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Numerical Simulation of the Effect of Protection Layer Mining on the Underlying Strata

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Abstract

Protection layer mining is an effective gas control measure, in which a protection layer adjacent to the high outburst risk layer is removed first before mining the latter. The failure of protected underlying coal seam affected by the stoping of upper protection layer is analyzed in this paper. For a particular mine, the physical and mechanical parameters and geological characteristics of the underlying strata beneath the working face of the protection layer are investigated first, before numerical model of the studied area is established with FLAC3D simulation software to simulate the stress and deformation field variation during the stoping of the upper protection layer. The simulation results reveal the onset and stabilization of shear failure and tensile failure as the working face advances in the overlying stratum. The protected coal seam area begins unloading, producing a large number of cracks penetrating into the protection layer, and gas migration through these cracks leads to the increased permeability of coal seam. The pressure relief and permeability enhancement effect on the protected strata by the protection layer is verified, providing a reference for stoping of the protection layer.

Key words: Numerical Simulation, Variation of Stresses, Plastic Deformation, Pressure Relief and Permeability Enhancement.

1. Introduction

The increasing mining intensity and depth of coal mines in China give rise to a series of serious concerns. As the mash gas content and ground stress both increase with burial depth, mines are at higher risk of more devastating outbursts, which are more difficult to prevent and control. Studies on the theory and practice to control outbursts have yielded fruitful results. Among them, the protection layer mining has been widely established and applied in the form of regulations to prevent coal and gas outburst in China and abroad. For instance, Coal Mine Safety Regulation and The Control of Coal and Gas Outburst Regulations both take it as the main method to prevent and control the coal and gas outburst accidents[5,6]. Li Shuqing[1] et al numerically simulated the variation of stress field and deformation field of the protected layer in the mining process of the underlying protection layer to reveal the scope of protection of the mine protection layer in terms of tilt and orientation. Using the RFPA numerical simulation software, Shi Biming [2] et al simulated the influence of seam thickness, the horizontal deformation characteristics as well as the distance between the protection and protected layers on the protection effect. Yang Wei [3] et al analyzed the temporal and spatial evolution characteristics of stress and displacement fields in the mining of protection layer with numerical simulation software. Xiao Tongqiang [4] et al simulated the pressure relief effect of two non-outburst coal seams as the protection layers, and certain characteristics were dawn after analysis and comparison.

2. Plant Overview of the Study on the Working Face of Regional Protection Layer

The upper limit of the working face studied is the wind roadway (elevation -448.0 -560.2m) and the lower limit is the machine roadway (elevation -501.6 - -619.5m); the face length is 2000m, the average tilt width is 200m; the occurrence of coal seam is stable, with thickness ranging between 1m ~3m (average 2.5m). The underlying main coal seam is yet to be stoped. Immediate roof: light gray and gray mudstone with an average thickness of 3.0m. Under the natural state, the unidirectional compressive strength is 10.0~14.0Mpa with an average of 12.0Mpa. Main roof: grey and dark gray fine sandstone with an average thickness of 4.0m. Under natural condition, the unidirectional compressive strength is 46.0Mpa. Immediate floor: gray and dark gray mudstone of 1.0~4.0m with an average of 2.0m. Under natural condition, the unidirectional compressive strength is 14.0Mpa. Main floor: light gray fine sandstone, 0~3.0m thick with an average of 2.0m. Under natural condition, the unidirectional compressive strength is 52.0Mpa. The coal seam strata are shown in Table 1.

Table 1. The stratigraphic column of the coal seam

Accumulated thickness (m)	Seam thickness (m)	Rock type	Lithology description
17.80	4.80	72, 73 coal goaf	
13.00	2.40	Mudstone and coal line	Gray, 1-3 layers of unequal thin coal lines, containing plant fossils and locally siltstone
10.60	4.60	Fine sandstone	Light gray - gray, with more coarse siltstone, and thin layer of mudstone and siltstone, with fine lines and wavy stratification line
6.00	6.00	Fine sandstone Cross layer	Deep gray mudstone- siltstone and grayish fine sandstone show a gentle wavy bedding in lineation and strip, containing plant fossils above the level, and calcite crystals and dark matter filled with local cracks.
	2.16	82 coal	82 coal, black, massive, a small amount of powder, grease luster, half bright, coal thickness of 2-2.8m, average 2.16m.
0.92	0.92	Mudstone	Light gray, dark gray, massive, containing plant fossils, thickness of 0.1-2.5m, average 0.92M
1.62	0.70	83 coal	83 coal, black, massive, powder, grease luster, half bright, coal thickness of 0.53-0.80m, average 0.70M.

