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Numerical Optimization of Roadway Excavation Mode in Soft Surrounding Rock with High Ground Stress

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Abstract

Aiming at the large deformation geological disaster in the process of deep roadway excavation, taking the -420m horizontal substation of hecaijiu mine as the engineering background, this paper analyzes five excavation schemes by using the numerical simulation software FLAC3D: full section method, double step method, super pilot tunnel method, excavation after advanced bolt support and excavation after advanced grouting reinforcement, The distribution characteristics of displacement field and plastic zone in the excavation section of roadway are compared and analyzed. The results show that the arch crown settlement of roadway construction with advance pilot tunnel method is the smallest; The roadway adopts the construction method of advance grouting reinforcement and excavation, and the plastic area of surrounding rock is the smallest.

Keywords

Excavation Method; Numerical Simulation; Vault Settlement; Plastic Zone.

1. Introduction

Since entering the 21st century, China's underground engineering construction has ushered in rapid development. In terms of transportation, by the end of 2020, China has put into operation a total of 16798 railway tunnels, with a total length of about 19630 km. With the promotion of Western Railway Construction, there will be more and more large buried deep and super long railway tunnels[1]; In terms of energy, according to incomplete statistics, 60% of China's proven coal resources are buried at a depth greater than 800m. At present, there are more than 50 coal mines with a mining depth of more than kilometers. The construction of various deep buried underground projects has been gradually strengthened, and the scale, quantity and complexity of rock mass projects have increased significantly. Among them, the geological disaster of large deformation of soft rock caused by high ground stress is particularly prominent, such as Wushaoling Tunnel of Lanzhou Xinjiang Railway[2], Muzhailing tunnel of National Highway 212[3], Zhaolou coal mine -900m shaft bottom parking lot roadway[4], which have caused huge property losses. Therefore, it is urgent to simulate and analyze the construction of underground engineering under the condition of high ground stress.

At present, numerical methods are mainly used to analyze the influence of different excavation methods on the deformation characteristics of surrounding rock and the distribution range of plastic zone of underground engineering. Duan Huiling[5] used the numerical simulation method to compare and select the excavation methods of long-span tunnel under the conditions of different surrounding rock grades, and gave a reasonable excavation method. Tang Jinsong[6] conducted numerical and theoretical analysis on the excavation and support mode of long-span flat tunnel under broken surrounding rock. Taking the -420m horizontal substation of hecaijiu mine as the engineering background, this paper uses the numerical simulation method to explore the influence of different excavation methods on the deformation of roadway surrounding rock and the distribution range of plastic zone.

2. Project Overview

The buried depth of the new auxiliary shaft horizontal large section substation of No. 9 coal mine is 420m, the section shape is straight wall arch, and the section size is 5.2m×4.1m (width×high). According to the geological exploration results, the lithology revealed by the substation includes gray siltstone, black mudstone, limestone and fine sandstone, mainly black mudstone, which belongs to typical soft rock stratum. According to the indoor physical and mechanical test results, the density of mudstone is 2600kg/m3, the average uniaxial compressive strength of rock block in dry state is about 29MPa, the average tensile strength is about 1.84MPa, the elastic modulus is about 21GPa, the cohesion is about 1.2MPa, the internal friction angle is about 26°, and the Poisson's ratio is about 0.3[7].

3. Numerical Simulation Scheme

In this paper, FLAC3D developed by Itasca company is selected for numerical simulation calculation, which has unique advantages in the fields of large deformation analysis and simulation of construction process.

3.1 Calculation Model

The left and right sides of the model are symmetrical. In order to simplify the calculation process, only half of the model is established. The size of the model is: the length of the x-axis in the horizontal direction is 10m, the length of the longitudinal Y-axis is 10m, and the length of the Z-axis in the vertical direction is 20m. The size of the cavern shall be consistent with the actual project. The calculation model is shown in Figure1.

