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Numerical Simulation of Mining Stress Characteristics and Ground Pressure Law in Working Face Combining Fully Mechanized Mining with Caving

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Abstract: The mining stress characteristics and ground pressure law in working face combining fully-mechanized mining with caving are important to guarantee the safety production in mines. In this paper, the FLAC3D numerical simulation software is employed to simulate the collaborative mining process of combined fully-mechanized caving and fully-mechanized mining method at the 14022 working face in Zhaogu No.2 mine. The stability of coal rock masses during the mining process and the distribution of vertical stress in 100 meters below the excavation face are analyzed separately. In addition, the Y-axis direction displacement of the coal wall is extracted, and the deformation and movement of the coal mass under the influence of advanced support pressure are studied. Finally, a summary is made of the stress distribution in the collaborative mining working face and potential issues arises during the mining process.

Keywords: Numerical simulation, Mining stress, Coal displacement, Monitoring and forecast.

I. Introduction

The coal resources is rich in China, but it is also severely limited by mining safety and environmental conditions. In response to this, Academician Qian Minggao proposed the efficient mining and green mining method to improve the extraction rate of coal resources[1-3]. At present, there are coal resources in the form of coal pillars left underground in China. Therefore, maximizing the recovery of residual coal resources is crucial for achieving efficient and sustainable development in mining industry[4,5].

The residual coal resources in the inner part of the second mining area of Zhaogu No.2 mine are abundant and of superior quality[6]. If the safe, green, and highly efficient mining can be achieved, it undoubtedly promotes the sustainable development of the mine and meets the urgent demand for high-quality coal resources in the regional economy, thereby advancing the scientific and technological progress of the coal industry. Among the major challenges in controlling mining ground pressure, the roof issue poses a significant problem in coal mining[7]. Especially in the backfilling operation where comprehensive mechanized mining and fully mechanized caving cooperate with each other, the mining pressure at the junction of the comprehensive mechanized caving and fully mechanized mining areas shows significant differences from the conventional comprehensive mechanized caving or the fully mechanized mining working faces. In order to understand and solve the relevant problems in the backfilling process[8], the numerical simulation softwareFLAC3D is employed in the driving process of the 14022 working face, and the constitutive model selected for the model is the Mohr-Coulomb model based on the mechanical characteristics of engineering materials and the applicable range of the constitutive model.

II. Numeric Simulation Design

Based on the actual geological conditions of the mining site, a numerical model is established for the 14022 working face of the Zhaogu No.2 mine, using the strata of the 21# coal seam, the roof and floor layers as a foundation. 20m boundary coal pillar is set at both the horizontal and inclined positions, with a working face width of 170m and a length of 170m in the direction. The model size is thus 210m×210m×76m ($x \times y \times z$).

Based on the burial depth and ground stress tests of the 14022 working face, a simulation of the initial stress field is conducted. Velocity boundary conditions are applied to the bottom and surrounding areas of the model, and the load in the model is adjusted until the vertical stress at the position of the coal seam in the model, which is equal to the vertical stress 15.9 MPa obtained from the borehole stress gauge test. Besides, the horizontal stress is set to 1.25 times the vertical stress, shown in Figure 1.

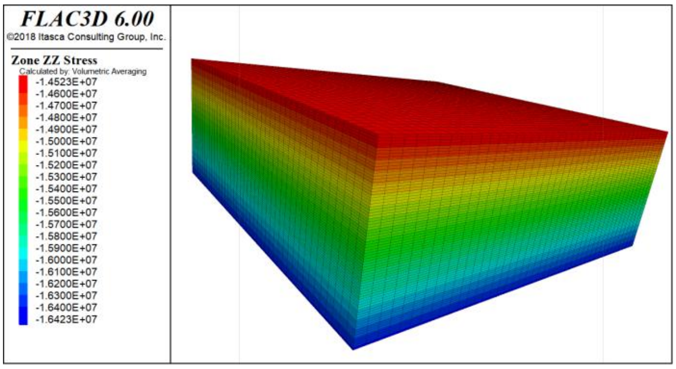
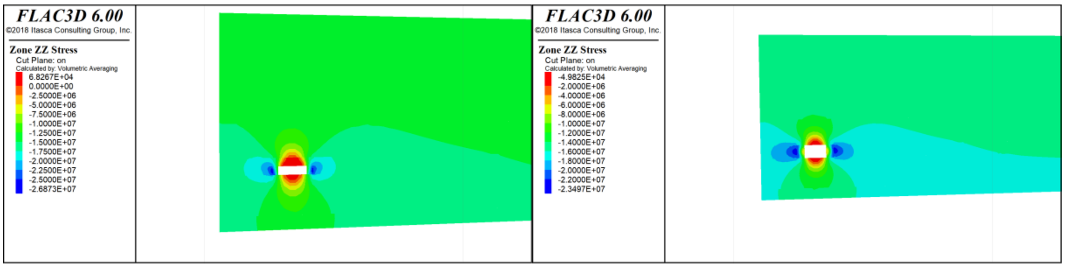


