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Overburden Failure and "Three-Zone" Development Patterns at the 13050 Working Face in Yunding Coal Mine

Jie Chen

Ecological Environment Technology Co., Ltd, China Coal Technology and Engineering Group, Beijing 100013, China

Abstract: Taking the 13050 working face of Yunding Coal Mine as the engineering background, and addressing the practical issue that this working face, although not yet extracted, is subjected to disturbance from adjacent mining panels, with the overlying strata facing the risk of fracture and instability, this study systematically investigates the development characteristics and evolution patterns of the caved zone and water-conducting fracture zone in the mining-induced overburden through a combined approach of numerical simulation and field measurement. A two-dimensional model with a strike length of 800 m and a height of 400 m was established using the 3DEC discrete element numerical simulation software to simulate the stepwise excavation process of the working face, reproducing the complete evolutionary sequence of overburden failure from immediate roof caving and bed separation propagation to final stabilization. The simulation results indicate that the ultimate height of the caved zone ranges from approximately 13.7 to 15.8 m, while the height of the water-conducting fracture zone ranges from approximately 35.3 to 38.1 m. To verify the reliability of the simulation results, boreholes were arranged outside the stopping line of the tailgate, and borehole televiewer technology was employed to scan the fracture conditions of the rock mass. The vertical boundaries of the caved and fractured zones identified through field measurements align closely with the numerical simulation outputs. The study demonstrates that the conclusions derived from numerical simulation and field measurement mutually corroborate each other, proving that the numerical model can accurately characterize the spatial morphology of the overburden "three zones" under mining disturbance. The research findings provide a reliable geological basis for roof management, waterproof coal pillar design, and water hazard prevention during the subsequent safe extraction of this working face, and also offer reference for mining operations in similar geological conditions.

Keywords: Overburden Failure; Water-conducting Fracture Zone; Caved Zone; Numerical Simulation.

1. Introduction

After coal seam extraction, the overlying strata above the goaf undergo deformation, fracturing, and even collapse under the effects of gravity and in-situ stress, forming from bottom to top the caved zone, the fractured zone, and the continuous bending zone, which are collectively referred to in the industry as the "three zones" [1], wherein the caved zone and the fractured zone are also designated as the water-conducting fracture zone. Accurate determination of the development height of the "three zones" constitutes a critical basis for evaluating roof water hazard risks, designing waterproof coal pillars, and ensuring safe extraction. Extensive research on overburden failure laws has been conducted by both domestic and international scholars. Qian Minggao developed the "voussoir beam" structural model, which characterizes the compression and hinging relationships among fractured rock blocks as a load-bearing framework [2, 3]. Building on this, the "key stratum" theory subsequently demonstrated that overburden deformation and fracturing are primarily controlled by one or several thick, competent rock layers. Around the same period, Liu Tianquan established the "three horizontal zones and three vertical zones" classification system for mining-induced overburden, providing a clear geological framework for predicting the extent of failure [4, 5]. These foundational contributions not only established the disciplinary basis but also enabled a shift from empirical estimation to mechanism-based interpretation.

In recent years, the integration of multiple detection and simulation techniques has advanced overburden failure research into a phase of three-dimensional validation. Numerical simulation platforms such as UDEC and FLAC3D, for example, can reproduce the stepwise upward propagation of fractures [6, 9]; microseismic monitoring captures elastic waves generated by rock fracturing to delineate the spatial configuration of the water-conducting zone in real time; and distributed optical fibers installed in boreholes continuously record strain and temperature changes, from which the locations of bed separation and fracture development can be inferred [10, 14]. These methods complement one another and collectively improve the interpretive accuracy concerning "two-zone" development patterns. Previous studies have identified the primary controls on overburden "three-zone" distribution as including lithology and compositional structure of the overlying strata, mining height, panel dimensions, and coal seam dip angle [15, 18].

This investigation focuses on the 13050 working face at Yunding Coal Mine, integrating 3DEC discrete element numerical simulation with borehole televiewer field measurements to systematically characterize the overburden "three-zone" development and the evolution of overburden failure. The findings are intended to provide both a theoretical foundation and an engineering reference for mining operations under comparable geological conditions.

2. Engineering Geological Overview

The strata from the coal seam roof upward are mainly composed of mudstone, sandy mudstone, siltstone, and fine-grained sandstone, with an overall medium-hard rock classification. The immediate roof is mudstone about 2.5 m

thick, the basic roof is sandy mudstone and siltstone interbedded with a total thickness of about 20.3 m; the details are shown in Table 1.

