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Application of Adit-strip Pillar Mining System for Recovering Remaining Coal in Open Pit Mine

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Abstract: *Because of low slope angle in truck-shovel inpit dumping system and great mining depth, a great deal of remaining coal was left around the final end-wall slope in Chinese open pit mines. This paper describes an adit-strip pillar extraction system to recover the remaining coal. Meanwhile, the strip pillar design methodologies in adit-strip pillar system were investigated. It is indicated that the strip coal pillar width will increase with mining strip width and mining height. However, the coal extraction ratio will increase. Then, the reasonable design equation of the width of the adit-strip system was obtained.*

Keywords: *adit-strip pillar system; recover; remaining coal; end-wall slope; in pit dumping; open pit coal mine*

1. INTRODUCTION

As is known, open pit mining has many advantages such as large output, low cost, simple mining technology and operating safety. Therefore, it is adopted prior in main coal producing countries of the world[1].Currently, the average dip angle of coal seams in most of Chinese open pit coal mines is usually less than eight degrees, which belongs to flat coal seams[2, 3]. In order to reduce haul distance of truck, truck-shovel in pit dumping system is commonly adopted. For this system, haul roads of trucks are usually arranged above the end-wall slope[4, 5]. To meet requirements of haul roads, wide transportation benches have to be left, which makes the slope angle of end-wall slope become small, and the final slope angle is usually less than the stable one. Consequently, a large quantity of coal has to be left under the final end-wall slope, that is called remaining coal. For these remaining coal resources, they will be buried again by the in pit dumping site. Therefore, the remaining coal around end-wall slope is, essentially, the coal occupied by final end-wall slope due to the limitations of mining operation technologies in open pit coal mines and that is normally discarded and wasted in traditional mining systems.

Based on geological data of mining depth, coal seam thickness, end-wall slope angle and end-wall slope length in some main open pit coal mines of China, we have calculated the remaining coal quantity of main large-scale open pit coal mines in China. It is shown that remaining coal quantity is usually more than 100 Mt in most of the coal mines, and some can reach nearly 400 Mt. Therefore, total quantities of remaining coal in Chinese open pit coal mines are very considerable. However, if these remaining coal resources cannot be extracted in time, they will be impossible to be recovered once more in future.

Even though more and more researchers begin to focus on the study of remaining coal[5, 6], in terms of the literatures about acceptable extraction systems for remaining coal, there are seldom until now. A simple room and pillar extraction system was carried out to recover some remaining coal resources [7], but there are some prominent disadvantages for this system, such a slow recovery ratio and production efficiency, poor safety and so on. Therefore, the system only can be considered to carry out in small-scale open pit mines with simple geological conditions. Considering these mentioned results, an alternative mining system has to be introduced to extract remaining coal under current conditions in a manner that is both safe and economical, and then the introduction of an adit-strip pillar system is flexible.

2. ADIT-STRIP PILLAR EXTRACTION SYSTEM

In the system, to recover the remaining coal of final end-wall slope in an open pit coal mine, firstly the interval haulage and ventilation a dits are excavated from the exposed coal seam of the end-wall slope. After the haulage and ventilation a dits are formed, exploitation roadways will be excavated. The adits and roadways are excavated by a continuous miner or a road header and supported by conventional steel roof bolts and glass fiber rib bolts. After that, working face is laid out and a retreat mining manner by continuous miner is carried out. Each mining area is alternately established in a similar way. In this mining system, the coal field is divided into some long and regular strips, one strip is mined and the next strip is reserved. The reserved strip coal pillars can efficiently support the load of overburden strata, as a result only minor and uniform movement happens on the benches of end-wall slope. Meanwhile, because the length of pillar is long, it will have a good long-term stability. While mining, if the coal seam is very thick, then the coal seam should be divided into multiple exploitation layers, where each layer is about 3 m to 5 m thick. For these multiple exploitation layers, the upper layer is mined first. Moreover, the working face is generally supported by single hydraulic props. For this mining system, because the coal around final end-walls has been exposed, there is no extra stripping engineering quantity any more. Meanwhile, existing transportation lines of open pit mine can be utilized to transport the coal extracted from end-walls, so the transportation cost is also low. Based on these reasons, lower initial investment and mining and transportation costs are available, and the economic benefits are good.

3. STRIP PILLAR WIDTH OF THE ADIT-STRIP PILLAR SYSTEM

Pillar design is one of the most important issues in the field of ground control in coal mine[8-10]. Similarly, the strip pillar design affects the whole mining project goes well. The whole final end-wall must be stable before it is buried by inner dumping site. Meanwhile, the transportation benches should not cause failure, such as crack failure that affects the transportation system. As is known, if the strip pillar width is designed too wide, maybe it can ensure the end-wall stable, however, a lot of coal pillar will cannot be recovered, and thus the coal recovery ratio is low. But if the strip pillar width is not designed reasonably, serious end-wall failure will occur and it disturbs the regular production of the whole open pit mine.

