field distribution of three excavation modes is selected.

3.1.1 Stress field distribution of delayed support

On condition of not supporting in time after excavation with those three excavation methods, The distribution of stress field around the tunnel is shown in Fig.2. Fig. 2 shows that the stress concentration will occur in the middle rock column and the right part of the left tunnel when the ultra-shallow-buried short net distance tunnel under unsymmetrical pressure is excavated with those three construction schemes. However, the stress concentration area caused by double sides heading method is small, while the area of other two methods is larger. It is considered that the creep flow phenomenon will occur in the stress concentration area, and the plastic volume will increase gradually, while that of the double sides heading method is opposite. Therefore, delaying the formation time of the intermediate pillar can reduce the stress at the intermediate pillar.



a)Full Face Method b) Up and Down Short Bench Methodc)Double Sides Heading Method
Figure 2 Third principal stress nephogram (kPa)

At the same time, the surrounding stress of the tunnel excavated by the full face method is the smallest, double sides heading method is the second, and the up and down short bench method is the largest, which shows that thefull face method is the most conducive to the release of surrounding rock stress.

3.1.2 Stress field distribution of timely support

The nephogram of stress field around the tunnel with three excavation methods and timely support is shown in Fig.3. Through comprehensive analysis of Fig. 3 and Fig. 2, it is considered that the stress field of the tunnelwhen the initial support is carried out in time by using the three excavation methods is larger than that with the delayed support, which indicates that the stress release of the surrounding rock will be limited to a certain extent when the initial support is carried out in time after the construction of the three excavation methods. Figure 3 shows that the surrounding stress is the largest after the tunnel is excavated with up and down short bench method. The surrounding stress of the tunnel is smaller when the excavation method of double sides heading methodorfull face method is adopted andThe surrounding stress of the tunnel by the double sides heading method is slightly larger than that by the full face method.The results show that the stress released by up and down short bench method is small before the initial support time is applied, because the initial support bears larger stress; The stress release of full face method or double sides heading method is larger, because the stress of initial support is smaller. Therefore, the full face method and the double sides heading method are relatively conducive to the stress release, while the up and down short bench method is the least conducive to the stress release

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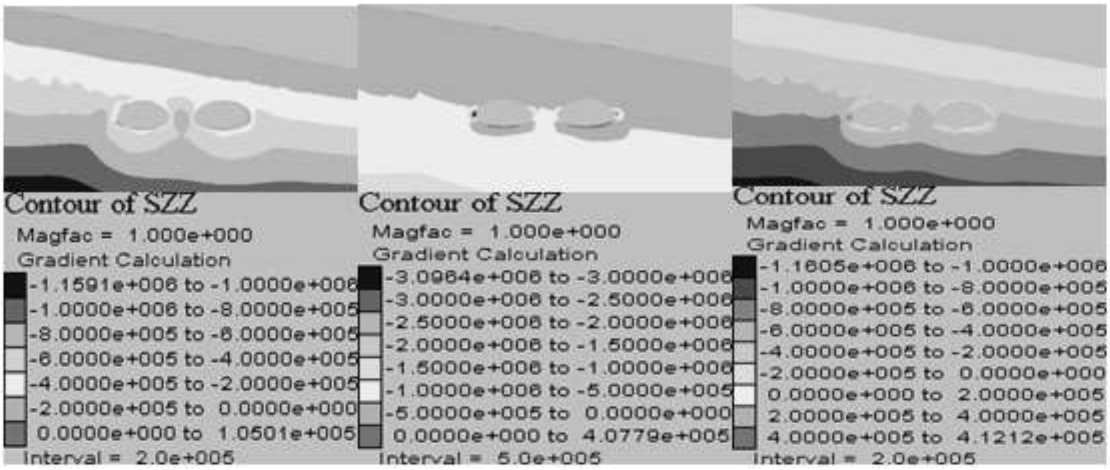

a)Full Face Method b) Up and Down Short Bench Methodc)Double Sides Heading Method
Figure 3 Third principal stress nephogram (kPa)

3.1.3Stress field distribution after second lining applied

The distribution of stress field around the tunnel after second lining appliedby three excavation methods is shown in Fig.4.Compared with figures 3-4, with the three excavation methods, the stress of secondary lining is greater than that of initial support. Therefore, the construction of secondary lining is not only a safety reserve, but also an important support for ultra-shallow-buried short net distance tunnel under unsymmetrical pressure. At the same time, the invert will bear the vertical upward normal stress after the secondary lining construction. The normal stress with full face methodand double sides heading method is larger, while that of up and down short bench method is the smallest, which indicates that the double sides heading method is conducive to the release of invert stress;The stress that the second tunnel support bears is the largest by up and down short bench method, while that in the other two methodsis smaller, which indicates that during the interval from the initial support construction to the secondary lining construction, the stress release is small by using the double sides heading method, and the stress release is slow after the initial support.However, the support of the tunnel by full face method and up and down short bench method bears less pressure and release more stress. The stress release is faster after the initial support is applied, and the up and down short bench method are better than full face method.