At present, the 13050 working face has not yet been extracted; however, due to the overburden movement induced by mining disturbances in the No. 12 mining area, the stress field within the overlying strata has been redistributed, posing a potential risk of fracture and instability. In response to this phenomenon, it is necessary to ascertain the development height of the overburden "three zones" in this working face, so as to ensure the subsequent safe extraction of the panel.

3. Model Establishment

Based on the borehole column of Y506 adjacent to the 13050 working face, a numerical model was established. The model is 800 m in length and 400 m in height, covering approximately 340 m of strata above the coal seam roof, with a total of 37 rock layers divided. The thickness of the No. 2_1 coal seam is taken as 5.3 m. The mechanical parameters of each rock layer are presented in Table 1. To ensure full extraction in the strike direction, the model is designed to be excavated sequentially from left to right, with each excavation step of 5 m, and the model is computed to equilibrium after each step until the completion of the entire excavation. To prevent boundary effects from influencing the calculation results, an outward extension of 40 m is applied along the strike direction of the working face.

Table 1. Mechanical parameters of overburden strata

Lithology	Density kg·m-3	Elastic modulus GPa	Tensile strength MPa	Bulk modulus GPa	Internal friction angle °	Cohesion MPa
Fine-grained sandstone	2850	33.40	1.29	21.01	42	3.20
Sandy mudstone	2510	5.43	0.75	2.36	36	2.16
Siltstone	2450	19.50	1.81	10.83	38	2.75
Medium-grained sandstone	2550	5.99	1.20	3.30	37	3.60
Mudstone	2460	8.75	0.61	6.08	30	1.20
Coarse-grained sandstone	2800	7.16	1.50	4.40	32	0.21
Coal seam	1320	5.30	0.15	4.91	32	1.23
Limestone	2800	10.69	6.70	2.57	38	11.40

The spatial constraint scheme of the numerical model is as follows: the four lateral boundaries of the model are fully fixed in the horizontal direction, while the bottom boundary is fixed in both horizontal and vertical directions to ensure that no displacement occurs at the model base. Given that the overburden thickness above the model top is approximately 200 m, the vertical stress from the self-weight of the overlying strata is estimated at about 5.5 MPa; a load of this magnitude is therefore applied to the top boundary to replicate the in-situ stress field. The Mohr–Coulomb criterion is adopted to describe the failure behavior of the rock mass, while the mechanical response of discontinuities is represented using the zone-contact elastoplastic model based on the Coulomb slip failure framework. These settings integrate formation constraints, gravitational loading, and material nonlinearity. The resulting numerical model is presented in Figure 1.

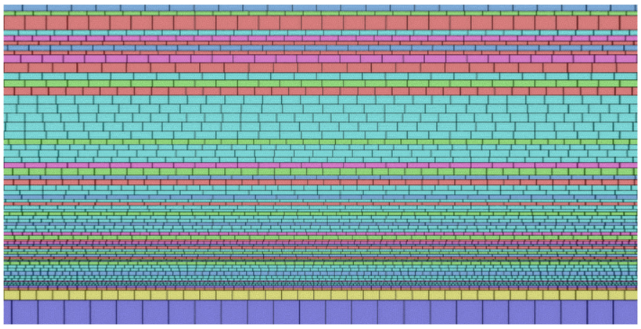


Figure 1. Numerical model

4. Study on the Movement Laws of Overburden Strata above the Working Face

4.1. Failure Laws of Overlying Strata

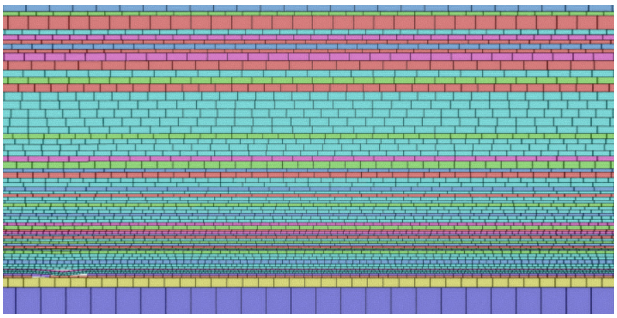
The relationship between overburden failure characteristics and the advancing distance of the working face is shown in Figure 2.

Figure 2 depicts the full progression of overburden failure as the working face advances. At an advance distance of 75 m, the immediate roof lost its support and collapsed completely, filling the goaf floor and forming the caved zone with a maximum height of about 13.7–15.2 m. At this stage, the caved zone had not yet reached its full development, and failure remained largely confined to the immediate roof.