3. Numerical Simulation of Protection Layer Mining

According to the physical and mechanical properties of the site studied, a numerical model is set up in accordance with the actual situation, as shown in Figure 1.

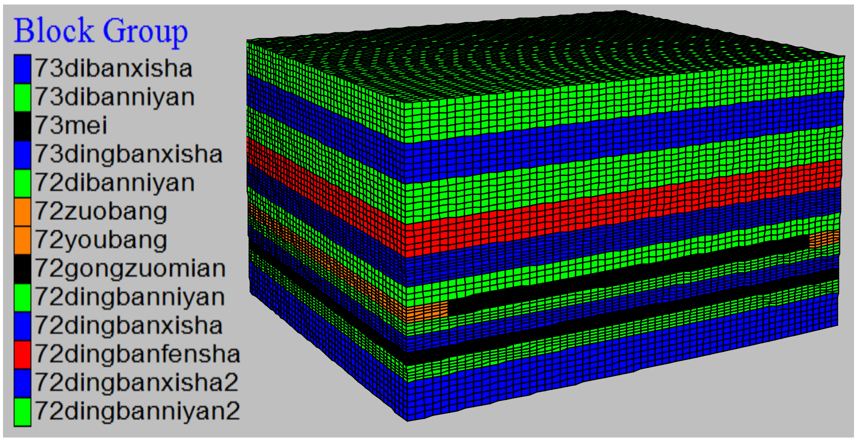

Figure 1. Numerical simulation model.

According to research on the regional structure, the model consists of 12 layers of coal rocks: a protection layer of 72 coal of 2.5m thickness, the immediate roof is 3m thick mudstone, the main roof is 4.5m fine sandstone, the immediate floor is 2m thick mudstone, the main floor is 2.5m thick sandstone; the protected layer is 73 coal with the thickness of 2m, the immediate floor is 2.5m thick mudstone, the main floor is 6m thick sandstone. The mechanical parameters of the coal and rock strata are shown in Table-2.

Table 2. Mechanical parameters of coal and rock strata

Name	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesion (MPa)	Internal friction angle (。)	Tensile strength (MPa)	Density (kg/m3)
Coal	1.199	0.368	2	25	0.03	1400
Mudstone	1.613	1.26	3.5	34	0.8	2100
fine sandstone	2.02	1.709	4.1	33	0.86	2400
Siltstone	5.914	4.622	5	38	1.03	2660

The size of the model is 120m*100m*48m, which is divided into 19200 units. This numerical simulation is based on the elastoplastic constitutive model and the Mohr Kulun yield criterion. The initial vertical stress is applied at the top, the horizontal stress is applied on both sides, and the excavated coal seam is simulated with empty elements. Each time 4m is excavated, and the time step is set to 1000. The width of the working face is set to 100m, with 20m coal pillars. The stoping starts from y= -20m and ends at y=-80m (the simulated stoping length is 60m). In the process of numerical simulation, 72 coal is used as the protection layer, as to investigate the failure condition and stress change of underlying strata in the mining process of protection layer.

4. Analysis of Numerical Simulation Results

When the working face is pushed out, numerous cracks are formed in the floor strata in the process of complex stress change, and the permeability of the rock mass will be significantly improved. The released gas in the protected coal seam will flow along the fracture development area to the working face of the protection layer.

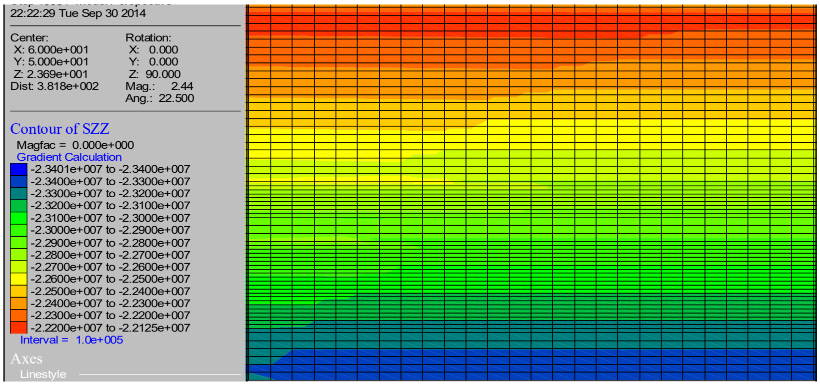

Figure 2. The vertical stress distribution after stress initialization of mode.

