Study on optimization design of roadway cross-section form in Xinyu mine

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Abstract: The stability of roadway is of great significance to mine safety production. In this paper, according to the geological conditions of Xinyu coal mine, the cross-section form of track roadway is optimized. Under the condition of the same ratio of height to width, rectangular section, circular arch section and straight wall semicircular arch section are designed respectively. FLAC3D is used to establish numerical model to simulate three kinds of section forms. The optimal section form is obtained by analyzing displacement field, plastic zone distribution and stress field. The results show that: (1) The cross-section form of coal mine roadway is an important factor affecting the stability of roadway. (2) Under the same ratio of height to width, the stability of roadway from high to low is straight wall semicircular arch, circular arch and rectangle. (3) The field test data show that the straight wall semicircular arch roadway has good engineering effect. (4) Comprehensive comparison shows that the straight wall semicircle arch is the best roadway section form. The research results can provide reference for the design of roadway section form in the future.

1. Introduction

With the rapid development of computer technology, numerical model analysis method has been widely used in the field of geotechnical engineering. FLAC3D software can effectively solve the problems of roadway excavation and nonlinear large deformation of surrounding rock stability, and its simulation results of coal mine roadway and other projects have also been widely recognized by the industry [1-3].

In the design of roadway, the design and optimization of roadway section form should also attract a high degree of attention, and the form of roadway section also has a certain degree of influence on the stability of surrounding rock. Therefore, the influence of roadway section form on surrounding rock stability and the selection of reasonable roadway section form under the same constraint conditions still need to be further discussed and analyzed [4-6].

Jin [7] use ANSYS to compare the stress distribution between arc bottom angle roadway and straight wall semicircular arch roadway. It is found that arc roadway can better improve the stress distribution of surrounding rock and reduce the deformation of roadway. Wang [8] and others used UDEC to simulate different roadway sections, and found that the shape of roadway cross section will also have a certain impact on the supporting effect of roadway. Gao [9] uses FLAC3D to simulate and analyze the roadway with different rise-span ratio. It is found that when the rise-span ratio is 0.2 to 0.3,
the surrounding rock stability of the roadway is relatively good, and the surrounding rock stress and deformation of the roadway will be reduced obviously.

In this paper, FLAC3D software is used to simulate different roadway sections and analyze their influence on surrounding rock stability, and then the optimal cross section form is selected to ensure the safe use of roadway, and to provide reference for the tunnel section design under similar construction conditions.

2. Engineering situation
The length of track roadway in Xinyu mine is 1940 m, the ground elevation is 965 m ~ 1060 m, and the working face elevation is 350 m ~ 480 m. The roadway is driven along the No.2 coal seam. The average thickness of No.2 coal seam is 1.5m. The direct roof is sandy mudstone and the direct bottom is mudstone, as shown in Table 1. In this paper, FLAC3D software is used to design and analyze the cross section of track roadway in Xinyu mine.

Table 1. Rock stratum of roadway

| Name           | Rock condition     | Thickness(m) |
|----------------|--------------------|--------------|
| Main roof      | Medium sandstone   | 4.7          |
| Immediate roof | Sandy mudstone     | 1.6          |
| False roof     | Shale              | 0.3          |
| Immediate bottom | Mudstone      | 0.9          |
| Main bottom    | Sandy shale        | 2.2          |

3. Design of roadway Section
Under the condition of consistent aspect ratio, three kinds of cross-section roadways with rectangular, circular arch and straight wall semicircular arch are designed, as shown in Figure 1. Because the roadway is a permanent roadway, the thickness of shotcrete layer is designed to be 120 mm.

1) Roadway tunneling width: According to the Coal Mine Safety regulations and the layout of the equipment in the roadway, the net width of the roadway is 4800mm and the driving width is 5040mm.

2) Determination of roadway heading height: The total height of the designed rectangular roadway is 4.02 m, the net height is 3.9 m; the arch height of the circular arch roadway is 1.52 m, the wall height is 2.5 m, the total height is 4.02 m, and the net height is 3.9 m; the arch height of straight wall semicircular arch roadway is 2.52 m, the wall height is 1.5 m, the total height is 4.02 m, and the net height is 3.9 m.

4. Numerical simulation of roadway

4.1 Establishment of model
The model length × width × height = 30m × 20m × 30m, and the roadway is buried at the depth of 600m. The origin of the coordinates is set at the center of the model, with the x axis to the right, the y axis to the depth, and the z axis up[10]. In order to analyze the influence of section form on roadway, the mechanical response and deformation of roadway without support are simulated.
The dimensions of three kinds of roadway are as follows: rectangular roadway gross height 4.02m × gross width 5.04m, net height 3.9m × net width 4.8m. Circular arc arch roadway gross height 4.02m × gross width 5.04m, net height 3.9m × net width 4.8m, the net radius of circular arc arch is 3.9m, and the side height of roadway is 2.5m. Straight wall semicircular arch roadway gross height 4.02m × gross width 5.04m, net height 3.9m × net width 4.8m, semicircular arch net radius 3.9m, roadway side height 2.5m.

