Numerical Simulation of Surrounding Rock Stress under Different Overlying Strata Combinations in Sijiazhuang Mine

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Abstract. Sijiazhuang coal mine is taken as an example in this paper. Both the theoretic model and the numerical simulation are carried out to analyze the stress distribution regularity on the surrounding rock of stope face under different overlying strata combinations by using discrete element method. Under different combinations of the overlying strata, the results indicate that the regularity of stress distribution around stope face is roughly the same, i.e. the stress concentration of different degree appears in both ends, and the region of pressure relief exist above the stope face. Furthermore, destruction degree of the roof in stope face is different under various overlying strata combinations. On the eve of the first weighting, the different combinations present different phenomenon of concentration, especially the soft-hard-soft combination and hard-soft-hard combination.

1 Introduction

During advancing in the stope face, all kinds of disasters, such as surging water, fire, gas explosion, coal-dust explosion and large area of roof falling, frequently happen. The property of overlying strata is a major factor affecting the regularity of stress distribution around stope face. When the property of overlying strata changes, the weighting step and the position of key strata will be affected, leading to the influences on the stress regions around the stope face [1-5].Through the mechanical behavior study on overlying strata combinations around the stope face, the breakage process of rock layer can be better understood by means of mechanics, to provide a theoretical guarantee for the safety of coal mining production.

Discrete element method is an effective method to study on dynamic problems of discontinuous medium such as rock and particle, and has been widely applied in the geotechnical engineering [6-9]. Based on the theory of discrete element method and UDEC software, numerical simulations are carried out to analyze the stress field of surrounding rock in the stope face during excavation of single coal seam, to provide a theoretical guarantee for the safety of coal mining production.

2 Engineering Situation

Sijiazhuang coal mine, topographically high in the west and low in the east as well as high in the south and low in the north, is located in the west of northern of Taihang Mountains, which presents a complex terrain and severe faults. The large valleys are nearly in EW and NE strike, while the smaller ones are crisscross. A large area of bedrock is exposed, with only a little loess remaining on the top of mountain. The highest point is the broken rock of ridge closed to the southwest corner of minefield, with an elevation of 1613.3 m a.s.l. The lowest point is near the Shangzhuang Village, with an elevation of 891 m a.s.l. The difference between these two points is 722 m and the relative difference is generally 100~200 m, which indicates a low mountains terrain. Table 1 shows the parameters of coal and rock in Sijiazhuang coal mine.

Table 1 Parameters of Coal and Rock in Sijiazhuang Coal Mine

Combination 1	Aluminum mudstone	Sandy mudstone	Coal seam	Sandy mudstone	Fine-grained sandstone	Limestone
Combination 2	Sandy mudstone	Mud rock	Coal seam	Fine-grained sandstone	Sandy mudstone	Mud rock
Combination 3	Fine-grained sandstone	Sandy mudstone	Coal seam	Sandy mudstone	Moderate sandstone	Sandy mudstone

3 Model Establishment

3.1 Basic Model

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The model is established as shown in Fig.1. In the model, coal seam thickness is designed as 5 meters, and the position of key strata can be calculated based on all kinds of the rock stratum parameters in different overlying strata combinations.

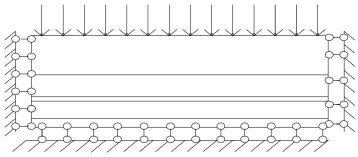


Fig.1 Basic Model in Different Overlying Strata Combination

3.2 Basic Theories

The coal is elastic-perfectly plastic material [10], so the Mohr-Coulomb model is adopted here, and its failure criterion is the linear failure surface of shear failure.

$$f_s = \sigma_1 - \sigma_3 N_\phi + 2c\sqrt{N_\phi} \quad (1)$$

Where, N_Φ= (1+sinΦ)/ (1-sinΦ); σ_1 is the maximum principal stress; σ_3 is the minimum principal stress; Φ is the internal friction angle; c is the cohesion.

If $f_s < 0$, shear yielding is developed. The yield surface expand to the area which equals to its tensile strength, the minimum principal stress should not exceed the tensile strength.

$$f_s = \sigma_3 - \sigma^t \quad (2)$$

If $f_s > 0$, the tensile yield is developed. The tensile strength should not exceed σ_3, and this value corresponds to the upper limit of Mohr-Coulomb criterion. The maximum value is determined by the following equation.

$$\sigma^t_{\max} = \frac{c}{\tan\varphi} \quad (3)$$

The equation (3) is the intensity-stress ratio [11]. The stress state of arbitrary unit can be expressed by σ_1 and σ_3. This stress state is the circle "a" of which the radius is ra in the Mohr's stress circle (Fig.2). If the circle just contacts the envelope, the failure is developed. The intensity of stress state expressed by circle "a" is constant by maintaining σ_3, and σ_1 is increased or decreased to the circle "b" of which radius is r_b. The radius ratio F of two circles is intensity-stress ratio. F is also called "damage index" or "safety factor". If $|F<1|$, all points of the circle "a" are beyond the envelope. If σ_3 is larger than the ultimate tension, F equals to zero. According to the Mohr-Coulomb criterion, the minor tensile strength should be adopted.

