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Study on Similarity Simulation Test of Overburden Movement Law in Fully Mechanized Mining Face

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Abstract: The overburden structure in the mining of steeply inclined coal seams is a complex, dynamic, and nonlinear spatial problem, influenced by multiple factors such as the coal seam dip angle and geological structure. This paper focuses on the large-scale overlying strata structure of steeply inclined coal seam stopes as the research subject. Utilizing the similar material simulation method, the study investigates the patterns of overburden migration. The findings reveal that the working face experiences both major and minor pressure cycles, with the initial roof pressure being less intense. As the working face advances, the bedrock layer initially undergoes separation before collapsing again. The height of the collapsed layer and the separation layer does not exhibit a linear relationship with the advancement distance of the working face; instead, it follows a step-like ascending curve. These results provide a valuable foundation for field measurement studies and the design of data analysis methods.

Keywords: Coal mine safety; Fully mechanized mining face; Overlying rock movement; Similarity simulation.

1. Introduction

As the main energy in China, the safe and efficient mining of coal is very important for the national economy and social development [1]. As the main mining method of modern mine, fully mechanized working face has a direct impact on mine safety production and surface ecological environment due to overlying rock movement and ground pressure behavior caused in the mining process [2]. Therefore, in-depth study on the movement law of overburden rock in fully mechanized mining face has important theoretical significance and practical value for guiding mine pressure control, preventing roof accidents, and protecting surface buildings and ecological environment. As an intuitive and effective research method, similarity simulation test can simulate complex geological conditions and mining process, reproduce the whole process of overlying rock deformation and failure, and provide an important basis for revealing the law of overlying rock movement [3-6]. Qiu Yuming et al. [7] took the 1102 working face of Zuoquan Fusheng coal industry as the background, and used similar simulation test to study the movement law of overlying rock, roof structure and distribution characteristics of advance abutment pressure during mining. The results show that: during the weighting period of the working face, the roof overburden presents an obvious "inclined step" structure, the roof caving height is maintained at 60~65 m, and the peak abutment pressure is about 20 m away from the coal wall of the working face. Liu Hongtao et al. [8] took the 160206 working face of Yangchangwan Coal Mine as the engineering background, and used the comprehensive research methods of similar simulation test, numerical simulation and theoretical analysis to systematically study the fracture process and movement law of overlying rock in the fully mechanized top coal caving face with large mining height. Hou Jianjun et al. [9] took the 11210 working face of Zhaojiazhai coal mine as the engineering background, and used the physical similarity simulation experiment method to study the evolution characteristics of mining induced fractures in the overlying strata caused by the superimposed mining of coal seams, and found that during the superimposed mining of coal seams, a large stress concentration was formed outside the pressure relief area, and the stress concentration phenomenon was not obvious within the pressure relief protection range. The superimposed mining of coal seams caused the superimposed pressure relief of the overlying strata in the stope, which made the displacement field of the overlying strata superimposed and changed, and the maximum subsidence of the strata further increased; After the superposition mining of coal seams, the middle part of the overlying strata in the goaf is compacted, and the fractures at both ends are relatively developed, forming a certain range of fracture development areas. Kang Zhipeng et al. [10] took the 15028 working face of Xinjing coal mine as the engineering background, and conducted an experimental study on the overburden fracture and stress migration law of the large mining height working face in the "Three Soft" thick coal seam through the physical similarity simulation experiment. Therefore, this paper aims to study the law of overburden movement in fully mechanized mining face through similar simulation test, and provide theoretical support for coal mine safety production and ecological environment protection.

2. Similar Model Design and Production

The experiment is conducted based on the fully mechanized mining face of the B8 coal seam in Xiaogou Mine, Nanshan Coal Mine. According to mine data and field investigations, the working face has a strike length of 950 m, a tendency length ranging from 114 m to 136 m, and a cutting length of 114 m. The thickness of the coal seam varies generally between 2.23 m and 4.79 m, with an average thickness of 4.2 m and a coefficient of variation of 45%. The coal seam is characterized by a strike direction of 320°, a tendency of 69°, and a dip angle ranging from 38° to 42°. The coal seam structure is relatively stable, providing favorable conditions for the study.

