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Comparison of construction methods for shallow burial tunnel with soft rock and large span

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Comparison of construction methods for shallow burial tunnel with soft rock and large span

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Abstract. Engineering accidents often occurred in new tunnel construction because of the shallow burial tunnel with soft surrounding rock and large span. In this paper, the Three-step excavation method, ring excavation reservation method, CD method and double pilot tunnel method were compared by the numerical simulation method. The results show that: the settlement of the surface caused by the double pilot tunnel method is the smallest in the four excavation methods and the settlement of the surface can be effectively controlled by this method. The vault crown settlement and convergence deformation values by the double pilot tunnel method are the smallest in the four excavation methods. The stable condition of the surrounding rock by the double pilot tunnel method can be reached earlier than the other three methods. There are little differences in the stress of surrounding rock among the four excavation methods. However, the stress level of the support structure is different. The stress of the support structure by the double pilot tunnel is the smallest and it is less than the allowable tensile stress of shotcrete. Through the comparative analysis of various parameters, the double pilot tunnel method in the construction of shallow tunnel with soft rock and large span is recommended.

1. Introduction

The tunnel has been widely used for its unique advantages. However, in the tunnel construction process, there are also great difficulties and risks. For tunnel construction under conditions such as shallow burial, long span and soft surrounding rock, it has always been the focus of research. Scholars have done a lot of research on how to ensure the safe excavation of tunnels under such conditions.

W.F. Wang et al [1]. Aimed at many problems such as surrounding rock collapse, large-area settlement of ground surface have happened during soft rock and shallow buried tunnel construction of express highway. FLAC3D is used to simulate the full section method, shot shoulder method, unilateral pilot tunnel method and double pilot tunnel method. To determine a reasonable construction method; G Wei et al [2]. In order to solve the problem of surrounding rock deformation and the selection of excavation method during tunnel excavation, the crowntop settlement, hance convergence and inverted arch settlement of Zizhi Tunnel are monitored, and the monitored data and influencing factors are

analyzed. J.W. Zhang et al [3]. makes numerical simulations about construction methods by Ansys, which was studied for large-span, shallow embedded and side stress tunnel with small interval of the soft wall rock is made in this paper, show the development discipline of displacement deformation and stress propagation for the surrounding rocks and support system during tunnel excavation and support, which provides basis for tunnel design and construction; Y.Z. Ren et al [4]. Studied the deformation characteristics of the shallow tunnel in soft rock by numerical simulation and site monitoring. The research shows that bench construction reduces the affected scope and deformation in front of the work face. More strict pre-reinforcement measures should be taken to control deformation caused by tunnel construction if more strict requirements for control of surrounding deformation of the soft rock tunnel are specified, in order to ensure the safety of tunnel construction and its surroundings.

From the existing research results, it's important to use reasonable construction methods for project safety. In order to better analyze and compare the applicability of different construction Methods in Shallow Tunnel with Soft Rock and Large Spans tunnel engineering. Taking a shallow buried tunnel as an example, the common tunnel excavation method is compared and analyzed according to the surrounding rock geological conditions, topographic conditions and design parameters of the shallow buried section.

2. Project Overview

The surrounding rock condition of a highway tunnel is poor and the tunnel depth is shallow. The tunnel surface covers the residual soil of the Quaternary slope, clay, and artificial fill. Complex geology, multi-fissure water, tunnel geology is completely weathered to severe weathered metamorphic sandstone and conglomerate. Excavation reveal, the metamorphic sandstone and conglomerate become soil after full weathering, and the gravel is severely weathered. Layered, multi-fissure water, poor stability, comprehensive judgment of all tunnels are V-class surrounding rock. There is a great risk in tunnel construction, and reasonable construction methods must be chosen to ensure construction safety.

### 2.1. Engineering geological parameters.
According to the survey results, the classification and final parameters of the surrounding rock are determined as shown in Table 1.

