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Overlying strata movement rules and safety mining technology for the shallow depth seam proximity beneath a room mining goaf

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ABSTRACT

Aiming at the shallow depth seam proximity beneath a room mining goaf, due to that the shallow depth seam is exploited using the longwall mining and overlain by thin bedrock and thick loose sands, many accidents are likely to occur, including roof structure instability, roof step subsidence, damages of shield supports, and the face bumps triggered by the large area roof weighting, resulting in serious threats to the safety of underground miners and equipment. This paper analyses the overlying strata movement rules for the shallow seams using the physical simulation, the 3DEC numerical simulation and the field measurements. The results show that, in shallow seam mining, the overburden movement forms caved zone and fractured zone, the cracks develop continuously and reach the surface with the face advancing, and the development of surface cracks generally goes through four stages. With the application of loose blasting of residual pillars, reasonable mining height, and roof support and management, the safe, efficient and high recovery rate mining has been achieved in the shallow depth seam proximity beneath a room mining goaf.

1. Introduction

The coal seams located in the Shendong coalfield have many advantages including shallow depth and simple geological conditions. Prior to the large-scale longwall mining, room mining method and knife-pillar mining method were commonly employed so that the left coal pillars or backfilled boardroom can support the roof and control surface subsidence [1,2], e.g., Shigetai coal mine, Dadijing coal mine and many mines in the Yushen mine area. In Ordos alone, the area of abandoned room goaf exceeds 300 km^2, and the sterilized coal reserves are more than 1.8 billion tons.

The typical shallow coal seams have following major characteristics: shallow depth (less than 100–150 m depth), overlain by thin bedrock (no more than 30–50 m thick) and thick loose sands, the longwall mining. Under those conditions, it is likely to cause the whole overburden strata to collapse or roof step subsidence [3,4]. Huang et al. used physical simulation models to analyze ground pressure for mining under shallow coal seams, and obtained the key stratum dynamic load distribution and their load transfer for shallow coal seams with thick sand layer [5–8]. Hou applied the key stratum theory to the shallow coal seams with thick unconsolidated materials, and analyzed the roof "Rotation-Slide"(R-S) stability, which pointed out that the key to roof control is to control the stability of the combined key strata [9]. Longwall mining of shallow depth seams with small interburden under the room mining goaf exhibits many unique features in overlying strata movement and ground pressure, resulting in many accidents such as roof structure instability, large roof step subsidence, damages of shield supports, and the face bumps triggered by large area roof weighting. These problems pose serious threat to the safety of underground miners and equipment [10]. However, few studies have been made to investigate the overlying strata movement rules under the mining conditions mentioned above [11,12].

Based on the geological conditions of shallow depth seam at Shigetai coal mine, Ordos City, this paper employed the combined methods of physical simulation, numerical simulation, and field observation to investigate the overlying strata movement rules and put forward the corresponding prevention technology for the longwall mining of shallow depth seam under a room mining goaf, which can serve as an excellent guide to mining in similar geological and mining conditions.

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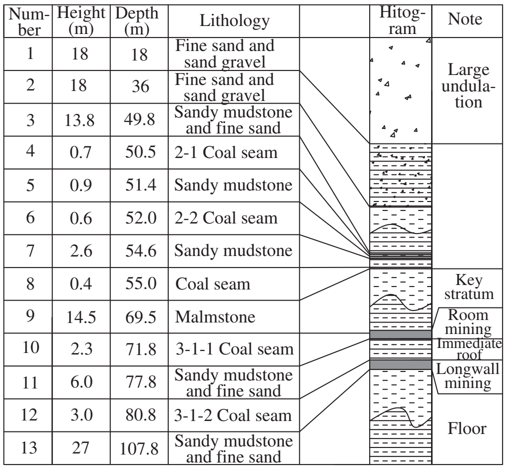


Fig. 1. Composite histogram of 3-1-2 seam.

2. Geological conditions

The 3-1-2 seam at Shigetai coal mine is a typical shallow depth seam with average depth about 80.8 m, thin bedrock (50 m or less), and thick unconsolidated sand. Its average thickness is 3.0 m, and its roof is mainly sandy mudstone and fine sandstone, with localized sandstone roof. The floor is mainly sandy mudstone, followed by siltstone and fine sandstone. The average thickness of the 3-1-1 seam is 2.3 m without rock partings. Its roof is mainly sandstone and sandy mudstone. The three boreholes in panel 131201 showed that the spacing between the 3-1-1 and 3-1-2 seams is 0.20–13.41 m with an average of 6.0 m, and its roof is mainly sandy mudstone and sandy mudstone. The composite histogram of 3-1-2 seam is shown in Fig. 1.

