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Research on Stability of Mining Roadway of "Three Soft" Coal Seam based on FLAC^{3D}

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Abstract: In order to reduce the serious roadway deformation during mining, the support scheme is optimized. Based on the actual geological data of mining roadway 11070, the plastic zone morphology, stress field and displacement distribution of roadway under different support schemes are analyzed by numerical simulation. The results show that scheme 1 has better supporting effect and higher roadway stability, which provides a reference for the same type of roadway support.

Keywords: Numerical Simulation; Roadway Support; Surrounding Rock Stability.

1. Introduction

The Surrounding rock control of roadway refers to the sum of mine pressure and surrounding displacement measures to control surrounding rock of roadway. Its purpose is to ensure the normal use of roadway and create necessary conditions for mine safety production. The development of roadway surrounding rock control has generally experienced two stages: first, passive support stage; Mainly represented by the support, it is considered that the surrounding rock of the roadway has been damaged and lost its self-stability, and artificial support is needed to resist the formation pressure. Second, active support stage; Mainly represented by the bolt support, it is considered that the surrounding rock of roadway still has a certain residual strength and self-stability, which is a good natural carrier. The key point of support is to strengthen the surrounding rock, give full play to the strength and stability of the surrounding rock, and form an anchor structure together with the surrounding rock to resist external formation pressure.

Weijian Yu [1] formed the main compression arch in the shallow part of the roadway through the primary anchor support, the secondary compression arch through the secondary anchor cable support, and formed the superimposed arch support through the coupling of the two compression arches, so that the supporting structure and surrounding rock jointly maintain the stability of the surrounding rock mass. Zhu Tang [2] optimized the cable support parameters of coal mine roadway based on PSO algorithm, and obtained the best design scheme of roadway cable support under different horizontal stresses. Yang Yu [3] studied the stability of roadway with composite roof, and discussed the influence degree of roadway width, overburden load and other factors on roadway. It is pointed out that the bolt support can effectively reduce the interlayer separation between the composite roof and improve the overall failure resistance of the composite roof. On this basis, it is proposed that active bolting of composite roof can effectively improve the integrity and bearing capacity of composite roof.

Manchao He [4] proposed a new negative Poisson ratio anchor cable (NPR anchor cable) with good impact resistance and large deformation resistance. The field test and numerical simulation show that NPR anchor cable has superior anti-shock and anti-blasting performance. NPR anchor cable has a broad application prospect in chamber and roadway support with high risk of rock burst and rock burst.

In this paper, the finite difference numerical simulation software FLAC^{3D} is used to analyze the distribution law of plastic zone, stress and displacement field of surrounding rock, and a reasonable support scheme is obtained, which provides a reference for the same type of roadway support.

2. Project Overview

The 11070 working face is located on the east side of the 11 mining area. 11070 working face elevation -238m ~ -256m, ground elevation +266.8m ~ +371.4m. The surface is hilly area, gully development, the middle of the working face has a few residential distribution, no tall buildings and rivers. Buried depth 513m ~ 627m. The roadway on the 11070 working face is located at the upper part of the working face, to the F29 fault protection coal pillar in the east, and to the return air main roadway in the 11 mining area in the west. The occurrence of coal seam is relatively stable, there is no large fluctuation, the thickness of coal seam is 1.3m ~ 6m, the average is 3.4m. The joint cracks of coal bodies on two sides of the roadway are highly developed and show the characteristics of soft and crushing. The roof and floor of the roadway are sandy mudstone, the internal fissure is developed, the stability is poor, and the rock strength is low, which belongs to the typical "three soft" coal seam.

3. Numerical Simulation

FLAC refers to fast Lagrangian differential analysis, which comes from fluid dynamics. FLAC software is developed by Itasca Company in the United States and is based on fast Lagrangian differential analysis method. In recent years, with the rapid development of computer level, FLAC software has also been continuously upgraded, and the FLAC^{3D} software used now is the development of two-dimensional finite difference program FLAC^{2D}. FLAC^{3D} software has powerful simulation and analysis function, and is widely used in geotechnical engineering, which promotes the development of numerical calculation. It can simulate the mechanical characteristics of soil, rock and other materials in ^{3D} structure and analyze the plastic flow, and fit the actual structure by adjusting the polyhedral elements in the ^{3D} mesh.