Table 1. Geological parameters

Formation	Cohesion(KPa)	Angle of internal friction(°)	Severe(KN/m³)	Elastic Modulus(MPa)
Fill	50	25	19.5	80
Silty clay	150	25	21.5	100
highly weathered sandstone	500	30	22.5	210

2.2. Tunnel design parameters
The tunnel is a separation type three-lane with a clearance area of 85.26m², which belongs to the large-section tunnel. The inner contour section is a three-hearted plus invert arch, the radius of the dome is 9.12m, the radius of the shoulder is 6.05m, and the radius of the invert is 23.15m. The tunnel width is 16.05m, and the height is 11.03m. The average distance between the left and right tunnels is 48.65m. The tunnel section is shown in Figure 1.
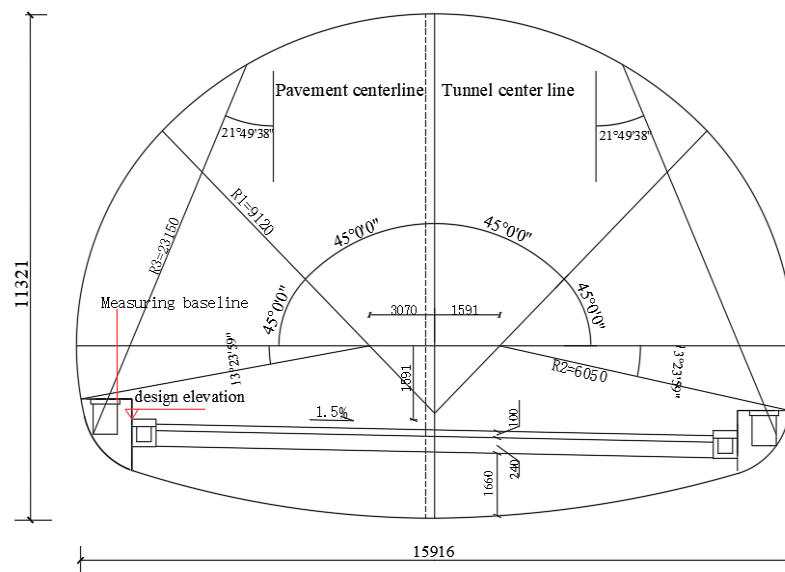
Figure 1. Tunnel section

    The tunnel adopts composite lining and support parameter design: secondary lining is C30 concrete, thickness 50cm; The waterproof layer is made of 350g/m² non-woven fabric and 1.5mm PVC waterproof board; Shotcrete C25, thickness 25cm at the arch and side wall, 15cm at the invert. Anchor rod selection $\phi 25$, length 4m, hoop spacing 0.5m. Vertical spacing 1.0m; the steel arches are 80cm apart, reinforcing mesh with $\phi 8$, spacing 20×20 cm.

3. Common method comparison analysis

The tunnel is proposed to adopt the three-step method, the ring excavation reservation method, the CD method, and the double pilot tunnel method. The overall comparison of the four methods is now shown in Figure 2.
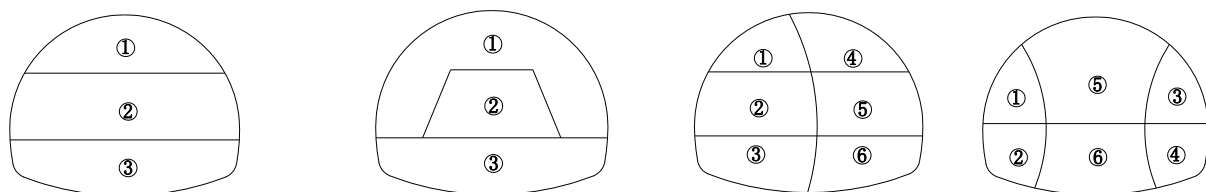
  (a) Three-step excavation   (b) Ring excavation reservation   (c) CD method   (d) Double pilot tunnel