4.1 Vertical Stress Change of Underlying Stratal

Figure 3~ Figure 6 are the cloud map of the stress variation in the underlying strata during the protection layer stoping.

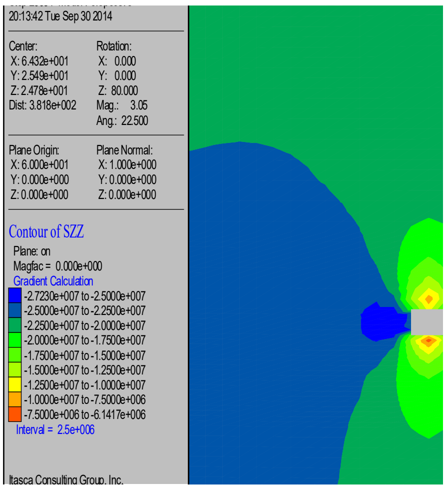

Figure 3. Vertical stress cloud map after 4m excavation.

After the removal of the protection layer, the stress of the floor rock changes. When the working face has just been pushed away, the vertical stress within a close range in the floor plate decreases rapidly. The stress decrease drops gradually, from top to bottom, to the original rock stress. The initial floor strata vertical stress of 23Mpa quickly drops to 7.5-12.5Mpa at the place close to the immediate floor plate after 4m excavation; after 8m excavation, zero vertical stress area is seen in the floor strata. With the advance of working face, the area of vertical stress drop area grows continuously. When at the end the 60m excavation is completed, the stress is reduced to zero in both the floor strata and the protected layer. The pressure relief function of the protection layer mining is quite significant.

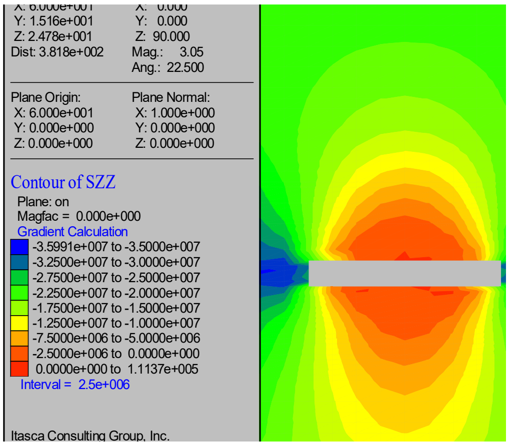

Figure 4. Vertical stress cloud map after 8m excavation.

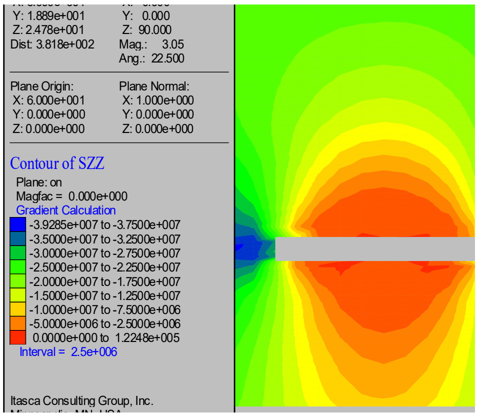

Figure 5. Vertical stress cloud map after 20m excavation.

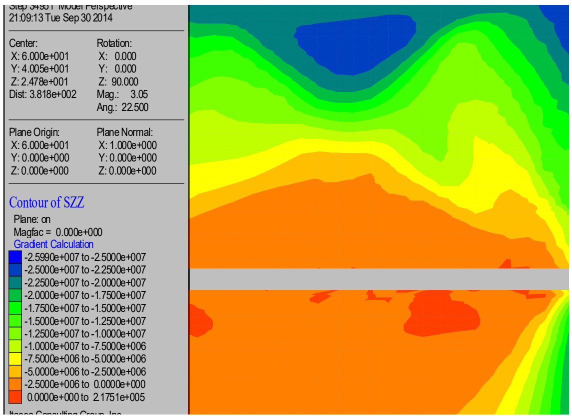

Figure 6. Vertical stress cloud map after 60m excavation.

4.2 The Vertical Displacement of Underlying Strata

After the exploitation of the protection layer, the vertical displacement occurs on the floor strata. In order to study this change, we record the displacement map of the floor rock in the stoping process, as shown in Figure 7~ Figure 10.