Figure 1 the numerical simulation model

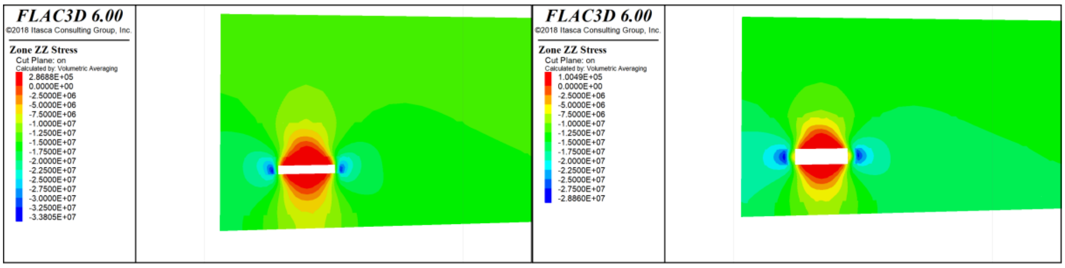
After the initial equilibrium of the model, according to the field situation, 14022 working face is simulated to advance from the starting position of the cut, along the positive Y-axis direction (the direction of the working face), where the starting position of the cut is 20 m along the positive Y-axis direction of the numerical model. The width of the fully-mechanized area is set to 35 meters, and the width of the longwall mining area is set to 135 meters. The excavation process is simulated accordingly. Firstly, the excavation of the bottom coal layer to a depth of 10 meters is calculated to achieve equilibrium, followed by excavation and calculation of the top coal layer to a depth of 10 meters to achieve equilibrium, and this is regarded as a cycle. This process simulates the collaborative mining method of fully-mechanized mining and fully-mechanized caving mining during the advancing process.

III. Analysis of Mining Stress Simulation Process

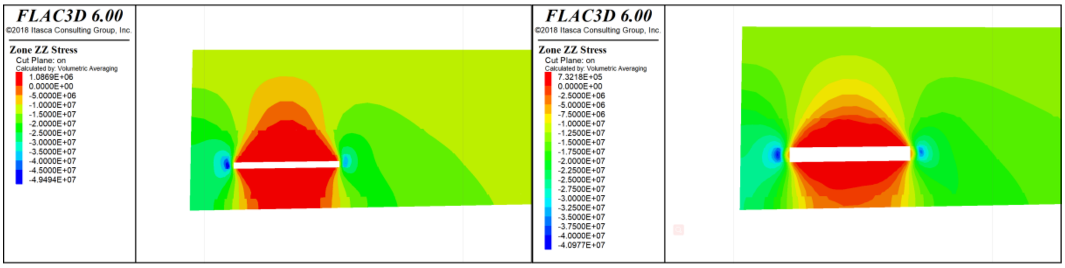
Given the stress variation pattern during the working face recovery process, an indirect reflection of the current state of the coal-rock mass on the working face is demonstrated. Subsequently, the analysis is conducted on how the stability of the coal-rock mass during the recovery process is affected by mining. As the working face advances, the overall stress of the mining area demonstrates dynamic variations. The self-equilibrium of stress gradually transforms into a state of regional pressure concentration and release. The stress variation of the mining area at the working face in advancement of 10m, 20m, 50m, 100m, and 150m is illustrated in the Figure 2.



