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Ground pressure and overlying strata structure for a repeated mining face of residual coal after room and pillar mining

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ABSTRACT

To investigate the abnormal ground pressures and roof control problem in fully mechanized repeated mining of residual coal after room and pillar mining, the roof fracture structural model and mechanical model were developed using numerical simulation and theoretical analysis. The roof fracture characteristics of a repeated mining face were revealed and the ground pressure law and roof supporting conditions of the repeated mining face were obtained. The results indicate that when the repeated mining face passes the residual pillars, the sudden instability causes fracturing in the main roof above the old goaf and forms an extra-large rock block above the mining face. A relatively stable "Voussoir beam" structure is formed after the advance fracturing of the main roof. When the repeated mining face passes the old goaf, as the large rock block revolves and touches gangue, the rock block will break secondarily under overburden rock loads. An example calculation was performed involving an integrated mine in Shanxi province, results showed that minimum working resistance values of support determined to be reasonable were respectively 11,412 kN and 10,743 kN when repeated mining face passed through residual pillar and goaf. On-site ground pressure monitoring results indicated that the mechanical model and support resistance calculation were reasonable.

1. Introduction

For many years, the major working of small coal mines in China involved the room and pillar mining method. This mining configuration involved great degrees of risk and uncertainty, with numerous abandoned coal pillars and a low recovery rate. Consequently, large coal resources were abandoned. A relatively unique mining method, the repeated mining of residual coal, has been proposed for the retrieval of residual coal deposits that were damaged and abandoned by this old-style mining method [1,2]. This repeated mining is performed in a residual coal deposit damaged by disorderly mining. However, the abnormal roof fracturing and movement in such repeated mining practices have resulted in serious threats to the safety of workers and equipment, such as those associated with mine pillars [3,4]. In repeated mining of residual coal, there have been frequent accidents by way of abnormal roof collapse such as mine-face roof falls and support failures, resulting in great economic losses and casualties [5].

To address the challenges of abnormal pressure characteristics of the face roof and its control, Zhang et al. [6] conducted theoretical analysis of a main roof fracture step size based on Ref. [7]. Believing that the roof rock in the residual coal zone rock is in a state of coexisting "complete-not completely collapse-complete collapse", Zhang et al. proposed four structures for the roof above a residual-coal repeated mining face and constructed corresponding mechanical models. Ref. [8] developed a "dispersion-block" structural model for the repeated mining face roof and studied the roof structure instability and roof-fall mechanism associated with a residual pillar based on dispersion and block theories. Building on a study of Ref. [8], Zhu et al. [9] developed a force model for a repeated mining face support system associated with a "dispersion-block" roof structure and derived a calculation equation for support loading. It is inevitable that repeated mining of residual coal will encounter empty areas resulting from the original mining. Based on key-block theory, Bai and Hou [10] and Zhang et al. [11] established a mechanical model for an unsupported roadway roof and proposed a high-water-content backfill material and a roof-control method when the mining face passes through empty roadways. Liu et al. [5] developed a fracture mechanical model for a repeated mining face that passes under an unsupported roadway roof to reveal the basic initial fracture mechanism; they also derived calculation equations for support loading to represent conditions before and after the repeated mining face passes through an empty roadway.

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However, current research on the damage characteristics of roof movements and control mechanism when a repeated mining face passes through old mining residual pillars and goafs is relatively scarce. Old mining residual pillars and goafs alternate in small coal mines, which significantly increases the roof fracture complexity and control difficulties in repeated mining.

To address issues such as ground pressure abnormalities and roof control difficulties in a repeated mining fully mechanized caving face of residual coal after small scale room and pillar mining, a specific residual coal repeated mining project in an integrated mine in Shanxi province was studied. The repeated mining face roof movements and fracture characteristics were analyzed, and a mechanical model of the roof-support structure for a mining face that passes through old residual pillars and goafs was developed. The study results yielded repeated mining face roof-control mechanisms, a reasonable resistance calculation formula for the working resistance of support, and a basis for selecting supports and working resistance settings in a repeated mining face.

2. Geological overview of the project

The integrated coal mine in Shanxi consists of five small coal mines and has a design production capacity of 0.60 Mt/a, primarily from mining of 3# coal seam. This coal layer is at an average depth of 370 m and has a thickness of 3.06–5.02 m, with an average of 4.23 m. The coal is sufficiently stable for mining. The intermediate roofs are composed mostly of siltstone and mudstone with a thickness of 15.0–18.1 m. The roof rocks are thinly to moderately thickly bedded, and this particular level contains abundant plant debris and relatively well-developed fissures. The floor is composed of black mudstone with some siltstone.

