Numerical analysis of stress distribution and deformation and failure characteristics of surrounding rock in coal road excavation

Liping Yang 1, 2, *

1China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing, 400037, China
2National Coal Mine Safety Technology and Engineering Research Center, Chongqing, 400037, China

*Corresponding author e-mail: 2007130@cqcteg.com

Abstract. In order to further provide a basis for determining the reasonable sealing depth of the coal seam drainage hole, based on the geological data of the W33011 working face of Sihe Mine, the FLAC3D numerical simulation software is used to analyze the stress, displacement, and plastic zone of the surrounding coal body after the excavation of the W33011 roadway in Sihe Mine. And the distribution law of vertical stress, horizontal stress, vertical displacement, horizontal displacement and elastoplastic failure characteristics of the coal body around the roadway are obtained.

1. Engineering background
The No.3 coal seam is mined at W33011 working face of Sihe Mine. The ground elevation is +760~+700m, the underground elevation is +475~+440m, the working face length is 1000m, the slope length is 240m, and the average coal seam thickness is 6.31m. The working face adopts the longwall one-time full-height fully mechanized coal mining method, and all caving method manages the roof. After the excavation of the roadway, there will be three stress zones on the surrounding coal and rock masses, namely the pressure relief zone, the stress concentration zone and the original rock stress zone. Among them, problems such as borehole deformation, hole collapse, and crack air leakage are likely to occur in the pressure relief zone and stress concentration zone, which seriously affect the gas drainage effect of the borehole. Therefore, this paper mainly analyzes the stress change characteristics of the surrounding rock after the excavation and support of the roadway through numerical simulation, determines the pressure relief area and the stress concentration area, and provides technical support for drilling and sealing.

2. Numerical simulation scheme design
Numerical simulation method is a method developed with the advancement of computer technology in the past two to three decades. FLAC3D is an extended program of FLAC. On the basis of continuing all the original functions of FLAC, it has been further developed to enable it to simulate and calculate the force and deformation forms of engineering structures in the surrounding rock mass, soil mass and other media. The simulation results of this time are processed by the post-processing software Tecplot, which makes the image output more vivid and clear.
2.1. Roadway support plan
The working face is a solid coal roadway along the channel W33011, the roadway section is rectangular, and it is driven along the bottom. The section size is 5000×3800mm.

(1) Roof support. The anchor rod length is 2.4m, the anchor rod row spacing is 1000mm, each row has 6 anchor rods, the anchor rod spacing is 900mm, and the vertical roof is laid. Resin lengthened prestressed anchoring, the drill diameter is 30mm, the anchoring length is 1208mm, and the anchoring force is not less than 190kN. The anchor cable length is 7300mm, high-strength mining steel stranded anchor cable, anchor cables are laid along the middle of the roadway, 2-0-2 arrangement, two anchor cables in every two rows, the spacing is 1800mm, the distance between the sides is 1600mm, and the row spacing is 2000mm. The top anchor cables are all installed perpendicular to the top plate, and the pre-stressed anchorage is extended. The drilling diameter is $\phi 30mm$, and the anchoring length is 1970mm. The anchor cable pre-tightening force is $\geq 250kN$. (2) Two groups of support. Each row has 4 bolts with a distance of 900mm, a row spacing of 1000mm, and an anchoring height of 800mm. The top bolt is 300mm from the top plate, and the side bolts are installed perpendicular to the side of the road. The anchoring method adopts two anchoring agents, the bore diameter is 30mm, the anchoring length is 1208mm, and the anchoring force is not less than 190kN.

2.2. Calculation model establishment
Use FLAC3D numerical simulation software to build a roadway model, and use Mohr Coulomb material model to build a hexahedral brick model unit. The model size is 50m×20m×50m, and the simulated roadway length is 20m. The anchor rod and anchor cable are applied in the form of cable. Each grid in the X direction is 0.5m, each grid in the Y direction is 2m, each grid in the Z direction coal seam is 0.2m, and each other grid in the Z direction is 1m. The model frame is shown in Figure 1.