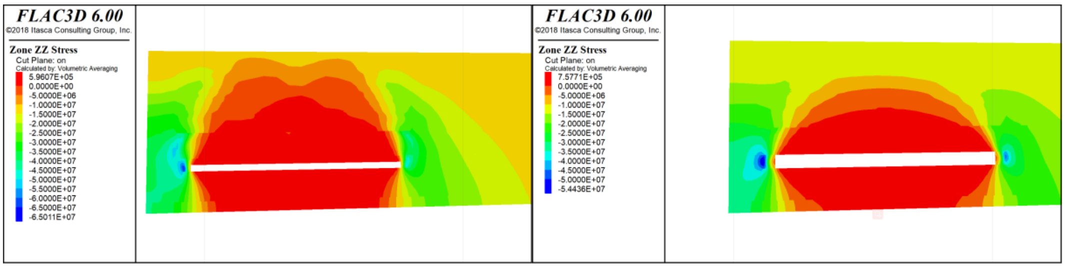
(a) Excavation of 10m (Left: Comprehensive mining area; Right: Comprehensive release area)



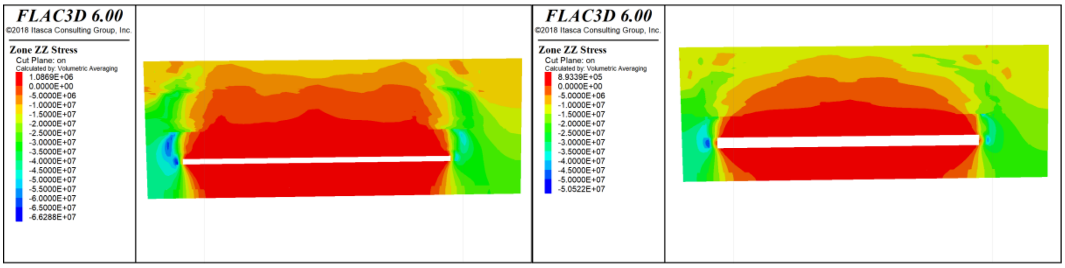
(b) Excavation of 20m (Left: Comprehensive mining area; Right: Comprehensive release area)



(c) Excavation of 50m (Left: Comprehensive mining area; Right: Comprehensive release area)



(d) Excavation of 100m (Left: Comprehensive mining area; Right: Comprehensive release area)



(e) Excavation of 150m (Left: Comprehensive mining area; Right: Comprehensive release area)

Figure 2 Vertical stress map for varying excavation distances in different directions

There are two measurement lines in the numerical model, with one each in the comprehensive release area and comprehensive mining area. The two measurement lines are arranged in the middle of the comprehensive mining area and comprehensive release area, at a height of 1.5m above the coal floor. The stress distribution in the comprehensive mining area is similar to that in the comprehensive excavation area. After the working face is mined, the area in front of the working face is affected by the pressure of advanced support and the maximum vertical stress value increases as the working face advances until the working face reaches the 150m position, where the maximum vertical stress value decreases. During the advance of the working face, the area in front of it is consistently subjected to advanced support pressure. The further away from the coal wall of the working face, the gradually decreasing advanced support pressure eventually returns to the original vertical stress.

According to the vertical stress distribution cloud map of 100 m excavation at the working face, the pressure relief is behind the working face and the front of the working face is affected by the advancing bearing pressure. By comparing the vertical stress distribution of the comprehensive mining and excavation areas at different distances in front of the working face, it is observed that the peak advanced stress position in the two areas is different. Specifically, the peak stress position in the comprehensive mining area is closer to the coal wall of the working face, while in the comprehensive excavation area, it is further away. The vertical stress at this position is shown in Figure 3.

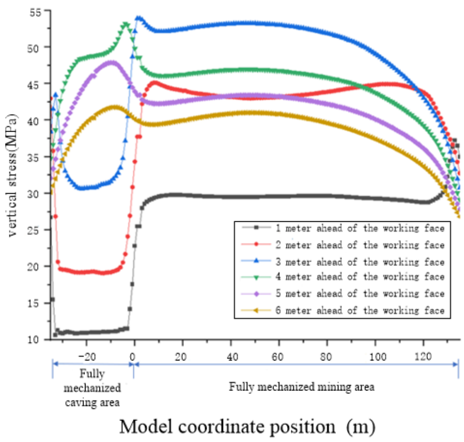


Figure 3 Vertical stress at various distances in front of the working face at 100m.