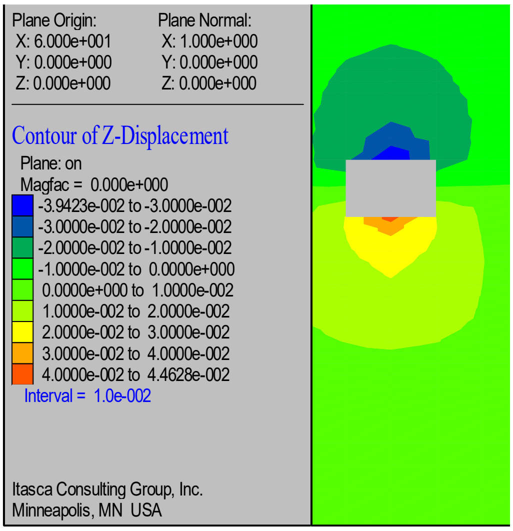

Figure 7. Vertical displacement cloud map after 4m excavation.

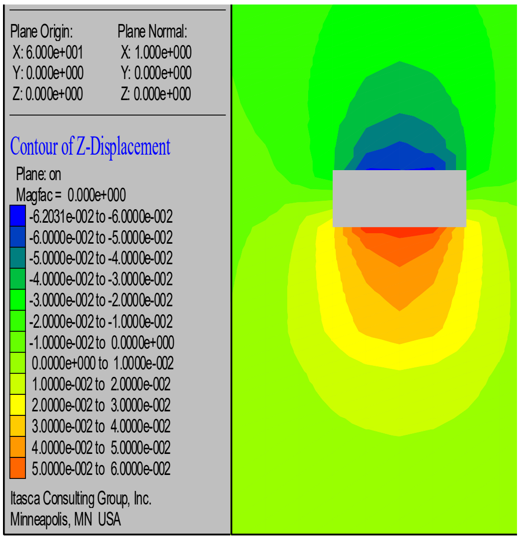

Figure 8. Vertical displacement cloud map after 8m excavation.

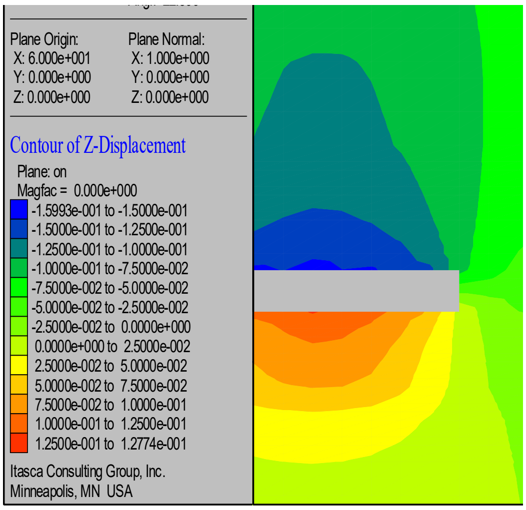

Figure 9. Vertical displacement cloud map after 20m excavation.

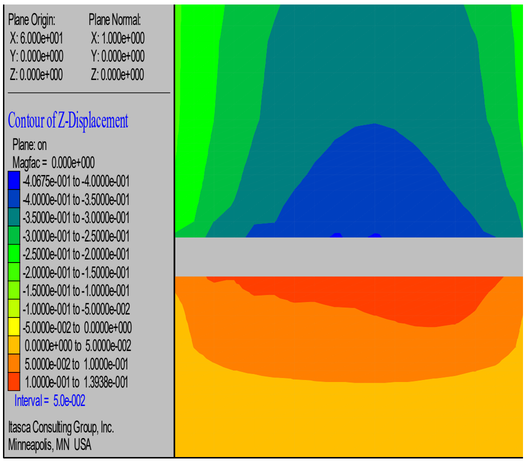

Figure 10. Vertical displacement cloud map after 40m excavation.

At the beginning of working face stoping, the vertical displacement of floor strata declines gradually from top down, which is 2cm at the 73 coal roof. When stoping at 8m, the vertical displacement of floor strata is 4-5cm. The vertical displacement of the floor strata further increases with continued stoping. As free surface appears after the coal seam removal, the floor strata underground stresses moves into the gob space, which is the pressure relief process.

4.3 Plastic Failure of the Underlying Strata

In order to show more clearly the failure of floor strata in the stoping of protection layer, we record the plastic deformation of the floor rock mass during the protection layer stoping, as shown in Figure 11~ Figure 14.