The FLAC^{3D} program can simulate the elastic-plastic and large deformation of materials well, and the application of this software to simulate the deformation of rock mass around the roadway has a certain reliability [5]. In addition, the software contains a variety of material constitutive models, of which three elastic models and seven plastic models are widely used. The software is simple to operate and can reflect the deformation characteristics of rock strata qualitatively.

3.1. Basic Principle

1) In the design of the model as far as possible to match the actual, and as much as possible to fully reflect the physical and mechanical characteristics of rock.

2) The main influencing factors of roadway were highlighted when the model was constructed. There are many factors affecting roadway stability. The main factors are taken into account when building the model, and the influencing factors are abstract and generalized, and other non-major influencing factors are considered as far as possible.

3) The underground engineering problem is essentially a semi-infinite problem, and only a limited range of influence is taken into account in numerical simulation. Therefore, reasonable boundary conditions should be selected in modeling.

4) When designing the model, it should be as easy as possible to simulate the calculation.

3.2. Basic Assumption

The surrounding rock of the roadway is a special medium with discontinuous, non-homogeneous, nonlinear and complicated loading conditions and boundary conditions [6]. At present, the mathematical mechanics method cannot be used to accurately solve the stress distribution in the surrounding rock of the roadway, so the approximate solution is very necessary for the design and support of the roadway. Therefore, we make the following assumptions:

1) The rock mass surrounding the roadway is an ideal elastoplastic body, which meets the Mohr-Coulomb yield criterion.

2) All the rock layers are distributed in layers, and the rock mass is homogeneous isotropic.

3) Do not consider the impact of steel mesh.

4) The influence of groundwater seepage on roadway support is not considered.

3.3. Model Building

In order to select a reasonable and effective support scheme, numerical simulation software FLAC^{3D} was used to establish a numerical model according to the geological conditions of 11070 working face and the coal rock column diagram. Because the excavation of the roadway only affects the distance from the center of the roadway 3-5 times, the model size is established as 100m×50m×54m, the direct top is sandy mudstone, the basic top is medium grained sandstone, and the floor is sandy mudstone, as shown in Figure 1. The horizontal direction of the bottom and left and right edges of the model are fixed boundary conditions. The unsimulated rock layer on the upper surface of the model is subjected to uniform load according to the weight of its overlying rock layer. The initial stress field balance of surrounding rock is carried out first after the model is established. In the process of model calculation, Mohr-Coulumb criterion was used as the basis for identifying overburden failure, and the rock physical and mechanical parameters of each rock stratum were shown in Table 1.

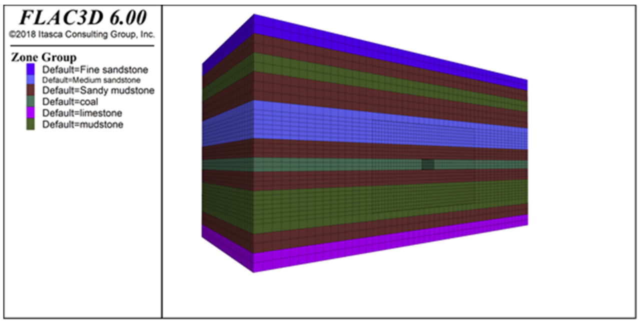


Figure 1. Numerical model diagram

Table 1. Physical and mechanical parameters of different rock formations

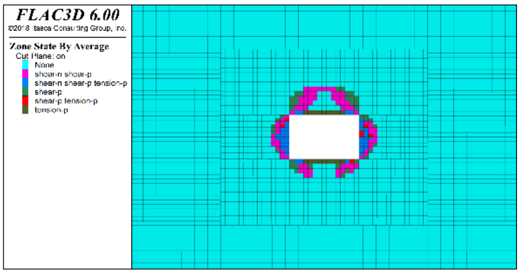
Surrounding rock	Density /(kg/m^3)	Elasticity modulus /GPa	Internal friction angle /(°)	Cohesion /MPa	Tensile strength /MPa	Poisson
Fine sandstone	2746	24.21	32.1	34.7	3.23	0.25
Sandy mudstone	2688	19.34	37.2	6	1.99	0.35
mudstone	2419	19.46	37.3	8.5	1.27	0.35
Medium sandstone	2720	42.85	27.8	27.2	4.1	0.25
coal	1435	0.09	35.5	6.99	0.5	0.3
limestone	2638	37.56	42	6.72	2.43	0.3

