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Numerical Simulation Study on the Development Characteristics of the "Two Zones" in the Overlying Strata of the 13050 Working Face in Yunding Coal Industry

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ABSTRACT

To accurately grasp the failure pattern of the overlying strata under the conditions of top-coal caving mining in the thick coal seam of the 13050 working face at Yunding Coal Industry, a systematic study was conducted on the development height and distribution characteristics of the "three zones" (caved zone, water-conducting fracture zone) in the overlying strata. This study was based on the geological and mining conditions of the working face and utilized a combination of theoretical calculations, downhole borehole television measurements, and 3DEC numerical simulation. The results show that the theoretical calculation yielded a caved zone height of 10.48–14.88 m and a water-conducting fracture zone height of 39.77–58.83 m. The field measurements indicated a caved zone height of 12.93–20.21 m and a water-conducting fracture zone height of 38.79–60.63 m. The numerical simulation showed a maximum water-conducting fracture zone height of approximately 43.9 m. The results from the three methods exhibit a high degree of agreement. Consequently, the caved zone height for this working face is determined to be 13–16 m, and the water-conducting fracture zone height is determined to be 40–44 m. This can provide a reliable basis for roof control, the design of waterproof coal/rock pillars, and safe mining operations at the working face.

KEYWORDS

Overlying strata failure; Numerical simulation; Overlying strata movement; Distribution characteristics.

1. INTRODUCTION

The mining of coal seams leads to the movement and failure of the overlying strata. Based on the degree of rock failure, the affected zones can be roughly divided into three distinct mining-influenced zones: the caved zone, the water-conducting fracture zone, and the bending subsidence zone. Since the bending subsidence zone primarily involves surface movement and rock displacement laws, which fall under the scope of mining subsidence studies, it is not the focus of analysis in this paper. Hereafter, the caved zone and the water-conducting fracture zone are collectively referred to as the "two zones"[1].

For working faces in thick and extremely thick coal seams, the development height of the "two zones" in the overlying strata is greater, the extent of failure is larger, and the spatial distribution is more complex compared to conventional mining conditions in medium-thick coal seams. To address this, numerous domestic and international scholars have conducted extensive research on the height distribution, spatiotemporal evolution patterns, and control techniques of the "two zones" in the overlying strata of working faces under thick seam mining conditions. This has led to the establishment of a comprehensive research framework based on theoretical analysis, field measurements, physical simulation, and numerical simulation.

Among these, theoretical analysis relies on national and industry standards, employing empirical formulas, theoretical models, and statistical fitting methods to calculate and classify the height of the "two zones" under different lithological conditions, mining thicknesses, and mining scenarios [2-5]. Field measurement is the most direct and reliable method for obtaining the height of the "two zones." Common techniques include borehole televisual inspection, water injection loss method, resistivity method, and acoustic logging. While these methods offer high accuracy, they are often associated with challenges such as difficult underground construction, complex procedures, long cycles, and high costs [6-8].

Simulation studies are primarily divided into two categories: physical simulation with similar materials and numerical simulation [9-10]. Numerical simulation, leveraging advantages such as repeatability, visualization, and adjustable parameters, is widely applied in mining engineering. Commonly used software includes UDEC, 3DEC, FLAC3D, and COMSOL, which enable the dynamic representation of overlying strata failure processes, stress evolution, displacement fields, and fracture development characteristics [11-15].

Based on existing research on the development patterns of the "two zones," this paper takes the 13050 working face of Yunding Coal Industry Co., Ltd. in Xin'an County, owned by the Yima Coal Group, as the engineering background. Considering the technical conditions of thick coal seams, fully mechanized top-coal caving mining, and the use of the complete caving method for roof management at this working face, a combined research approach employing downhole borehole televisual field measurements and 3DEC numerical simulation is adopted. This study systematically measures and analyzes the development height, distribution range, and failure characteristics of the "two zones" in the overlying strata of the working face. Ultimately, the key parameters of the "two zones" are determined, providing reliable data support and a theoretical basis for the safe roof management of the 13050 working face and the safe, efficient production of the mine at Yunding Coal Industry.