The Mohr-Coulomb constitutive model is used in the model, and the physical and mechanical parameters of rock strata used in the process of numerical simulation are obtained by field measurement and investigation. In the process of numerical simulation, the vertical stress obtained from the calculation of the rock layer with a thickness of 600m is applied to the top surface of the model as a uniformly distributed load, and the fixed normal boundary is set to the lower boundary and the left and right boundary. The initial ground stress cloud diagram is shown in Figure 2.

4.2 Analysis of roadway Simulation results
According to the excavation simulation of the roadway, the three kinds of roadways are excavated 10 meters without support, and the deformation monitoring section is set up at the depth of Y=1.5m.

4.2.1 Simulation Analysis of rectangular Section
Figure 3 (a) and (b) show the displacement nephogram of the roadway, and the deformation of the left and right side of the roadway and the roof area is the most obvious. The maximum deformation of the left side is 25.365 cm, the maximum deformation of the right side is 24.280 cm, the roof subsidence is mainly in the middle, the maximum subsidence is 20.389 cm, but the bottom heave phenomenon is not obvious, the maximum deformation of the bottom plate is only 2.038 cm.

Figure 3 (c) and (d) show the failure nephogram of the plastic zone and the maximum principal stress nephogram of the roadway. It can be seen that there is a large shear and tensile failure area around the roadway, especially the shear failure range is very large. The maximum principal stress of the surrounding rock near the roadway is 0 to 2.4Mpa, the stress reduction area is very large, the lower surrounding rock stress has an adverse effect on the stability of the roadway.
4.2.2 Simulation Analysis of Circular Arch Section

Figure 4(a) and (b) show the displacement nephogram of the arc arch roadway. It can be seen that the deformation of the left and right side of the roadway and the roof area is the most obvious, the maximum deformation of the left side is 11.884 cm, and the maximum deformation of the right side is 13.409 cm. The roof subsidence is mainly in the middle, the maximum subsidence is 7.860 cm, and the floor heave is not obvious, and the maximum deformation of the bottom plate is only 1.895 cm.

Figure 4(c) and (d) show the failure nephogram of the plastic zone and the maximum principal stress nephogram of the roadway. There is a large range of shear and tensile failure area around the roadway, especially the shear failure range is large. However, compared with the rectangular roadway, the arc arch stability is obviously improved. There is a maximum principal stress range of 0~1.6 Mpa near the cross section of the circular arch roadway.

4.2.3 Simulation Analysis of Straight Wall Semicircular Arch Section

Figure 5 (a) and (b) show the displacement nephogram of straight wall semicircular arch roadway. The subsidence of roof is smaller than that of rectangular roadway, and the phenomenon of floor heave is not obvious. The deformation of the left and right sides of the roadway is 9.928 cm and 10.225 cm respectively, the maximum subsidence of the roof is 6.774 cm, and the maximum displacement of the floor is only 1.719 cm.
Figure 5 (c) and (d) show the failure nephogram and the maximum principal stress nephogram. The failure range of the plastic zone of the straight wall semicircular arch roadway is smaller than that of the first two, but the shear failure and tensile failure still exist. The distribution of the maximum principal stress is similar to that of the circular arch, but it is more reasonable.

![Nephograms](image)

(a) vertical direction  (b) horizontal direction
(c) plastic zone  (d) maximum principal stress

Figure 5. Results of straight wall semicircular arch section

4.2.4 Comprehensive comparison of cross section

According to the above analysis, it can be found that among the three forms of roadway section, the deformation and plastic failure area of rectangular roadway are much larger than the other two roadways. The deformation of the circular arch top and bottom plate is 57% lower than that of the rectangle, and the deformation of the straight wall semicircular arch roof and bottom plate is 62% lower than that of the rectangle. The convergence of the two sides of the circular arch is 49% lower than that of the rectangle, and the straight wall semicircular arch is 59% lower than that of the rectangle. It can be seen that the stability of straight wall semicircular arch roadway is relatively high. The stability of the three types of roadway from large to small is straight wall semicircular arch roadway, circular arch roadway and rectangular roadway. Therefore, after comprehensive consideration, the section form of straight wall semicircular arch roadway is selected as the optimal section.

5. Field application

The straight wall semicircular arch is applied to the engineering practice as the roadway section form. After excavation and support, monitoring points are set to monitor the deformation of roof and side, which is used to evaluate the stability of roadway surrounding rock. The monitoring results are shown in Figure 6. It can be seen from Figure 6 that the straight wall semicircular arch roadway can effectively control the surrounding rock deformation of the roadway with reasonable support scheme. The roof deformation is 24 mm and the side deformation is 30 mm, which ensures the safety of the roadway, which shows the rationality and feasibility of the section scheme.
6. Conclusion

(1) The cross-section form is an important factor affecting the stability of roadway. The deformation of roadway and the range of plastic zone from small to large are straight wall semicircular arch < circular arch < rectangle.

(2) The stress distribution of rectangular section roadway is the most unreasonable, and the stress reduction area is very large. The stress distribution of semi-circular arch section of straight wall is more reasonable.

(3) Under the same ratio of height to width, the stability of roadway from high to low is straight wall semicircular arch, circular arch and rectangle.

(4) Through the analysis of underground monitoring data, the rationality, applicability and feasibility of straight wall semicircular arch section are verified.

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