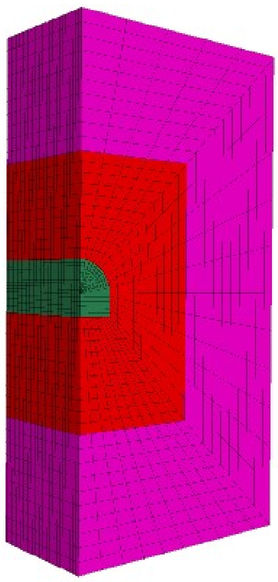

Figure 1. Calculation Model

3.2 Model Boundary Conditions

The upper boundary of the numerical calculation model is a stress constrained boundary condition, and the load is 15.2MPa (the lateral pressure coefficient is 0.3). It simulates the self weight of the overlying rock mass, and the other boundaries are displacement constrained boundary conditions. Figure 2 is the schematic diagram of model boundary conditions.

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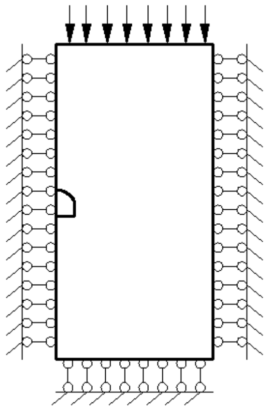


Figure 2. Model boundary conditions

3.3 Model Constitutive Relation

In the numerical calculation, the selection of constitutive relationship should have a high degree of agreement with the mechanical properties of engineering materials. Therefore, the Mohr-Coulomb elastic-plastic model commonly used in geotechnical mechanics is selected to describe the rock mass around the cavern structure; Mohr Coulomb elastic-plastic model is used to describe the rock mass of grouting reinforcement circle of cavern; Null model is adopted for some rock mass of cavern excavation.

3.4 Excavation Scheme

The excavation footage depth of the cavern is 3m. In order to explore the stability of surrounding rock of caverns with different excavation methods, five excavation schemes are adopted in this paper:

(1) Full face excavation;

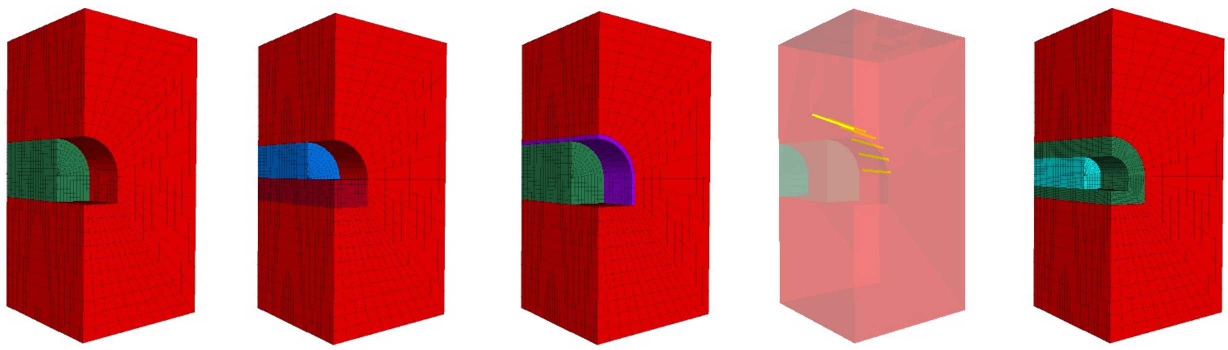
(2) Excavation by double bench method, in which the height of the upper bench is 2.4m and the height of the lower bench is 1.7m;

(3) Excavate after advance grouting reinforcement, and the thickness of grouting reinforcement layer is 25cm;

(4) Excavation shall be carried out after the support of advance anchor rod, and the length of advance anchor rod is 5m;

(5) The pilot tunnel is excavated in advance, and the cross-sectional area of the pilot tunnel is half of the cross-sectional area of the tunnel.

Figure 3 shows the schematic diagram of different excavation methods of the model.