2. OVERVIEW OF THE WORKING FACE

The 13050 working face at Yunding Coal Industry is the first mining face in the 13th mining district of the 2_1 coal seam. The surface elevation ranges from +399 m to +448 m, while the floor elevation of the working face ranges from -118 m to -156 m. The coal seam burial depth is between 530 m and 585 m, with an average of 560 m. The working face exhibits a monoclinal structure, with a stratum strike of 51° to 61°, a dip direction of 141° to 151°, and a dip angle of 7° to 11°, averaging 8°. The coal seam thickness varies from 1.2 m to 10.4 m, with an average of 5.96 m, classifying it as a stable thick coal seam. The immediate roof primarily consists of Dazhan sandstone, the main roof is composed of Xiangtan sandstone, and the overlying strata are medium-hard rock layers. The floor consists of sandy mudstone and silt-fine sandstone. The working face employs a retreating longwall mining method along the strike, utilizing fully mechanized top-coal caving technology, with roof management by the complete caving method. Although mining has not yet commenced, the surrounding rock stress and stratum stability have already been affected by mining-induced disturbances from the adjacent 12th mining district. To accurately understand the failure patterns of the overlying strata, prevent risks of water inrush and roof collapse, and ensure safe mining operations, a systematic study on the height distribution of the "two zones" in the overlying strata of this working face is essential.

3. MODEL ESTABLISHMENT

Based on the lithological column data from borehole Y506 near the 13050 working face, a three-dimensional numerical model was established. Considering the actual dimensions and mining conditions of the working face, the model's strike length was set to 400 m, with a vertical height of 200 m. The simulation involves mining 150 m along the strike of the working face to ensure a fully mined state. To eliminate boundary effects, 20 m extensions were added on both sides of the model along the strike. The thickness of the coal seam roof in the model is approximately 170 m, consisting of 37 rock layers. The lithology of each layer was accurately assigned according to the borehole data. The thickness of the 2_1 coal seam was set to 6 m according to actual conditions. The physical and mechanical parameters of each rock layer were assigned based on laboratory tests and geological reports, as detailed in Table 1.

Table 1. Mechanical parameters of overlying strata

Lithology	Density/ $kg\cdot m^{-3}$	Elastic Modulus/GPa	Bulk Modulus/GPa	Shear Modulus/GPa	Tensile Strength/MPa
Siltstone	2460	19.50	10.83	8.13	1.81
Mudstone	2470	8.75	6.08	3.47	0.61
Sandy mudstone	2500	5.43	2.56	2.36	0.75
Fine-grained sandstone	2830	33.40	21.01	13.52	1.29
Medium-grained sandstone	2510	5.99	3.30	2.43	1.20
Coarse-grained sandstone	2780	7.16	4.40	2.87	1.50
Limestone	2780	10.69	2.57	4.53	6.70
coal	1310	5.30	4.91	2.01	0.15

Horizontal and bottom boundaries of the model were fixed, while equivalent self-weight stress from the overlying strata was applied to the top. The Mohr-Coulomb constitutive model and the joint Coulomb slip model were adopted to accurately reflect the failure characteristics of the in-situ rock mass.

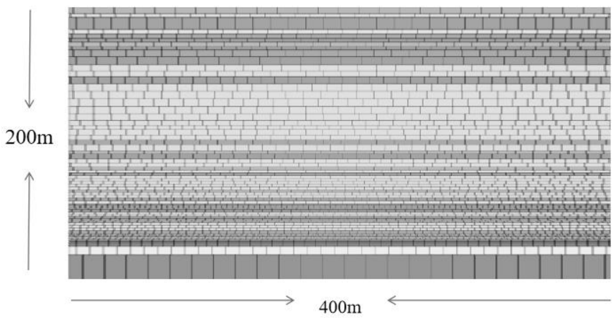


Figure 1. Numerical Simulationl

4. STUDY ON THE MOVEMENT PATTERNS OF OVERLYING STRATA IN WORKING FACE

4.1. Evolution Patterns of Displacement Field in Overlying Strata

The evolution characteristics of overlying strata displacement are illustrated in Figures 2 and 3. As the working face continues to advance, the peak displacement exhibits a clear stage-wise growth. This trend not only reflects the progressive accumulation of mining-induced disturbances but also reveals the underlying mechanical process of the overlying strata transitioning from elastic bending to fracture-induced instability.