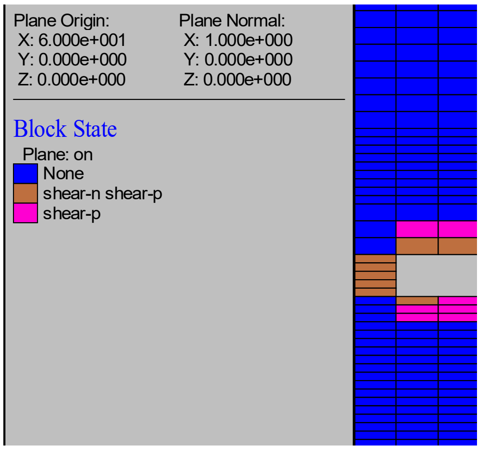

Figure 11. Plastic zone after 4m excavation.

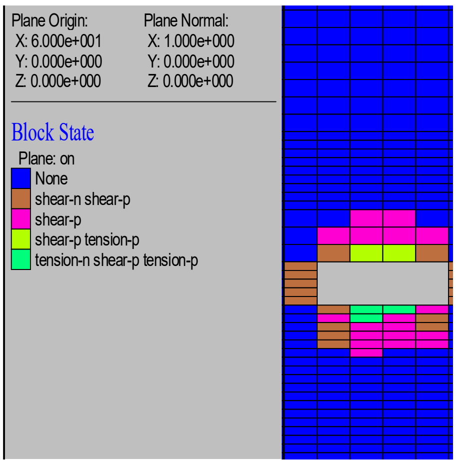

Figure 12. Plastic zone after 8m excavation.

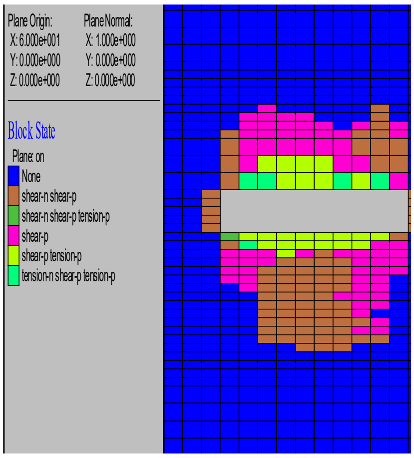

Figure 13. Plastic zone after 20m excavation.

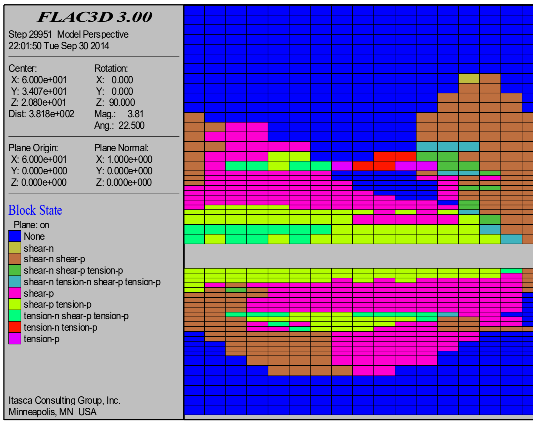

Figure 14. Plastic zone after 40m excavation.

At the beginning of protection layer stoping, shear failure is first seen in the floor strata, with 1.5m plastic zone. When 8m is removed, tensile failure occurs, and the plastic zone grows to 3m. With the continued stoping of the working face, the floor strata is constantly under the action of shear failure and tensile failure, thus a large number of fissures develop to form gas drainage channels, facilitating the gas release from the protected layer to the protection layer. When the working face is completely pushed away, the failure range of the underlying strata is 0-11m, which reaches the coal seam to be protected.

5. Conclusions

(1) The stoping of the protection layer area is a very effective measure to prevent coal and gas outburst, and it is very important for the safety production of coal mine. The removal of the protection layer creates safe working conditions for the mining of the protected layer, and can greatly improve the speed of mining at the protected layer.

(2) During the stoping of the overlying protection layer, the underlying strata go through continuous failure for stress relief, giving rise to swelling deformation in a certain range. As the protection layer stoping carries on, the swelling deformation becomes stable after reaching a certain level. The development of coal fractures within the region and the enhanced permeability of the coal seam have a positive effect on the gas pressure relief and gas drainage.

(3) The numerical simulation on the stress change, displacement change and plastic deformation zone in underlying strata after protection layer removal in a certain mine shows significant stress relief and fracture failure throughout the protected layer, signifying that the protection layer mining is an effective measure for the mine studied.

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