(a) Full face excavation | (b) Double bench excavation | (c) Advance grouting excavation | (d) Advance bolt excavation | (e) Advance pilot tunnel excavation

Figure 3. The different excavation methods of model

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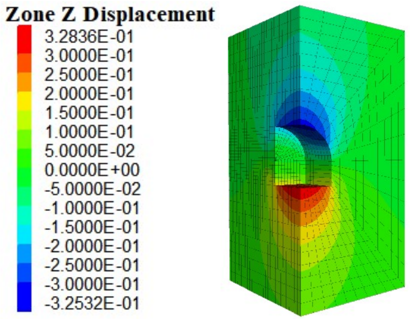
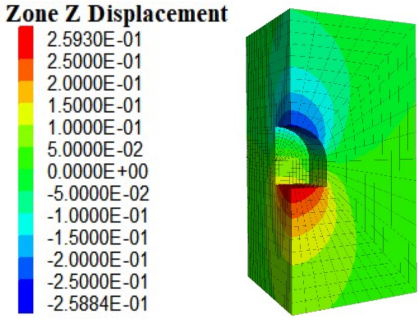
4. Analysis of Numerical Simulation Results

4.1 Displacement Field Analysis

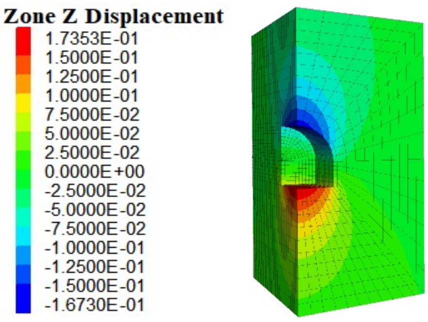
Figure 4 shows the vertical displacement nephogram of the model with different excavation methods. As shown in the figure, when the roadway is constructed by full face excavation method, the vault subsidence is 32.5cm; When the roadway is constructed by double bench excavation method, the vault subsidence is 25.9cm; When the roadway adopts the construction method of advance grouting reinforcement and excavation, the vault subsidence is 16.7cm; When the roadway adopts the construction method of advance bolt support and excavation, the vault subsidence is 19.9cm; When the tunnel is excavated by superconducting tunnel, the vault subsidence is 15.4cm. When the roadway adopts the full section excavation method, the vault subsidence is the largest, and when the superconducting tunnel is used, the vault subsidence is the smallest. The closer the whole excavation section of the roadway is to the face, the smaller the settlement of the vault is. When taking the maximum settlement of roadway vault after excavation as the selection index of several excavation methods, the advance pilot tunnel method is the best excavation method.



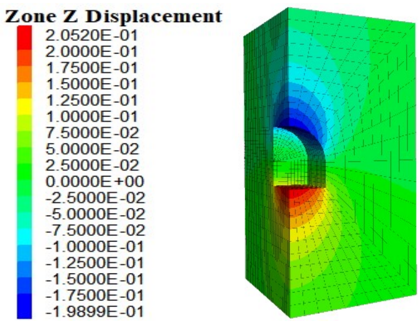
(a) Full face excavation



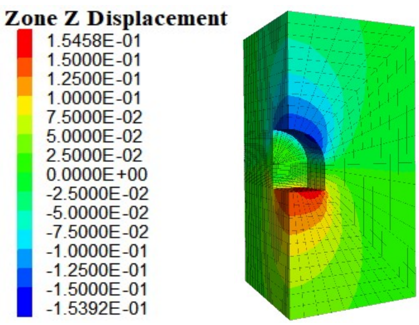
(b) Double bench excavation



(c) Advance grouting excavation



(d) Advance bolt excavation



(e) Advance pilot tunnel excavation

Figure 4. Cloud diagram of vertical displacement of model

4.2 Plastic Zone Analysis

Figure 5 shows the distribution of plastic zone of surrounding rock after full section excavation, advance pilot tunnel excavation, double bench excavation, excavation after advance bolt support and