![Figure 1. Numerical model](image)
2.3. Parameter selection
The model parameters include bulk modulus K, shear modulus G, cohesion C, and internal friction angle φ. The values of each parameter are based on the measured data of mine exploration. The mechanical parameter values of coal and rock mass are determined as shown in Table 1.

| Coal seam or rock formation | Thickness/m | Elastic Modulus/GPa | Poisson's ratio | Bulk modulus/GPa | Shear modulus/GPa | Friction angle/° | Cohesion/MPa | Bulk density/Kg.m³ |
|-----------------------------|-------------|---------------------|-----------------|------------------|-------------------|-----------------|--------------|----------------------|
| Medium sandstone            | 8.89        | 7.02                | 0.352           | 7.91             | 2.6               | 33              | 2.6          | 2730                 |
| Sandy mudstone              | 4.00        | 6.99                | 0.304           | 5.94             | 2.68              | 33              | 2.5          | 2390                 |
| Carbonaceous mudstone       | 0.30        | 6.9                 | 0.34            | 7.19             | 2.57              | 30              | 2.0          | 2340                 |
| 3° coal seam                | 5.90        | 1.5                 | 0.26            | 1.04             | 0.6               | 25              | 1.0          | 1400                 |
| Fine siltstone              | 2.10        | 6.89                | 0.33            | 7.34             | 2.46              | 30              | 2.1          | 2350                 |
| Medium sandstone            | 3.20        | 7.02                | 0.352           | 7.91             | 2.6               | 33              | 2.6          | 2730                 |

2.4. Stress application
The original rock stress field is simplified as the self-weight stress field and tectonic stress field of the overlying rock. The buried depth of W33011 roadway is 300m, and the lateral pressure coefficient is 0.5. The weight of the overlying coal layer is converted into vertical stress and applied to the top of the model. The model is simulated after initial stress.

2.5. Boundary conditions
The bottom and sides of the model adopt zero-displacement boundaries, and the left and right boundaries of the model adopt single-constrained boundaries, and take \( u = 0, v \neq 0 \), \( u, v \) respectively as the displacement of \( X, Y \). The lower boundary of the model is defined as the fully-constrained boundary, and take \( u = v = 0 \). The upper boundary of the model is defined as the free boundary; the overlying rock layer of the model. The weight is applied to the upper boundary of the model as an external load.

3. Analysis of simulated roadway results
After the model is built and excavated, the anchor rods and cables at the top side are applied to the model, and after the operation is completed, the graph is sliced from multiple angles to analyze the vertical stress, horizontal stress, vertical displacement, and level of the coal body around the roadway. Displacement distribution law, analysis of elastoplastic failure characteristics.

3.1. Stress analysis
(1) Vertical stress analysis
After the excavation of the roadway, the original stress state of the surrounding coal and rock mass was destroyed, and the vertical stress was redistributed. The vertical stress distribution characteristics are shown in Figure 2, where the FLAC3D plotting effect is shown in Figure 2(a), and the Tecplot post-processing software effect is shown in Figure 2(b).
From Figure 2, it can be seen that the maximum vertical stress of the surrounding rock of the roadway is 20.59 MPa, which is 4 m away from the bank wall. From Figure 2(b), it can be seen that the stress concentration area is 3–14 m away from the bank wall, and at the top and floor. The vertical stress of the surrounding rock appears to be small. Because the surrounding rock here has been severely damaged and the degree of fragmentation is high, the strength of the surrounding rock is reduced, and the stress of the surrounding rock is transferred to the depth of the surrounding rock, which belongs to the pressure relief area. The principle of rock self-stability.

(2) Horizontal stress analysis

After the excavation of the roadway, the original stress of the surrounding coal and rock mass was destroyed, and the horizontal stress was redistributed. The horizontal stress distribution characteristics of the surrounding rock of the roadway are shown in Figure 3. It can be seen from Figure 3 that the maximum horizontal stress is 7.98 MPa, and the horizontal stress concentration area is 4–8.5 m. There is a certain range of stress reduction areas in the roadway and floor. The minimum horizontal stress is 0.026 MPa. To severe damage, it reduces the strength of the surrounding rock and weakens the bearing capacity of the surrounding rock. The four corners of the rectangular roadway are stress superimposed areas, which are easy to cause stress concentration. After the load-bearing range of the surrounding rock is exceeded, a pressure relief area will be formed, which is a key protection object for support.

