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Study on Numerical Simulation of Overburden Failure Height in Stratified Full-Mechanized Caving of Extremely Thick Coal Seam

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Abstract: In order to determine the failure characteristics of overburden rock under the condition of multi-layer fully mechanized caving mining of soft overburden rock in super thick coal seam, the 1101 working face of Jundong No. 2 Coal mine is taken as the object, the key layer theory and numerical calculation are used to analyze the failure height of overburden rock in the process of regional stratified fully mechanized caving mining, and the relationship between the mining thickness and the failure height of overburden rock is determined. The research shows that the overburden failure height is linearly positive correlated with the mined thickness under the condition of hard overburden in the huge thick coal seam of Jundong No. 2 mining area, and the overburden failure height is 5.3 times of the mined thickness. Failure height of overburden in No. 2 ore in Jundong is much lower than that of common hard overburden.

Keywords: Ultra Thick Seam; Stratified Fully Mechanized Caving Mining; Overburden Failure Height; Numerical Simulation.

1. Introduction

After coal seam mining, overlying rock movement and destruction will be caused, which has an important impact on mine pressure appearance, surrounding rock stability and mine water control. The mining space of very thick coal seam is large, and the disturbance to overlying strata is more intense than that of ordinary coal seam [1, 2, 3].

A large number of scholars have conducted in-depth research on the law of overburden failure. Based on the traditional "three zones" theory, Gao Yan method [4] puts forward a "four zones" model of rock displacement, which can be divided into fracture zone, separation zone, bending zone and loose alluvial zone according to the overburden failure pattern. Qian Minggao et al. [5, 6] put forward the "key layer" theory, pointing out that the key layer is the key to the overall movement of overlying rock, and proposed a method to judge the location of the key layer of overlying rock, revealing the two-stage development law of mining fracture of overlying rock in longwall working face and the distribution characteristics of "O" ring. Xu Jialin [7, 8] proposed a new method to predict the development height of water-conducting fracture zones based on the location of key layers in overlying rock, which can adapt to the prediction of the height of water-conducting fracture zones under different mining thickness conditions, and can distinguish the height anomalies of water-conducting fracture zones caused by structural changes of key layers in overlying rock. Yu Xueyi, Mu Chi et al. [9] applied the physical simulation method and numerical calculation simulation method to the mine under the special geological mining conditions of "three thick, two hard and one strong", and proved that the layered coordinated mining of the working face effectively reduced the development height of the water-conducting fracture zone in overburden rock. Yang Daming et al. [10] proposed the concept of "height adjustment coefficient of water-conducting fracture zone" on the basis of empirical formula calculation, numerical simulation and measured data. Liu Yingfeng et al. [11] used the borehole TV system and the borehole simple hydrologic observation method to investigate the development height of the water-guide fracture zone in fully mechanized caving of extremely thick deep coal seam.

As the calculation method of overburden failure in Mining Regulations for Coal Pillar Maintenance and Compression in Buildings, Water Bodies, Railways and Main Shafts is applicable to single-layer mining thickness of 1~3m, and the cumulative mining thickness of layered mining is no more than 15m, there are certain limitations to the analysis of overburden failure law in mining extremely thick coal seam. For this reason, the author takes the 1101 working face of No. 2 Coal Mine in Jundong, Xinjiang Uygur Autonomous Region as the background. Theoretical analysis method and numerical simulation method are used to study the overburden migration and evolution law of stratified fully mechanized caving mining of super thick coal seam, and the relationship between the mined thickness of super thick coal seam and the overburden failure height is determined, which provides basic parameters for the safe and efficient production of No. 2 coal mine in Jundong and provides references for the overburden failure law under similar conditions.

2. Engineering Geological Survey

The research area is located 140km north of Qitai County, Xinjiang Uygur Autonomous Region, with an altitude of 549 ~ 840m, a relative elevation difference of 291m and an average topographic slope of 2°. B1 coal seam, the main mining seam in the region, can be mined with a thickness of 30.30 ~ 70.57m, an average mining thickness of about 56m, containing 0 ~ 5 layers of dirt, which is a stable and recoverable thick coal seam. The length of the working face is 240m, and the mining depth is about 600m. The southern part of the working face is the main lane of the first layer in the east wing of the 11 panel area, the northern part is the 51 panel area of the second zone, the western part is the western boundary of the 11 panel area, and the eastern part is the protective coal pillar of the 01 and 03 working face of the first layer of the 11 panel area. The roof type of the working face is "weak-hard" type, and there is no thick hard roof within 30m height. The main structure form of the roof rock is thin layer and fragment, and the structural plane such as bedding and joint is relatively developed, and the content of mud is high.

