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Research on pressure-relief effort of mining upper-protective seam on protected seam

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Abstract

Based on the mining and geological conditions in No.12 Mining District of Jining No.3 Coal Mine, the variation laws of stress and deformation of the lower-protected seam along with the mining operation of upper-protective seam are studied by numerical simulation and field test in this paper. The results show that the distribution of in situ stress in protected seam is changed correspondingly during the protective seam mining. While mining the protected seam, the vertical stresses around the protected seam experienced three stages: stress increasing before mining, decreasing after mining and stepwise steady stage. In addition, the protective seam mining can also cause expansive deformation in protected seam and its surrounding rock, destroy the strata structure and release the elastic energy in advance, thus reducing the rock burst risk in protected seam. The results of numerical analysis and the field monitoring results are basically in agreement. The study in this paper will provide theoretical basis and practical value for reasonable design and safety mining of coal seams with rock burst propensity.

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Keywords: rock burst; protective seam; protected seam; numerical simulation; stress-meter monitoring

1. Introduction

In China, rock bursts have been encountered in many coal mines, and the problem becomes progressively more severe as the average depth and extent of mining operations increase\textsuperscript{(1)}. According to Article 15 in “Temporary Provisions of Safety Mining in Rock Burst Coal Seam” in China, the protective
coal seam should be extracted first during the mining design of rock burst coal seams. According to existing research results, the technique of mining protective seam, which is an efficient and fundamental regional precaution measure, is even considered as the most effective strategic measure to prevent rock burst. Furthermore, mining the upper protective seam should be given the first priority[2,3].

Plenty of researches and practices have shown that mining protective seam would change the rule of strata motion, lower the coal and gas outburst hazard and increase seam permeability, and consequently be in favor of gas drainage[4-10]. However, limited researches have focused on the stress relieving effect on reducing rock burst hazard of coal seam, and the mechanism of protective action. In this paper, according to actual mining conditions in Jining No.3 Coal Mine of Yanzhou Mining Group, the stress distribution, deformation and movement rules of coal seam being protected during the extraction of upper protective coal seam, as well as pressure-relieve mechanism were investigated mainly by means of numerical simulation and site observation, and thereby providing basis for reasonable layout and safety mining of coal seams with rock burst propensity.

2. Description of the site

The primary mineable coal seams of Jining No.3 Coal Mine are Upper and Lower No.3 coal seams, and the Lower No.3 coal seam has stronger burst tendency. As the expanding of mining depth and operation range, the geological structure becomes more complex, and the released energies from the movement of surrounding rocks have been rising gradually, which inducing the burst risk of the mine increasing year by year.

The Upper No.3 coal seam can be mined first as the upper protective seam for the Lower No.3 seam. LW12304 in the upper protective seam is the first working face in No.12 Mining District, while the corresponding face in the Lower No.3 seam is LW 12303 with strong burst tendency. The elevation of LW12304 ranges from -555.8m to -652.6m, averaging -610.5m, and the length along the strike and dip direction are 2196.0m and 150.4m, respectively. The structure of Upper No.3 coal seam is simple, with the dip angle varying from 0° to 12°, averaging 3°, and the average thickness is 1.72m. The immediate roof of Upper No.3 coal seam is composed of siltstone and fine siltstone, while the immediate floor is mudstone and the main floor is constituted of hard medium-sandstone and fine siltstone. Meanwhile, the thickness of Lower No.3 coal seam fluctuates between 5.80m and 7.36m, averaging 6.86m, while the interval between the Upper and Lower No.3 coal seam is 32.33m~41.79m, averaging 34.27m.

3. Establishment of Simulation Model

3.1. Numerical model and boundary conditions

The influence scope of mining operation is virtually quite large while the simulation model size is limited. To build the required model and eliminate the influence of edge conditions on simulation results, the distance between the original line (open-off cut) and the model boundary was set to 110m, while the distance from the stopping line to the other boundary is the same. The mining direction of Upper No.3 coal seam was from left to right, while the mining length is 180m and the width of the model is 400m. The height of the model is 150m, ranging from 26.6m under the floor of Lower No.3 coal seam to 83m above the roof of Upper No.3 coal seam. The rock masses in this model are mainly comprised of sandstone and clay rock.

The bottom boundary of the model employed full constraints, which means both the left/right and up/down movements were restricted, while the left and right boundary applied horizontal constraint, i.e. confining the left/right movement but not the up/down movement, so that the stress iterative calculation of
inner rock would not be influenced by the boundary rock. Stress boundary conditions were employed to the top boundary in consideration of the uniformly distributed load generated by gravity of overlying rock\cite{11}. The mechanical model is shown in Figure 1.