Figure 2. Excavation sequence diagram

    The four methods have their own advantages and disadvantages: the three-step excavation method [5] divides the entire section excavation into three small parts, which reduces the disturbance of the surrounding rock by tunnel excavation, and maximizes the self-supporting ability of the surrounding rock, and the construction process relatively simple, However, when the upper and lower steps are simultaneously constructed, there is some interference between them; The ring excavation reservation method [6] divides the section into three parts: the annular arch, the upper core soil, and the lower step. During construction, the length of steps can be increased appropriately to reduce the interference of upper and lower steps, and the degree of construction mechanization is high, but the effect of settlement and deformation control is general; The CD method [7] can effectively control the settlement and surrounding rock deformation, which is conducive to the stability of surrounding rock. But there are many excavation steps, low level of mechanized construction and long construction period; The double

pilot tunnel method [8] is larger than the span, which can bear larger vertical loads and effectively avoid stress concentration. Therefore, the deformation of the tunnel is smaller in the construction process. However, the construction speed is slow, the cycle is long, and the cost is high. In order to understand the advantages and disadvantages of the four methods in a clearer way, the numerical simulation of the four methods is carried out, and the analysis is made from the aspects of displacement deformation and force.

4. Numerical simulation analysis

This paper uses Midas Gts NX finite element numerical simulation analysis software. Numerical simulation has a series of advantages such as accurate analysis, simple operation and low operating cost. It has been widely used in the analysis of geotechnical engineering problems. Numerical simulation analysis mainly includes three parts: parameter selection, model establishment, operation and result analysis.

4.1. selection of calculation parameters

For initial support, the principle of equivalent stiffness is adopted. Converting the elastic modulus of the steel frame and the steel mesh into the concrete [9].

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

Where E is the elastic modulus of shotcrete after conversion; E_0 is the original concrete elastic modulus; S_g is the Cross-sectional area of steel arch; E_g is the elastic modulus of steel. S_c is the Cross-sectional area of concrete. Equivalent method is also used for bulk density, support parameters are shown in Table 2.

Table 2. Support parameter

Parameter	Elastic modulus(GPa)	Poisson ratio	Severe(KN/m³)	Size(m)
Shotcrete	23	0.2	23	0.25
Invert				0.15
Bolt	200	0.3	78.5	0.025(diameter)

4.2. Calculation model

The calculation model is shown in Figure 3. Due to space constraints, the double pilot tunnel method is taken as an example.

(a) Integrated graph   (b) Detail drawing
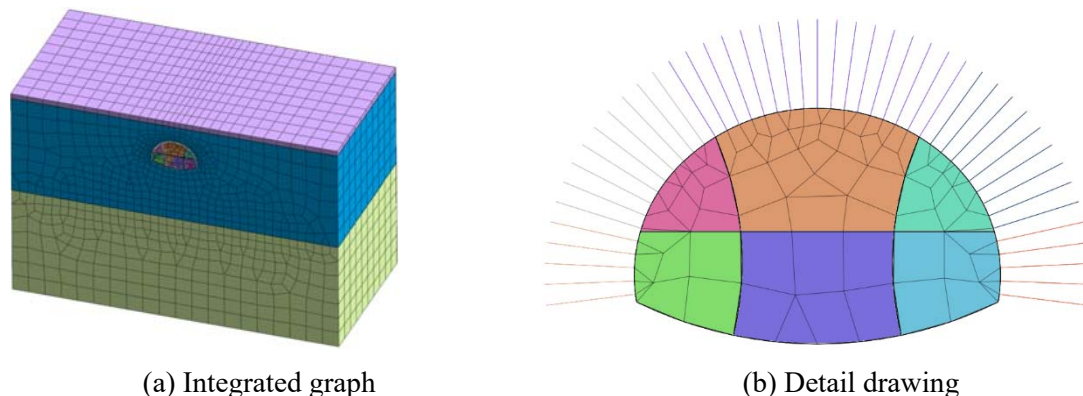
Figure 3. Calculation model

The model nodes and the number of elements are shown in Table 3.

