Definition of Pressure Relief Range and Effect Analysis of Regional Measures in Long-distance Mining of Protective Seam

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Abstract. Based on the engineering background of the protection layer mining of the long distance and near horizontal coal seam group in Zhujixi Coal Mine, by means of theoretical analysis, numerical simulation and field investigation, the scope of pressure relief protection of the protected layer after the protection layer mining is studied and determined, and the effect of regional measures of surface drilling and underground perforation extraction measures is evaluated. The results show that the pressure relief angles in strike and dip directions are 63.7° and 80.8° respectively. The maximum residual gas content is 5.28m³/t and the gas extraction rate is 81.4%. The pressure relief protection effect is remarkable, effectively eliminating the outburst risk of the protected layer.

1. Introduction
Protective seam mining combined with gas drainage as the most effective regional outburst prevention measures has been paid more and more attention, which improves the safety and reliability of outburst prevention and control [1-3]. With the gradual depletion of shallow coal resources and the entry of coal mines into deep mining, the mechanical properties of surrounding rock of stope change, the increase of mining intensity and mining space, gas disasters become more and more serious, and the characteristics of surrounding rock pressure relief damage are quite different from those of shallow mining [4-6]. After entering deep mining, the effective pressure relief protection range of protective layer is different from that of shallow part [7]. At present, there are few studies on the effective pressure relief protection range of protective layer in deep mine. Based on this, the effective pressure relief protection range is determined by means of theoretical analysis, numerical simulation and field investigation, and the regional outburst prevention effect is analyzed. As a result, it can be used for reference in the design of gas prevention and control in working face of protected layer under similar geological conditions.

2. General situation of Engineering
The 11-2 and 13-1 coal seams of Zhujixi Coal Mine are mainly mined at the first level. The buried depth of 11-2 coal seam is 960~1083m and the average thickness is 1.6m. The inclined strip arrangement is adopted. The cut width is 220m and the mining length is 1480m. The comprehensive mechanized mining technology is adopted. The average thickness of overlying 13-1 coal seam is 4 m, and the average
distance between overlying 13-1 coal seam and 11-2 coal seam is 70m. Both coal seams are near horizontal seams with an average dip of 5 degrees. Mudstone and silty (fine) sandstone are the main interlayer lithologies. Both coal seams are outburst seams. According to the mining experience of adjacent mines, 11-2 coal seam is exploited as the lower protective seam of 13-1 coal seam.

3. Establishment of numerical simulation and analysis of results

3.1. Model establishment and boundary conditions

According to the occurrence of coal and rock strata in the test area, a model of 400m long, 380m wide and 165m high is established. Zero displacement boundary is adopted at the bottom and left and right boundary, and the upper boundary is free boundary. The equivalent load of 21.16MPa is applied. Horizontal stress is applied around the model, and 80m coal pillars are set at the boundary. The calculation model is Mohr-Coulomb model. The model diagram simulated by FLAC3D5.0 software is shown in Fig. 1.

![Figure 1. Numerical simulation model diagram](image)

