Research on the characteristics of overlying strata movement in downward and upward mining longwall panel in steeply inclined seam by similar physical simulation

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Received 1 December 2014,www.cmnt.lv

Abstract

To study the failure and collapse rule of overlying strata movement in the downward and upward mining longwall panel in a steeply inclined seam, panel B in mine A was used as the engineering background. Experimental methods for similar physical simulations were applied to study the overlying strata movement in different mining stages. Experimental results showed that during the upward and downward mining stages, the main breaking span for the crack development rule inside the overlying rock was significantly different. During the downward mining stage, the internal vertical fissures tended to close, whereas crack development of the vertical fissures was exacerbated in the upward mining stage. In addition, the main breakage span in the upward mining stage was obviously less than that in the downward mining stage. Field measurement results validated the experimental results, which were significant to the retreating panel under similar conditions.

Keywords: Downward and Upward Mining; Steeply Inclined Coal Seam; Overlying Strata; Similar Physical Simulation

1 Introduction

With the increase in coal resource depletion, many coal mines have transferred their main panels to a deep area or to a complicated geological structure area in the east of China. The proportion of the steeply inclined seams comprises around 50% of the coal reserves in the west of China, and the total annual coal production reaches 10%. Meanwhile, under the influence of geological structure, such as fold and fault, many panels are affected by the difficulties of up-dip mining or down-dip mining.

Many studies have been conducted to ensure coal mine safety and production. Researchers are concentrating on the equipment used in mechanized longwall mining rather than the inherent characteristics of overlying strata movement [1, 2]. In recent years, many developments have been made in steep seam mining techniques[3-10]. Zhang and Cheng et al. established a mechanical model to study the mechanism of roof break on the up-dip and down-dip panels in steep coal seams [11]. Yin et al. considered that the law of overlying strata movement was affected by the angle of coal seam[12]. Huang analyzed the limiting balance conditions of voussoir beam structure in the different places of panel [13]. Wu et al. conducted a series of studies and experiments on longwall in steeply inclined seams and built a dynamic model of roof-support-floor (R-S-F) system, thereby revealing the inherent characteristics of strata control [14]. However, studies on the effect of angle variation during the mining process using the theoretical analysis and numerical simulation are few. Therefore, initiating a physical simulation experiment to understand the traits of the overlying strata movement for this special geological condition is necessary.

2 Geological Conditions

Coal mine A is located in Anhui Province in East China, where the coal in panel B is more stable. In this location, the average tilt of the coal seam was 30°, and the average thickness was 2.83 m. Inside the panel, the coal seam conducts fold development with gentle undulating upward trend, which presents a pan shape in the coal seam direction (figure1). Because the coal seam strike varied greatly within the scope of the panel, panel advancing was initially subjected to the downward mining stage, and subsequently, the upward mining stage, of which the maximum downward mining and upward

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mining angles were 42° and 25°, respectively. The overlying rock lithology and mechanical properties are shown in Table 1. The cross section along headgate and tailgate of panel B are shown in figure 2.

