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Research on the Evolution Law of Overlying Strata Movement in Fully Mechanized Coal Mining Face Based on Similarity Simulation

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Abstract: Based on the similarity material simulation experiment method, a systematic study was conducted on the movement law of overlying strata in the B8 coal seam fully mechanized mining face of Xiaogou Branch Mine, Nanshan Coal Mine. By constructing a similarity material model, the collapse, separation, and displacement changes of the overlying strata during the coal seam mining process were simulated. The roof pressure behavior, bedrock movement law, and development characteristics of the "three zones" were analyzed. The experimental results indicate that the initial roof pressure step distance of the working face is approximately 50m, with periodic pressure step distances ranging from 15m to 30m. The height of the roof caving zone is 8.25 times the mining height, the height of the fractured zone is 22 times the mining height, and there exists a 40m bent subsidence zone at the uppermost part of the bedrock. The research findings provide a scientific basis for mine safety production and support design.

Keywords: Similarity simulation; Fully mechanized mining face; Overlying strata movement; Roof pressure behavior; Development of the "three zones".

1. Introduction

Coal, as a crucial component of the global energy structure, not only plays a pivotal role in ensuring national energy security but also profoundly influences regional economic development and ecological environmental balance [1-2]. With the continuous advancement of coal mining technologies, particularly the widespread application of fully mechanized coal mining (FMCM) techniques, coal mining efficiency has significantly improved. However, this progress has also brought about more complex issues related to mine pressure manifestation and overlying strata movement. The study of the movement law of overlying strata, as a fundamental topic in the field of mine pressure and strata control, holds paramount significance for ensuring safe coal mine production, enhancing resource recovery rates, mitigating surface subsidence, and protecting the ecological environment [3].

During the coal mining process, as the working face advances, the overlying strata undergo a series of complex mechanical responses under the influence of self-weight and mining activities, including processes such as bending, separation, collapse, and surface subsidence. These processes not only directly impact the support design and mine pressure management of the working face but also pose potential threats to the safety of underground workers. Therefore, gaining a deep understanding and accurately predicting the movement law of overlying strata is of inestimable value for optimizing mining plans, enhancing mining efficiency, and ensuring safe production. Traditionally, research on the movement law of overlying strata has mainly relied on field measurements and theoretical analyses [4-5]. However, field measurements are often constrained by factors such as complex geological conditions, limited monitoring means, and high costs, making it difficult to comprehensively and systematically reveal the entire process of overlying strata movement. Theoretical analyses, on the other hand, are often based on simplified assumptions, making it challenging to accurately reflect the complex mechanical behaviors during actual mining operations. Against this backdrop, similarity material simulation experiments, as an important research tool, have gradually become a significant means for studying the movement law of overlying strata due to their advantages of intuitiveness, economy, and repeatability.

Similarity material simulation experiments are based on similarity theory and involve constructing physical models that are similar to actual mining conditions to simulate the movement, changes, and failure patterns of overlying strata during the coal seam mining process. This experimental method not only visually demonstrates the entire process of overlying strata movement but also enables the study of the effects of different geological conditions and mining parameters on overlying strata movement by adjusting model parameters, thereby providing scientific evidence for mine pressure and strata control. Since its first proposal by Soviet scholar Kuznetsov in the 1930s, similarity material simulation experiments have been widely applied both domestically and internationally, yielding fruitful research results. In China, numerous scholars have conducted in-depth studies on coal seam mining under different geological conditions using similarity material simulation experiments [6-8]. Therefore, this study takes the B8 coal seam fully mechanized mining face of Xiaogou Branch Mine, Nanshan Coal Mine, as the research object and employs similarity material simulation experiments to delve into the movement law of overlying strata in fully mechanized mining faces. The aim is to unveil the motion and change characteristics, pressure behavior, and development morphology of the "three zones" of overlying strata during the coal seam mining process, thereby providing scientific evidence and technical support for safe coal mine production under similar geological conditions.

2. Similar Model Design and Production

2.1. Similar model design and production

The test is conducted based on the fully mechanized mining face of the B8 coal seam in Xiaogou Mine, which is part of Nanshan Coal Mine. According to the mine's data and field investigations, the working face is 950 meters long, with a strike length ranging from 114 to 136 meters and a cutting length of 114 meters. The thickness of the coal seam generally varies between 2.23 meters and 4.79 meters, with an average thickness of 4.2 meters and a coefficient of variation of 45%. The coal seam strikes at 320° in the working face, dips at 69°, and has an inclination angle ranging from 38° to 42° within the working face. Additionally, the coal seam structure is relatively stable. For this similar material simulation test, a test bench with dimensions of 5 meters × 2 meters × 0.4 meters and an effective height of 1.8 meters is utilized. Based on the actual mining conditions of Nanshan Coal Mine, combined with the size of the similar simulation test bench and relevant data, the similarity constants for the test have been comprehensively set.