When the coal seam advances to 40 m, displacement is primarily concentrated near the open-off cut side. During this stage, the mining-affected area is limited, and the roof predominantly undergoes integral bending and subsidence, with no significant fracture network yet formed within the rock layers. As a result, the displacement magnitude remains relatively small. By 60 m of advancement, although the increase is still not pronounced, an initial enhancement in the response of the overlying strata to mining-induced disturbances becomes evident.

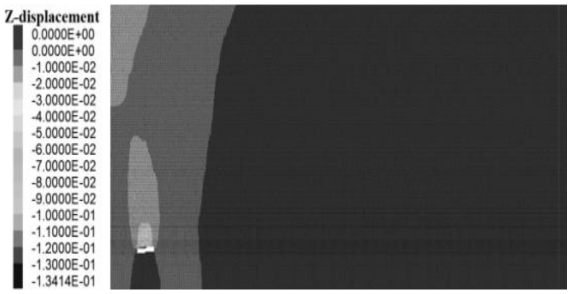


Figure 2. Displacement field at 20m advance

Figure 3. Displacement field at 40m advance

A significant turning point occurs after advancing 80 m, as shown in Figure 4, where the stress state of the roof structure undergoes a transformation. Based on field observation experience under similar lithological conditions in coal mines of western Henan Province, it can be inferred that at this stage, fractures begin to propagate or even cause local breakage in strata such as the roof siltstone layers, weakening the structural integrity and directly leading to a noticeable amplification of displacement.

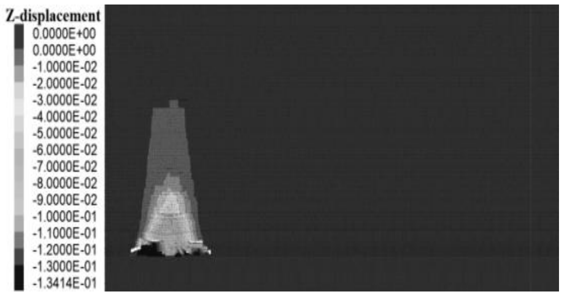


Figure 4. Displacement field at 80m advance

When advancing to 100 m and 140 m, as depicted in Figures 5 and 6, the peak displacement increases at a significantly accelerated rate, indicating a deepening extent of overlying strata failure. The squeezing and stress-transfer effects between the overlying and underlying rock masses are progressively intensifying.

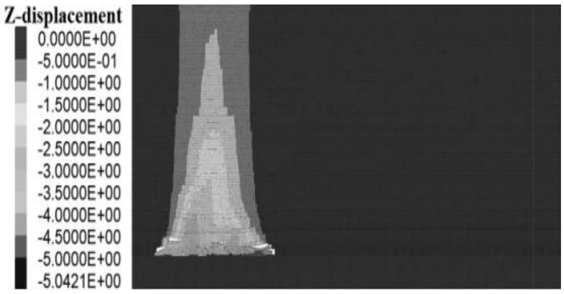


Figure 5. Displacement field at 100m advance

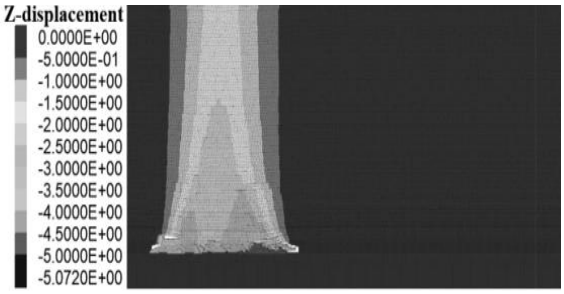


Figure 6. Displacement field at 140m advance

4.2. Evolution Patterns of Stress Field in Overlying Strata

As the coal seam is gradually mined, the original stress equilibrium is disrupted, and the surrounding rock begins to undergo complex stress redistribution. The spatial pattern and numerical changes of this process clearly reveal the cumulative effects and stage-wise characteristics of mining-induced disturbances in the simulation results.

