

Numerical simulation of the migration laws of supports and surrounding rock for coal seams of large dip angle

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ABSTRACT

SDIC Nileke mine district is located in Xinjiang and it contains 6 minable seam layers. The 45° average dip angle of the mine results in the complex processes of the mining working face. Processes such as support moving and mining working face advancing are restricted. The lateral stress of the roof increases, and at the same time the problem of controlling the working face roof becomes serious. Based on practical conditions, the process of excavation and support of the mine working face are simulated using FLAC^{3D}. The results can provide technical support for safety production through the reasonable support mode obtained through the simulation of mine pressure behaviour of the working face.

KEYWORDS: steep seam mining; numerical simulation; support resistance; hydraulic support stability

Deep inclined seam refers to coal seams with an inclination between 35° and 55°. In China, deep inclined seams account for about 15%-20% of all coal resources. Over 50% of the deep inclined seams are high-quality coking coal and anthracite. As we all know, high-quality coking coal and anthracite is a scarce coal in China. (Xie, P. S. et al., 2015a ; Wen, M. M. 2014b; Qu, Q. Y. 2014c). The mine pressure behaviour changes significantly when compared to gently inclined seams while mining. Problems such as the increasing of roof lateral stress and the increasing possibility of dumping and sliding of hydraulic support are highlighted. It is of particular importance to study the relative movement of the support and the surrounding rock of deep inclined coal seams. To solve this problem, much research has been carried out by scholars. For example, the interaction characteristics between surrounding rock movement and support system in large mining height fully-mechanized faces in steeply inclined seams were analyzed by Xie Panshi (2015). The pressure of the surrounding rock of A₆ coal seam was analyzed in this paper using FLAC^{3D}. A₆ coal seam is a part of SDIC Nileke mine

1. MINE INTRODUCTION

SDIC Nileke mine is located east of Nilka county town. The production capacity of the mine is 1.2 Mt/a. The mining district contains 6 coal seams. It is about 2.15-8.06 km from east to west and 1.21-4.38 km from north to south, for a total area of about 28.01 km². This paper mainly discusses the A₆ layer, which is characterized by:

(1) The average thickness is 6.42 m. It is a stable coal seam. The roof of the coal seam consists of carbonaceous mudstone, mudstone, and silty sandstone, and the bottom plate consists of carbonaceous mudstone, silty sandstone, and fine sandstone. It can be concluded that its structure is relatively simple.

(2) The average thickness of A_{6-lower} is 2.94 m. The number of the gangue layer is from 0 to 2, and the gangue layer is mainly composed of carbonaceous mudstone. The roof of the coal seam consists of carbonaceous mudstone, mudstone, and silty sandstone, and the bottom plate is composed of carbonaceous mudstone and mudstone.

2. MODEL ESTABLISHMENT

After the coal resource is exploited, the subsidence of overlying strata occurs. The numerical model is built by using FLAC^{3D}, and Moore-Coulomb criterion were used to judge the destruction of rock.

The depth of N11 working face is 150-350 m. To be safe, the thickness of the overlying rock was set to 350 m in the simulation. The weight of the overlying strata is 2.5 MPa/100 m. A distributed load is set to the top of the model to simulate the overlaying strata's weight. The vertical pressure of the overlaying strata is 8.75 Mpa. The scale of module is 100×130×180 m. The inclination of the coal seam is 45°. The model is built using the 8-points method, it contains 14400 units and 17702 nodes. The four sides of the model are displacement boundaries and cannot be moved in the horizontal direction. The bottom side

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of the model is a fixed boundary. The fixed boundary means it cannot be moved either in a horizontal direction or in a vertical direction. The thickness of the coal seam is 8.7 m, and the mining height and caving height were set to 4 m and 4.7 m, respectively.

The roof thickness of the working face is 25.2 m and the height of the bottom floor is 10.2 m. The model and the mesh are shown in Figure 1. Other parameters were obtained by an experiment, as shown in Table 1.