2.2. Similar material production

(1) Arrangement of observation points

A 50 cm boundary is established, and 20 dial gauge points are arranged on the surface of the model. The distance between these measuring points ranges from 20 to 40 cm, allowing for the observation of surface displacement. Additionally, displacement measuring lines are set up at specific depths: 35.8 cm for the bottom argillaceous siltstone, 83.2 cm for the bottom coarse sandstone, 111.7 cm for another layer of bottom argillaceous siltstone, and 141.6 cm for yet another layer of bottom argillaceous siltstone. Each measuring line is equipped with 24 displacement measuring points, spaced 20 cm apart. 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 are numbered from left to right as A0, A1, A2, A3, ..., A20 for Measuring Line A; B0, B1, B2, B3, ..., B20 for Measuring Line B; C0, C1, C2, C3, ..., C20 for Measuring Line C; and D0, D1, D2, D3, ..., D20 for Measuring Line D. The arrangement of the dial gauges, lines, and measuring points is illustrated in Figure 1.

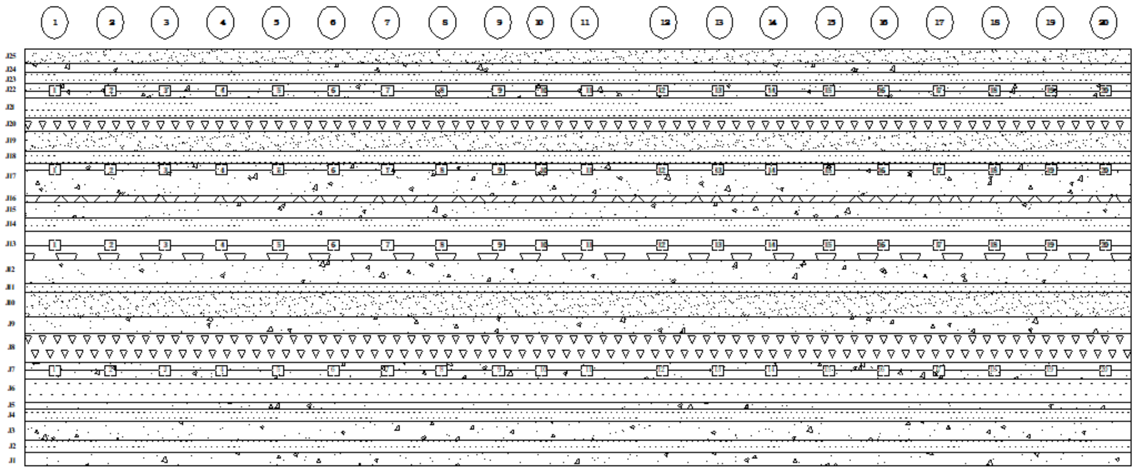


Figure 1. Dial indicator, line and measuring point layout

According to the experimental design, a 5m similar simulation model was paved, and the model was excavated according to the experimental scheme. As the mining progressed gradually, the roof gradually collapsed, and the measuring points on the model gradually shifted.