3.2. Analysis of simulation results

3.2.1. Analysis of Vertical Stress Change of Protected Layer. The simulation of the excavation step 20m, mining length 200m, protection layer face to promote 20m, 40m, 80m, 100m, 120m, the protected layer stress distribution as shown in Fig. 2. In order to observe more intuitively the dynamic change process of the stress of the protected layer at different distances when the protective layer advances, the observation points are arranged on the floor of 13-1 coal seam by TECPLT software, and the dynamic change of the stress is recorded. The stress data of each observation point are processed comprehensively, and the curve of the vertical stress of the protected layer changing with the mining of the protective layer is drawn as shown in Fig. 3. The distance of propulsion is represented by d in the graph.
According to the analysis of Fig. 2 and Fig. 3, the original rock stress of the protected layer is 22.2 MPa, and the vertical stress of 13-1 coal seam is 21.74~21.99MPa when the protective layer face advances 20m. Because of the small mining space, the pressure relief effect has not developed to the protected layer, and the vertical stress drop is very small. When the working face advances 40m, the mining space increases further, the overlying strata moves downward, and roof caving occurs. The vertical stress of 13-1 coal seam is 20.07~21.19MPa, with a certain degree of pressure relief, and the influence range of pressure relief is about 30m. When the working face advances 100m, the overlying strata gradually move to the goaf under the influence of self-weight and other functions. Because of the difference of the strength of the strata, there are strata separation between the strata, the height of pressure relief and the influence range gradually increase, and the working face is 12~88m norm. The stress of 13-1 coal seam is 7.61~16.34MPa, and the pressure relief zone shows an inverted parabola trend, and the pressure relief effect in the central region is the best. As the protective face continues to advance, the back goaf is gradually compacted, the vertical stress of 13-1 coal seam tends to be stable, the stress reduction rate is no longer increased, and the pressure relief range is gradually expanded. When the working face advances to 120m, the stress recovery zone appears in the protected layer 13-1
coal seam in the range of 60-90m in front of the cutting face, and the stress value is 12.02~14.37MPa. With the advancing of the working face, the range of the stress recovery zone gradually increases.

3.2.2. Analysis of Vertical Displacement Change of Protected Layer. During the mining process of protective seam face, the change trend of the roof and floor closure of 13-1 coal seam with the mining of protective seam is shown in Fig. 4, in which the normal value is compression deformation and the negative value is expansion deformation.

![Figure 4. Variation of relative displacement of protected layer with mining of protected layer](image)

From Fig. 4, it can be seen that the relative displacement of the roof and floor of 13-1 coal seam is zero and there is no expansion phenomenon when the protective seam face advances to 40m. When the protective seam face advances to 60m, the mining space increases, the roof strata collapses, the overlying strata moves and deforms, and the separation occurs. The maximum relative displacement of the roof and floor is 4mm, and the expansion deformation is 1‰. When the protective seam advances to 120m, the protective seam is protected. The maximum relative displacement of roof and floor is 17mm and the expansion deformation is 4.251‰, which indicates that the working face continues to advance and the relative displacement of roof and floor of 13-1 coal seam gradually increases. This area is within the effective pressure relief protection range, and the effect of pressure relief is the best. With the increase of mining length, the roof strata gradually collapse to the goaf, the goaf is gradually filled and compacted, and the relative displacement of the roof and floor in the middle of the goaf decreases gradually, and tends to be stable.

3.2.3. Numerical simulation results of pressure relief angle of protected layer. The numerical simulation results show that the stress of 13-1 coal seam decreases greatly in the mining process of protective seam, and the maximum expansion deformation of coal seam is 4.25‰. The mining of 11-2 Coal Seam has an effective pressure relief protection effect on the overlying 13-1 coal seam. According to the numerical simulation results, the pressure relief angles of the direction and inclination of the protective layer are 82.6° and 66.8°, respectively. The pressure relief lines are 9m along the trough and 32m through the hole of the internal fault protective layer respectively.

4. Field Investigation of Pressure Relief Protection Range

4.1. Investigation drilling design

The numerical simulation analysis shows that the pressure relief range of the cut, stop line and two grooves is symmetrical in the mining process of the near-horizontal protective layer face. This time, the pressure relief angle is only inspected at the stop line and the corner of the track along the groove of the protective layer face. According to the numerical simulation results of pressure relief angle and the
relevant requirements of "Regulations for the Prevention and Control of Coal and Gas Outburst", the theoretical pressure relief angles of coal seam strike and inclination direction are divided into 77° and 60° respectively. The theoretical pressure relief lines are separately staggered by 16.2m in two parallel troughs and 40.4m in cut-in and stop-out lines. Four inspection boreholes are arranged in the area near the theoretical pressure relief line along the coal seam direction and inclination respectively. One borehole is arranged on the pressure relief line, two measuring points are arranged on the outside of the pressure relief line, and one borehole is arranged on the inside. The plan of borehole arrangement is shown in Fig. 5.