a)Full Face Method b) Up and Down Short Bench Methodc)Double Sides Heading Method
Figure 4 Third principal stress nephogram (kPa)

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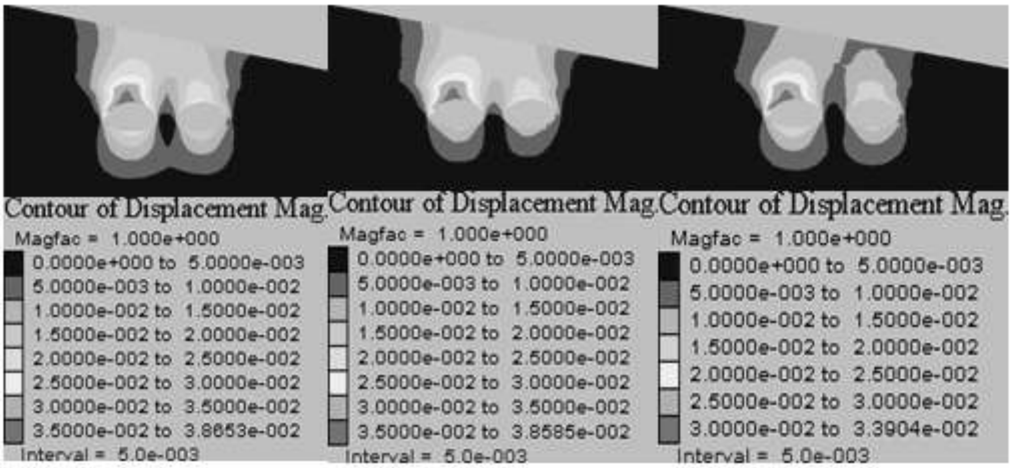
3.2 Displacement field distribution

3.2.1 Displacement Field Distribution of Delayed Support

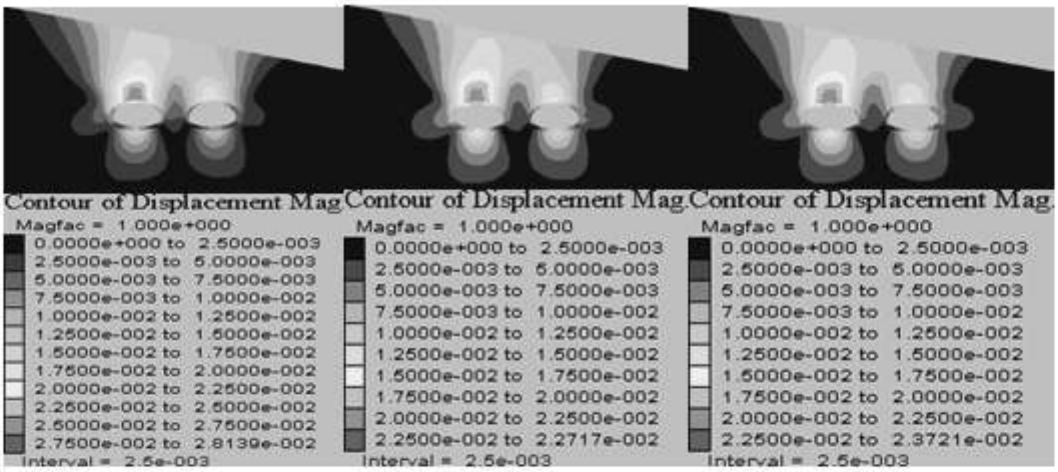
If the initial support is not carried out in time, the nephogram of displacement field around the tunnel is shown in Fig.5. According to Fig.5, when those three construction schemes are adopted, if the initial support is not carried out in time after the excavation of that kind of tunnel, the phenomenon of sharp deformation of the section appears. Withen those threemethods, deformation of the tunnel by using the full face method and up and down short bench methodis the most serious, while the deformation of double sides heading method is the least. The results show that the double sides heading method makes full use of the self-supporting capacity of surrounding rock, which is not enough by using the full face method and up and down short bench method.