Table 1: Numerical simulation parameters

Rock properties	Thickness (m)	Density ρ_0 (kg/m ³)	Compressive strength (MPa)	Elastic modulus E (GPa)	Poisson's ratio/ μ	Cohesive strength/ C (MPa)	Internal friction angle (°)	Tensile strength (MPa)
Fine sandstone	3.40	2660.00	75.13	18.92	0.23	14.50	47.60	7.67
Powder sandstone	2.00	2540.00	74.17	17.00	0.22	14.70	47.40	9.97
Middle sandstone	2.00	2580.00	68.52	29.20	0.18	15.31	45.25	11.60
Powder sandstone	3.60	2540.00	74.17	17.00	0.22	14.70	47.40	9.97
Coarse sandstone	4.80	2620.00	105.63	33.87	0.16	21.95	48.69	7.89
Powder sandstone	1.60	2540.00	74.17	17.00	0.22	14.70	47.40	9.97
Middle sandstone	4.20	2580.00	68.52	29.20	0.18	15.31	45.25	11.60
Conglomerate	2.40	2500.00	49.78	14.23	0.28	17.80	45.30	7.22
Powder sandstone	1.00	2540.00	74.17	17.00	0.22	14.70	47.40	9.97
A ₆ minelayer	8.70	1400.00	7.26	3.65	0.29	4.05	41.00	4.19
Powder sandstone	10.20	2540.00	74.17	17.00	0.22	14.70	47.40	9.97

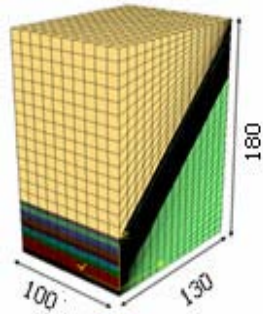


Figure 1: The model and

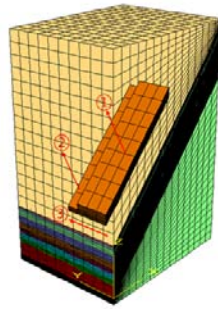


Figure 2: Excavation model: ① goaf ② stent location ③ advanced direction

In the simulation, 25 meters of coal were left in the starting side in the direction of the working face. The excavating speed along the working face advanced direction was 5 meters per time step, and the mining height was 4 meters. Until it came to a balance, the iteration was stopped. During the calculation, the caving coal was 30 to 60 meters the supporting area of the working surface 60 to 65 meters, and the top coal did not collapse. The excavation model is shown in Figure 2.

According to Moore - Coulomb criterion (Wu J. B., 2010), the intensity of rock is calculated as follows:

$$f_s = \sigma_1 - \sigma_3 \frac{1 + \sin \varphi}{1 - \sin \varphi} - 2c \sqrt{\frac{1 + \sin \varphi}{1 - \sin \varphi}} \quad (1)$$

$$f_t = \sigma_1 - \sigma_3 \quad (2)$$

Where: σ_1 —— the maximum principal stress.

σ_3 —— minimum principal stress.

C ——material cohesion.

φ —— internal friction angle

σ_t is the tensile strength of rock. If $f_s \leq 0$, shear failure of rock will occur; if $f_t \geq 0$, rock tensile failure will occur (Wang H. W., 2010).

Due to the complicated rock properties of SIDC and the effect of weak surface structure, laboratory calculated parameters are inconsistent with the engineering practice. In order to fit the actual situation, the elastic modulus of coal and rock is set to 50% of the test values from the laboratory.

3. RESULTS ANALYSIS

3.1 Analysis on the trend of surrounding rock before supporting

The vertical direction stress of the surrounding rock after excavation is shown in Figure 3. From

Figure 3 it can be seen that stresses were concentrated in the front of the working face. In the position 6 meters ahead of the coal wall, the maximum stress is 2.24 MPa. However, in the middle of the goaf, the roof undergoes tensile stress because of the damage of rock layer.