For this similar material simulation experiment, a test bench with dimensions of 5 m (length) × 2 m (width) × 0.4 m (height) and an effective height of 1.8 m was utilized. Based on the actual mining conditions of Nanshan Coal Mine, combined with the dimensions of the similar simulation test bench and relevant data, the similarity constants for the experiment were comprehensively determined. This setup ensures that the simulation accurately reflects the geological and mining conditions, enabling a detailed investigation into the overburden movement and failure mechanisms associated with the mining process.

A 50 cm boundary is set on the model, and 20 dial gauge points are arranged on its surface to observe surface displacement. The spacing between the measuring points ranges from 20 cm to 40 cm. The observed displacements include 35.8 cm for the bottom argillaceous siltstone layer, 83.2 cm for the bottom coarse sandstone layer, 111.7 cm for the middle argillaceous siltstone layer, and 141.6 cm for the upper argillaceous siltstone layer. Additionally, 24 displacement measuring points are arranged along each measuring line, with a spacing of 20 cm between points. The measuring lines are numbered from bottom to top as Measuring Line A, Measuring Line B, Measuring Line C, and Measuring Line D. The measuring points along each line are numbered from left to right as A0, A1, A2, ..., A20; B0, B1, B2, ..., B20; C0, C1, C2, ..., C20; and D0, D1, D2, ..., D20. The arrangement of the dial gauges, measuring lines, and measuring points is illustrated in Fig. 1. This setup ensures comprehensive monitoring of displacement patterns across different strata layers, providing detailed insights into the overburden movement during the mining process.

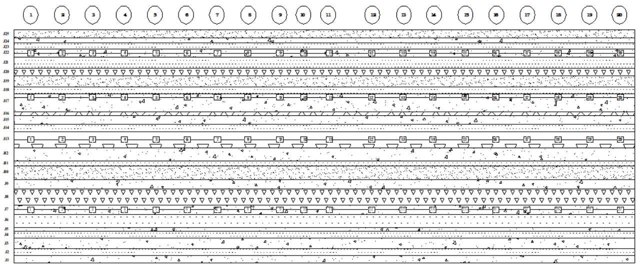


Figure 1. Dial indicator, line and measuring point layout

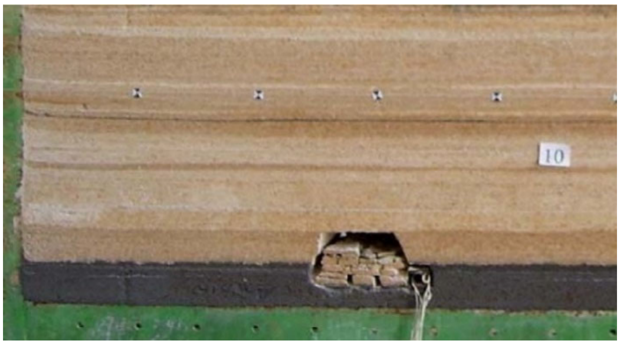
According to the experimental design, a 5-meter similar simulation model was constructed and paved to replicate the geological conditions of the mining area. The model was then excavated in accordance with the predefined experimental scheme, simulating the mining process. As the excavation progressed incrementally, the overlying strata began to exhibit gradual roof collapse, accompanied by the displacement of measuring points on the model. These measuring points, strategically placed to monitor deformation and movement, recorded the dynamic response of the overburden to the mining activities. The observed shifts in the measuring points provided valuable insights into the patterns of roof collapse and strata movement, reflecting the complex interactions between the mining-induced stress redistribution and the overlying rock layers.

3. Test Results and Analysis

3.1. Bedrock movement and pressure law

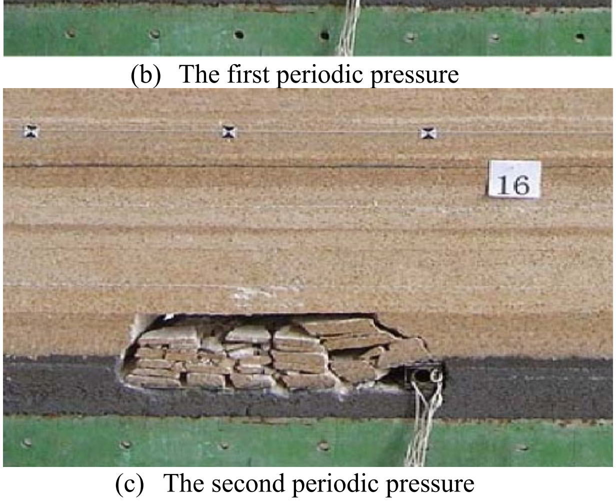
When the working face advances to 50 m (corresponding to 20 cm in the model; for clarity, all subsequent data are converted into prototype values), the readings on the strain gauge undergo a significant change, indicating a sharp increase in the load on the hydraulic supports. At this stage, the slump height reaches 13.75 m, and the height of the separation layer is 16.25 m. This marks the first occurrence of roof pressure, with the initial pressure step observed at 50 m of advancement, as illustrated in Fig.2. This phenomenon highlights the critical point at which the overburden begins to respond dynamically to the mining activity, providing valuable insights into the initial stages of roof collapse and strata movement.

