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Strata behavior in extra-thick coal seam mining with upward slicing backfilling technology

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ABSTRACT

Based on the character of upward slicing backfilling mining and the condition of Gonggeyingzi coal mine in Inner Mongolia, this paper describes the studies of the strata behavior and the stress distribution in the process of backfilling mining in extra-thick coal seams. This was achieved by setting up and analyzing the elastic foundation beam model using the ABAQUS software. The results show that: (1) With the gradual mining of different slices, the roof appears to bend continuously but does not break. The vertical stress in the roof decreases and the decreasing amplitude reduces, while the tensile stress in the roof grows with the mining slices and the maximum tensile stress will not exceed the allowable tensile stress. (2) The front vertical stress at the working face exceeds the rear vertical stress and both show a trend of decrease with decreasing amplitude of decrease. (3) The slices mined early have more influence on the surrounding rock than the later ones. Similarly, the strata behavior experiences the same trend. The field measured data show that the roof does not break during the mining process, which is consistent with the conclusion.

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1. Introduction

There are many extra-thick coal seam reserves of over 10 m thickness in Shanxi [1], Gansu, Inner Mongolia, and Xinjiang provinces in China. The special conditions of these reserves make it difficult to exploit them. The mining method and rock control in extra-thick coal seams have always been an important topic for researchers [2–4]. So far, the main method of exploiting the nearly horizontal and gently-inclined extra-thick coal seams is caving mining [5–8]. As for the steeply-inclined extra-thick coal seams, slicing mining is widely applied [9–11]. However, these methods lead to severe strata movement and serious surface subsidence, and fail to meet the requirements for mining extra-thick coal seams under bodies of water, buildings, and railways. In order to solve those problems, the backfilling mining group in China University of Mining and Technology (CUMT) has developed an upward slicing backfilling mining technology.

Researchers have carried out many studies on exploiting extra-thick coal seams and strata behavior in backfilling mining. By setting up a narrow plate model, Shi et al. [10,11] analyzed the failure characteristics of surrounding rocks in steeply-inclined extra-thick coal seams. Ju [9,12] developed the model of the main roof of an inclined extra-thick coal seam by using the cantilever beam theory and studied the strata behavior in steeply-inclined extra-thick coal seams using similar materials and numerical simulation methods. Lu et al. [13] analyzed the equilibrium structure of the fully mechanized caving method and studied the interaction between roof and coal. Based on the key strata theory, Kong and Yu [2,8] studied the method for determining the working resistance of the support in caving mining. As for the strata behavior of backfilling mining, Miao and Zhang [14–20] developed the equivalent mining height theory, which is helpful in studying the particularity of strata behavior. All these theories focused on the study of the mining of extra-thick coal seams and backfilling technology, but did not deal with strata behavior in upward slicing backfilling technology.

Based on the condition of Gonggeziying coal mine, this paper describes the construction of a model of a combined beam on an elastic foundation from which the equation of the deflection curve of the roof during the mining process was derived. The strata movement and stress distribution are produced by numerical simulation using ABAQUS. Combining the theoretical analysis with the numerical simulation, the strata movement in extra-thick coal seam mining is predicted with the new method and described in this paper. All the data collected from the field monitoring validate the conclusions from this study.

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2. Geological conditions and mining methods

2.1. Geological conditions

Gonggeyingzi coal mine of the Xilamulun group covers an area of about 0.42 km^2 with reserves of 12.7859 million tons. The #6 coal includes 6-1 and 6-2 coal seams, with the 6-2 seam as the main seam with an average thickness of 21.0 m and an inclination of 2.4°. The depth of the coal seam is 104 m with a 78.3 m bedrock. The Quaternary alluvium is 25.7 m thick and includes a 21.7 m aquifer. The roof of the 6-2 seam is 24.5 m thick grey sandstone. The floor is sandy shale 16 m in thickness. The relative gas emission is 1.78 m^3/t and the absolute gas emission is 0.99 m^3/min, making it a low gas mine.

The Laoha River passes through this area and provides an endless water supply for the aquifer, making the hydrological conditions complicated. The average water volume is 280 m^3/h and the maximum is 380 m^3/h. The buildings and farms on the surface also contribute to the difficulty of mining. The specific geological conditions are shown in Fig. 1.

2.2. Mining method

The upward slicing backfilling mining technology (hereinafter referred to as "USBMT") makes it possible to ensure that the operation will not be influenced by the water body and can protect the buildings and farms on the surface from damage caused by mining operation. The 21.0 m thick seam is divided into 6 slices, each 3.5 m in height. The first slice to be mined should be the lowest slice, followed by the upper slices.