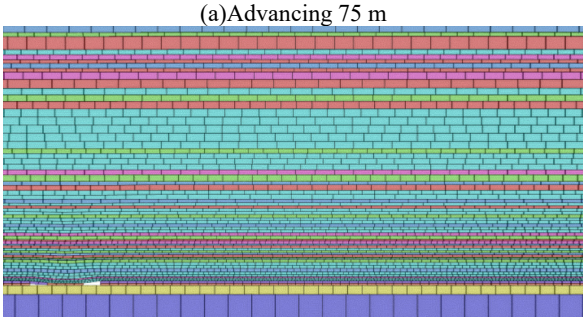
As the working face continued to advance to 100 m, the height of the caved zone did not show a significant increase. A pronounced bed separation was observed in the stratum located 35.3 m above the roof, marking the upward limit reached by the water-conducting fracture zone at this stage.

When the advancing distance reached 125 m, the overburden failure height no longer showed a significant increase, indicating that the mining disturbance had become fully developed. At this point, the maximum height of the caved zone stabilized at approximately 15.8 m, while the top bed separation position of the fractured zone further rose to 38.1 m above the roof, indicating that the ultimate development height of the fractured zone was approximately 38.1 m. During the subsequent continuous advancement of the working face, this height remained essentially unchanged,

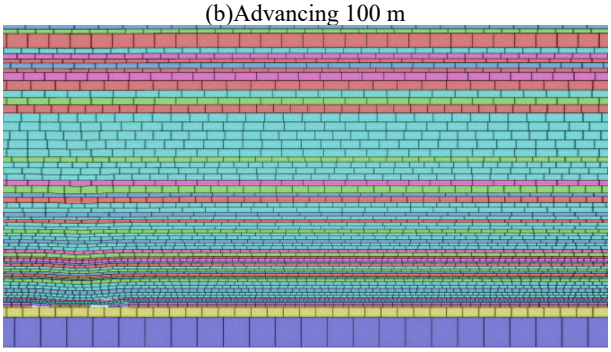
indicating that the three-zone pattern of overburden failure had become well established.



(a)Advancing 75 m



(b)Advancing 100 m



(c)Advancing 125 m

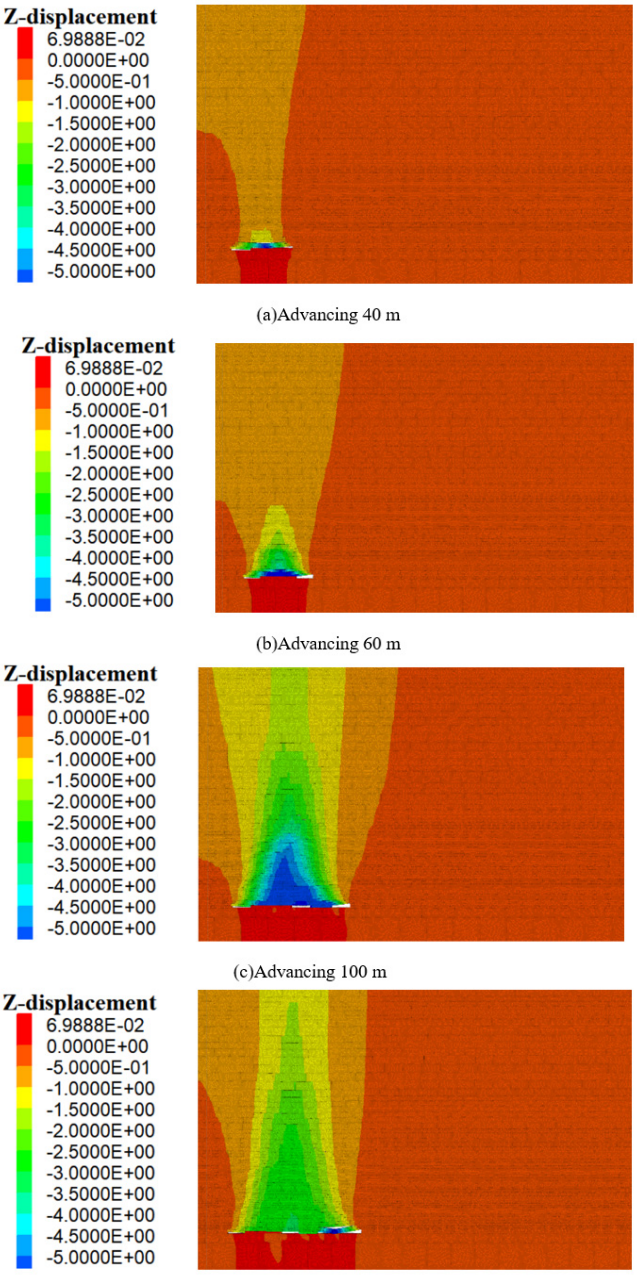
Figure 2. Overburden failure characteristics

4.2. Evolution Laws of the Overburden Displacement Field

Figure 3 presents the evolution of overburden displacement. As the working face advances, the peak displacement values show a distinct stepwise increase, reflecting the progressive accumulation of mining-induced disturbance and the transition of overburden structure toward failure instability.