When the working face advances 20 m, as shown in Figure 7, the mining-affected area is still small, and stress adjustment is mainly confined to both sides of the coal pillars. Significant stress concentration is evident at the edges of the coal pillars, while the stress field in the displacement domain exhibits a fan-shaped distribution in the roof strata above the coal seam. At this stage, the roof is still in the initial bending phase, stress release is limited, and the overall structure maintains relatively high continuity.

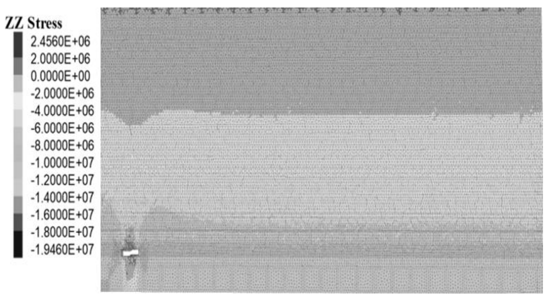


Figure 7. Stress field at 20m advance

As the advance distance increases to 60 m, as shown in Figures 8, the degree of stress concentration gradually intensifies. During this stage, although the stress increase is relatively steady, the concentrated area expands significantly. The rock mass above the goaf gradually loses its load-bearing capacity, and the load progressively shifts toward the coal pillars on both sides and the coal body ahead.

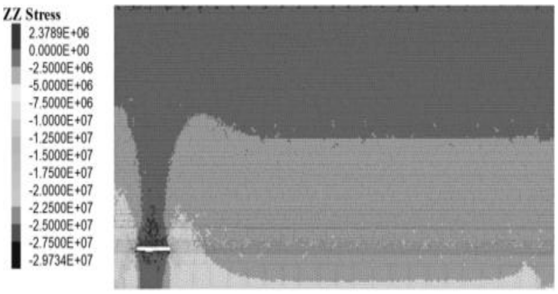


Figure 8. Stress field at 60m advance

At the 100 m advance stage, as shown in Figure 9, the magnitude of stress increase becomes more evident. The growth in compressive stress begins to accelerate, a change often closely associated with the fracture and collapse of the immediate roof layers, which form a new load-bearing structure. During the compaction of fragmented rock mass, the overlying strata exert stronger compressive forces on the lower structure, leading to a significant increase in local compressive stress within the roof. Concurrently, the vertical stress above the working face and the goaf continues to rise, and the extent affected by tensile failure keeps expanding. The rock layers behind the open-off cut and near the working face, subjected to greater compressive stress from the overlying rock mass, bear the weight of the overlying strata, thereby forming a supporting stress zone. The overall stress distribution pattern roughly takes on an "M" shape. Meanwhile, the range of tensile stress influence at the bottom of the goaf continues to extend downward.

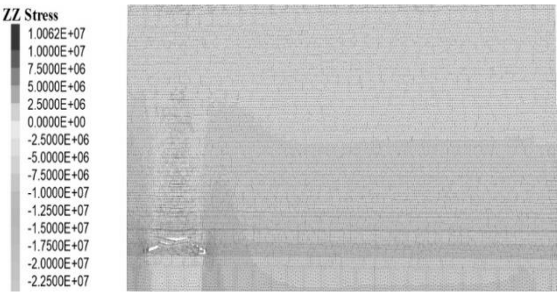


Figure 9. Stress field at 100m advance

When excavation reaches 150 m, as shown in Figure 10, the peak stress shows a declining trend. At this stage, the high-stress zone shifts from being predominantly tensile to compressive, and the surrounding rock gradually enters a phase of compaction and rebalancing. The goaf within the range of 50 to 80 meters from the open-off cut progressively undergoes compaction. During this process, the roof of the coal seam assumes the primary load-bearing role, and the stress on the sub-key layer continues to increase accordingly. The rock mass is gradually compacted, and the tensile stress acting on the roof of the lower coal seam during mining gradually transforms into compressive stress, with this compressive stress showing a continuous upward trend. Once the working face has advanced completely, a central compaction zone forms within the range of 60 to 100 meters from the open-off cut. This compaction zone extends and connects to the main key layer.