Table 3. Number of model elements and nodes

Construction method	Three-step excavation method	Ring excavation reservation method	CD method	Double pilot tunnel method
Number of elements	12654	13129	12965	12451
Number of nodes	23158	27085	23859	23920

*4.3. Numerical simulation analysis*

4.3.1. Analysis of displacement variation in tunnel. Vault crown settlement and convergence deformation are the key monitoring projects in tunnel construction process, which deformation rate and total deformation are an important indicator for the stability of surrounding rock [10]. The vertical displacement of the tunnel is shown in Figure 4. During tunnel excavation, the vertical space-time displacement curve is shown in Figure 5.

Figure 4 shows, in different excavation methods, the value of vault crown settlement differs greatly, but the maximum value appears near the midline of vault. The maximum value of vault crown settlement: Three-step excavation method is 43.4mm, Ring excavation reservation method is 36.2mm, CD method is 24.5mm, double pilot tunnel method is 14.3mm. Double pilot tunnel method caused the smallest displacement, mainly because of the installation of vertical temporary support, which effectively limits the deformation in the vertical direction. Figure 5 shows, the vault crown settlement basically reaches a stable state when excavation is about 8m on the tunnel face by the method of the double pilot tunnel. However, when three-step excavation method and ring excavation reservation method are used, the vertical deformation of the surrounding rock needs to be stabilized until it is excavated to 24 m, which indicates that the surrounding rock can reach stability earlier when the double pilot tunnel method is excavated.
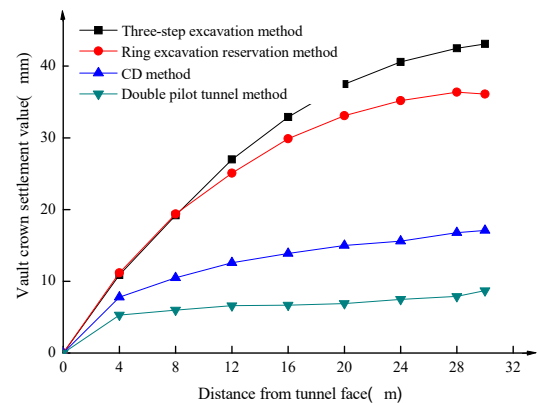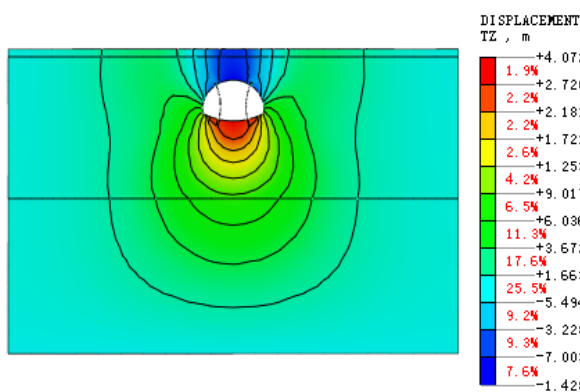
Figure 4. Vertical direction displacement diagram   **Figure 5.** Vertical space-time displacement curve

The horizontal displacement of the tunnel is shown in Figure 6. The maximum convergence deformation appears near the hance of the tunnel. The maximum value : Three-step excavation method is 37.91mm, Ring excavation reservation method is 23.51mm, CD method is 15.7mm, double pilot tunnel method is 6.24mm.As can be seen, Minimum convergence deformation caused by excavation with double-sided guide pit method.
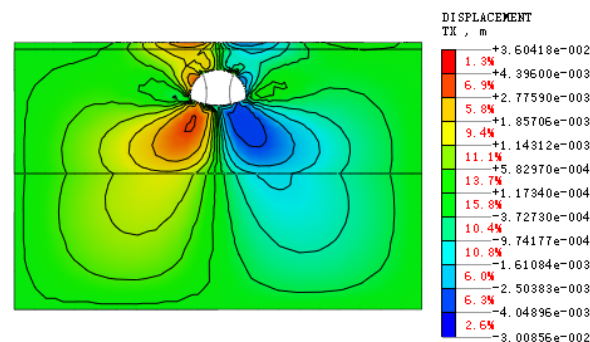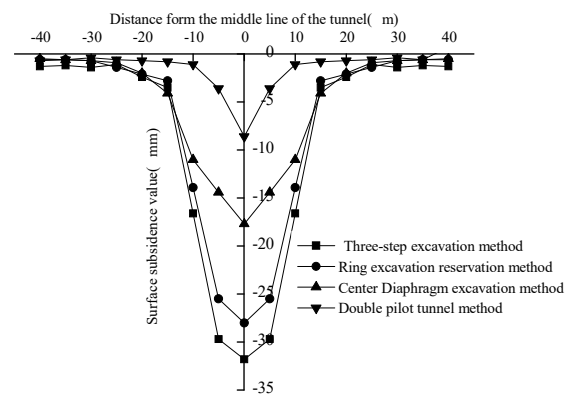
Figure 6. Level direction displacement diagram