![Diagram of borehole arrangement](image)

Figure 5. Examines the drilling layout plan

4.2. Determination of effective protection range of protected layer

During the mining process of protective seam, the inclination of 13-1 coal seam and the amount of moving towards roof and floor are shown in Fig. 5 and Fig. 6. According to Fig. 5, the relative displacement of the relief line from the inside to the outside roof and floor decreases gradually, and the relative deformation of the 1-1 and 1-2 boreholes is greater than 3‰, which is within the effective relief protection range. The relative deformation of the 1-3 and 1-4 seams is less than 3‰. Using the interpolation method, the relief angle of the inclination direction is 63.7°, and the stopping line of the staggered protective layer in the relief line is 37.2m. Similarly, the pressure relief angle along the strike direction of the protective layer working face is 80.8°, and the track of the fault protective layer working face along the relief line is 11.8m.

![Graph of coal seam deformation](image)

Figure 6. 13-1 coal seam expansion deformation with working face propulsion curve
5. Analysis of Outburst Prevention Measures in Effective Protected Areas

5.1. Analysis of Gas Drainage Quantity in Protected Layer

During the mining of the protective layer, the pressure relief gas of the protected layer is extracted by the combination of surface drilling and underground drilling. Among them, the surface drilling is arranged in the middle of the working face with a distance of 240 m, the final hole is located on the top plate of the protective layer of 15 m, and the row spacing between the perforated holes is 20 × 40 m, and the aperture is 108 mm. Control the mining area of 13-1 coal seam corresponding to 11501 working face.

The mining of protective face began in February 2015 and ended in July 2016. As of October 2016, surface drilling and cross-layer drilling accumulated to extract 128.31 million m³ of gas from the relief layer of the protected layer. Combined with the 13-1 coal gas reserves in the area of pressure relief protection, which is 15755,000 m³, the extraction rate of the protected layer is about 81.4%, and the residual gas content is 3.58 m³/t. The residual gas content in 13-1 coal seam is much less than 8 m³/t in the pressure relief protection area, which indicates that the gas extraction by ground drilling wells and cross-layer drilling wells is better and the outburst risk of 13-1 coal seam is reduced.

5.2. Effect test of regional measures

In order to verify the effect of gas drainage in protected layer, residual gas content was used to test the effect of regional measures. According to the theory of O-shaped pressure relief ring, the effect of pressure relief at the corner of the working face is poor. Therefore, this time, one measuring point is arranged at each corner of the protected area, and four boreholes are drilled at each measuring point. They are located in the side and outside of the pressure relief range, respectively. The layout of measuring points is shown in Fig. 7.

![Figure 7. Layout of measuring points for residual gas content](image)

The maximum residual gas content measured is 5.25 m³/t, which is less than the critical value of 8 m³/t provided by relevant regulations. Therefore, through the analysis of protective effect of protective seam mining, pressure relief gas drainage effect of protective seam, combined with residual gas content of protective seam, it shows that 13-1 coal seam regional measures within protective area of 11-2 Coal Seam protective seam are effective.

6. Conclusion

The stress and deformation characteristics of the protected layer under the mining conditions of Zhujixi Coal Mine are analyzed by numerical simulation method. The results show that with the mining of the protected layer, the pressure relief characteristics of the overlying long-distance protected layer are obvious, and its pressure relief range is shallower.

The effective pressure relief angles along the inclination and strike direction are 63.7° and 80.8°, respectively. The effective pressure relief range is 37.2 m for the stopping line of the inclined inner fault protective layer working face and 11.8 m for the track along the trough of the upper inner fault protective layer.
layer working face, which is basically consistent with the pressure relief angle obtained by numerical simulation.

After surface wells and drilling holes were used to extract gas from protective seam during mining, the residual gas content of coal seam in protected area was 2.17~5.25 m³/t, and the extraction rate was 81.4%. The gas extraction effect was good, the pressure relief protection effect was remarkable, and the outburst danger of protected seam was eliminated.

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