3. Theoretical Analysis of Overburden Failure Height

3.1. Related Theory of Overburden Failure Height Calculation

For the hard rock layer, the mechanical model of fixed beam is used to estimate its limit span [12],

$$l_G = h\sqrt{\frac{2\sigma_t}{q}} \tag{1}$$

Where: h is the thickness of the rock layer; σ_t is the ultimate tensile strength of rock layer; q is the load on the rock layer.

For weak rock formations, the limit span [13] at maximum horizontal tensile strain is

$$l_R = h\sqrt{\frac{8E\varepsilon_{max}}{3q}} \tag{2}$$

Where: E is the elastic modulus of rock formation; ε_{max} is the maximum horizontal tensile strain of rock strata.

The maximum deflection of the soft rock formation [14] is

$$w_{max} = \frac{5ql^4}{384EI} \tag{3}$$

Where: I is the moment of inertia of the section.

The height of the free space under the rock layer is

$$\Delta_i = M - \sum_{j=1}^{i-1} h_j(k_j - 1) \tag{4}$$

Where: Δ_i is the height of free space under layer i; M is the mining height of coal seam; h_j is the thickness of the J-layer; k_j Is the residual dilatation coefficient of the J-layer rock.

The critical mining length at the time of fracture is

$$L = \sum_{i=1}^{m} h_i \cot\phi_q + l + \sum_{i=1}^{m} h_i \cot\phi_h \tag{5}$$

Where: m is the number of all rock strata from the top of coal seam to the lower part of the rock layer; h_i is the thickness of layer i; l is the limit fault span of the rock formation; φ_q,φ_h respectively are the front and rear fracture angles of rock strata.

The development of fault zone is influenced by the tensile strength of key layer, the strain resistance of soft rock layer, the free space height of lower rock layer and the advancing distance of working surface. The development of fault zone can be judged by the relationship between the fracture of key layer and soft rock and the height of free space below.

3.2. Theoretical Calculation of Overburden Failure Height

The presence of predominantly hard rock in the overlying strata renders consideration of weak rock unnecessary when calculating the failure height. Utilizing formulas (1)~(5), the advancement of the working face to different positions can be used to determine the development of overburden failure based on key layer determination results (Table 3-1). As indicated in Table 3-1, at advancements of 98.2m and 201.3m, subcritical layers I and II fracture, leading to subsequent fractures in the controlled rock strata above them. The fault zone develops to heights of 46.8m and 80.7m respectively. Upon reaching an advancement of 497.5m, fractures in key layer III extend to the bottom of the main key layer, resulting in a fracture zone developing at a height of 156.9m. Continuing advancement reveals that due to a dip overhanging distance within limits, the fault zone extends into lower parts of the main key layer.

Table 1. The first failure of each key layer with the advance of the working face

Advancing distance of the working face /m	Overburden failure height /m	The first breach of the key layer
100	47	Subcritical Layer I
200	82	Subcritical Layer II
1000	158	Subcritical Layer III

From the above theoretical analysis, it can be seen that when the fracture develops to the lower part of the main key layer, the fracture stops developing upward because the main key layer does not meet its fracture conditions. Each sub-key layer controls the development of local overburden rock fractures, while the main key layer controls the development of all rock fractures.

4. Numerical Simulation Analysis of Overburden Failure Law

In order to study the migration law of overburden rock in layered mining of super thick coal seam in No. 2 Jundong Mine, FLAC3D numerical simulation software was used to simulate and Mohr-Coulomb model was used to analyze the developmental stage characteristics of overburden failure height during coal seam excavation, and the influence law of overburden failure height in layered mining of super thick coal seam was revealed.

4.1. Model Design and Simulation Scheme

Based on the geological and mining conditions of the 1101 working face of Jundong No. 2 Mine, the design model size is 1300m×540m×600m (length × width × height), the design buried depth of coal seam is 600m, the mining height is 56m, and the strike length is 1000m. The excavation is divided into three layers, and the first layer working face is excavated step by step along the strike direction. The designed excavation step distance is 50m, and the excavation method of the second and third layer working face is the same as that of the first layer. The size of the model element is set reasonably according to the thickness and properties of overlying rock of 1101 working face. In order to eliminate the boundary effect of the model and better reveal the failure characteristics of the overlying rock, 150m protective coal pillar is set in both the strike and dip directions. The basic simulation three-dimensional model is shown in Figure 1, and the mechanical parameters of the overlying rock are shown in Table 2.

