Study on reasonable width of coal pillar near the edge of panel based on prevention and control of rock burst

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Abstract: The reservation of the coal pillar with reasonable width is the key to ensuring safe recovery of mining areas and working faces along the goaf. This paper studies the reasonable width of the coal pillar in the south wing of the 302 and the 301 panels by taking a mine in the Mengshan Base as an example, using theoretical research, numerical simulation and on-site measurement analysis. The three-zone theory is adopted to estimate the lateral bearing pressure of the goaf, showing that the width of the low stress zone is not less than 83 meters. The results of numerical simulation analysis show that the 20-meter coal pillar between the 1# and 2# ventilation roadways of the 201 working face has a high stress concentration, thus unable to meet the requirements for arranging small coal pillars. The high stress zone is concentrated within the lateral range of 90 meters. The micro-seismic data analysis shows that the micro-seismic accidents during the recovery of 202 working face are concentrated within the lateral direction of 80 meters. With the resource recovery and the impact of rock burst disaster prevention and control taken into consideration, this paper sets the reasonable width of the boundary coal pillar of the 302 panel to be no less than 85 meters.

1. Introduction
The reservation of the coal pillar with reasonable width is the key to the layout of the working face. It not only helps to maintain the overall stability of the coal pillar when the cut-through of plastic zone is generated during mining and excavation, but also reduces the influence of the lateral support pressure and the dynamic pressure on the tunnel of the working face to ensure the roadway safety [1-3]. The mines such as Nalinhe No. 2 in Mengshan Base has suffered from scouring problems caused by the unreasonable width of coal pillars [4-5], which threatens the safe recovery of the working face.

2. Project overview
The major production of the 302 penal of a mine in the western mining area is 3-1 coal. The mine has an average depth of 640 m and an average coal seam thickness of 5.7 m. In the south wing, the recovery of the 201 working face has been completed, and now the 202 working face is being recovered. The cumulative width of the two mining faces reaches 540 m. The traditional double lane...
excavation is used in the 201 working face, with a 2# ventilation roadway arranged 20 m outside the air return way. During the recovery of 201 working face, the frequent dynamic pressure of 2# ventilation roadway leads to serious roadway deformation. In addition, due to the impact of secondary recovery of 202 working face, it no longer meets the requirements for being a mining roadway of the adjacent 101 working face.

Based on the mining experience of adjacent mines, the reasonable coal pillar width directly determines the scouring pressure of the continuous 101 working face. This paper conducts analysis on the reasonable width of the coal pillar in the south wing of the 302 panel (hereinafter referred to as the coal pillar in the panel), through theoretical calculation, numerical simulation, and on-site measurement analysis.

3. Theoretical estimation of coal pillar width

Generally, the range excluding the impacted area of the peak pressure of the dynamic support is taken as the main basis for determining the position of gob-side entry or the width of the coal pillar in the penal [6-8]. The three-zone theory of overburden migration [9] is used to estimate the distribution of the lateral stress.

3.1 Estimation of the height of three zones

The thickness of the three zones is co-determined by the height, depth and width of mining. Understanding of the impact of mining on overburden migration and its evolution laws is of great significance in rock burst prediction and prevention. Based on the three-zone theory, this paper estimates the development height of the three loading zones under the influence of overburden mining. The calculation formula is as follows [10].

\[ H_{ILZ} = \frac{h}{K_A} - 1 \]  
\[ M_{ILZ} = H_{ILZ} \approx 10h \]  
\[ M_{DLZ} = H_{DLZ} - M_{ILZ} = \frac{L}{2} - 10h \]  
\[ M_{SLZ} = H - M_{ILZ} - M_{DLZ} \]

In the formula:
- \( H \)—height (m); \( K_A \)—hulking coefficient of rock; \( L \)—width of goaf.

From equations (1) to (3), the height of the three zones are estimated to be:

Given the characteristics of the coal seam roof layer exposed by B22 borehole, it is estimated that the thickness of the immediate loading zone is 42 meters, and that of the delayed loading zone is 186 meters (42 meters to 228 meters above the coal floor), and the height of the static load zone is 368 meters (228 meters above the coal seam floor to the surface).

3.2 Estimation of lateral static stress based on three loading zones

According to the mechanical model, the stress distribution \( \sigma \) of the coal pillar in the panel is composed of \( \sigma_\gamma \), the self-heavy stress of the overlying strata, and \( \Delta \sigma_1 \) and \( \Delta \sigma_2 \), the stress increments transmitted from the overburden of the lateral goaf.

\[ \sigma = \sigma_\gamma + \Delta \sigma_1 + \Delta \sigma_2 \]

In the formula, \( \Delta \sigma_1 \) and \( \Delta \sigma_2 \) are the lateral superimposed stresses transmitted to the coal pillar in the penal from the overburden layer of the immediate loading zone and the delayed loading zone, respectively.

Establish a coordinate system with the direction of the 2# ventilation roadway as the x-axis and the coal wall at the edge of the goaf of the 201 working face as the original point. The estimation formula of the distribution of \( \sigma_\gamma \) is:

\[ \sigma_\gamma = \begin{cases} \gamma x \tan \alpha & x \in [0, h/\tan \alpha] \\ \gamma H & x \in [h/\tan \alpha, +\infty) \end{cases} \]
In the formula, $\gamma$ is the average bulk density of the overburden.