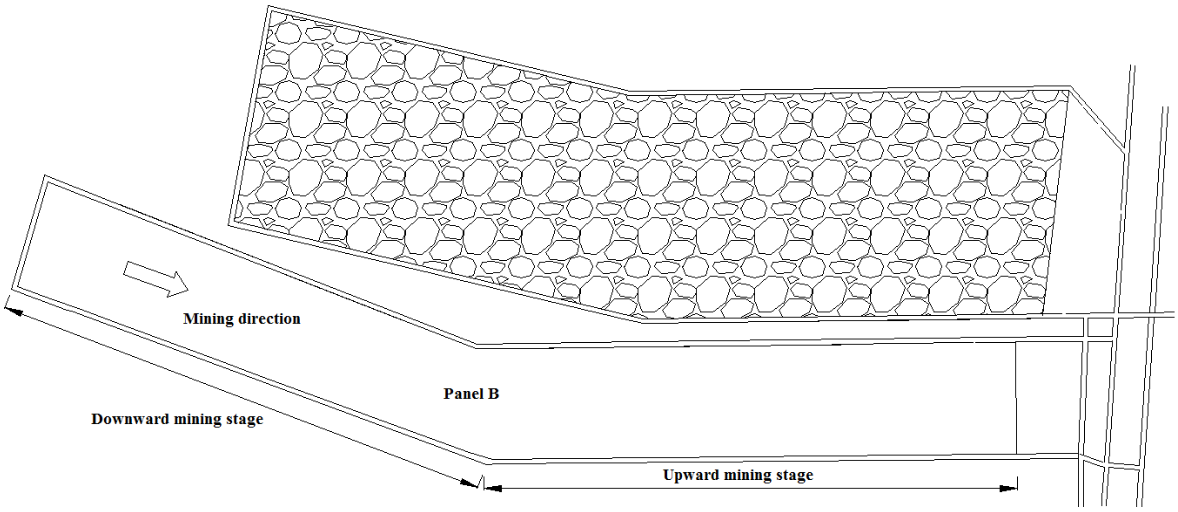


FIGURE 1 Panel Layout

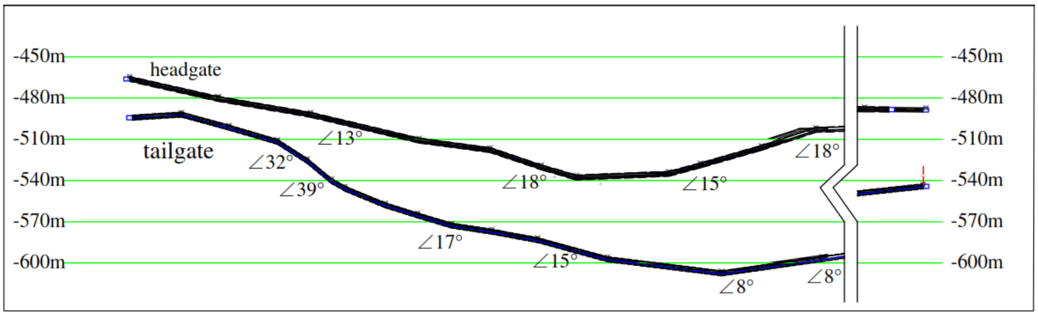


FIGURE 2 Cross section along headgate and tailgate of panel B

3 Experimental Program

A plane-strain model frame was applied in the experiment. The thickness and length of simulated strata are 201.7 m and 500 m, respectively. The model size was determined according to the coal seam conditions of mine A, as follows: length × width × height of 2.5 m × 0.2 m × 1.16 m, in which the geometric similar ratio of the model was 1:200, and the time similar ratio was 1:14.14. Mechanical parameters for parts of similar materials in the simulated rock are listed in Table 1.

When the model was dry, we arranged four displacement measurement lines in the model and observed the movement during the retreating process. The first and second survey lines were placed in the downward mining section, the third survey line was placed in the synclinal axis part, and the fourth survey line was placed in the upward mining section. Each survey line was equipped with 3 to 4 migration transducers (Figure 3).

TABLE 1 Lithology and mechanical properties of rock

No.	Strata	Thickness, m	Young's Modulus, /GPa	Density, 10^3/kg.m-3	Unconfined Compressive Strength, /MPa
1	Sandstone	4.9	35	2.6	72.51
2	Mudstone	3.7	10.2	1.7	44.52
3	Sandy mudstone	2.3	11.6	1.8	43.62
4	Mudstone	0.7	10.2	1.7	45.98
5	Sandstone	4	35	2.6	43.71
6	Mudstone	2	10.2	1.7	34.06
7	Coal seam	2.83	-	-	2.61
8	Mudstone	1	10.2	1.7	23.67
9	Sandstone	2.1	35	2.6	64.09