Limited by coal mining technology and equipment, small coal mines have been using room and pillar mining for the 3# coal seam prior to integration, with a criss-crossing roadway layout. A site survey revealed that the mining of small coal mines has usually included manual construction of cut-in holes in the floor of 3# coal seam. These holes are 2 m wide, 2 m high, and approximately 20 m long, and the pillar spacing is approximately 15 m. Subsequently, rib expansion was performed on the cut-in holes a distance of 2–3 m on either side. A residual coal pillar was formed between adjacent goafs after mining; these residual pillars are roughly 20 m long and 11 m wide, as shown in Fig. 1. The mine roadways are approximately 3 m wide and 2 m high. This type of old small coal mine room and pillar mining poses many difficulties for control of the repeated mining face roof.

3. Numerical simulation of the repeated mining face

3.1. Model construction

The numerical calculation software product FALC3D was used to construct a numerical model. The model takes into account the geologic conditions of repeated mining of the 3rd-layer residual coal in such a mine. The dimensions of the model are 222 m × 158 m × 69.5 m. The model includes displacement control boundaries. The side horizontal displacement is set to zero, and the vertical and horizontal displacements of the bottom are both set to zero. The top surface is allowed to move freely. A uniform vertical load of 7.5 MPa is exerted on the top surface to simulate the load from the weight of the overlaying strata.

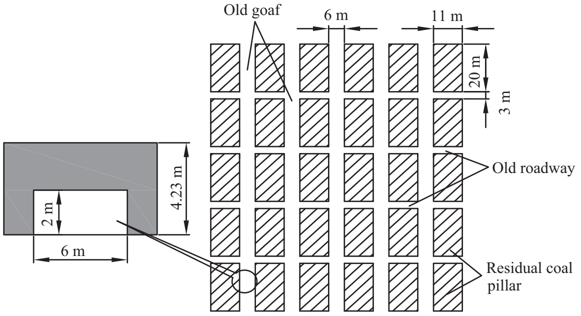

Fig. 1. Small coal mine room and pillar mining layout (m).

The model uses Mohr–Coulomb constitutive relations. Due to the original mining damage and the long-term effects of the overlying rock load, the residual coal layer is modeled as a low-elasticity-modulus medium with a Poisson's ratio of nearly zero [12]. Specific parameters are shown in Table 1.

3.2. Simulated plan

After constructing the initial model, a null command is used to model a series of original 3 m × 2 m (width × height) roadways and 20 m × 6 m × 2 m (length × width × height) goafs. The coal pillars cut by the roadways and goafs are the residual coal pillars, with lengths and width of 20 m and 11 m, respectively. Model calculations were performed until a balance was achieved.

The coal shearing is simulated by stepped excavation of the repeated mining face. Due to the limitations of the model's dimension, the excavation step size is set to 1 m, the sheared excavation height is set to 2 m, and the support coal caving is set to 2.23 m. The simulated excavation plan is shown in Fig. 2. In the simulation, to characterize the continuous advancement of the mining face and the delayed impact of caving on the mining face advancement, 98% of the maximum balance force release rate [13,14] is selected to limit the number of calculation steps between two cavings of the mining face.

3.3. Analysis of simulation results

3.3.1. Repeated mining face passing residual coal pillar

The curves of vertical stresses and deformation associated with the repeated mining face roof with various advancing step sizes when passing a residual coal pillar are shown in Fig. 3.

Due to the old residual coal pillars and goafs, the roof vertical stress and deformation curves in front of the repeated mining face generally display wavy variations. Fig. 3a shows that after exposing an old residual coal pillar and as the mining face continues to advance, the vertical stress in the roof above the coal pillar in front of the mining face gradually decreases. The roof vertical stress above the second coal pillar in front of the mining face gradually decreases after an initial increase. The roof stress gradually increases starting from the third coal pillar, and the amount of increased stress decreases with distance from the mining face. Moreover, as shown in Fig. 3b, with continuous advancement of the repeated mining face, the roof deformation in front of the mining face displays a gradual increasing trend; however, abnormality appears at the second coal pillar in front of the face. As the mining face advances, the deformation at the second coal pillar gradually increases. When the advancement of the mining face into the coal pillar exceeds 6 m, the deformation of the roof above the first pillar and goaf increases sharply, whereas the deformation of the second coal pillar starts to decrease and displays a roof rock "rebound" phenomenon.

Fig. 4 shows variations, with various sizes of advancement steps, in the extent of elastic deformation in the repeated mining face roof rock upon passing the residual coal pillar.

As shown in Fig. 4, due to the impact of repeated mining face advance pressure bearing, the exposed coal pillar is already in a state of elastic deformation as the face exposes the pillar. At the initial stage of repeated mining face excavation, there is no clear