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Stability of roof structure and its control in steeply inclined coal seams

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ABSTRACT

To improve the effectiveness of control of surrounding rock and the stability of supports on longwall top-coal caving faces in steeply inclined coal seams, the stability of the roof structure and hydraulic supports was studied with physical simulation and theoretical analysis. The results show that roof strata in the vicinity of the tail gate subside extensively with small cutting height, while roof subsidence near the main gate is relatively assuasive. With increase of the mining space, the caving angle of the roof strata above the main gate increases. The characteristics of the vertical and horizontal displacement of the roof strata demonstrate that caved blocks rotate around the lower hinged point of the roof structure, which may lead to sliding instability. Large dip angle of the coal seam makes sliding instability of the roof structure easier. A three-hinged arch can be easily formed above both the tail and main gates in steeply inclined coal seams. With the growth in the dip angle, subsidence of the arch foot formed above the main gate decreases significantly, which reduces the probability of the roof structure becoming unstable as a result of large deformation, while the potential of the roof structure's sliding instability above the tail gate increases dramatically.

1. Introduction

Steeply inclined coal seams widely exist in many coal-producing areas, such as Xinjiang, Ningxia, Shanxi, Guizhou, Chongqing, Huainan, Gansu and Beijing [1–3]. As the major mining area has moved to western China, where half of the mines exploit steeply inclined coal seams, research on mining steeply inclined seam has become a high priority [4,5]. There are remarkable differences in mining method, structure of overlying strata, rules of mine pressure and stability control of supports between mining steeply inclined seams and horizontal seams [6–12]. The emphasis on surrounding rock control is determined by the structure of the overlying strata along the inclination, which is one of the main bases of stope support design.

Domestic scholars have made great research on the problem of surrounding rock control in steeply inclined panels. Wang [13,14] studied the fracture mode and evaluation of the main roof in a steeply inclined thick seam based on elastic mechanics. Xie [8] studied the interaction characteristics between strata movement and the support system around a large mining height fully-mechanized face in a steeply inclined seam. Yin [15] obtained the ground pressure of the surrounding rock on a large dip angle face by photo-elastic experiment. Tu [16] studied deformation and fracture features in asymmetrical filling along an incline based on the theory of thin plates. Through comprehensive methods such as similar simulation, Wu [17–19] proposed the inclined masonry structure of dip direction and anti-dip direction pile types, and pointed out that the unbalanced movement of these structures was the primary factor in the instability of the "R-S-F" system. Nevertheless, the principal feature by which the steeply inclined face is different from an approximately horizontal face lies in the discrepancy in structure of the surrounding rock along an incline caused by the dip angle. There is a lack of in-depth study on the structural forms, instability forms and causational rules of mine pressure.

Taking panel 1201 of Dayuan coal mine as engineering background, the rules of overlying strata movement along the inclination and roof structure in mining steeply inclined seam are researched through similar simulation experiment. The instability conditions of the roof structure in the dip direction were studied by theoretical analysis and was verified through in-situ rules of mine pressure. The research achievements are expected to have significance for designing roof control in mining steeply inclined seams.

2. Engineering situation

The depth of #2 coal seam of panel 1201 in Dayuan coal mine is from 195.6 m to 242.6 m and the panel width is 60 m. The average

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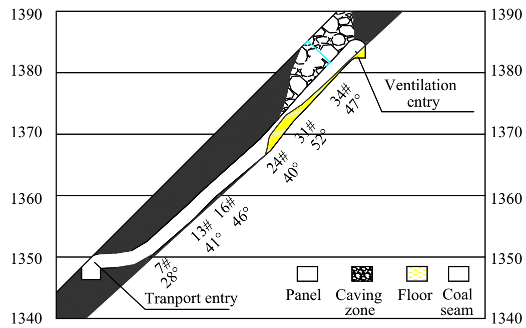

Fig. 1. Schematic diagram of the roadway arrangement in panel 1201.