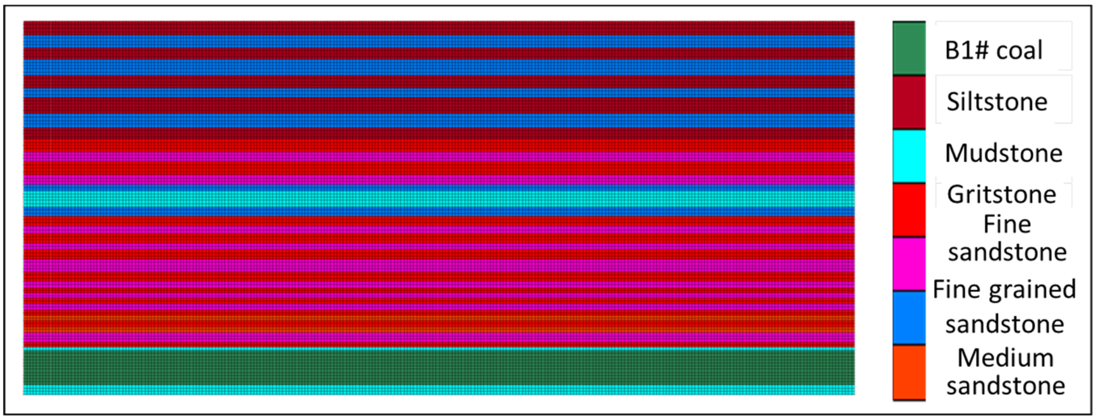

Figure 1. 1101 working face basic calculation model diagram

Table 2. Basic parameters of overlying rock

Lithology	Bulk modulus/GPa	Shear modulus/GPa	Cohesion/MPa	Internal friction Angle/°	Tensile strength/MPa
Siltstone	4.23	3.12	2.63	30	2.36
Fine sandstone	5.47	4.01	3.24	31	2.85
Medium sandstone	6.68	5.21	4.41	33	3.74
Gritstone	8.17	7.36	5.9	35	5.1
Mudstone	2.2	1.96	1.23	26	1.56
B1# coal	1.4	1.35	1.16	20	1.24
Fine grained sandstone	4.11	3.05	2.51	30	2.17

4.2. Analysis of Numerical Simulation Results

The figure below illustrates the failure patterns of overlying rock at different advancing distances in the first layer of working face 1101. When the working face advances to 100m, a "trapezoid" shaped strike and dip plastic zone is formed with a narrow upper and wide lower, resulting in an overlying rock failure height of 47m. As the working face advances to 200m, the inclined plastic zone takes on a "trapezoid" shape with a narrow upper and wide lower, and its center of gravity slightly shifts towards the cutting hole, leading to an overburden failure height of 82m. Upon completion of mining (1000m), the dip plastic zone approximates an "arch" shape with a narrow top and wide bottom, while the strike plastic zone forms an "arch" shape with its center of gravity shifting towards the cutting hole. The overlying rock failure height measures at 159m. Numerical simulation results validate that the fracture height of overburden in the first layer of working face 1101 is approximately 159m, consistent with theoretical calculations.

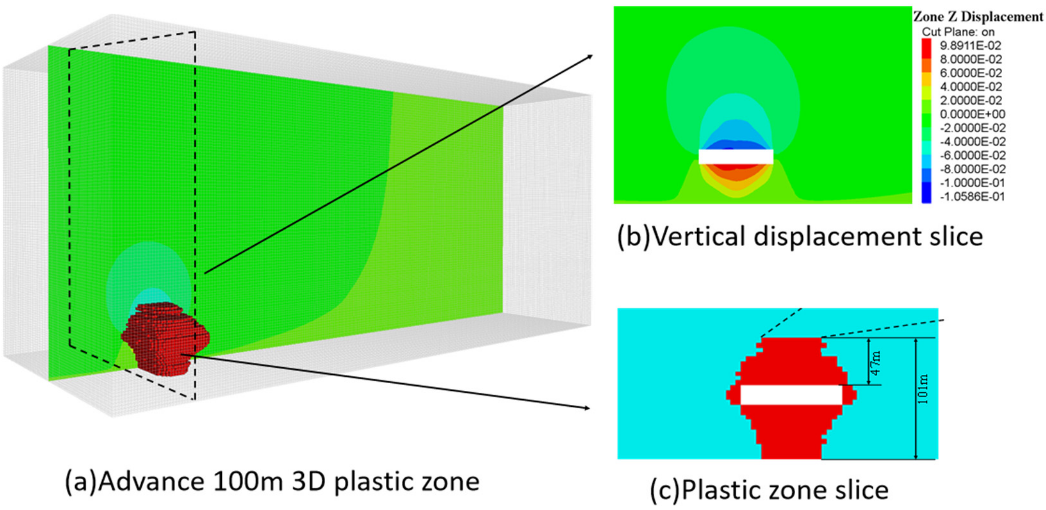

Figure 2. The working face advances 100m

After the end of mining, the overburden failure height of 1101 was about 159m; after the end of mining in the second layer, the overburden failure height increased to 213m; after the end of mining in the third layer, the overburden failure height increased to 297m; cracks still developed to the upper part of the key layer, and no obvious settlement occurred on the surface.