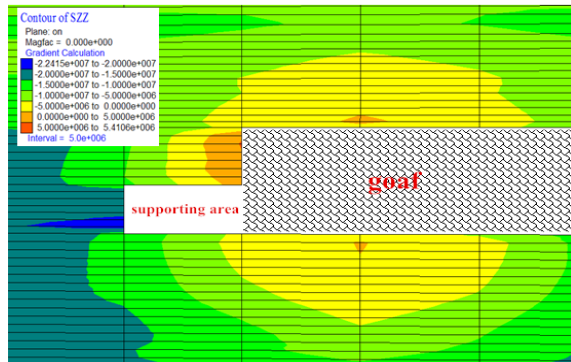


Figure 3: Stress of section along trend.

The change of vertical displacement along the direction of the goaf after excavation without support is shown in Figure 4. Due to the influence of caving coal behind the working face, the maximum displacement of the working face is 4-5 meters from the coal wall, and this is the contact zone of goaf and support. The distribution of maximum displacement boundary looks like a triangular, and the maximum displacement is 36 cm. While the distribution of roof subsidence is arched, the maximum shift is 28.43 cm. In the middle bottom, the maximum displacement is 14.98 m while vertical displacement decreases on both ends at the goaf bottom. The floor may be bulged in the process of excavation. Effective measures should be taken to solve the problems of the roof.

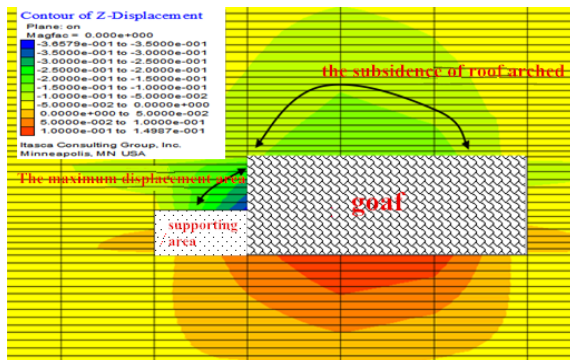


Figure 4: Displacement nephogram of section along trend.

3.2 Analysis on the inclination of surrounding rock before supporting

According to the analysis of Figure 4, four monitor points were set in the model. The first one is 5 meters in front of the coal wall, the second is on the

coal wall, the third is 2.5 meters behind the coal wall, and the last one is 5 meters behind the coal wall. The monitors were set to study the deformation of the inclined plane along the coal seam. The specific displacement is shown in Figures 5 and 6.

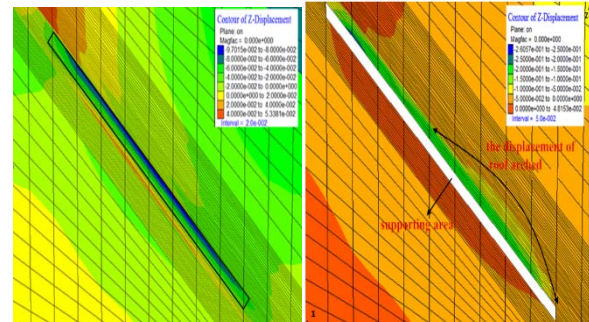


Figure 5: Vertical displacement along coal seam 5 meters ahead coal wall and on the coal wall.

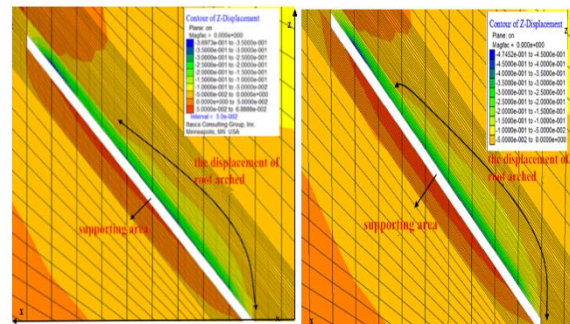


Figure 6: Vertical displacement along coal seam 2.5 meters behind the coal wall and 5 meters behind the coal wall.