4.3.2. Surface subsidence. Tunnel excavation will cause disturbance of the original reservoir, the balance will be broken, and the rock mass will produce downward displacement, which will cause the settlement of the surface. The surface subsidence is shown in Figure 7.

From the Surface subsidence situation, the Surface subsidence under the four construction methods shows the same regular pattern. The maximum value of surface subsidence appears directly above the center of the tunnel. When it is far from the middle line of the tunnel, the surface subsidence decreases gradually, showing a trend of sectional line. Figure 8 shows that the maximum Surface subsidence caused by different excavation methods is as follows, Three-step excavation method is 31.8mm, Ring excavation reservation method is 30.7mm, CD method is 17.7mm, double pilot tunnel method is 8.6mm, by comparison, the Surface subsidence caused by double pilot tunnel method is the smallest. When the double pilot tunnel method is used for excavation, the vertical temporary support is added, which effectively improves the overall bearing capacity of the tunnel structure and limits the deformation of the rock mass, thus resulting in relatively small Surface subsidence. At present, 30 mm is used as the Surface subsidence control standard [11], however, the Surface subsidence value caused by Three-step excavation method and Ring excavation reservation method exceeds standard.
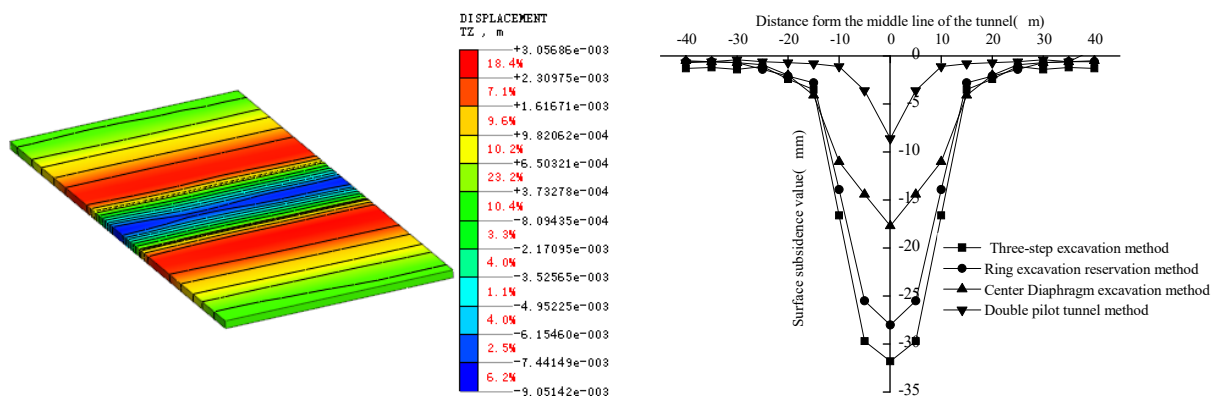
Figure 7. Surface subsidence   **Figure 8.** Surface subsidence curve of different methods