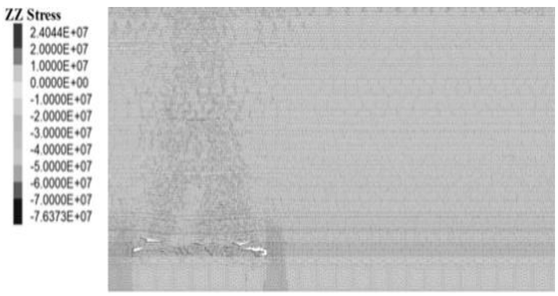
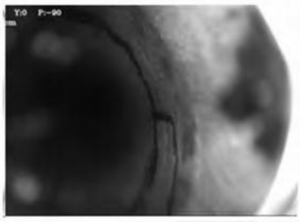


Figure 10. Stress field at 150m advance

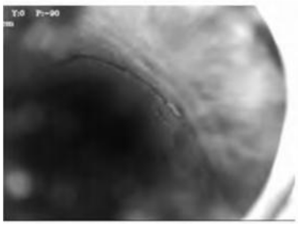
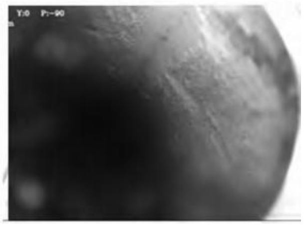
5. ANALYSIS OF FIELD MEASUREMENT RESULTS

By conducting downhole borehole televisual inspection of Observation Borehole #1 located 50 m from the stopping line in the haulage roadway of the 13050 working face, the development of mining-induced fractures, rock mass fragmentation, and bedding separation characteristics in the overlying strata were obtained. Based on this, the height and distribution range of the "two zones" in the overlying strata were determined.

Figures (a)-(d) show the fracture information of the mining-induced overlying strata at different locations during the upward drilling process of Borehole #1. It is clearly evident that in Figures (a)-(b), the rock strata maintain relatively good integrity, with no noticeable mining-induced fractures observed. However, at a depth of 8.26 meters from the coal seam roof, distinct mining-induced fractures appear in the rock strata, and they become more pronounced as the drilling depth increases. At this point, the manifestation of ground pressure begins to be evident. Based on the condition of the mining-induced overlying strata within the drilling depth range of 13.77–37.5 meters, as shown in Figures (c)-(d), it can be observed that mining-induced fractures in the overlying strata of this area develop upward from the coal seam roof, and the degree of fracture development decreases as the distance increases. This negative correlation is a key basis for determining the development height of the water-conducting fracture zone and evaluating roof stability. The height of Figure (b) from the coal seam is approximately 13.77 meters, which is consistent with the theoretical calculated height of the caved zone for the 13050 working face.

(a) (b)

(c) (d)

Figure 11. the fracture information of the mining-induced overlying strata at different locations during the upward drilling process of Borehole #1

6. CONCLUSIONS

(1) The overlying strata of the 13050 working face at Yunding Coal Industry are medium-hard rock layers. Under the conditions of large mining height and top-coal caving, the height of the caved zone is 13–16 m, and the height of the water-conducting fracture zone is 40–44 m.

(2) The results obtained from the two research methods are essentially consistent and fall within a reasonable range. This indicates that the numerical simulation method can effectively reflect the distribution range of the "three zones" in the overlying strata of the working face. The numerical simulation results can provide reliable data support for the safe and efficient mining of the working face.

(3) The findings can be directly applied to roof management, the design of waterproof coal/rock pillars, and safe mining operations, and have reference value for similar mining conditions.

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