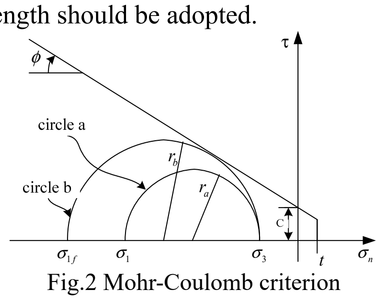


Fig.2 Mohr-Coulomb criterion

3.3 Joint constitutive mode

As to the joint sets of which the joint attitude is perpendicular to loading direction and with equal spacing, there exists the following relationship:

$$\frac{1}{E_m} = \frac{1}{E_r} + \frac{1}{k_n s} \quad (4)$$

Where, E_m is the young modulus of rock mass; E_r is the young modulus of rock; k_n is the normal stiffness of joint; s is the joint spacing.

The shearing rigidity of joint can be expressed as:

$$k_s = \frac{G_m G_r}{s(G_r - G_m)} \quad (5)$$

Where, G_m is the shear modulus of rock mass; G_r is the shear modulus of rock; k_s is the shear stiffness of joint.

4 Model's Mechanical Property and Initial Stress

The self-weight stress field and tectonic stress field are main components of the in-situ rock mass stress field, which is the foundation to analyze stress redistribution around mining space. Due to that, the study about initial stress state of rock mass can provide basis for reasonably analysing the internal stress variation of rock mass in the process of excavation and designing of roadway supporting.

Self-weight stress: If rock mass is uniform and continuous medium, the self-weight stress of rock mass should be calculated based on the principle of continuum mechanics. The rock mass is assumed as semi-infinite body and the ground is horizontal, and then a unit can be taken randomly below the surface at a depth of H. The horizontal stresses acting on that unit are σ_x and σ_y, and vertical stress is σ_z. They form a state of self-weight stress and can be expressed as follows:

$$\begin{cases} \sigma_Z = \gamma H \\ \sigma_x = \sigma_x = \lambda \sigma_Z \\ \tau_{xy} = 0 \end{cases} \quad (7)$$

In the formula, γ is average body force of overlying strata and its unit is kN/m^3; H is the depth from units to ground and unit is m; λ is a constant called side pressure coefficient. The side pressure coefficient, when tectonic stress is not considered, can be expressed as:

$$\lambda = \frac{\mu}{1-\mu} \quad (8)$$

Tectonic stress: Tectonic stress iscaused by geological tectonic movement in rock mass, and can be divided into modern tectonic stress and residual stress of geological structure. Modern tectonic stress is produced in rock mass due to the geological tectonic movement, while the residual stress of geological structure is a residual stress after geological tectonic movement is over.

The main stress in tectonic stress is mainly horizontal force, which has distinct characteristics in region and direction. Its basic characteristics are as follows: 1) Tectonic stress is mainly a horizontal force as the main pattern of crustal movement is horizontal; and compressive stress has an absolute advantage in horizontal force because general movement trend in earth crust is extruding each other. 2) Tectonic stress distribution is not uniform, so the size and direction of the maximum principal stress are variable in the area where geological structure is changed tempestuously. 3) Because of the distinct characteristic of directivity, there is a big difference between the maximum principal stress and the minimum principal stress. 4) Tectonic stress is ubiquitous in hard rock layer, while is rarely in soft rock.

5 Numerical Simulation and Analysis

5.1 Coal and Rock Parameters

The setting of parameters in model can be varied for different combinations of overlying strata, which can also affect the boundary conditions. For this reason, how to choose the proper parameters is important before making the simulation, and the different combinations of overlying strata are shown in Table 2, Table 3 and Table 4.