4.3.3. Stress analysis of surrounding rock. After excavation, rock mass forms a new balance, the total stress nephogram of surrounding rock is shown in Figure 9. Under four different excavation methods, the stress distribution of surrounding rock appears similar, and the maximum value is reached at the hance, which is the tensile stress. Because the surrounding rock is too loose to be self-stabilizing, it moves to the inside of the tunnel under the gravity of the upper rock mass, thus forming tensile stress. The maximum value: Three-step excavation method is 0.75Mpa, Ring excavation reservation method is 0.71MPa, CD method is 0.78MPa, double pilot tunnel method is 0.50MPa, From the results, there is little difference in the stress of surrounding rock. In addition, it can be clearly seen on the Figure 9 that

stress concentration at the intersection of the vertical support structure and the tunnel, so the support parameters of the junction should be strengthened during the construction design.
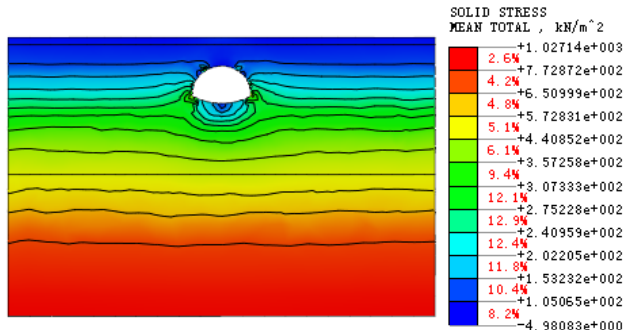

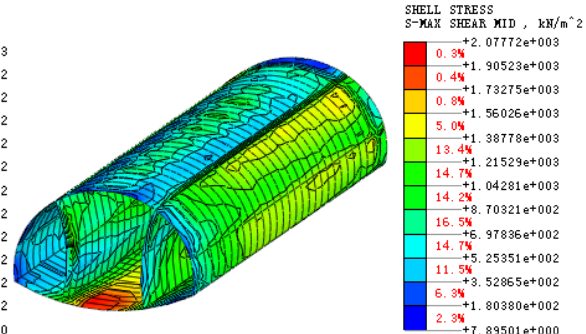**Figure 9.** Total stress of surrounding rock   **Figure 10.** Total stress of support structure

4.3.4. Total stress analysis of supporting structure. Due to the surrounding rock conditions are poor so the self-supporting ability is limited, most of the surrounding rock pressure is borne by the supporting structure. The supporting structure plays a key role in the stability of the surrounding rock of the tunnel, the total stress nephogram of support structure is shown in Figure 10. The primary support mainly bears tension stress, which is due to the displacement of the support structure to the tunnel under the extrusion of surrounding rock mass. When different construction methods are used, the location of maximum tensile stress is different. The maximum tensile stress of the Three-step excavation method and the Ring excavation reservation method appears near the dome, which is 2.78 MPa and 2.26 MPa, respectively. The maximum tensile stress of CD method and double pilot tunnel method appeared near the arch wall, which is 1.95MPa and 0.23MPa respectively. When excavating by double pilot tunnel method, the stress in the supporting structure is the minimum. According to the "Design Rules for Highway Tunnels" (JTG/T D70-2010), the tensile strength of shotcrete is 1.3 MPa. Except for the double pilot tunnel method, the stress of the supporting structure during excavation exceeds the allowable value of the specification. , has a devastating effect on the structure.

5. Conclusion

Based on the actual project, the settlement of the surface, the stress of the surrounding rock and the supporting structure in different excavation methods are compared and analyzed by the numerical simulation method.

(1) The settlement of the surface caused by the double pilot tunnel method is 8.6mm which is the smallest in the four excavation method.

(2) The vault crown settlement value is 14.3mm and the convergence deformation value is 6.2mm by the double pilot tunnel method which are the smallest in the four excavation methods.

(3) There are little differences in the stress of surrounding rock among the four excavation methods. However, the stress level of the support structure is different. The stress of the support structure by the double pilot tunnel is 0.23MPa which is the smallest in the four excavation methods. And it is less than the allowable tensile stress of shotcrete.

Through the comparative analysis of various parameters, the double pilot tunnel method in the construction of shallow tunnel with soft rock and large span is recommended.

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