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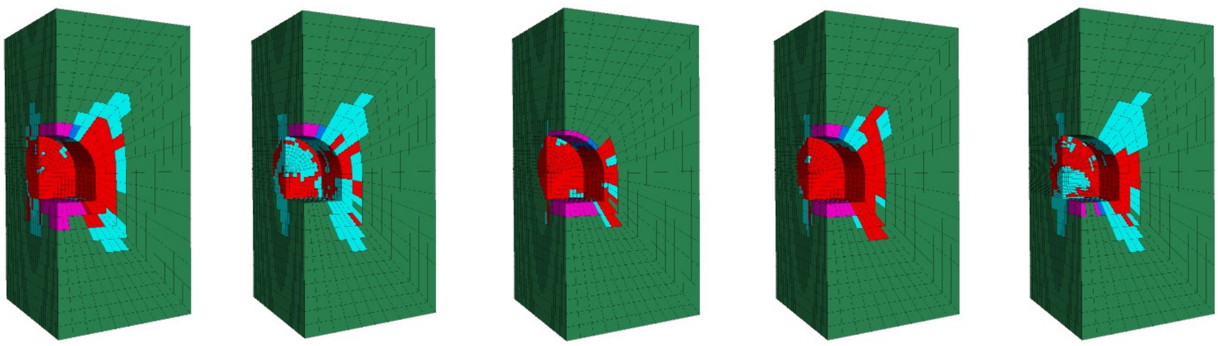
advance grouting reinforcement. ‘Shear-n’ and ‘Tension-n’ in the figure show that at the end of numerical calculation, the surrounding rock around the roadway meets the yield criterion, produces plastic flow, and shear failure and tensile failure occur. ‘Tension-n’ and ‘Tension-p’ indicate that plastic flow occurs in the calculation stage, and then the region exits the plastic state due to stress redistribution[8]. It can be seen from the figure that the failure form of roadway surrounding rock mass is mainly shear failure. Table 1 shows the range of plastic zone of surrounding rock in different excavation methods of roadway.

Table 1. Range of plastic zone of surrounding rock in different excavation methods of roadway

Plastic zone volume /m3	Full face excavation	Double bench excavation	Advance grouting excavation	Advance bolt excavation	Advance pilot tunnel excavation
Shear-n	112.5	48.4	37	79.3	62.8
Shear-p	112.6	48.5	37.1	79.4	62.9
Tension-n	0	0	0	0	0
Tension-p	8	3	6.3	6.6	3.9

As shown in Figure 5 and Figure 6, when the roadway is constructed by full face excavation method, the plastic area of surrounding rock is the largest, and the plastic area is mainly concentrated at the junction of roadway bottom and side wall and arch waist. When the roadway is constructed by double bench method, the distribution of plastic zone of surrounding rock is basically consistent with that of full section method, but the range of plastic zone is small. When the roadway is constructed by the advance pilot tunnel method, the surrounding rock of the arch crown is kept intact without plastic damage, and the main concentrated parts of the plastic area are consistent with the first two excavation methods. When the roadway adopts the construction method of pre bolt support and post excavation, the plastic zone of surrounding rock is mainly concentrated in the arch waist of the roadway. When the roadway adopts the construction method of advance grouting reinforcement and excavation, the plastic area of surrounding rock is the smallest, and it is mainly concentrated at the junction of the roadway bottom and side wall.



(a) Full face excavation (b) Double bench excavation (c) Advance grouting excavation (d) Advance bolt excavation (e) Advance pilot tunnel excavation

Figure 5. Distribution of plastic zone of surrounding rock

To sum up, when the roadway is constructed by full section excavation method, the plastic area of roadway surrounding rock is the largest. When the construction method of excavation after advance

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grouting reinforcement is adopted, the plastic area of surrounding rock is the smallest. The plastic area of surrounding rock is mainly concentrated at the junction of roadway bottom and side wall and arch waist.

Taking the plastic zone of surrounding rock after roadway excavation as the selection standard of several excavation methods, the method of grouting reinforcement before excavation is the best excavation method.

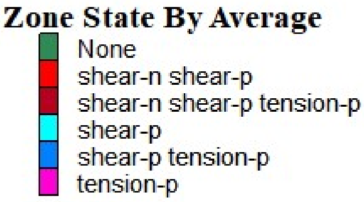

Figure 6. Legend

5. Conclusion

In this paper, the numerical analysis method is used to simulate and compare the different development modes of roadway with high stress and weak surrounding rock. The results show that:

(1) When the roadway is constructed by full face excavation method, the vault subsidence is the largest, and when the advance heading method is adopted, the vault subsidence is the smallest. The closer the whole excavation section of the roadway is to the face, the smaller the vault subsidence is.

(2) The plastic area of surrounding rock is the largest when the full section excavation method is adopted, and the plastic area of surrounding rock is the smallest when the construction method of excavation after advance grouting reinforcement is adopted. The plastic zone of surrounding rock is mainly concentrated at the junction of roadway bottom and side wall and arch waist.

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