At an advance distance of 40 m, displacement was primarily concentrated near the open-off cut side. The mining influence at this stage remained spatially confined, with the roof undergoing overall bending and subsidence and no distinct fracture network having developed within the rock mass; accordingly, the displacement magnitudes were relatively modest. By the time the face had advanced to 60 m, although the increase remained moderate, it already suggested that the overburden response to mining disturbance was intensifying.

At an advance distance of 100 m, the rate of increase in peak vertical displacement accelerated noticeably. This trend indicates that overburden failure was progressively propagating upward, while the compressive load transmitted from the overlying strata to the lower layers was also intensifying concurrently.



(a)Advancing 40 m

(b)Advancing 60 m

(c)Advancing 100 m

(d)Advancing 140 m

Figure 3. Displacement nephogram

At an advance distance of 140 m, the peak displacement value decreased slightly, suggesting that the overburden had largely completed its primary failure process. The rock mass within the mining-affected zone was progressively transitioning from a phase of intense deformation toward compaction and stress redistribution.

5. Field Measurement Analysis

To precisely determine the overburden "three-zone" development height at the 13050 working face, Borehole No. 1 was positioned 50 m outside the tailgate stopping line, and borehole televiewer technology was used to scan the fracture condition of the rock mass. The imaging results are presented in Figures a–d below.

Figures 4(a) through 4(d) sequentially present the fracture distribution across the depth interval from 1.58 m to 35.8 m above the roof. The borehole televiewer images provide a clear delineation of the vertical zonation of overburden failure. Within the range of 0–1.58 m, mining-induced fractures can

be observed around the borehole wall, indicating that this section of strata was also affected by mining disturbance, with its integrity being damaged to a certain extent. However, the aperture and density of fractures in this range are both lower than those in the core area of the caved zone, reflecting a certain vertical differentiation in the failure degree of lower overlying strata—the closer to the roof surface, the denser the fractures, with a gradual attenuation downward.

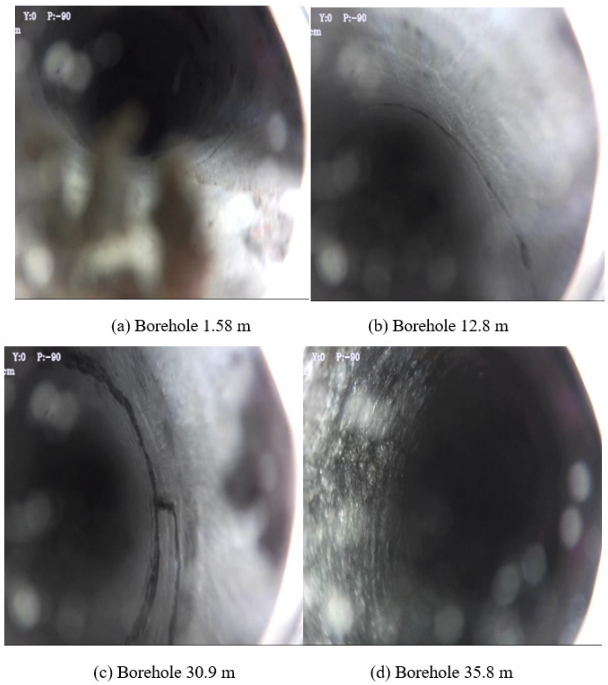


Figure 4. Borehole televiewer images

In the range of 1.58–12.8 m above the coal seam roof, the borehole wall rock mass is severely fragmented, with fractures densely interconnected and mostly chaotically distributed, conforming to the basic characteristics of the caved zone. In the interval of 12.8–30.9 m, the fractures are predominantly open fractures and bed separations with clear bedding planes, indicating that this section belongs to the fractured zone. Beyond 35.8 m in depth, the borehole wall tends to be smooth, with only occasional fine closed fractures visible, and the overall integrity of the strata remains good, which can be classified as intact rock zone above the water-conducting fracture zone. This measured classification not only corroborates the numerical simulation results but also provides an intuitive geological basis for roof management and water hazard prevention during subsequent mining operations.