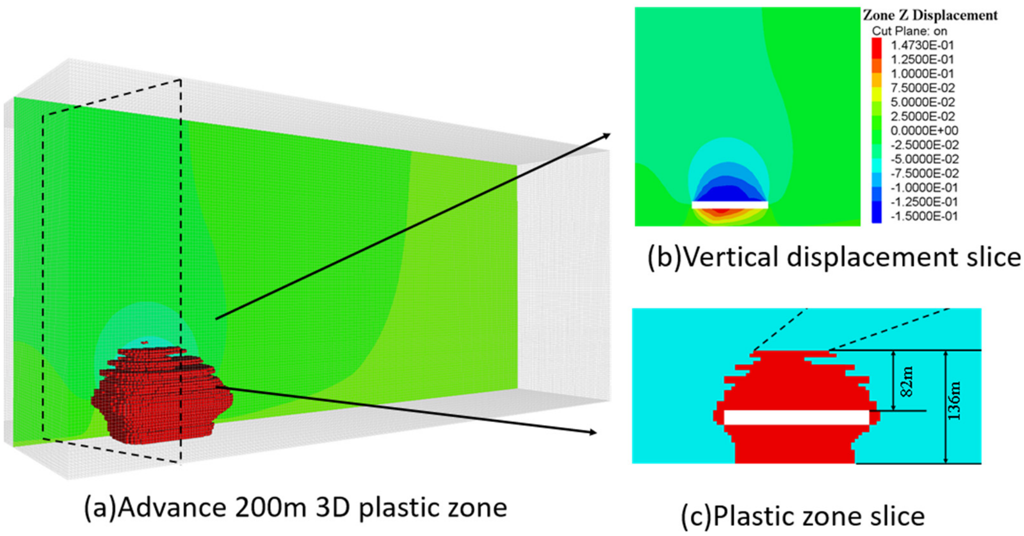

Figure 3. The working face advances 200m

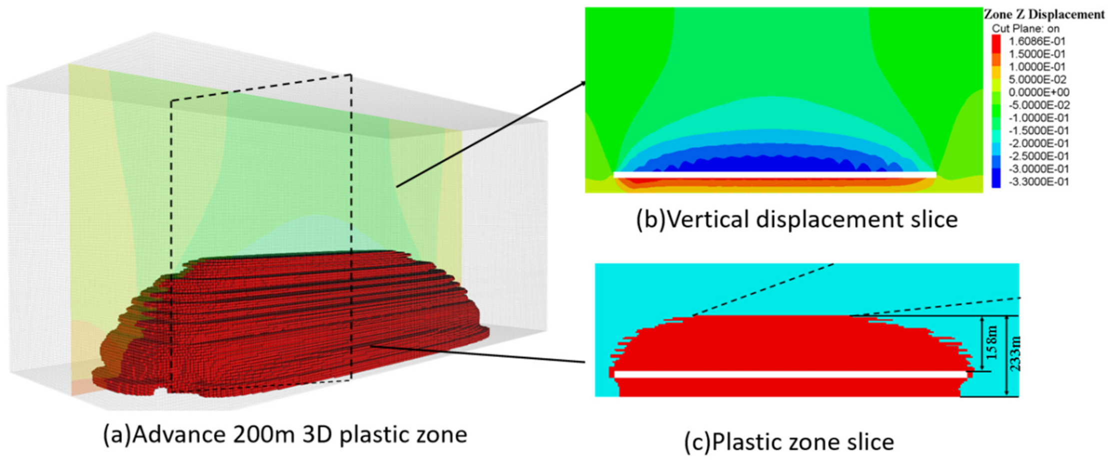

Figure 4. The working face advances 1000m

According to the comprehensive statistics of the overburden failure results of B1 coal seam mining in three layers in Jundong No. 2 Mine, it is determined that the fissure mining ratio is 5.30, that is, the overburden failure height of Jundong No. 2 Mine is about 5.30 times the mining thickness.

5. Conclusion

Based on the key layer theory and numerical simulation method, it is determined that the overburden failure height of the first layer is 158m, that of the second layer is 213m, and that of the third layer is 297m. The ratio of overburden failure height to mining thickness is 5.30. Failure height of overburden in No. 2 ore in Jundong is much lower than that of common hard overburden.

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