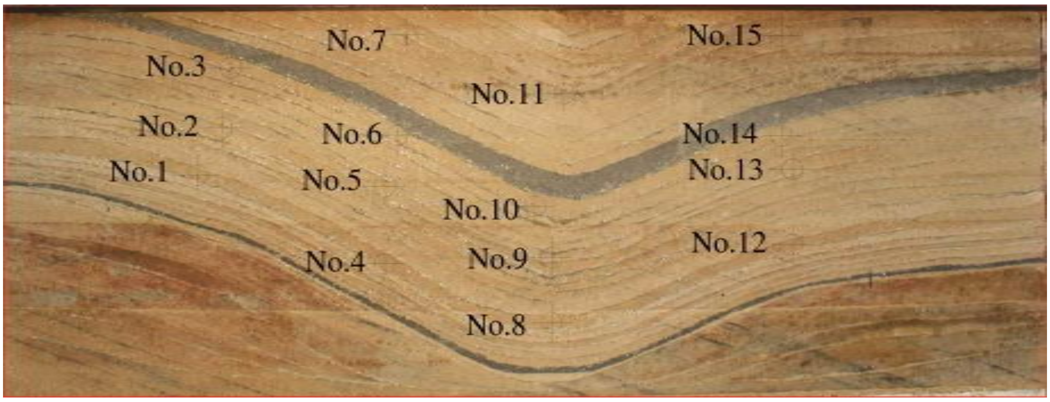


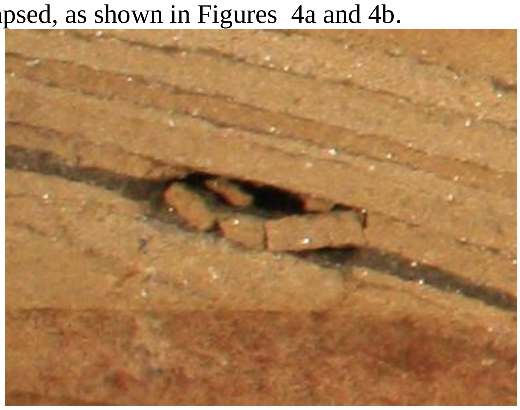
FIGURE 3 Panorama of the model and observation point of placement

4 Experimental Results and Analysis

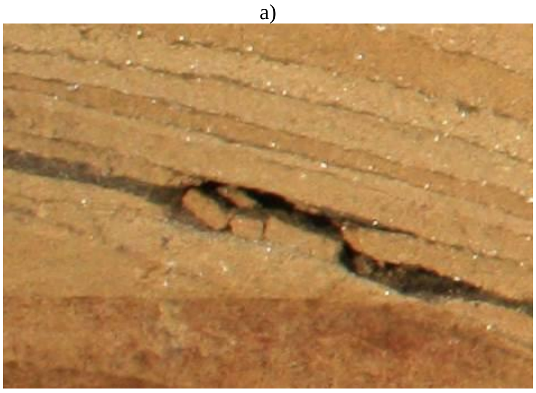
4.1 EXPERIMENTAL RESULTS

4.1.1 Downward mining section

When the advancing distance of panel reached 12.5 m from the setup entry (according to the numerical similarity ratio after conversion, the same as that presented below), separation and micro fracture in the vertical direction started to appear in the immediate roof. Advancing to 20 m, the immediate roof completely collapsed, as shown in Figures 4a and 4b.



a)



b)

FIGURE 4 First collapse of immediate roof: a) Collapse of immediate roof, b) Development of vertical micro-fissures

Advancing to approximately 41.5 and 69.5 m from the setup entry, the first weighting and the first periodic weighting appeared in the major roof. During the downward mining process, the maximum separation in the overlying strata reached 400 m. The maximum separation was located between the third and fourth seams at approximately 50 m from the coal wall. Simultaneously, the separation phenomenon of other overlying strata was intensified. When the panel continued to advance to 146 m, rotating instability phenomenon occurred in some major roofs, with a breaking length of approximately 30 m. After breaking, a three-hinged arch balance formed.