Table 2 The rock layer parameters of soft-hard-soft combination

Position	Immediate bottom	Basic bottom	Immediate roof	Basic roof	Overlying strata
Density kg/m^3	2500	2300	1500	2800	1500
Shear modulus MPa	9000	8000	8000	9000	17900
Bulk modulus MPa	10400	11500	11500	30100	10500
Internal friction angle	37	35	35	37	50
Cohesion MPa	11	10.2	10.2	31	12.68

Table 3 The rock layer parameters of soft-soft-hard combination

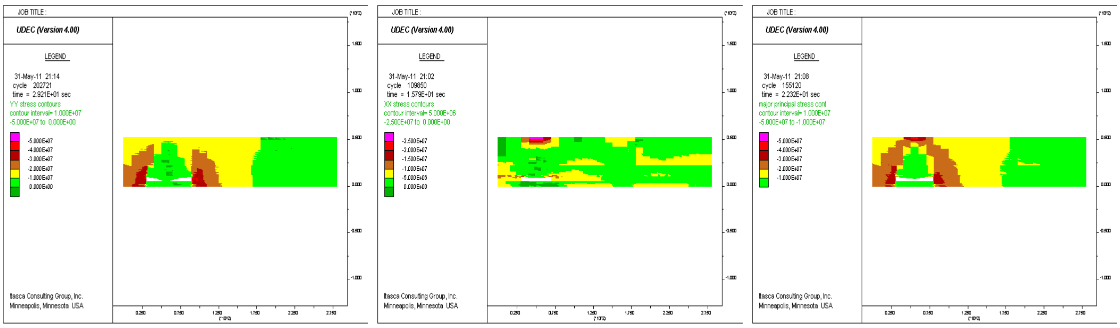
Position	Immediate bottom	Basic bottom	Immediate roof	Basic roof	Overlying strata
Density kg/m^3	2500	2300	1500	1500	2800
Shear modulus MPa	9000	8000	8000	9000	9000
Bulk modulus MPa	10400	11500	11500	10400	30100
Internal friction angle	37	35	35	37	37
Cohesion MPa	11	10.2	10.6	11.4	31

Table 4 The rock layer parameters of hard-soft-hard combination

Position	Immediate bottom	Basic bottom	Immediate roof	Basic roof	Overlying strata
Density kg/m^3	2500	2300	2800	1500	2800
Shear modulus MPa	9000	8000	8000	9000	17000
Bulk modulus MPa	10400	11500	13500	10400	31100
Internal friction angle	37	35	28	37	50
Cohesion MPa	11	10.2	11.2	11.4	31

5.2 Simulation and analysis

(1) Soft-hard-soft combination of rock stratum



(a) Stress in z-direction (b) Stress in x-direction (c) Maximum principal stress

Fig. 3 The stress distribution of soft-hard-soft combination with the thickness of 5 meters when advancing for 50 m

Through the comparison and analysis in Fig. 3a, Fig. 3b and Fig. 3c, the results can be concluded as follows: the regularity of stress distribution in z-direction is about the same with the regularity of the maximum principal stress. It indicates that the stress in z-direction has larger influence on the maximum principal stress compared with other directions. In this case, the stress in z-direction plays a leading role in all the stresses.

(2) Hard-soft-hard combination of rock stratum

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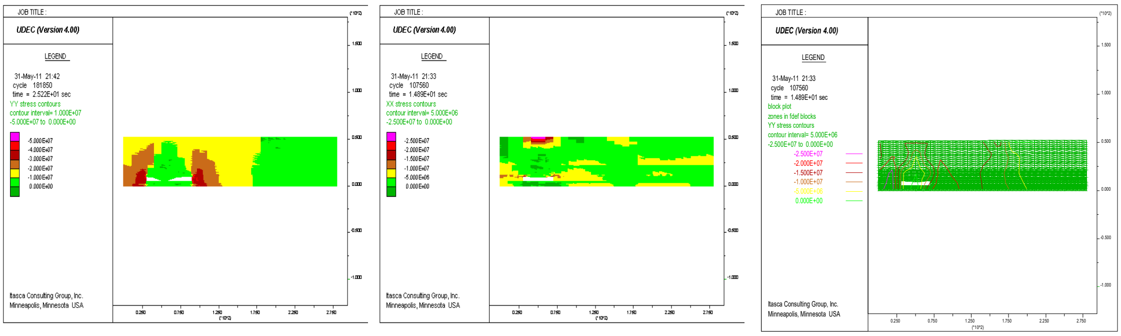


(a) Stress in z-direction (b) Stress in x-direction (c) Maximum principal stress

Fig. 4 The stress distribution of hard-soft-hard combination with the thickness of 5 meters when advancing for 50 m