The stress increment transmitted by the overburden layer in the goaf to the coal pillar in the panel is divided into two parts, namely, the stress increment of the immediate loading zone and the stress increment of the delayed loading zone. The stress transmitted to the coal pillar in the panel from each layer of the immediate loading zone is half of its weight, and the stress distribution is approximately in the shape of an isosceles triangle. The stress increment $\Delta \sigma_1$ on the coal pillar transmitted from the $i$-th rock layer of the immediate loading zone is:

$$
\Delta \sigma_1 = \begin{cases} 
\sigma_i \times \left(2H_0 \cot \alpha \right)^2 & x \in [0,H_0 \cot \alpha] \\
\sigma_i \times \left(2H_0 \cot \alpha - x \right)/\left(2H_0 \cot \alpha \right)^2 & x \in [H_0 \cot \alpha, 2H_0 \cot \alpha] \\
0 & x \in [2H_0 \cot \alpha, +\infty]
\end{cases} 
$$

where $\sigma_i$ is the weight of the $i$-th layer of the suspended rock in the immediate loading zone; $\sigma_i \approx \left(\cot \alpha + \cot \beta \right) H_0 \gamma$; $h_i$ is the thickness of the $i$-th layer in the immediate loading zone; $H_0$ is the distance between the center of the $i$-th stratum and the coal seam in the immediate loading zone. The calculation of the stress distribution on the coal pillar of each zone in the delayed loading zone is similar to equation (7), which is:

$$
\Delta \sigma_j = \begin{cases} 
\sigma_j \times \left(2H_0 \cot \alpha \right)^2 & x \in [0,H_0 \cot \alpha] \\
\sigma_j \times \left(2H_0 \cot \alpha - x \right)/\left(2H_0 \cot \alpha \right)^2 & x \in [H_0 \cot \alpha, 2H_0 \cot \alpha] \\
0 & x \in [2H_0 \cot \alpha, +\infty]
\end{cases} 
$$

where $\sigma_j$ is the weight of the $j$-th layer of the delayed loading zone; $h_j$ is the thickness of the $j$-th layer in the delayed loading zone; $H_j$ is the distance between the center of the $j$-th stratum and the coal seam in the delayed loading zone, $\sigma_j = \left(2H_0 \cot \alpha + L_c \right) h_j \gamma$; $L_c$ is corresponding width of the goaf.

Based on the distribution of rock formation in Table 1, the width of the goaf $L_c$ is taken as 544 meters, and the angle of rock migration $\alpha$, 71.5°. Based on the mining experience of adjacent mines with similar overburden conditions, the angle between the gangue-touching line and the horizontal direction is taken as 59°, the mining depth, 640 m, and the average bulk density of the overburden $\gamma$, 2.5 t/m³.

The formula for calculating the lateral stress of the coal pillar in the panel, as shown in equation (9), is obtained by adding the equations (6) to (8). The peak is 32.6 m from the coal wall, and the influence distance is about 121 m. The discriminating line is set to be 1.2 times of the original rock stress ($\gamma h = 16$ Mpa), so the width of the coal pillar is not less than 83 meters.

### 4. Numerical simulation analysis of coal pillar width

Flac3D, a finite element numerical simulation software, is used to simulate the lateral influence range of the 201 and the 202 working faces. Establish a model based on the geological conditions of the mine exposed by B22, and then the range of the simulated plastic failure zone and vertical stress distribution are shown in Figure 1 and Figure 2, respectively.
The numerical simulation results show that the plastic damage range of the coal pillar caused by the mining of the 201 and the 202 working faces is 40~45m, and the peak is located in the 20-meter coal pillar between the 1# and the 2# ventilation roadways. The stress concentration coefficient reaches 4.5 times of the original rock stress, thus the condition of arranging small coal pillars is not met. The range of lateral stress of the coal pillar in the 302 panel is mainly concentrated within the range of lateral 90 meters.

5. Analysis of monitoring data of coal pillar width
The distribution of micro-seismic accidents during the mining of 202 working face is shown and the statistical analysis of the lateral micro-seismic accidents in the goaf is shown. Eighty percent of the number and energy of micro-seismic accidents are distributed within the 80-meter range of coal pillars. Therefore, it is inferred that the lateral impact of the goaf is within 80 meters.

6. Conclusion
1) The results of the lateral static stress estimation of the coal pillar in the panel based on the three-zone theory indicate that the total internal stress within the 83 m range of the boundary coal pillar in the 302 panel is relatively high;

2) The numerical simulation results show that the range of plastic damage of the coal pillar caused by the recovery of the 201 and the 202 working faces is 40~45m, and the peak is located at the 20 m coal pillar between the 1# and the 2# ventilation roadways of the 201 working face, where the stress concentration coefficient is high, thus unable to arrange small coal pillars. The numerical simulation reveals that the lateral stress of the coal pillar in the 302 panel is mainly concentrated in the range of 90 m;

3) According to the data analysis of micro-seismic monitoring, the micro-seismic frequency and energy index of the solid coal side of the 202 working face indicate that the range of severe impact is within 80 m in the lateral direction.

In summary, the width of the coal pillar in the panel should be set to reduce the lateral stress on the continuous 101 working face, and to increase the recovery rate of coal resources. It is suggested that the width should be no less than 85 m, and comprehensive measures for scouring prevention should also be taken based on the monitoring result.

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