3.1. Determination of the Load on the Strip Pillar

By loading experiment of coal pillar, it is found that the stress of coal pillar changes during loading, as shown in Fig.1. The range from stress peak (σ_{max}) to coal pillar edge is called yield (plastic) zone, where the coal stress has exceeded its yield stress. The width of the yield zone is expressed as W_Y . Moreover, the minor deformations are occurred range yield zone to coal body and the stress is less than the yield stress. This zone is surrounded and confinement by the yield zone and subjected to the elastic rule, which is called core zone[11]. It has already obtained the width of yield zone by lab experiment as Equation (1).

$$W_Y = kH_m H \tag{1}$$

where k is the proportionality factor, (m^{-1}); H_m is the coal seam thickness, (m) and H is the cover thickness, (m).

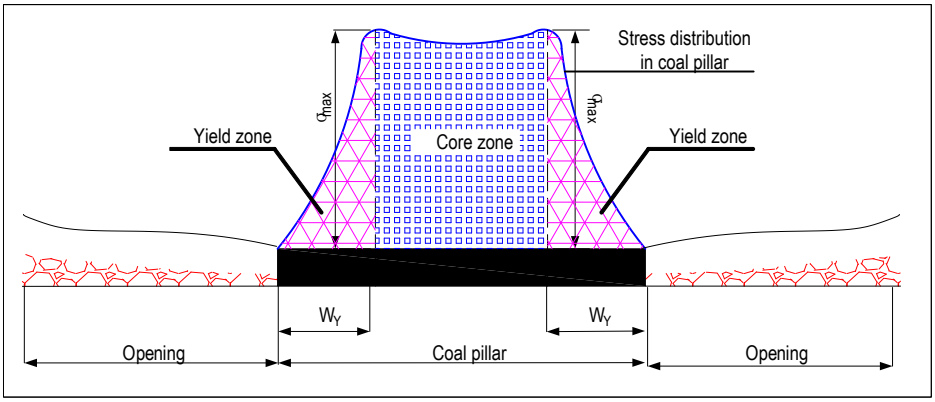

Fig1. *Yield and elastic areas of coal pillar.*

Meanwhile, it is also found that vertical stress of gob was in direct proportion to the distance from the coal wall. The vertical stress of gob will return to original rock stress (γH) when the distance from gob to coal wall reaches about 0.3*H*, as shown in Fig.2. Then, the average stress on the coal pillar can be calculated as follows:

$$\frac{a}{\gamma H}=\frac{W_{\mathrm{m}}/2}{0.3H} \tag{2}$$

$$a=\frac{W_{\mathrm{m}}\gamma H}{0.6H} \tag{3}$$

$$b=\gamma H-a=\gamma H(1-\frac{W_{\mathrm{m}}}{0.6H}) \tag{4}$$

$$\sigma_{\mathrm{L}}=\frac{W_{\mathrm{p}}\cdot\gamma H+2[\frac{1}{2}(b+\gamma H)\cdot\frac{W_{\mathrm{m}}}{2}]}{W_{\mathrm{p}}}=\frac{\gamma H(W_{\mathrm{p}}+W_{\mathrm{m}}-\frac{W_{\mathrm{m}}^{2}}{1.2H})}{W_{\mathrm{p}}} \tag{5}$$

where σ_{L} is the average stress on the coal pillar, (MPa); γ is the average bulk density of the cover rock, (MN/m^3); H is the thickness of the cover rock, (m); W_{p} is the coal pillar width, (m) and W_{m} is the mining strip width, (m).