The Figure 3 shows that the stress reaches the maximum value of 53.9 MPa at 2m in the fully mechanized mining area on the right side of the interface with the fully mechanized caving section as the coordinate zero-point, 3 m in front of the working face. The stress reaches the maximum value of 53.2MPa at 4m in the left fully mechanized mining area of the interface. Based on the distribution of the maximum stress values, it is concluded that the range of 4m in the comprehensive excavation area and the range of 2m in the comprehensive mining area at the joint position are under relatively high advanced support pressure. This area is monitored during the mining process, and timely measures should be taken to prevent coal wall sloughing and support failure. During the mining process of the working face in the initial stage of excavation, the advanced support pressure in the comprehensive mining area is closer to the coal wall, while in the comprehensive excavation area, the effect of advanced support pressure on the crushing of the roof rock releases the stress, resulting in relatively smaller values of advanced support pressure compared to the comprehensive mining area, and the stress is transferred towards the inside of coal wall. As the excavation distance increases, the difference between the peak stress in the comprehensive excavation area and the comprehensive mining area gradually decreases. Moreover, at the 150m position, the peak stress in the comprehensive excavation area has exceeded that in the comprehensive mining area. The rate of stress reduction in the coal pillar area is faster than that in the layered area.

IV. Analysis of Coal Displacement Simulation Process

The Y-axis displacement of coal wall in front of the working face, which refers to the displacement of the coal wall towards the working face direction, is shown in Figure 4.

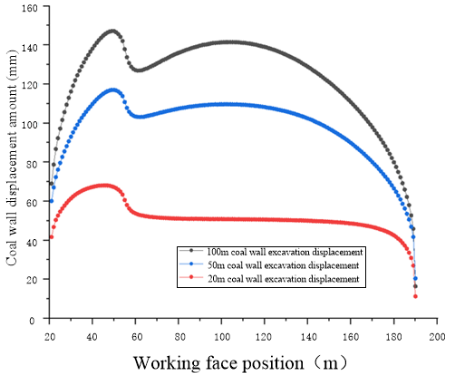


Figure 4.Displacement of coal wall position in front of working face

As shown in Figure 4, the initial deformation and movement of coal body are mainly due to the effect of advanced supporting pressure, which causes compressive deformation and shear failure of the coal seam. The coal body begins to show a slight horizontal displacement at this time. As the working face advances, the coal body gradually undergoes a transition from the tri-axial stress state to the bi-axial or uni-axial stress state. Due to the rapid reduction of horizontal pressure, the coal body experiences a continuous increase in horizontal displacement towards the gob. Consequently, the coal body gradually transforms from a state of compression to one of tension. At macroscopic level, a large number of tensile fissures begin to appear inside the coal body, which eventually propagate into cracks. In the presence of external disturbances, it is easy for coal wall spalling to occur. As the advancing of the mining face, the displacement of the coal wall in the front of the face is continuously increasing. Due to the adoption of two different mining methods in the cooperating mining faces, there are changes in the displacement of coal wall at the joint position. The displacement of the working face increases continuously from the head to the tail. In the fully mechanized caving mining method, the displacement in the comprehensive mining and the comprehensive backfilling areas increases rapidly, but decreases slightly at the junction of the two areas. As the working face advances into the comprehensive mining area, the displacement gradually increases in the middle part of this area.

V. Conclusion

(1). During the coal mining process in a coordinated mining face, the stress distribution in the comprehensive mining area and the comprehensive caving area is similar, and a certain range of concentrated stress zone is formed in front of the working face. The existence of the advanced support pressure at the working face increases the degree of fracturing of the coal above the hydraulic support in the comprehensive caving area, which is beneficial for the release of the roof coal.

(2). Under the same excavation distance, the stress peak in the bottom layered area is closer to the coal wall compared to the coal pillar area, the stress decay rate in the coal pillar area is faster than that in the layered area.

(3). During the process of backfilling in the workplace, it is necessary to prevent the occurrence of caving problems on the coal wall side of the workplace. Due to the inconsistent plastic zone states and displacement amounts of two regions in the workplace, the possibility of caving at the joint location of two regions during cooperative mining is extremely high due to different mining methods.

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