There is an independent production system in each slice. All the entries will be backfilled after mining in each slice and then used as the floor of the immediate upper slice when the backfilled mass body becomes stable. When the lower slice is finished, a new system in the upper slice will be arranged. There are many ways to backfill the gob, for example; solid backfilling, paste backfilling, and cemented backfilling. According to the site specific conditions, cemented backfilling was selected to achieve the high backfilling ratio. Fig. 2 illustrates the backfilling mining system and Fig. 3 shows a field photo of the backfilling effect.

3. Analysis of the characteristics of roof movement

3.1. Mechanical model of USBMT

Research on the behavior of the roof of an extra-thick coal seam was performed by applying Winkler's elastic foundation beam theory. The support body is the combined strata, consisting of the backfilling mass body and coal seam. With the development of mining operations, the thickness of the combined strata changes. To simplify the problem, the filling ratio of the filling body, time and other factors are not taken into consideration. The load of the overlying plate is simplified as a vertical force q_0. The combination of elastic foundation beam model is set up along the advance direction of the working face. The elastic foundation beam is shown in Fig. 4.

In Fig. 4, M represents the total seam thickness, N represents the number of slices, h_1 represents the total coal seam thickness, h_2 represents the thickness of backfilled slices and k_1 and k_2 represent the elastic foundation coefficient of coal and filling body respectively.

According to the definition of an elastic foundation coefficient, k_1 and k_2 are:

$$\begin{cases} k_1 = E_1/h_1 \\ k_2 = E_2/h_2 \end{cases} \tag{1}$$

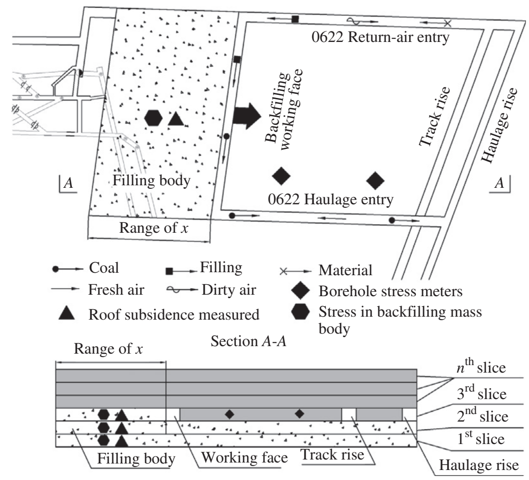

Fig. 2. USBMT system in extra-thick coal seam.

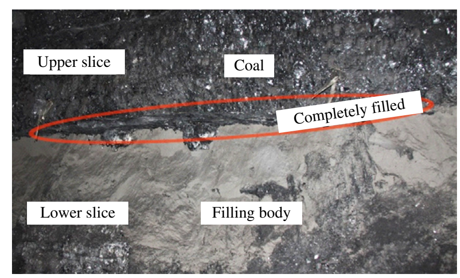

Fig. 3. Field photo of backfilling effect.

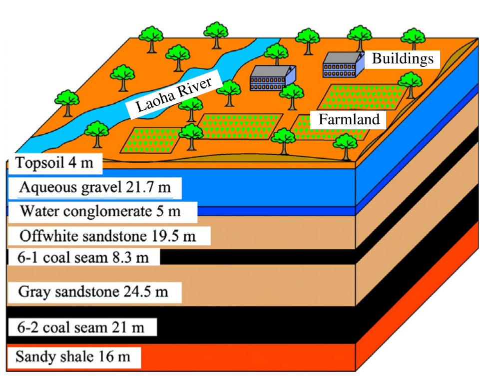

Fig. 1. Geological conditions.

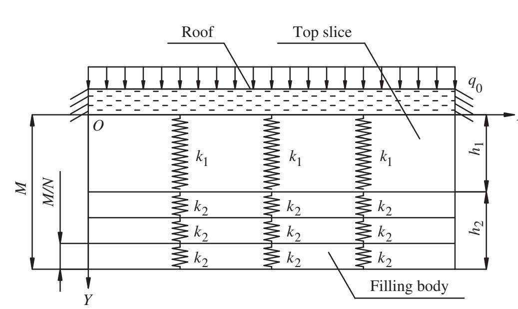

Fig. 4. Mechanical model of USBMT.

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