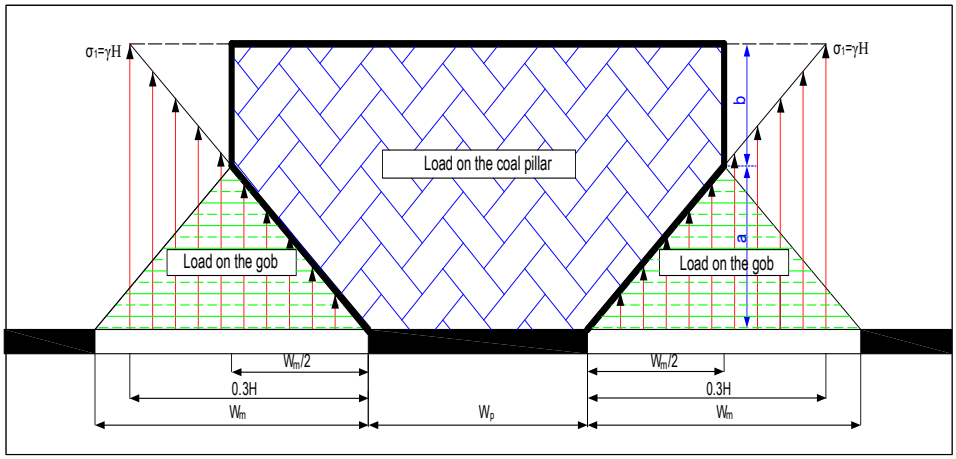

Fig2. *Sharing load on gob and coal pillar.*

3.2. Determination of the Strip Pillar Strength

According to the limit equilibrium condition under three-dimensional stress, the relation between the vertical and lateral stress is as follows:

$$\sigma_1=\frac{2c\cos\varphi}{1-\sin\varphi}+\frac{1+\sin\varphi}{1-\sin\varphi}\sigma_3 \tag{6}$$

where σ_1 is the vertical stress on coal body, (MPa); σ_3 is the lateral stress on coal body, (MPa); c is cohesion of coal, (MPa) and φ is friction angle of coal, (degree).
Moreover, the lateral stress can be expressed as:

$$\sigma_3=\lambda\gamma H \tag{7}$$

where λ is the lateral stress to the vertical stress ratio.
From Equations (6) and (7),

$$\sigma_1=\frac{2c\cos\varphi}{1-\sin\varphi}+\frac{1+\sin\varphi}{1-\sin\varphi}\lambda\gamma H \tag{8}$$

Because the length of coal pillar is much more than its width, it can be considered as a plane problem; and the coal pillar strength (σ_S) can be calculated according to the Figure 3:

$$\sigma_S = \frac{[W_p + (W_p - 2W_Y)]\frac{\sigma_1}{2}}{W_p} = \frac{\sigma_1(W_p - W_Y)}{W_p} \tag{9}$$

From Equations (1), (8) and (9), the coal pillar strength can be obtained:

$$\sigma_S = \frac{(\frac{2c\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\lambda\gamma H)\cdot(W_p - kH_m H)}{W_p} \tag{10}$$

3.3. Determination of the Strip Pillar Width

It is assumed that the safety factor is f, and then the coal pillar strength and load on coal pillar will have following relation:

$$\sigma_S = f \cdot \sigma_L \tag{11}$$

According to Equations (5), (10) and (11), the minimum coal pillar width should be:

$$W_p = \frac{kH_m H \cdot (\frac{2c\cdot\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\cdot\lambda\gamma H) + f\gamma H(W_m - \frac{W_m^{\ 2}}{1.2H})}{\frac{2c\cdot\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\cdot\lambda\gamma H - f\gamma H} \tag{12}$$

4. Mining Strip Width of the Adit-Strip Pillar System

The mining width is related to the mining depth[12]. Practice shows that lumpy displacements will not occur on the open pit if the mined width meets the following condition:

$$W_m \le \frac{H}{3} \tag{13}$$

where W_m is mining strip width, (m) and H is thickness of the cover rock, (m).

Actually, the mining strip width will affect the extraction ratio of working face for this mining system. As we know, for any mining operation, the calculation of the extraction ratio is very important, which determines the financial feasibility of the project. According to the mining system, extraction ratio of working face ρ can be expressed as follows:

$$\rho = \frac{W_m H_p}{(W_m + W_p)H_c} \tag{14}$$

where H_p is mining height or coal pillar height, (m); W_p is coal pillar width, (m); H_c is thickness of the coal seam, (m).

From Equation (12), we can obtain the relation between coal pillar width and mining strip width and mining height, and extraction ratio and the mining strip width and mining height. Based on the geological conditions of coal seam in an open pit coal mine[13], the relation between coal pillar width and the mining strip width and mining height is shown in Fig. 3, and the relation between extraction ratio and the mining strip width and mining height is shown in Fig.4.

From Fig. 3, it is indicated that the coal pillar width will increase with rises of mining strip width and mining height. However, the coal extraction ratio will increase, as shown in Fig. 4. To improve the coal extraction ratio, we should increase the values of mining height and strip width as much as possible under suitable conditions. Therefore, for the adit-strip pillar system, the mining strip width will be designed as Equation (15).