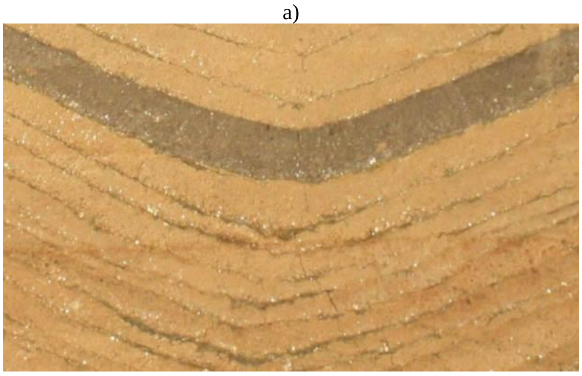
4.1.2 Synclinal axis section

When the panel advanced to the synclinal axis section, the motion trend of the overlying strata was consistent, and an entire deformation phenomenon appeared in the major roof and overlying strata with direct roof deformation. Overall collapse appeared in some major roofs along the vertical fissures. After the collapse, penetrating cracks formed between the second layer and twelfth layer of the overlying strata, as shown in figure 5. During this stage, the periodic weighting interval of the major roof decreased compared with the downward mining stage (one major roof weighting in one or two collapses of the immediate collapse each time), but the weighting strength significantly increased. In addition, separation phenomenon in overlying strata weakened with the overall bending.

4.1.3 Upward mining section

During the upward mining process, the roof shown an overall bending sinking-mode break, whereas the separation development between strata weakened or the separation generated in the former stage closed. The crushed rocks caving in the overlying strata showed a sliding trend toward the mined-out area. This trend further weakened the stability of the major strata, thereby causing the decrease in the collapse step distance. The measured major pressure period was 15.8 m. During retreating, three obvious connected cracks (whole or partial cracks) formed in the overlying strata on the panel, as shown in Figure 6. The entire model after retreating is shown in Figure 7.

a)



b)

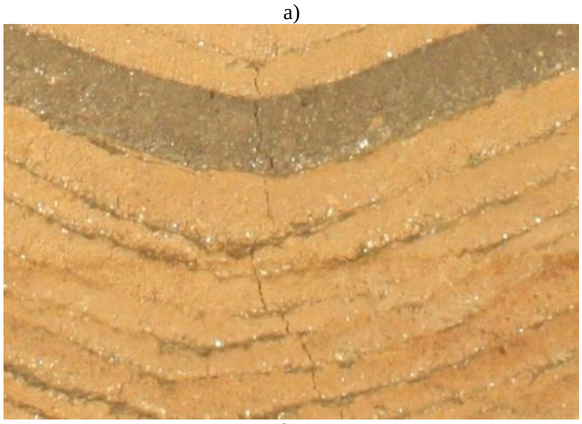
FIGURE 5 Development of major roof collapse and overlying strata fissure in the synclinal axis section: a) Entire collapse of a major roof, b) Vertical fissure in the overlying strata.

Combined with the above mentioned phenomenon, the main characteristics were as follows.

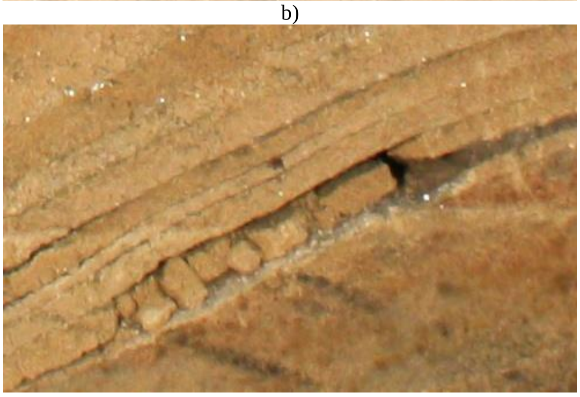
Component force pointing to the coal wall from the plane, which was generated from the immediate roof during the downward mining stage, resulted in the closing of micro cracks generated from the main roof. At the same time, supported by the gangue that fell from the front roof, the mined-out area after the retreating space did not collapse easily. During the upward mining stage, the roof, which was destroyed by the component force pointing to the synclinal axis section, collapsed easily because of the internally formed vertical cracks in this direction.

During the downward mining stage, the breaking step distance of the major roof was longer, and the separation of the overlying strata developed upward with the advancing panel. The breaking cycle of the main roof in the synclinal axis section was significantly shortened, and an obvious overall bending sinking movement appeared in various overlying strata. Thus, the separation weakened. During the upward mining stage, because the supporting role of gob below the major roof was weakened, the breaking step distance was shortened, and the overlying strata in breaking would sink as a whole.