![Fig. 1. Numerical simulation mode of mining protective coal seam](image)

### 3.2. Rock properties and mining method

The physical and mechanical parameters of the coal and rock seam in this simulation were basically determined by the real rock mechanic tests, referring to the data of Borehole C4-4 in LW12304.

When the protective seam is being mined, the movement, deformation and destruction of the surrounding rock mass will gradually change as the face advances, and the underground pressure manifests continually associated with the goaf range expanding. Numerical simulation was applied to simulate the excavation process of Upper No.3 coal seam to develop a clearer understanding of the evolution laws of the deformation and destruction of surrounding rock.

Moreover, for making the simulation better conform to the actual dynamic process, the protective seam was mined the whole height at one time and by step caving. In accordance with the real mining speed on site, the excavation step was set as 5m in each mining step, while the roof was managed by caving method.

### 4. Simulation Results Analysis

#### 4.1. Stress variation law in the protected seam

Monitoring points were set up at the middle of the Lower No.3 coal seam, 80m away from the open-off cut and in the overlying roof, 5m above the seam, to monitor the vertical stress variations of the protected seam.

Figure 2 shows the vertical stress changes associated with mining process. Seeing from the figure, with the mining advance in the protective seam (Upper No.3 coal seam), the vertical stresses in both of the protected seam (Lower No.3 coal seam) and its roof experienced three stages of stress increasing before mining, decreasing after mining and stepwise steady stage.

Meanwhile, during the mining of upper protective coal seam, the vertical stress distribution in the lower protected coal seam along the strike direction can be shown in Figure 3. Seeing from the figure, it is apparent that the mining scope of the protective seam had a great influence on the protected seam. During the early stage of protective seam mining, the influence caused by protective mining on vertical stress in the protected seam was relatively small. For example, when the working face was excavated about 45m, the vertical stress in the lower protected coal seam decreased slightly, and both the pressure relief extent and the scope were minor, which means the relief effect was not obvious.
As the working face advancing forward, the vertical stress in certain area of the protected seam below the goaf, further decreased due to the floor strata movement of Upper No.3 coal seam, and the pressure relief effect in protected coal seam gradually enhanced and tended to be steady, therefore the risk of rock burst during coal mining would be greatly reduced. The rear area of the goaf in protective seam was re-compacted owing to the adequate movement of strata when pressure relief scope continued to increase, thus the vertical stress in protected seam increased a bit and finally stabilized at about 13.6MPa, lower than the in-situ stress.

Moreover, the coal mass near open-off cut and just under the face in Lower No.3 coal seam turned to stress concentration areas caused by the stress transfer function of in the floor strata of Upper No.3 coal seam. The vertical stress in Lower No.3 coal seam where there was 15-20m inside the corresponding open-off cut in Upper No.3 coal seam, started to decrease under the in-situ stress level. Therefore, in the mining design of Lower No.3 coal seam, its open-off cut should be set 15-20m ahead of that in Upper No.3 coal seam along the advancing direction, so as to avoid the high stress concentration.

4.2. Displacement variation law in protected seam

Figure 4 shows the vertical displacement variations of Lower No.3 coal seam versus mining distance of protective seam. Seeing from the figure, certain areas in the protected seam appeared obvious expansive deformations caused by extraction of the protective coal seam, which means the elastic energy in the seam was released, and thereby providing sufficient protection for the protected seam.

Moreover, the maximum expansive deformation and most sufficient pressure-relief appeared at the
middle area of the protected seam. Expansive deformation area increased with the increment of protective seam mining distance. Meanwhile, some areas in the protected seam was compressed, and the greatest compression deformation emerged at the coal pillar area which was 20m behind the open-off cut of the protective seam, and at the coal pillar area which was 10~20m ahead of protective seam working face, while the largest abutment pressure appeared at these positions correspondingly.

![Distribution rule of vertical displacement in Lower No.3 coal seam versus mining distance](image1)

**Fig. 4. Distribution rule of vertical displacement in Lower No.3 coal seam versus mining distance**

The horizontal displacement variations of the protected seam with the mining process of protective seam can be seen in Figure 5. The Y-axis represents the horizontal displacement of the protected seam, while the positive value implies the movement direction of coal body is in line with the mining direction, and vice versa.

![Distribution rule of horizontal displacement in Lower No.3 coal seam versus mining distance](image2)

**Fig. 5. Distribution rule of horizontal displacement in Lower No.3 coal seam versus mining distance**

As shown in the figure, after the protective seam being mined, the horizontal deformation in the pressure relief area of protected seam arose in two different regions: the horizontal movement direction of protected seam under the first half of goaf was in accordance to the mining direction, while the situation was inversed under the latter half of goaf. Coal seam in pressure relief area was extruded to the middle zone by abutment pressure of the upper working face, while the horizontal movements in the middle zone were not symmetrical, which increased the mechanical damage of coal mass in this area and was beneficial to the development of secondary interstice in Lower No.3 coal seam, thereby releasing its elastic energy.