Through numerical simulation, the range of plastic zone and the change of stress and displacement field of roadway surrounding rock under three different support schemes are compared with that without support. The displacement change curves of roadway top and floor and waist line of roadway top and floor and two sides are monitored at the measuring points arranged on the roof and floor of roadway and two sides.

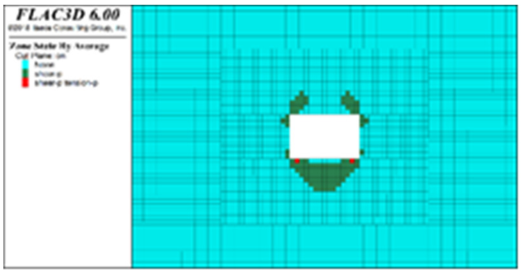
Table 2. Support scheme

Support scheme	Roof bolt row spacing /mm	Side bolt row spacing /mm	Roof cable row spacing /mm	Distance between anchor lines /mm
1	850*900	700*900	1100*1800	1200 from the top, 2100 one each
2	1000*900	700*900	1100*1800	1200 from the top, 2100 one each
3	850*1000	700*1000	1100*2000	1200 from the top, 2100 one each

3.4. Comparative Analysis of Plastic Zone of Roadway Surrounding Rock



(a) untimbering



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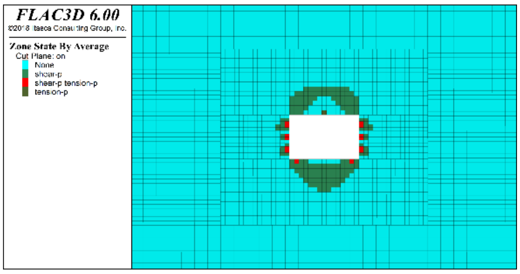

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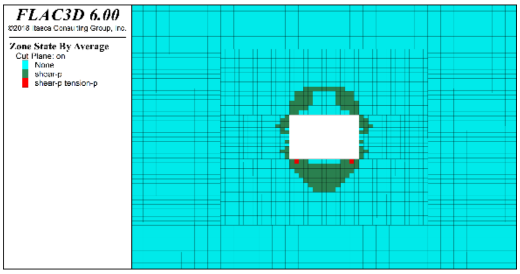
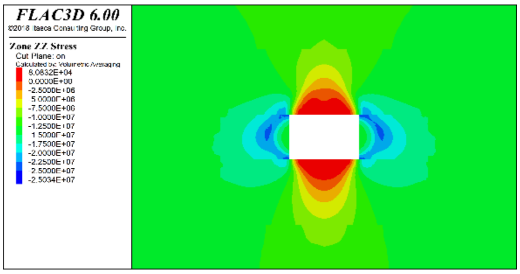