$$W_{\mathrm{m}} = \frac{H}{3} \tag{15}$$

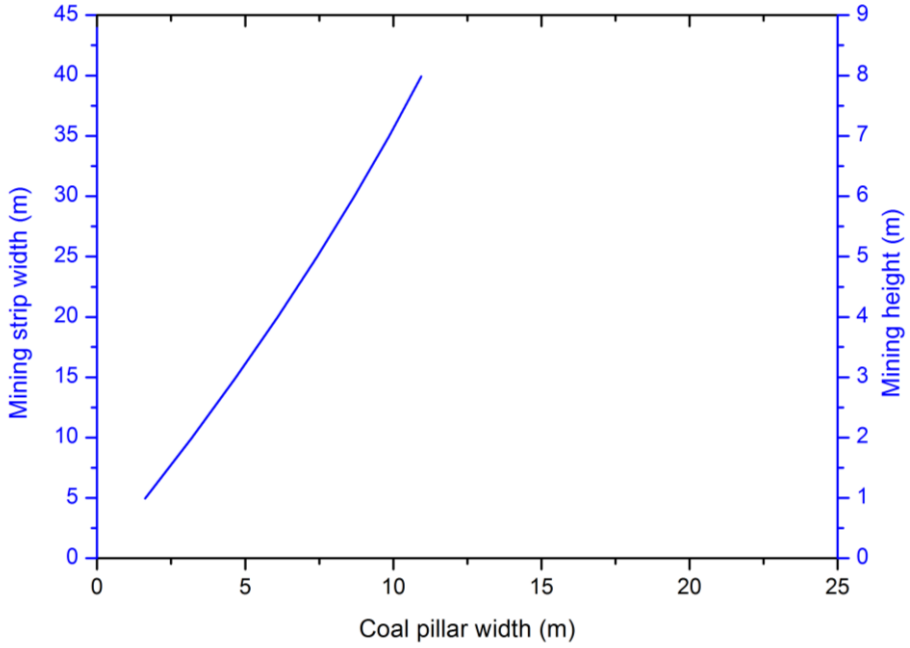

Fig3. *The relation between the coal pillar width and the mining strip width and mining height.*

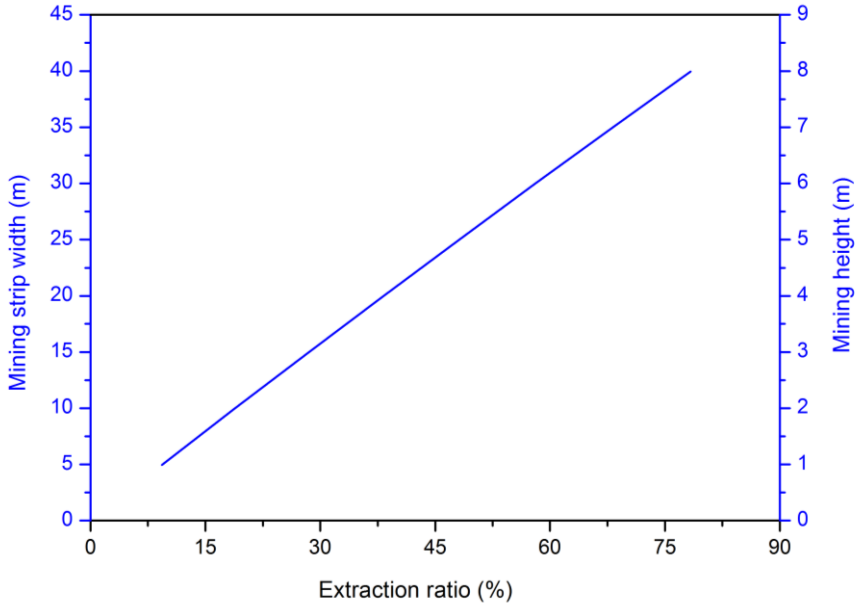

Fig4. *The relation between the extraction ratio and the mining strip width and mining height.*

5. CONCLUSIONS

The adit-strip pillar extraction was described to extract the remaining coal around end-wall slope in open pit coal mine. Also, the design method of the main parameters of the system was studied, such as the strip coal pillar width, mining strip width and shift analysis of the adits. For adit-strip mining system at open pit mines, because the coal around final end-walls has been exposed, there is no extra stripping engineering quantity any more. As a result, the mining cost may be reduced. Meanwhile, existing transportation lines of surface mine can be utilized to transport the coal extracted from end-walls, so the transportation cost is also low. Considering these results, the adit-strip pillar mining system is a considerable and effective method regarding the remaining coal around final end-walls in Chinese open pit coal mines. The system, if applied to open pit coal mines, would improve coal recovery and reduce environmental problems with less risk and greater.

Then, it is indicated that the strip coal pillar width will increase with increases of mining strip width and mining height. However, the coal extraction ratio will increase. Therefore, in order to improve the coal extraction ratio, we should increase the values of mining height and strip width as much as possible under suitable conditions. Then, the reasonable design equation of the width of the adit-strip system was obtained.

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