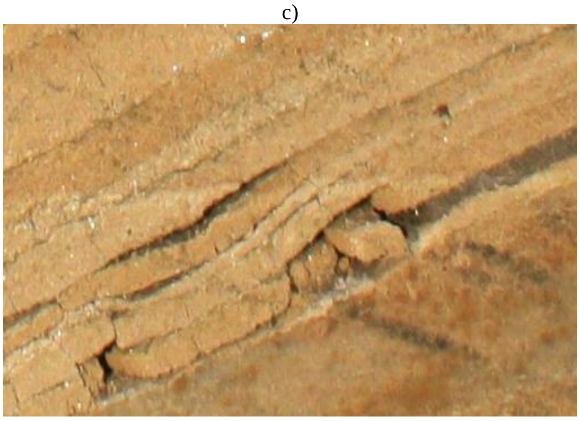
a)



b)



c)



d)

FIGURE 6. Periodic weighting of major roof in the upward longwall section: a) Separation closure, b) Development of vertical fissure in overlying strata, c) Before the major roof break, d) After the major roof break.

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FIGURE 7 General view after mining

4.2 ANALYSIS OF THE CHANGE IN THE DISPLACEMENT OF THE OVERLYING STRATA

Data were measured from four sets of displacement sensors placed in the downward mining, synclinal axis, and upward mining sections (Figure 8). Abscissas represented the horizontal distance from the faceline of the panel, and the ordinate represented the roof convergence (we calculated the value with a similar ratio). The zero position was set as the place directly below the panel advancing to the observation line.