As can be seen from Figure 7, the subsidence of top coal is different at different positions of the coal wall. The subsidence is less than 10 cm in front of the coal wall. While the subsidence of top coal in the coal wall is greater than 5 meters ahead of the coal wall, the maximum is 26 cm in the middle of the working face, and the minimum is 5 cm on two sides of the working face. The displacement is about 37 cm in the middle of the working face, while on both sides of the working face the displacement is 8 cm. Five meters behind coal wall, the greatest subsidence of top coal is 47 cm in the middle of the working face, while on both side of the coal wall the subsidence is 10 cm.

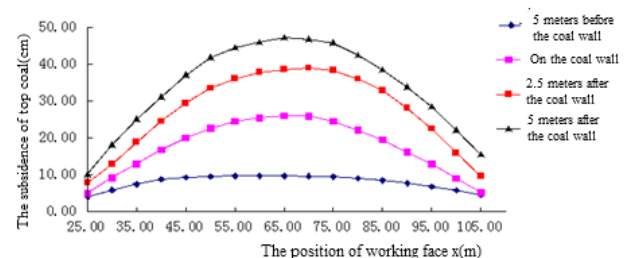


Figure 7: Cures of subsidence of top coal in different positions without supporting.

It can be concluded that the law of subsidence of the top coal along the direction of the working face is that the position of largest subsidence is 5 meters around the coal wall, and the subsidence of 2.5 meters behind the coal wall is the second, and, the subsidence on the coal wall is the smallest. The law of subsidence of the top coal on the inclination of the working face is complicated. In the middle of the working face the displacement is the largest, while on both side of the working face the displacement is the smallest. However, due to the slipping of the falling rock, the bottom of the goaf is filled. This will inevitably lead to less subsidence of the top coal in the bottom of the working face than for the top. Therefore the subsidence of the top coal of the working face is the largest in the central partial, the second largest on the upper, and the smallest on the lower. When the working face is excavated, not only the top coal will have a subsidence, as the coal wall will also produce a displacement. The horizontal displacement of the coal wall is shown in Figure 8.

From Figure 8, it can be seen that the coal wall will have greater levels of horizontal movement without supporting. It is close to 28 cm in the middle upper of the working face, which is the maximum amount. However, the minimum amount is about 10 cm on the both ends. Some measures should be taken to prevent spalling when supporting.

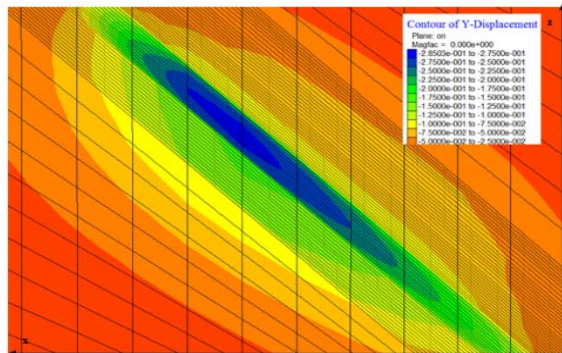


Figure 8: The horizontal displacement of the coal wall ahead supporting.

From Figure 9, it can be seen that the low stress distribution is similar to the law of displacement in the working face 2.5 meters away from the coal wall without supporting. The law is that the roof of the working face is mainly subject to tensile stress, which is arched. In the lower of the working face, the tensile stress is 2.396 Mpa, which is the largest. On both sides of the working face the stress gradually decreases and eventually becomes compressive stress. Due to the weight of rock, the stress of the

baseboard is mainly compressive stress. The compressive stress of the baseboard is about 3.0 MPa in the middle of the working face