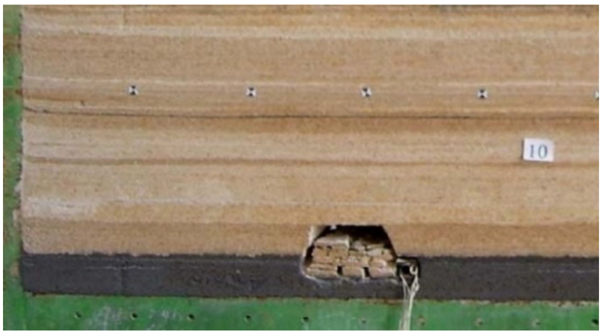
3. Test Results and Analysis

3.1. Bedrock movement and pressure law

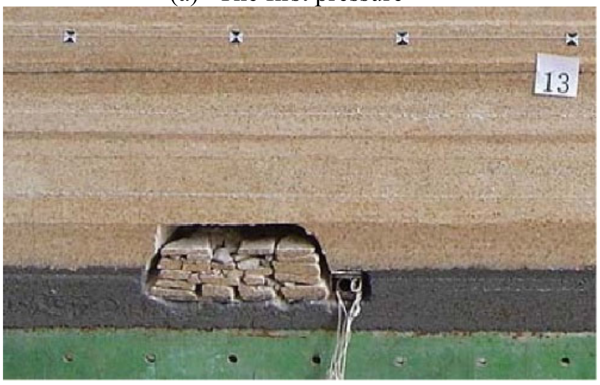
(1) When the working face is advanced to a distance of 50 meters (which corresponds to 20 cm in the model for ease of understanding; all subsequent data will be converted into prototype data), a significant change is observed in the readings of the strain gauge. This indicates a sharp increase in the load borne by the support structure, with a slump height of 13.75 meters recorded. The height of the separation layer is measured to be 16.25 meters, and this marks the first occurrence of roof pressure on the working face. The initial pressure is observed at an advancement distance of 50 meters, as illustrated in Figure 2.

(2) When the working face is advanced to 65 meters, the reading on the strain gauge undergoes another sharp change, indicating a renewed increase in the load on the support structure, and the old roof experiences pressure once again. This marks the first cycle of pressure exertion by the old roof, with a pressure step of 15 meters. The roof slump height remains at 13.75 meters, while the echelon development height (the height at which fractures propagate in a stepped manner) is measured to be 18.75 meters.

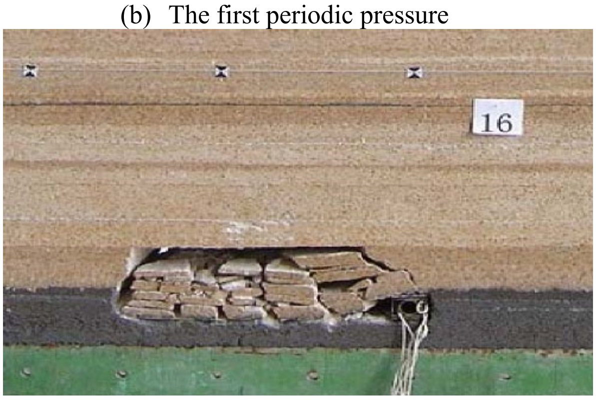
As the working face is further advanced to 80 meters, the pressure on the working face rises sharply again, indicating another instance of roof pressure. The pressure step remains consistent at 15 meters, and the roof slump height is still 13.75 meters. However, the height of the separation layer (the space between the roof and the underlying strata where fractures occur) has increased to 22.5 meters. As the working face continues to advance, the old roof continues to exert pressure over a distance ranging from 15 to 30 meters.



(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 employs strain gauges to record the deformation occurring on the simulated support brackets, which is then converted into corresponding load values. To facilitate easier understanding, all experimental ore pressure data have been transformed into prototype values, based on the hydraulic support brackets chosen for use on the working face. The results are as follows: the total average load borne by each support bracket is 4882 kN per frame; during the loading phase of the bracket, the load ranges from 5997 kN to 7125 kN per frame; and the average load experienced during support pressure is 6658 kN per frame. The working face undergoes periods of both high and low pressure, with the initial pressure exerted by the top plate not being the most intense phase observed.

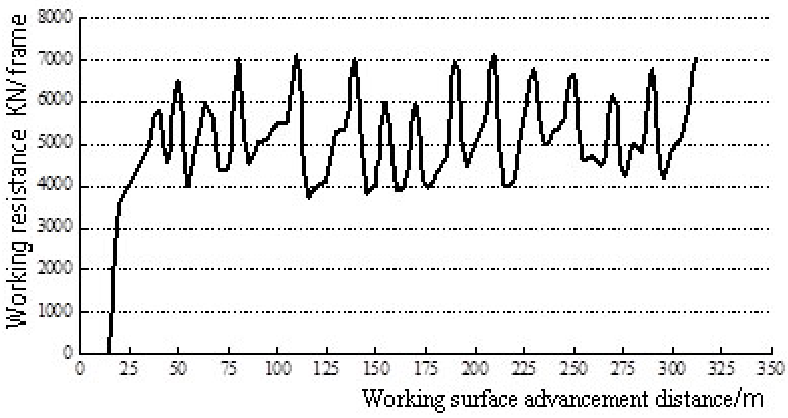


Figure 3. Simulated working surface top plate pressure and working surface propulsion diagram