(d) Option three

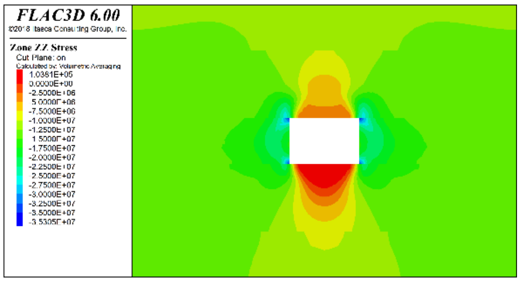
Figure 2. Plastic region distribution

According to Figure 2, the plastic zone of the surrounding rock has changed, and the distribution of the plastic zone shows the inherent law of the distribution of cracks in the roof and the two sides. It indicates that the thickness of the plastic zone of the roof after tunnel excavation is about 2000mm, the left side is about 1350mm, the right side is about 1350mm, and the bottom plate and two bottom angles have a small amount of plastic damage, the maximum is 1350mm. According to the change law of roadway displacement, although the roadway deformation is relatively small, there is a large range of plastic zone in the roof and two sides, which indicates that if timely support is not carried out, the potential caving hidden areas in the roof and two sides are large, and timely support should be carried out after roadway excavation, and floor management should be strengthened during the mining process of the working face [7]. Under the condition that the damage range is roughly the same, there is no great difference between scheme 2 and scheme 3 on both sides of the roadway. Scheme 1 is superior to Scheme 2 and scheme 3 and has better protection effect on the roof. Scheme 1 has the best supporting effect and the best maintenance effect on the roadway.

3.5. Comparative Analysis of Stress Field of Roadway Surrounding Rock



(a) untimbering



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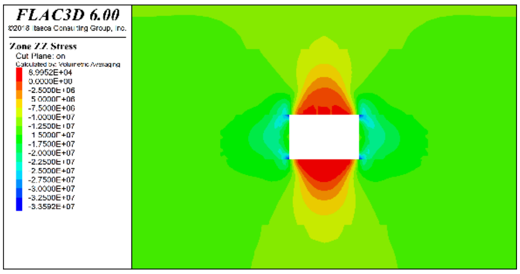

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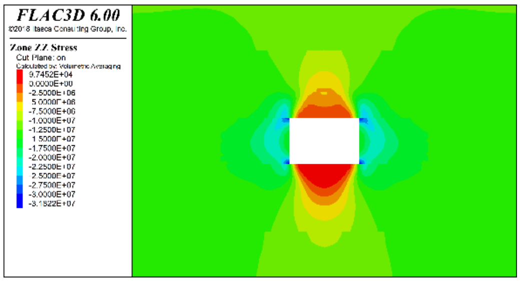

(d) Option three

Figure 3. Vertical stress cloud map

According to Figure 4, the vertical stress value of the roof and floor of the roadway gradually increases from the perimeter of the roadway to the outside, and finally returns to the original rock stress. On the two sides of the roadway, the vertical stress also develops symmetrically from the perimeter of the roadway, and the stress value gradually increases from small to large, and finally returns to the original rock stress. Within the horizontal distance of about 4.8m from the center of the roadway on the left and right sides, the vertical stress of the surrounding rock of the roadway appears in the stress concentration zone, and the maximum stress can reach 25MPa. This indicates that the rock mass has undergone plastic deformation within the horizontal distance of about

4.8m between the two sides of the roadway and the center of the roadway. Under the three support methods, the stress concentration area of the two sides of the roadway appears at the top corner and bottom corner of the roadway. Scheme 1 is closer to the center of the roadway than the other two support methods, which plays a good role in the overall support [8]. Considering the vertical stress distribution results of the surrounding rock under the three scheme conditions, the vertical stress of the roof of the roadway is in order of scheme 2, Scheme 3 and Scheme 1. Among them, the vertical stress value of coal pillar in the roadway is Plan 2, Plan 3 and Plan 1 in descending order, indicating that the vertical stress value of coal pillar in plan 1 is the smallest, so plan 1 is the best plan.

3.6. Comparative Analysis of Roadway Surrounding Rock Displacement

According to Figure 4 shows the vertical displacement diagram of roadway measurement line a (vertical median line from floor to roof direction) under different support schemes. It can be seen from the diagram that the vertical displacement of roadway along the direction of roof and floor under three different support methods is roughly as follows: with the increase of vertical distance from the center of roadway, the displacement gradually decreases, and the decline rate becomes smaller and smaller [9]. The roof subsidence and floor heave of each support scheme gradually tend to be stable at 4.5m in the upper part of the roof and 3.5m in the lower part of the bottom part, respectively. The roof subsidence of scheme 1 is reduced by 52.84mm compared with the unsupported state; scheme 2 is reduced by 10.15mm compared with the unsupported state; scheme 3 is reduced with the unsupported state. The roof subsidence is reduced by 36.36mm, so it can be seen from the comparison that the change of vertical displacement of the roof and floor of the roadway after adopting scheme 1 has a significant decrease compared with the other two supporting methods, indicating that scheme 1 has the best supporting effect.

