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Zonal extraction technology and numerical simulation analysis in open pit coal mine

Chen Yanlong [a,b,*], Cai Qingxiang [a], Shang Tao [a], Peng Hongge [a], Zhou Wei [a], Chen Shuzhao [a]

[a] School of Mines, China University of Mining & Technology, Xuzhou 221116, China

[b] Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University, Fukuoka 819-0395, Japan

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ABSTRACT

In order to enhance coal recovery ratio of open pit coal mines, a new extraction method called zonal mining system for residual coal around the end-walls is presented. The mining system can improve economic benefits by exploiting haulage and ventilation roadways from the exposed position of coal seams by utilizing the existing transportation systems. Moreover, the main mining parameters have also been discussed. The outcome shows that the load on coal seam roof is about 0.307 MPa and the drop step of the coal seam roof about 20.3 m when the thickness of cover and average volume weight are about 120 m and 0.023 MN/m^3 respectively. With the increase of mining height and width, the coal recovery ratio can be improved. However, when recovery ratio is more than 0.85, the average stress on the coal pillar will increase tempestuously, so the recovery ratio should also be controlled to make the coal seam roof safe. Based on the numerical simulation results, it is concluded that the ratio of coal pillar width to height should be more than 1.0 to make sure the coal pillars are steady, and there are only minor displacements on the end-walls.

1. Introduction

Because of slope angle, mining boundary, changes of coal seam thickness, and so on, a large number of coal will be left under the end-walls in the open pit coal mines [1–3]. In traditional mining systems, the coal under the end-walls will be buried by the inner dumping site. The coal resources are normally discarded and wasted in vain. So how to recycle the residual coal under the end-walls with safe and efficient methods is a valuable and challenging research.

To recover coal remnants around the end-walls, underground mining system is normally adopted by excavating some adits into end-walls [4–6]. Due to long wall underground mining system, the fully caving method is used to manage the coal roof, and it will cause a greater ground subsidence [7,8]. Hence, zonal mining is usually adopted in some regions where only minor ground placement is permissible [9,10]. In zonal mining system, the coal field is divided into some regular strips, one strip is mined and the next strip is reserved. The reserved strips can support the load of the overburdened strata, as a result only minor and uniform movements happen on the ground [11–15]. Thus, some unrecoverable reserves can be extracted on the premise of the controllable ground subsidence. Practice has proved that zonal mining is an effective method to control the overlying strata and ground subsidence, and is usually used for extracting coal seams under buildings and railway lines [16–21]. According to the past investigations about zonal mining technology, we try to recover the residual coal under end-walls of open pit mines. Thus, the key issue of this research is to ensure the extraction system and mining parameters.

2. Zonal extraction system for residual coal around end-walls

There was a lot of coal which could not be mined because of end-walls covering at the studied open pit coal mine. And it is a good solution to recycle the coal remnants by zonal mining with existing production systems.

In the extraction system, the interval at which the main haulage and ventilation roadways are excavated from the exposed position of coal seam in end-walls, and the exploitation zone during two haulage roadways in the mining area is shown in Fig. 1. Each mining area is alternatively established in a similar way. After the haulage and ventilation roadways are formed, exploitation roadways will be excavated. After the mining roadways are excavated, working faces will be laid out towards the left and right of the main ventilation roadway and a retreated mining manner is carried out.

3. Zonal mining parameters [6,21]

3.1. Load on the coal seam roof

In the zonal mining system, the roof is born the load includes not only the deadweight, but also the overburden load of upper

* Corresponding author. Tel.: +81 80 43163456.
E-mail address: chenyanlongcumt@gmail.com (Y. Chen).

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Table 1
Mechanics properties of the rock layers.

Lithology	Thickness (m)	Volume weight (MN/m^3)	Elastic modulus (MPa)
Loess	30	0.0196	150
Weathered sandstone	14	0.0230	2000
Sandstone	30	0.0238	4200
Mudstone	24	0.0249	2800
Siltite	12	0.0232	4600
Sandstone	12	0.0238	5500
Coal	8	0.0144	1000

rock. According to the combination beam theory, the nth load of rock layer on the rock (assumed the first layer) can be calculated with the following formula [22].

$$(Q_n)_1 = \frac{E_1h_1^3(\gamma_1h_1 + \gamma_2h_2 + \cdots + \gamma_nh_n)}{E_1h_1^3 + E_2h_2^3 + \cdots + E_nh_n^3} \quad (1)$$

where $(Q_n)_1$ is the nth load of rock layer on the first layer, MPa; E the elastic modulus of rock, MPa; h the thickness of rock, m; and γ the volume weight of rock, MN/m^3. According to the Table 1, the load on the coal seam roof is calculated as follows:

The first dead weight of the rock layer q_1 is: $q_1 = \gamma_1h_1 = 0.0238 \times 12 = 0.2856$ MPa

The second load of layer on the first rock layer $(q_2)_1$ is:

$$(q_2)_1 = \frac{E_1h_1^3(\gamma_1h_1 + \gamma_2h_2)}{E_1h_1^3 + E_2h_2^3} = 0.3071 \text{ MPa}$$

The third load of layer on the first rock layer $(q_3)_1$ is:

$$(q_3)_1 = \frac{E_1h_1^3(\gamma_1h_1 + \gamma_2h_2 + \gamma_3h_3)}{E_1h_1^3 + E_2h_2^3 + E_3h_3^3} = 0.1929 \text{ MPa}$$

If found that $(q_3)_1$ is less than $(q_2)_1$, then we should consider the first and second loads of rock layers on the first layer, because the third layer is thick, and has no effect on the first one. Therefore, the load of coal seam roof is about 0.307 MPa.

3.2. Drop step of the coal seam roof

In zonal mining system, the roof of coal seam is supported by coal pillars, so the immediate roof and the main roof can be considered as a fixed board while the drop step of the roof in the mining room can be derived from the stress analysis of a board model [22].

If we assume

$$l_m = \frac{h}{1-\mu^2}\sqrt{\frac{2S_t}{q}} \quad (2)$$

where l_m is the drop step criterion; h the thickness of the overburden rock, m; μ the Poisson's ratio of coal; S_t the tensile strength of the rock mass, MPa; and q the upper rock load on the coal seam roof, MPa.

Then Eq. (3) can be obtained as:

$$l = \frac{b}{\sqrt{2}l_m}\sqrt{b^2 - \sqrt{b^4 - 4l_m^4}} \quad (3)$$

where l is the drop step of coal seam roof, m; and b the length of the working face, m.

According to the design of mining system and geological data, the values of all variables in Eq. (3) and the calculation result of the drop step are shown in Table 2.

3.3. Mining width

The mining width is related to the mining depth. Practice shows that lumpy displacements will not occur on the surface if the mined width meets the following condition:

$$\frac{H}{10} \leqslant B_m \leqslant \frac{H}{4} \quad (4)$$

where B_m is the mining width, m; H the mining depth, m.

From Table 1, the coal seam is about 120 m from the ground. According to Eq. (4), the mining width of coal seam is: $12.0 \text{ m} \leqslant B_m \leqslant 30$ m.

Meanwhile, from the mentioned result, the drop step of coal seam roof is about 20.3 m. If the mining width is less than 20.3 m, it is good for controlling the roof. Hence, the reasonable value of the mining width is: $12.0 \text{ m} \leqslant B_m \leqslant 20$ m

3.4. Coal pillar width

In this paper, the coal pillar width was analyzed by invoking the Obert-Dwvall formula [22]:

$$R = R_c\left(0.778 + 0.222\frac{B_c}{h_m}\right) \quad (5)$$

where R is the strength of the coal pillar, MPa; R_c the uniaxial compressive strength of the coal block, MPa; B_c the width of the coal pillar, m; and h_m the height of the coal pillar, m.

The average stress on the coal pillar can be derived from the Tributary area theory:

$$\bar{R} = (B_m + B_c)k\gamma H/B_c \quad (6)$$

Table 2
Calculation result of the drop step.

Variables	b (m)	h (m)	μ	S_t (MPa)	q (MPa)
Value	100	12	0.30	0.40	0.307
Drop step of coal seam roof (m)	20.3				

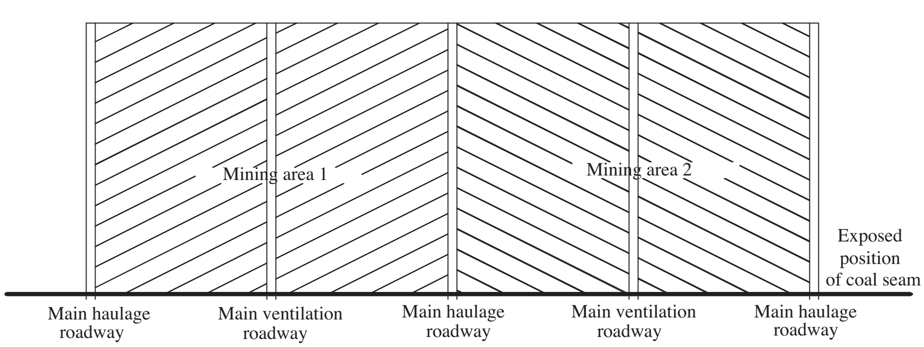

Fig. 1. Mining area of zonal mining system.