6. Conclusion

(1) Through numerical simulation calculations, the ultimate development height of the caved zone in the overburden of the 13050 working face is 13.7–15.8 m, and the development height of the water-conducting fracture zone ranges from 35.3 to 38.1 m. A comparative analysis between the simulation results and the field measurement data obtained underground shows good agreement between the two, demonstrating that the numerical model constructed in this study has high reliability, and the calculation results can serve as a valid basis for subsequent analysis of overburden evolution laws.

(2)From the research results, the heights obtained from numerical simulation calculations and field measurements are in strong agreement. The mutual corroboration of results from multiple approaches confirms, on the one hand, that the numerical model can accurately characterize the spatial development morphology of the overburden "three zones" under mining disturbance, and on the other hand, that the simulation data obtained can provide sufficient data reference for the safe and efficient extraction of the 13050 working face.

References

[1] Qian, M. G., Shi, P. W., & Xu, J. L. (2010). *Mine pressure and strata control*. China University of Mining and Technology Press.

[2] Qian, M. G., Miao, X. X., & Xu, J. L. (1996). Theoretical study on key stratum in strata control. *Journal of China Coal Society*, (3), 2–7.

[3] Qian, M. G., Mao, X. B., & Miao, X. X. (1998). Variation of loads on key strata in overburden of longwall face. *Journal of China Coal Society*, (2), 25–29.

[4] Liu, T. Q. (1986). Safe mining near unconsolidated strata under thick unconsolidated aquifer. *Coal Science and Technology*, (2), 14–18, 63.

[5] Liu, T. Q. (1995). Current status and prospects of mining technology under buildings, water bodies, railways, and above goafs. *Coal Science and Technology*, (1), 5–7, 62.

[6] Ma, Q. H. (2005). Study on "O"-shaped spatial structure of overburden in longwall face and related mine pressure [Doctoral dissertation]. Shandong University of Science and Technology.

[7] Ren, Q. (2007). Numerical simulation and sensitivity analysis of overburden deformation and failure laws in longwall face [Master's thesis]. Shandong University of Science and Technology.

[8] Zhou, H. S. (2008). Detection technology research on "three zones" development in fully mechanized mining area under reservoir in Daping Coal Mine [Master's thesis]. Northeastern University.

[9] Ma, S. J. (2012). Numerical simulation study on overburden failure induced by coal seam mining. *Safety in Coal Mines*, 43(12), 54–56.

[10] Chai, J., Wang, J. Q., Yang, J. F., et al. (2024). Application research on FBG monitoring of segment coal pillar deformation. *Coal Science and Technology*, 52(1), 126–137.

[11] Jiao, L. (2025). Real-time monitoring and stability analysis of mine roadway deformation based on optical fiber sensing technology. *Industry and Mine Automation*, 51(S2), 146–150.

[12] Wang, Y., Yu, S., & Wang, S. J., et al. (2018). Application of microseismic monitoring technology in early warning of coal mine floor water inrush. *Coal Science and Technology*, 46(8), 68–73.

[13] Wang, Y., Yu, S., & Wang, S. J. (2019). Construction and analysis of microseismic monitoring and early warning system for coal mine floor water inrush. *Safety in Coal Mines*, 50(5), 190–193.

[14] Liu, S. D., Yang, C., Zhang, J., et al. (2024). Coupled monitoring technology of mine microseismic and electrical method. *Journal of China Coal Society*, 49(1), 586–600.

[15] Li, Q. S., Li, X. B., Xu, J. L., et al. (2022). Research progress on evolution laws of mining-induced fractures in strata and ecological governance technology. *Coal Science and Technology*, 50(1), 28–47.

[16] Yang, X. J., Kang, X. H., He, M. C., et al. (2026). Development characteristics and prediction methods of the "three zones" in

overlying strata under the 110 mining method. *Rock Mechanics Bulletin*, 5(1), 100234. https://doi.org/10.1016/ j.rockmb. 2026. 100234.

[17] Jia, B. X., Chen, H., Yang, C. F., et al. (2022). Simulation experiment study on the activity law of deep overburden with large mining. *Arabian Journal of Geosciences*, 15(6), 12517. https://doi.org/10.1007/s12517-022-10517-9.

[18] Yang, H. W., & Qing, Z. L. (2020). Research on the height of overlying strata "three zones" in deep coal mining. *IOP Conference Series: Earth and Environmental Science*, 565(1), 012024. https://doi.org/10.1088/1755-1315/565/1/012024.