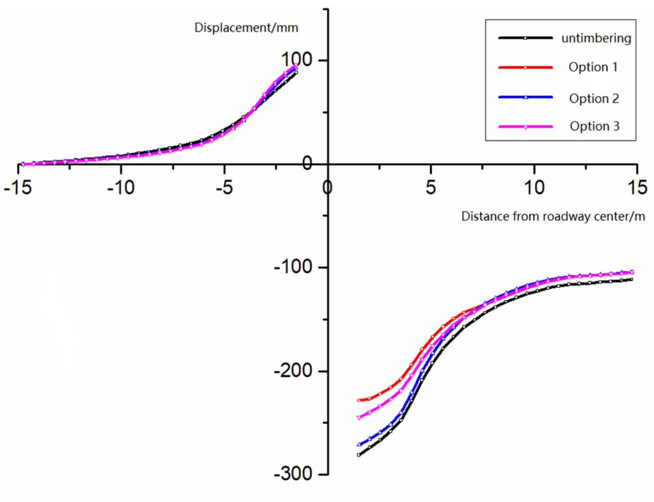

Figure 4. Vertical displacement curve of top and bottom plate

According to Figure 5 shows the horizontal displacement diagram on measured line b (horizontal center line in the direction of roadway left side to right side) under different support schemes. It can be seen from the diagram that the horizontal displacement changes along the two side directions of roadway under three different support modes are roughly as follows: The horizontal displacements of the two sides of the roadway are symmetrically distributed along the middle line of the roadway. With the increase of the horizontal distance from the roadway center, the displacements gradually decrease, and the decline rate becomes smaller and smaller [10]. The horizontal displacement of the two sides of each support scheme gradually tends to be stable at 8.3m of the two sides of the coal body, while the displacement of the two sides changes sharply from 3.5m of the side of the coal body to the surface of the roadway wall, and changes slowly from 3.5m of the side of the coal body to 8m of the two sides of the coal body. In scheme 1, the displacement of the two sides is reduced by 43.07mm compared with that without support. In scheme 2, the displacement of the two sides is reduced by 17.48mm compared with that without support. In scheme 3, the displacement of the two sides is reduced by 34.68mm compared with that without support, so it can be seen from the comparison that the change of horizontal displacement of the two sides of the roadway after the support of scheme 1 has a significant overall decrease compared with the other two support methods.

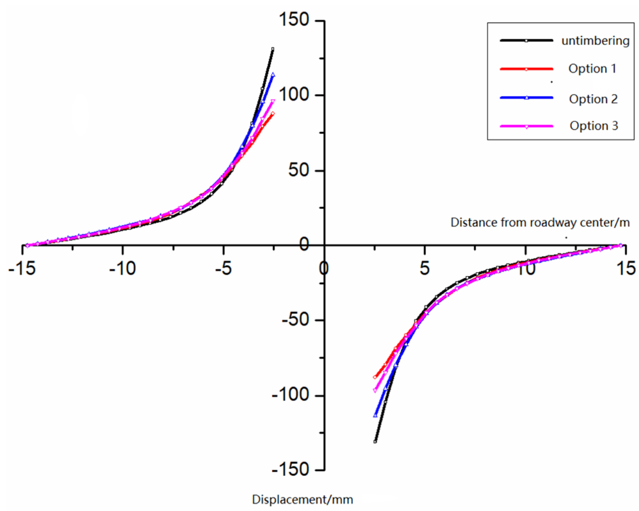

Figure 5. Change curve of horizontal displacement of two sides of roadway

Based on the distribution characteristics of vertical stress, horizontal stress and plastic zone of surrounding rock in 11070 upper roadways, as well as the change curves of roof and floor displacement and two-side displacement, it can be seen that scheme 1 has the best supporting effect and is conducive to the stability of surrounding rock of roadway.

4. Support Technology Control Scheme of Mining Roadway

Based on the analysis of the lithology of the roof and floor and the stress of the surrounding rock of the mining roadway on the 11070-working face, it is decided to adopt the bolt-cable combined support scheme, as shown in Figure 6.