In summary, after the excavation of the roadway, the vertical stress concentration area is in the range of 3–14 m away from the roadside, and the maximum vertical stress is 20.59 MPa, which is located 4 m away from the roadside. The horizontal stress concentration area is in the range of 4–8.5 m away from
the roadside. The maximum horizontal stress is 7.98 MPa, which is located 5 m away from the roadside. In the range of 0–3 m from the roadside, the stress value is less than the original stress, which is a pressure relief zone. The coal body in this area is severely damaged and there are a lot of cracks. In the stress concentration area, the stress value is much greater than the original stress. When the stress value is greater than the strength of the coal body, the coal body will undergo plastic deformation, and due to the larger stress value, the borehole is prone to deformation, hole collapse, and hole blockage. Therefore, the sealing depth of the bedding holes in this area must be greater than 14 m to ensure that the coal body is broken, the borehole is easily deformed, and the damage area is guaranteed.

3.2. Displacement analysis

(1) Vertical displacement analysis

Due to the stress field, the surrounding rock displacement changes during the construction of the underground space project, as shown in Figure 4. It can be seen from Figure 4 that the maximum vertical displacement of the roof of the roadway is 35.89 mm, and the area of greater vertical displacement of the roof is 0–7.6 m. The maximum vertical displacement of the floor of the roadway is 15.34 mm, and the area of greater vertical displacement of the floor is 0–3 m. The displacement is relatively small relative to the top plate.

![Vertical displacement map](image1)

![Tecplot processing result](image2)

Figure 4. Distribution characteristics of vertical displacement of surrounding rock of roadway

(2) Horizontal displacement analysis

Due to the horizontal stress, the surrounding rock will produce horizontal displacement changes, as shown in Figure 5. It can be seen from Figure 5 that the maximum horizontal displacement value of the roadway surrounding rock is 46.31 mm, and the horizontal displacement changes are mainly concentrated in the range of 0–2.5 m from the roadway side, which belongs to the broken area. The horizontal displacement decreases sharply within the range of 0–2.5 m from the sidewall, from the maximum value of 45.89 mm to less than 10 mm, and gradually decreases to zero as the distance from the sidewall. The displacement area of the sidewall of the roadway is mainly 0–2.5 m, and the length of the bolt for the roadside construction is 2 m. The bolt support of the roadway side effectively controls the deformation and damage of the surrounding rock of the sidewall.
3.3. Distribution of plastic zone

Flac3D can display the area that meets the yield criterion. This area is usually called the plastic zone. The plastic area distribution of the surrounding coal after the roadway excavation in the model is shown in Figure 6. It can be seen from Figure 6 that after the excavation of the roadway, the plastic zone of the roadway is 0~3m, the plastic zone of the roof is 0~2m, and the plastic zone of the floor is 0~1m. The plastic failure range of the roadway extends to the upper 45° angle of 3.0m, and surrounding rock damage is the most serious in the direction of 45°, the entire plastic failure zone is more in the middle and upper part, and the lower part is a larger elastic zone. There are many cracks in the coal body in the plastic zone that pass through to the roadway. If the sealing quality is not good or the sealing depth is insufficient, the roadway air will easily enter the drainage system through the cracks in the plastic zone, reducing the drainage effect.

4. Conclusion

(1) After the excavation of the roadway, the maximum vertical stress of the surrounding coal body is 20.59MPa, the vertical stress concentration area is 3~14m away from the roadside, the maximum horizontal stress is 7.98MPa, and the horizontal stress concentration area is 4~8.5m away from the roadside range. The stress value in the stress concentration area is much larger than the original stress. When the stress value is greater than the strength of the coal body, the coal body will undergo plastic deformation, and due to the larger stress value, the drilling is prone to deformation, hole collapse, and hole blockage.

(2) Within the range of 0~3m from the roadway, the coal body around the roadway is completely in a state of plastic failure, the stress value is less than the original stress, and the displacement and...
deformation rate is large. The coal body in the area is severely damaged and there are a large number of cracks. Broken area. This area is prone to the phenomenon that the tunnel air passes through the cracks and the drainage system is connected, so that the air enters the drainage pipeline and reduces the gas drainage concentration.

(3) The coal body around the roadway is a stress concentration area in the range of 3~14m away from the side of the roadway, and a broken area in the range of 0~3m from the side of the roadway. In order to ensure that the effective sealing section of the borehole passes through the coal body to break and the borehole is easy to deform, Damaged area, to ensure the air tightness of the borehole, increase the concentration of single-hole gas drainage, the borehole sealing depth must be greater than 14m, and the sealing section length must be greater than 11m.

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