3.3. Analysis of the "Three Zones"

In the experiment, the simulated roof caving behavior of the working face did not completely conform to the typical caving pattern observed in shallow-buried coal seams. The general caving rule for roofs in coal seams with smaller burial depths, particularly in typical shallow-buried coal seams, is characterized by the full-thickness shearing and caving of the bedrock roof, with a large fracture angle and direct propagation of fractures to the surface. During pressure manifestation periods, there are significant step-like subsidences of the roof and dynamic loading phenomena. Moreover, generally, only the caving zone and fractured zone exist above the working face, or even a phenomenon of "three zones merging into one" may occur. However, in this experiment, the roof caving of the working face did not extend to the surface but exhibited the characteristics of the "three zones." When the working face advanced to 315 meters, the caving height of the roof reached 110 meters. Through observation of the model, no vertical fractures were found in the bedrock between 110 and 150 meters in height. Therefore, it was concluded that the area above 110 meters in height was the bent subsidence zone, with a thickness of 40 meters for the bent subsidence zone of the bedrock. Based on the displacement measurements from the B survey line at the bottom of the clay layer and the surface displacement dial indicators, it was evident that the overlying strata underwent overall subsidence during the excavation process, and no vertical upward fractures were observed. By measuring the model, it was determined that the height of the roof caving zone was 41.25 meters from the coal seam roof, which is 8.25 times the mining height. The height of the fractured zone was 110 meters from the coal seam roof, which is 22 times the mining height. The uppermost part of the bedrock, with a thickness of 40 meters, was identified as the bent subsidence zone, as illustrated in the Figure 4.

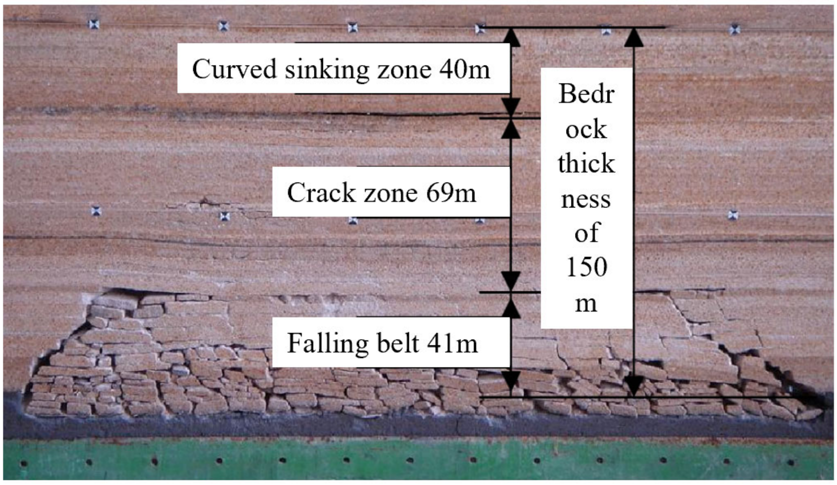


Figure 4. Morphological Diagram of the "Three Zones" in the Bedrock

4. Conclusion

(1) The simulation results of similar materials indicate that the initial pressure on the working face occurs at approximately 50 meters of advancement. The first instance of pressure on the old roof is observed when the working surface is advanced to 65 meters, with a pressing step of 15 meters and a slump height of 13.75 meters. The development height of the separation layer reaches 18.75 meters. When the working surface is further advanced to 80 meters, the second period of pressure on the old roof occurs, and the height of the separation layer increases to 22.5 meters. As the working surface continues to advance, the old roof continues to exert pressure, with the step size ranging from 15 to 30 meters. The working face experiences periods of both high and low pressure, and the initial pressure on the top plate is not the most severe phase.

(2) The law of bedrock movement: As the working face advances, the bedrock layer initially separates from the overlying strata and then collapses. There is no linear relationship between the height of the fallen layer, the height of the separation layer, and the advancement distance of the working surface; instead, they exhibit a step-like ascending curve. When the working surface has been pushed past the measuring point by about 75 meters, the measuring point located in the middle part of the bedrock, 70 meters away from the roof of the coal seam, begins to sink noticeably. The sinking at this stage is characterized by a "slowing down and large amplitude" pattern.

(3) The height of the roof caving zone is 41.25 meters from the coal seam roof, which is 8.25 times the mining height. The height of the fractured zone is 110 meters from the coal seam roof, equating to 22 times the mining height. The uppermost 40 meters of the bedrock is identified as the bent subsidence zone.

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