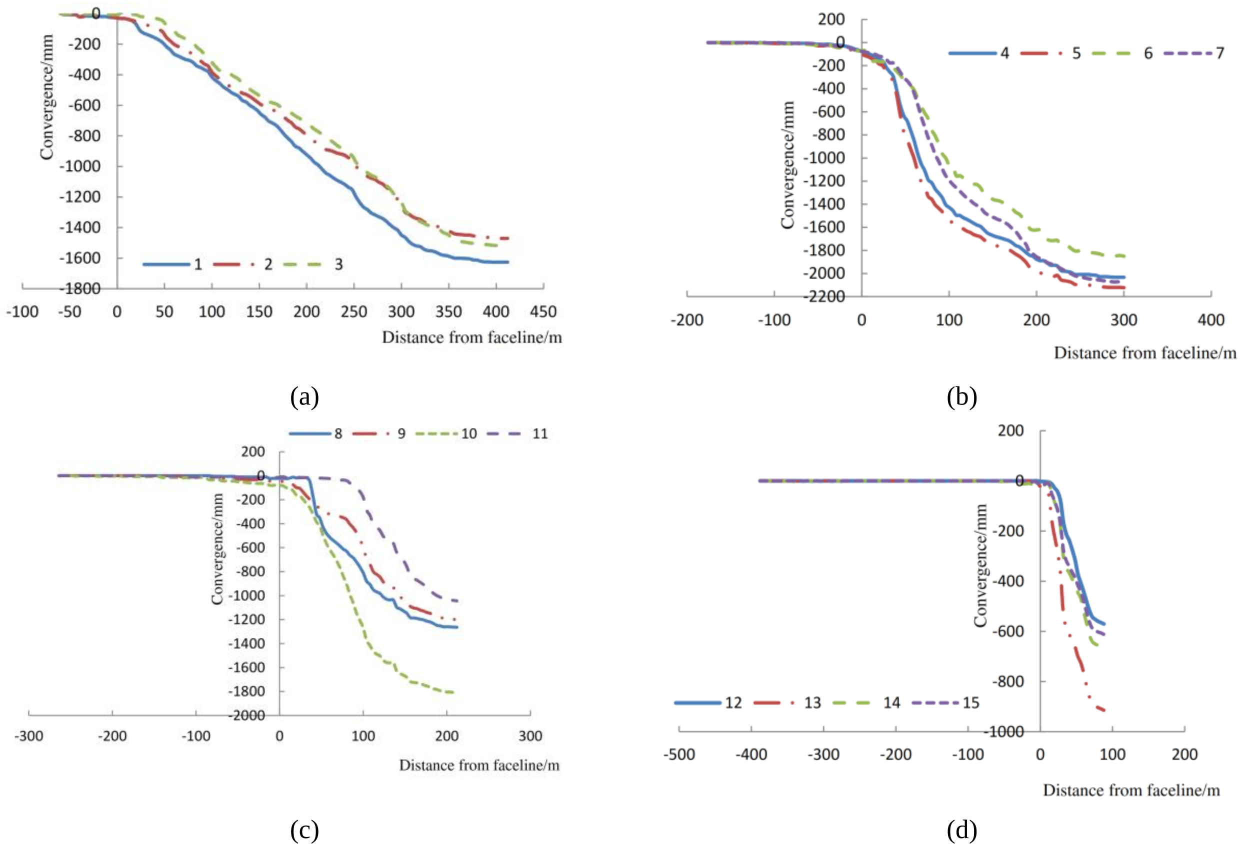

FIGURE 8 Displacement curve of the overlying strata: a) First survey line, b) Second survey line, c) Third survey line, d) Fourth survey line

As shown in Figure 8, during the panel retreating process, the following characteristics of displacement changes in the overlying strata were observed:

1) The displacement amounts of various survey points in the seventh layer or above on the coal seam

were consistent, thereby indicating that these rocks were present in an overall sinking form.

2) The changing process of displacement and the duration of overlying strata varied with different positions. Overlying strata in the first survey line presented a substantially uniform sinking state, which would tend to stabilize after the panel advanced to greater than 350 m. Deformation of the overlying strata in the second survey line was more intense when the panel advanced to approximately 30 m to 50 m. The displacement amount tended to stabilize after the panel continued to advance to greater than 200 m. In the third survey, the maximum of the changing displacement rate was reached when the panel advanced to approximately 30 m to 80 m. After advancing to 160 m, the deformation slowed down, and the displacement was stabilized.

5 Field measurement and analysis

The KBJ-60Ⅲ-1 continuous pressure recorder was adopted on the panel to observe the support resistance of the hydraulic leg, and the observation results were as follows:

1) In the downward mining section, because of the pseudo-oblique panel, when the distance from tailgate to setup entry was approximately 17 m and the distance from headgate to setup entry was 14 m, the first immediate roof collapse occurred (average interval, 16.5 m).

2) In the upward mining stage, the periodic weighting interval of the panel was 14.3 m to 20.2 m, with an average of 17.6 m, whereas roof weighting in different parts along faceline of the panel varied.

3) In the upward mining stage, rules of periodic weighting in different parts of panel were different. There are 3, 4, and 5 periodic weightings in the tailgate side, middle, and headgate side of the panel, respectively. The middle and tailgate side of weighting come before the tailgate side. The periodic weighting interval was short. The average periodic weighting interval in the tailgate side, middle, and headgate side of the panel were 9.15, 10.54, and 11.1 m, respectively.

6 Conclusion

We concluded the following:

(1) During downward mining stage, the main roof was pressurized by the closing trend of inner fissure that was formed in the roof and was supported by the falling rocks in the back mined-out area when subjected to component force of the coal wall from the plane of the formation. Thus, the main roof did not collapse easily. However, the opposite situation was observed in the upward mining, and different collapse step spans were present at different stages.

(2) The average periodic weighting interval in the downward mining section measured in the physical simulation was 28 m, and in the upward section, this distance was 15.8 m. According to the measured field data analysis, the average periodic weighting interval on the panel during the downward longwall stage was 17.6 m, whereas the average weighting interval during the upward mining stage was only 9.15 m to 11.1 m. Consequently, the trend observed in the field measurements was in agreement with that obtained in the physical simulation.

Acknowledgment

This study was sponsored by National High Technology Research and Development Program of China (No. 2012AA062100), the Program for New Century Excellent Talents in University of China (NO.NCET-10-0770), and China Scholarship Council.

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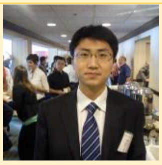

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