In addition, the horizontal displacement was getting smaller when the working face in protective seam was excavated about 135m than that of 90m, that’s because with the goaf area expanding, overlying strata gradually caved and were compacted, which made the deformation value of protective seam be decreased. When the face was excavated to 180m, the horizontal displacement under the first half of goaf...
approached 0mm.

4.3. Mechanism of protective effort

Through the above analysis of stress variation, deformation and rupture of surrounding rock in protected seam, some results can be obtained as follows:

(1) Protective seam mining has changed the distribution of in situ stress in protected seam, destroyed the strata structure and released the stored elastic energy in advance, thereby reducing the risk of rock burst and stress level.

(2) The advanced abutment pressure enabled the Lower No.3 coal seam to go through a process of loading and unloading consequently, the strength and integrity of coal mass was destroyed, expansive deformation and rupture area appeared and the capability of storing elastic energy was weakened largely. After Lower No.3 coal seam being mined, the roof would be bended, subsided quickly and was subject to rupture due to the formation of tensile stress in the fracture area, thus reducing rock burst risk caused by integral movement of hard roof.

(3) Artificial “loose and weak structure”, formed in the goaf of protective seam, can absorb and scatter seismic energy radiated by tremors in higher roof strata greatly. The strong dissipation capacity of seismic energy of this structure can supply sufficient protection for the safety mining of lower coal seam.

Based on the synergistic effects of protective mechanism discussed above, rock burst risk in the mining process of protected seam could be decreased efficiently, after the excavation of upper protective seam.

5. Field Stress Observation Results

To further analyze the disturbance effect on the lower seam during the protective seam mining process, a stress monitoring test was carried out in Jining No.3 Coal Mine. The stress distribution and variation in protected coal seam was monitored with borehole stress-meters installed in drainage roadway in the Lower No.3 coal seam. The installation depths of the stress-meters are 19m, 23m, 34m, and 30m, respectively, and the horizontal spacing between them is 2m. The stress-meters are 19m, 23m, 34m, and 30m, respectively, and the meters were constructed vertically to the headentry of LW12304. The layout of stress-meters can be seen in Figure 6.

The stress-meters started to collect data since 8th July, 2009 when the horizontal distance between
LW12304 and stress-meter array was about 150m. As working face passed about 190m away from the installation position of stress-meters on 2nd September, 2009, the stress monitoring work was stopped. The monitoring results are shown in Table 1.

Table 1. Geo-stress data measured in protected coal seam

<table>
<thead>
<tr>
<th>Stress-meter number</th>
<th>In situ stress $\sigma$ (MPa)</th>
<th>Stress after relieving $\sigma'$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.11</td>
<td>8.18</td>
</tr>
<tr>
<td>2</td>
<td>8.83</td>
<td>7.14</td>
</tr>
<tr>
<td>3</td>
<td>4.2</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>6.65</td>
<td>5.37</td>
</tr>
</tbody>
</table>

Stress release rate was applied to present pressure relief effect after the protective seam being excavated. As shown in Figure 7, stress release rate can be calculated by the following formula:[12]:

$$R = \frac{\sigma - \sigma'}{\sigma} \times 100\%$$  \hspace{1cm} (1)

Where $R$ is the stress release rate, $\sigma$ is the in situ stress of coal seam (MPa) and $\sigma'$ is the stress after relieving (MPa).

By analyzing the recording data, it can be seen that:

1) The stress within the working face in protected seam was released, and the relief effect got better when being closer to the middle position of upper working face, while the maximal stress release rate reached 19.2%. The results of field monitoring results and numerical analysis are basically in agreement.

2) The released rate in No.3 stress-meter which was installed near Fault HF75 was relatively small, that is because the in situ stress near the fault is lower due to the fracturing state of coal/rock mass, and the remained tectonic stress may be also reacted by the mining disturbance.

3) By calculation, the observed pressure-relief protection angles on the strike and inclination of working face were 77° and 79°, respectively. The excavation of upper protective seam formed a large pressure-relief protection area in the lower coal seam.

6. Conclusions

- Protective seam mining can change the distribution of in situ stress in protected seam, cause expansive deformation in protected seam and surrounding rock, destroy the strata structure and release the stored elastic energy in advance, thus reducing rock burst risk in protected seam.
- With the mining advance in the protective seam, the vertical stresses in the protected seam and its roof
strata experienced three stages: stress increasing before mining, decreasing after mining and stepwise steady stage.

- The stress monitoring tests have shown that the stress in protected seam was released well after the mining of upper protective seam, which improve the accuracy and feasibility of the simulation analysis.

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