a)Full Face Method b) Up and Down Short Bench Methodc)Double Sides Heading Method
Figure 5 Displacement nephogram (mm)

3.2.2 Displacement field distribution of temporary support

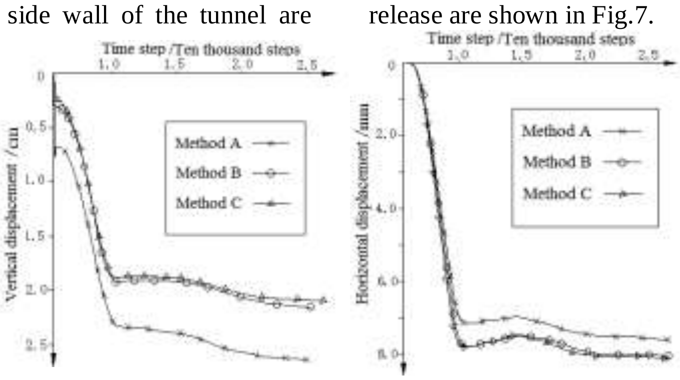
By using the three excavation methods, when the initial support is carried out at the right time, the tunnel displacement field change nephogram is shown in Fig.6. Compared with Fig.5, the initial support is carried out in time after the excavation of the ultra-shallow-buried short net distance tunnel under unsymmetrical pressure, so that the deformation of the tunnel section is reduced. According toFig.6, the deformation of tunnel section by usingfull face method is the largest, deformation of tunnel with up and down short bench method is the second, and the smallestdeformation occurs in the tunnel in double sides heading method, which shows that double sides heading method is the best method for making use of the self-bearing capacity of surrounding rock to restrain the deformation of tunnel section, up and down short bench method is the second, and full face method is the worst among those three methods.



a)Full Face Method b) Up and Down Short Bench Methodc)Double Sides Heading Method
Figure 6 Displacement nephogram (mm)

3.2.3 Displacement of monitoring points in model

According to Fig .5~6, The vault settlement of the left tunnel and the horizontal convergence deformation of the left side wall of the tunnel are large, which are the most dangerous points in the construction. The displacement history curves of the two monitoring points with excavation and stress release are shown in Fig.7.



a) Vault ofleft tunnel b) left wallof left tunnel
Figure 7 Graph of displacement (mm)

The method A in Fig.7 is full face method, the method B is up and down short bench method, and the method C is double sides heading method.

According to figure 7,when the full face method is adopted, the horizontal displacement is the smallest, while the vault subsidence displacement is the largest. The displacement difference between double sides heading method and up and down short bench method is small, but the radial horizontal displacement of the former is relatively small, which indicates that both excavation methods can make good use of the self-bearing capacity of surrounding rock. Thefull face method is beneficial to the release of surrounding rock stress, so as to reduce the stress of second lining and the deformation is small.

IV. CONCLUSION

1) After the excavation of ultra-shallow-buried short net distance tunnel under unsymmetrical pressure, the determination of support time is very important. If the support interval is too short, the stress release of tunnel surrounding rock is small, and the support structure bears large stress, which leads to large deformation and even cracking of the structure. If the support interval is too long, although it can release large stress, it will increase tunnel deformation and reduce structural stability. Therefore, the more appropriate construction process and time should be determined according to the actual construction conditions, construction experience of similar engieering experience and numerical calculation;

2) When there are no major structures around the tunnel, it is recommended to adopt the full face method and up and down short bench method;If the design has strict requirements on structural or environmental deformation, up and down short bench method is recommended;If the geological conditions around the tunnel are complex, up and down short bench method or double sides heading method can be used. In comparison, the construction of double side heading method is more difficult, and up and down short bench method is relatively convenient. However, if the self stability of surrounding rock is very poor, the double sides heading method is preferred;

3) In the face section of ultra-shallow-buried short net distance tunnel under unsymmetrical pressure, large tensile stress will be produced in the invert part, and even the tunnel pavement will crack when it is serious. Therefore, the design of reinforcement in invert should be increased through calculation

4) Those three excavation methods will lead to the stress concentration in the middle rock column and the right side of the left tunnel. As a result, the rock mass collapse occurs.The advance protection and reinforcement should be done in the corresponding part in the construction;

5) Thefull face method、up and down short bench method and double sides heading method are used to simulate the tunnel excavation support, and the stress field and displacement field of surrounding rock disturbance under the conditions of timely support and delayed support are calculated, and the beneficial research conclusions are obtained.It is recommended that a short net distance tunnelbe excavated by double side heading method.

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