Roof and side bolts are made of 22mm left-turn equal strength steel bar, the length is 2400mm. The row distance between roof bolts is 850mm×900mm, 7 in each row; The row distance between the side bolts is 700×900mm, 10 in each row (5 in each of the two sides), and the foot bolts are at a 75° Angle with the lane side.

The top anchor cable is 21.6mm steel strand with a length of 8000mm, and the side anchor cable is 18.9mm steel strand with a length of 4000mm. The row distance between roof cables is 1100mm×1800mm, with 5 cables per row. Anchor cable at the top 1200mm and 2100mm respectively. Cable eye distance 1800mm, vertical roof rock face.

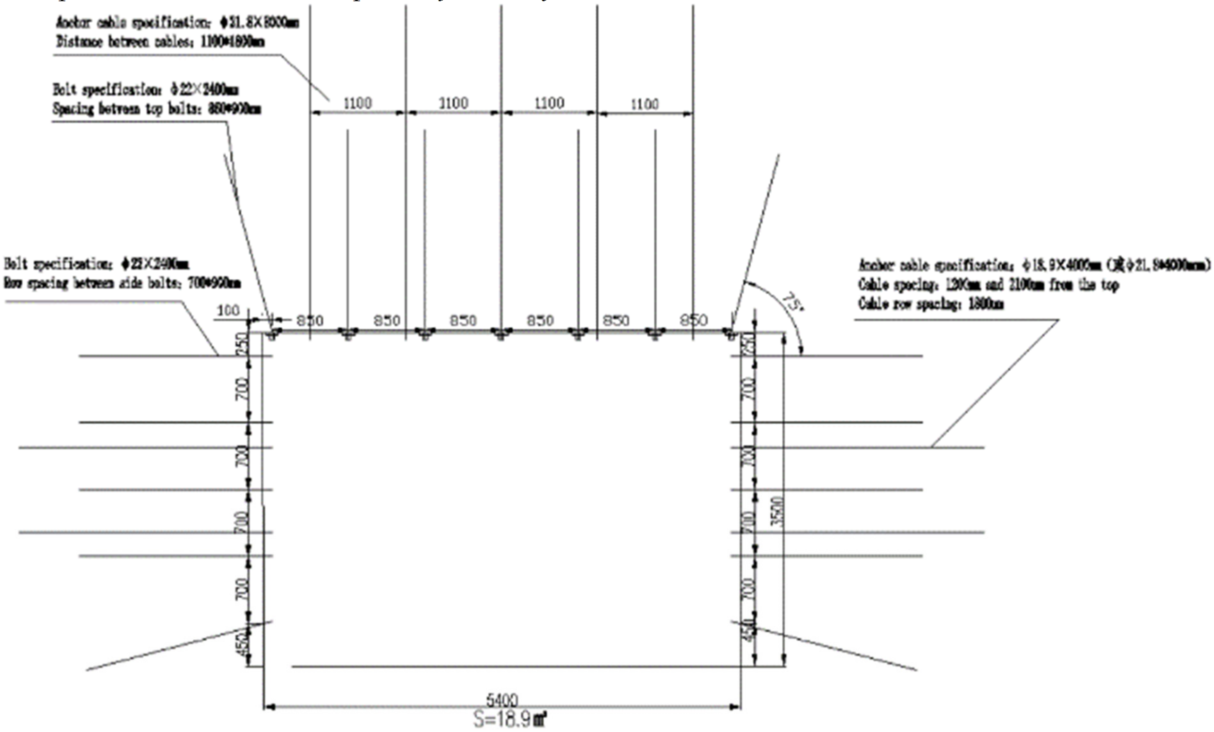

Figure 6. Support diagram

5. Conclusion

Through numerical simulation and on-site engineering, it can be seen that the technical scheme of bole-cable combined support for mining roadway 11070 working face has good effect. The subsidence of roadway roof is stable at about 150mm, the bulking volume of floor is 10mm, and the displacement of two sides is stable at about 50mm and 54mm respectively, which can be applied to mining roadway under the same type of geological conditions.

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