When the working surface is advanced to 65 m, the reading on the strain gauge changes sharply again, indicating that the load on the bracket is increased again, and the old top is again pressed. This is the first cycle of the old top, and the pressure step is 15 m. The drop height is still 13.75 m, and the echelon development height is 18.75 m. When the working surface is advanced to 80 m, the working face pressure rises sharply, the working face is pressed, the pressure step is 15 m, and the roof slump height is still 13.75. m, the height of the separation layer is 22.5 m, as the working surface continues to advance, the old roof continues to press for a period of 15 to 30 m.



(a) The first pressure

(b) The first periodic pressure



(c) The second periodic pressure

Figure 2. Cycle pressure situation

3.2. Mining surface pressure law

The experiment utilizes strain gauges to record the deformation on the simulated hydraulic supports, which is then converted into load values. For clarity and practical relevance, the experimental ore pressure data is converted into prototype values based on the specifications of the hydraulic supports used on the actual working face. The results are as follows: the total average load on the support is 4882 kN per frame; the load during the peak pressure period ranges from 5997 kN to 7125 kN per frame, with an average load of 6658 kN per frame during this phase. The working face exhibits both major and minor pressure cycles, with the initial roof pressure being less severe compared to subsequent pressure periods. This indicates that the most intense pressure occurs during the later stages of mining rather than at the initial collapse of the roof. These findings provide critical insights into the dynamic load distribution and pressure behavior of the supports, which are essential for optimizing support design and ensuring safe mining operations.

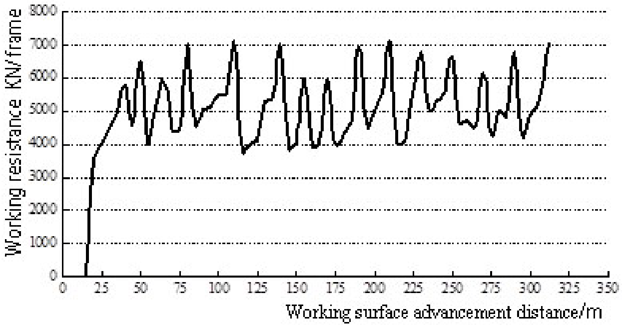


Figure 3. Simulated working surface top plate pressure and working surface propulsion diagram

4. Conclusion

(1) The results of the similar material simulation reveal that the initial pressure on the working face occurs at approximately 50 m of advancement. The first significant pressure from the old roof is observed when the working face advances to 65 m, with a pressure step of 15 m. At this stage, the slump height reaches 13.75 m, and the development height of the separation layer is 18.75 m. When the working face advances to 80 m, the second pressure period of the old roof occurs, and the height of the separation layer increases to 22.5 m. As the working face continues to advance, the old roof undergoes periodic pressure, with step sizes ranging from 15 m to 30 m. The working face exhibits both major and minor pressure cycles, and the initial pressure on the roof is not the most severe, indicating that the intensity of pressure increases during later stages of mining.

(2) The movement pattern of the bedrock layer is characterized by initial separation followed by collapse as the working face advances. There is no linear relationship between the height of the collapsed layer, the height of the separation layer, and the advancement distance of the working face. Instead, these parameters follow a step-like ascending curve. When the working face advances approximately 75 m past a measuring point, the measuring point located in the middle part of the bedrock layer, 70 m above the coal seam roof, begins to sink significantly. This stage of sinking is marked by a "slow but large amplitude" characteristic, reflecting the complex and nonlinear nature of bedrock movement in response to mining activities. These findings highlight the dynamic and progressive nature of overburden deformation and provide valuable insights for predicting and managing strata behavior during mining operations.

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