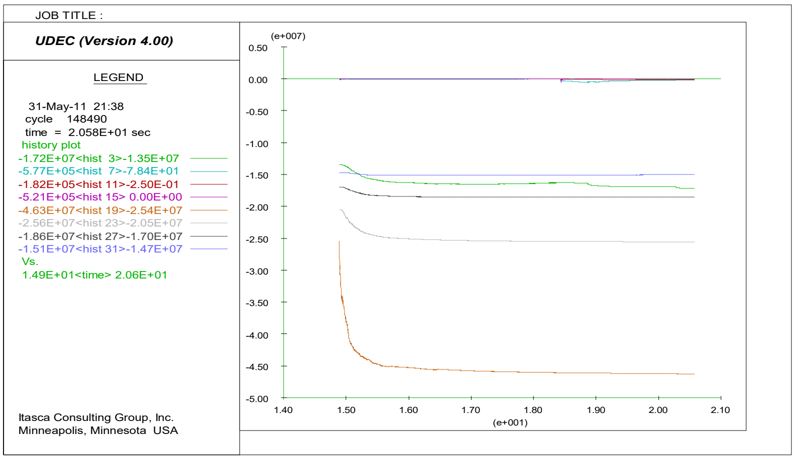
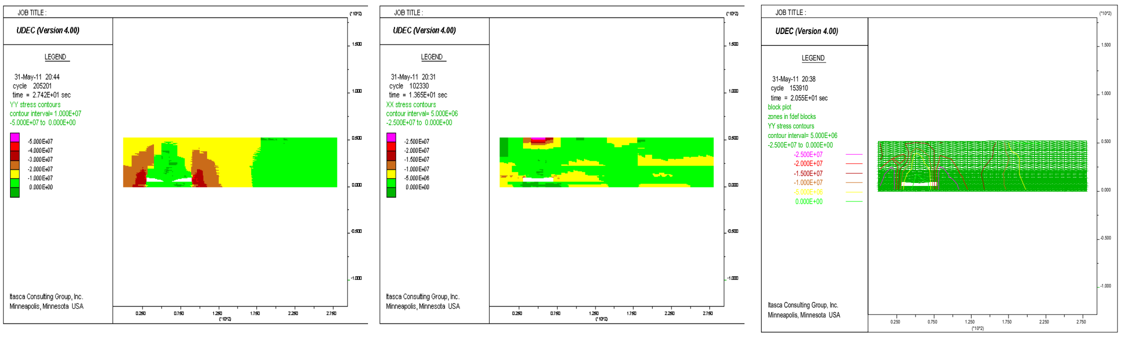


Fig.5 The stress values of hard-soft-hard combination in z-direction with 5 m thickness when advancing for 50 m

In the Fig. 5, the variation of stress values in z-direction over time is recorded. The positions of those points are respectively 30, 40, 50, 60, 80, 100, 120 and 140 meters in the roof, which are presented by different colors with different stress values. The specific stress values, which are in the front of working face and in the rear of roof, are shown directly in these figures.

(3) Soft-soft-hard combination of rock stratum



(a) Stress in z-direction (b) stress in x-direction (c) the maximum principal stress

Fig.6 The stress distribution of soft-soft-hard combination with 5m sickness when advanced 50 m

Through the comparison of different overlying strata combinations in Fig.3, Fig 4 and Fig 6, the regularity of stress distribution around stope face reveals that the division of stress region is about the same, that is to say, the stress concentration of different degree appears in both ends of stope face, and the region of pressure relief appears above the stope face. Moreover, fissures in different sizes appear, with stress values of zero, leading to the separation between key stratum and lower rock stratum.

In Fig.3, Fig.4 and Fig.6, the extent of destruction in the roof of stope face is varied under the different overlying strata combinations, and the regularity of stress distribution is different due to the influence caused by property of overlying strata. Through the comparison of Fig. 3a, Fig. 3b and Fig. 3c, the destruction extent under hard-soft-hard combination around the stope face is more obvious compared with other combinations.

Furthermore, on the eve of the first weighting, the stress distributions in x-direction under all combinations areas shown in figures are concentrated, and present different concentration extent under different overlying strata combinations. Among all the combinations, the stress concentration phenomenon in x-direction under soft-soft-hard combination is the least obvious.

6 Conclusion

Numerical simulation is carried out in this paper to analyze the stress distribution regularity about the surrounding rock of stope face under different overlying strata combinations. By taking the Sijiazhuang coal mine as an example, the comparative analysis results indicate that the thickness of unconsolidated layers and key stratum are the key factors affecting the comprehensive hardness in the overlying strata. In addition, unconsolidated layers incease the weight and stress value in overlying strata. When the key stratum is placed on the upper position, the deformation extent of roof in stope face will become severer, which is similar to the simulations in this paper. While compared with the soft-soft-hard overlying strata combination, the larger stress region appear in engineering project. The results of those simulations are not given in the paper, and the reason may that the selection of parameters and division of rock stratum are inappropriate.

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