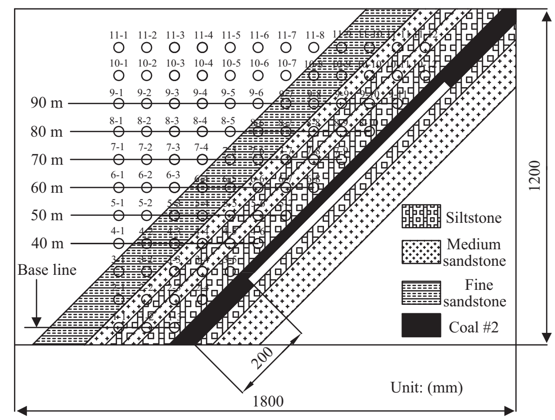

Fig. 2. Arrangement of measuring line.

thickness of the coal seam is 6.8 m and the average dip angle is 45°. A fully-mechanized longwall caving method is applied in the panel. The coal-cutting height is 2.3 m, and the caving height is 4.5 m. The immediate roof is an 8 m thick siltstone with a Protodyakonov coefficient *f* from 4 to 6.14. The basic roof is a medium sandstone from 3 to 5 m thick and a Protodyakonov coefficient *f* of 6.31. The direct floor includes carbon mudstone and siltstone with a thickness varying between 3.8 and 5.4 m. The basic floor is a 12 m thick medium sandstone. The ventilation entry was laid out in the floor and the transport entry is also in the floor [20]. The joint section is a circular arc, as shown in Fig. 1. 37 supports from the top down were installed along the tilt direction. The dip angle in the position of No. 31 support reaches its maximum value of 52°. During the three-month period of equipment installation, the supports in the upper end have worse stability including sliding, toppling and squeezing. The face advanced not more than 10 m from open-off cut.

3. Physical simulation of overlying strata movement

3.1. Program of similar simulation

In mining steeply-inclined coal seams, the emphasis on stability control of supports is determined by the rules of overlying strata movement and their forms of instability. For the extraction of an approximately horizontal seam, the roof structure in the strike direction is largely understood as a result of research. However, in steeply inclined seams, it is of greater significance to study the failure mode of the roof and its structure in the tilt direction. The differences in structure of overlying strata and its instability mode are factors causing great discrepancy in the 'support and surrounding rock' system between mining steeply inclined seams and approximately horizontal seams. Therefore, a plane analog simulation was applied in the experimental research on overlying strata movement and its structural instability in the tendency direction.

The experiment was designed on the basis of similarity theory, including geometric similarity, kinematic similarity and dynamic similarity. The ratio of geometric similarity, a_L is 100:1, the ratio, a_γ of volume-weight is 1.6:1 and the ratio of time similarity is 10. The physical and mechanical parameters of rock strata are shown in Table 1. The model is 180 cm long, 16 cm wide and 120 cm in height. The remaining weight of the overlying strata was uploaded by the compensation method. The displacement observation points were arranged from the bottom up after layout of the model. The layout density was 10 cm × 10 cm. There were 11 layers in total, which are shown in Fig. 2. Coal cutting and drawing in different panel widths were simulated after the strata reached its scheduled strength. Coal cutting of 2.3 m mining height in 100 m panel widths was firstly simulated based on practical production and then coal drawing was simulated to observe the rules of overlying strata caving.

3.2. Presentation of results

3.2.1. Rules of overlying strata movement

To be consistent with practical production, after the materials reached their scheduled strength, an initial advance of 2.3 m without drawing was simulated. Excavation started 20 m from the bottom boundary to simulate the rules of overlying strata movement on a fully-mechanized caving steeply-inclined seam. The simulated width of each panel was 100 m. The vertical displacement in different layers after coal drawing is presented in Fig. 3.

Fig. 3 demonstrates that the horizontal displacement after mining a steeply-inclined seam is mainly positive. The maximum vertical and horizontal displacement is biased towards the bottom end of the panel. The displacement of measuring lines 50 m and 60 m suddenly increase to respectively 50 m and 60 m away from the bottom end. The vertical displacement arrives at about 5.0 m and 5.5 m. The horizontal and vertical displacement of strata above the 80 m measuring line is very small. The strata above have bed separation from the lower layer. The rock strata within 80 m of the base line subsides extensively. Under the effect of forces perpendicular to the rock strata, the broken articulated rock moves

Table 1
Physical-mechanical parameters of rock strata.

No.	Lithology	Thickness (m)	Compressive strength (MPa)	Simulated strength (MPa)	Natural density (g/cm^3)	Simulated density (g/cm^3)
8	Fine sandstone	13.2	21.3	0.133	2.67	1.67
7	Medium sandstone	5.3	21.3	0.133	2.63	1.64
6	Siltstone	4.2	49.2	0.308	2.64	1.65
5	Medium sandstone	4	63.1	0.394	2.63	1.64
4	Siltstone	8	50.7	0.317	2.64	1.65
3	#2 coal	6.8	1.2	0.008	1.40	0.88
2	Siltstone	4.6	52	0.325	2.64	1.65
1	Medium sandstone	12	56	0.350	2.63	1.64