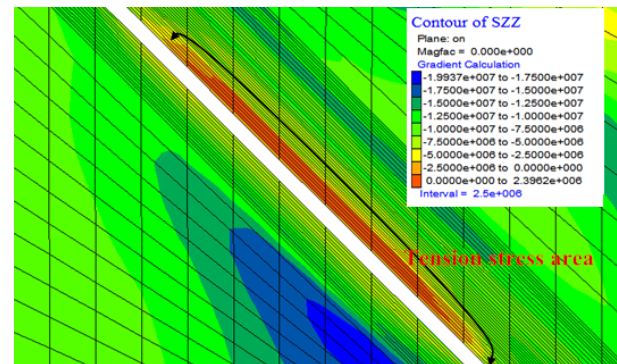


Figure 9: Analysis on the stress distribution along the dip of layer 2.5 m away from coal wall without supporting.

3.3 Analysis on the change of surrounding rock with supporting

From Figure 10 it can be known that the subsidence of the roof is reduced with supporting. The maximum displacement is 37.97 cm without supporting, while the displacement reaches only 28.29 cm with supporting. When comparing these two kinds of situations, the vertical displacement 2.5 meters away from the coal seam is shown in Figure 11.

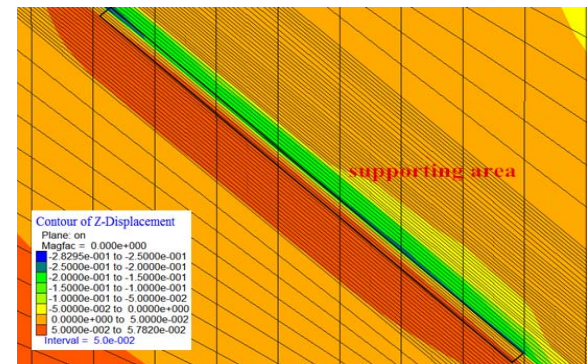


Figure 10: The vertical displacement nephogram along the coal seam 2.5 meters away from coal seam.

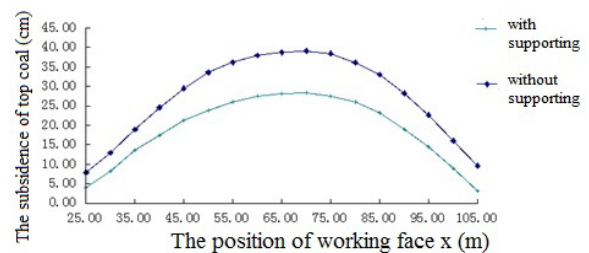


Figure 11: Vertical displacement curve of the support beam along coal seam 2.5 meters away coal wall.

From Figure 11, it can be concluded that the subsidence of the roof noticeably decreased, but the vertical displacement of the top coal is still arched. The maximum displacement is 37.97 cm without supporting in the lower working face, but it becomes 3.2 cm with supporting. At both ends of the working face, the minimum displacement is 3.2 cm. This explains how support can effectively reduce the subsidence of top coal.

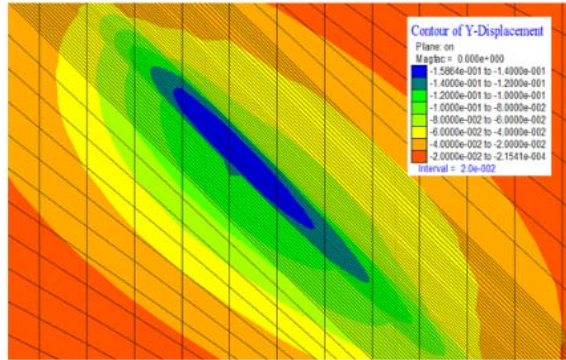


Figure 12: Displacement of coal wall near the working face with supporting.

Just as Figure 12 shows, the horizontal displacement of the coal wall reaches the largest value of 15 cm in the middle of the working face, and the minimum displacement is 4 cm on both sides of the working face with supporting. The maximum displacement of the coal wall is 26 cm without supporting. The supports can effectively reduce the displacement of the coal wall, but effective protective measures for mining should still be taken.