Shigetai coal mine had employed the room mining method to extract the 3-1-1 coal seam. The room mining method has the following disadvantages: low recovery rate (no more than 30%), high labor intensity, and plenty of potential risks [13]. In order to increase the recovery rate and economic and social benefits, the fully mechanized longwall mining method was implemented to exploit the 3-1-2 coal seam.

3. Physical simulation analysis

Physical simulation experiment is based on the similar theory and dimensional analysis. It was used to study the changing characteristics of stress field and the strata movement induced by the underground mining activity. It has been widely applied in the engineering fields such as mining, geology, and railway [14]. The materials used to simulate the strata consist of two parts: basic materials and cementing agent. The former includes sand and mica powder, and the latter includes plaster and calcium carbonate ($CaCO_3$). According to the field conditions, the simulation model of geometric ratio was determined as $Cl = 1/80$, and the volume-weight ratio of $Cr = 1.7/2.7$.

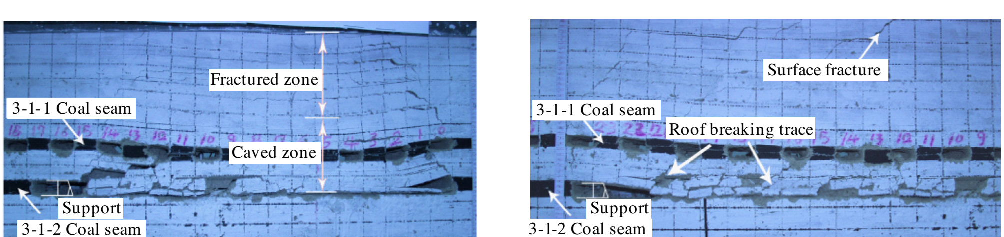
Based on the rock mechanics property tests, the proportion of each materials component used to simulate various strata are shown in Table 1.

The simulation strategy began with room mining in the 3-1-1 coal seam, and when the strata movement caused by the mining had stabilized, the longwall mining in the 3-1-2 seam began. When the mining face in the 3-1-2 seam had advanced 38.4 m, periodic weighting of the main roof began. As the face continued to advance, the main roof periodic weighting occurred at an interval of about 12.5 m. Area of crack development and displacement continued to increase until it reached the surface, forming "two zones" in the overburden: caved zone and fractured zone, as shown in Fig. 2a. The whole overburden collapse and surface step subsidence are shown in Fig. 2b.

The immediate roof collapsed frequently with the face advancing, some roof hanging phenomenon behind the support also occurred, with the longest value of 15 m. The room mining remnant pillars are in a state of "Elastic inside-Plastic outside" that will transfer the overburden load to the immediate roof. When the

Table 1
Material proportion of physical simulation experimental.

Lithology	Model depth (m)	Sand (kg)	Plaster (kg)	$CaCO_3$ (kg)	Water (kg)	Layer	Pressure cell
Fine sand and sand gravel	22.5						
Sandy mudstone and fine sand	17.3	113.5	6.5	9.7	17.3	8	
Coal seam	0.8	5.4	0.3	0.5	0.8		
Sandy mudstone	1.1	7.3	0.4	0.6	1.1		
2-1 Coal seam	0.7	4.8	0.3	0.4	0.7		
Sandy mudstone	3.3	21.3	1.2	1.8	3.3	2	
2-2 Coal seam	0.5	3.4	0.2	0.3	0.5		
Malmstone	18.1	119	8.5	8.5	18.1	5	
3-1-1 Coal seam	2.8	18.5	1.1	1.6	2.8		
Sandy mudstone and fine sand	7.5	48.9	2.8	4.2	7.5	4	10
3-1-2 Coal seam	3.3	22	1.3	1.9	3.3		
Sandy mudstone and fine sand	12.5	82	7.0	4.7	12.5		



(a) Caved zone and fractured zone (b) Whole overburden collapse

Fig. 2. Overburden movement caused by longwall mining under remnant pillars: (a) caved zone and fractured zone, (b) whole overburden collapse.