3.4 Analysis of the stress of the supporting bracket

In the simulation, the three-dimensional unit is used to simulate the supporting bracket, and the unit size is consistent with the support size. The length of the unit is 5.0 m, width is 1.5 m, and height is 4.0 m. The elastic modulus of the model is 1/15 of the coal layer, which is 581 MPa. The Poisson's ratio is 0.01. According to formulas (3) and (4), the bulk modulus and shear modulus of the unit can be calculated. The bulk modulus (K) is 197.73 MPa, and the shear modulus (G) is 287.79. The capacity (d) is 7500 kg/m³. The support force is shown in Figure 13.

$$K = \frac{E}{3(1-2\mu)} \quad (3)$$

$$G = \frac{E}{2(1+\mu)} \quad (4)$$

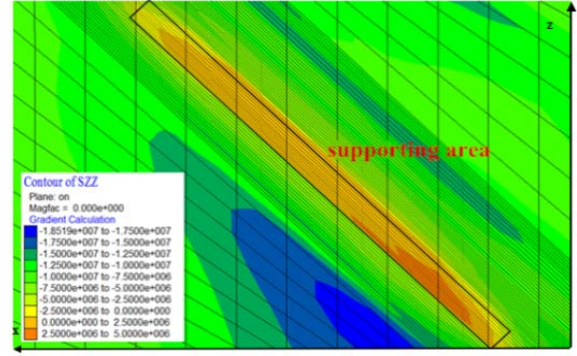


Figure 13: The stress distribution of the support region along the seam 2.5 meters away from coal seam.

As can be seen from Figure 13, the pressure of the support beam is 0.72 MPa in the lower working face. However, the pressure gradually decreases in both ends of the working face, and the smallest vertical stress is 0.28 MPa in the bottom layer. The minimum pressure is 0.21 MPa in the upper layer.

3.5 Determination the supporting resistance

According to the results of the simulation, the intensity of the supporting bracket from top coal is 0.72 MPa, and the supporting resistance was calculated according to the following formula (Wu, J. Y. et al., 2010a; Wu, Y. P. et al., 2007b; Zhao, Y. F. et al., 2007c):

$$P = n \cdot q \cdot \cos \alpha \cdot a \cdot b \quad (5)$$

Where: n—safety factor, take 1.4.

q—supporting intensity, take 0.72MPa.

α—angle of coal seam inclination, take 45°.

a—maximum control distance, take 5m.

b—centre distance of supporting, take 1.5m.

The supporting resistance is 5346 KN, so the working resistance of the support should be greater than 5346 KN in practice.

4. CONCLUSIONS

Through the numerical simulation by FLAC^{3D}, the change of the surrounding rock and the bracket forces with and without support was analysed. The following conclusions can be made:

(1) For deep inclined seams, the roof subsidence could be effectively reduced with stents supporting. The maximum displacement of the roof is 37.97 cm without supporting, while the amount of displacement reduced to 28.29 cm with supporting.

(2) The deformation of coal walls could also be effectively reduced through the use of stents supporting. The largest deformation of the coal wall is 26 cm without supporting. The largest horizontal displacement of the coal wall reaches 15 cm in the middle of the working face, and the minimum

displacement of the two ends is 4 cm with supporting.

(3) By numerical simulation, it is concluded that the supporting intensity should be 0.72 MPa. The reasonable supporting resistance desired by A₆ coal layer is 3818 KN without considering the safety factor, and if the safety factor is taken to be 1.3, the final support resistance is 5346 KN.

5. ACKNOWLEDGEMENT

It is with great pleasure that we acknowledge the generous financial support of National Natural Science Foundation of China (project number: 51474017) and Natural Science Foundation of Xinjiang Uygur Autonomous Region of China (2014211B013).

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