Study on upper and lower gas drainage and prevention and control technology in deep mine mining high gas mine

Xingang Niu (✉ 1197807770@qq.com)  
Anhui University of Science and Technology

Dongdong Pang  
Anhui University of Science and Technology

Xianchen Wang  
Wanbei Coal Power Co., Ltd

Chuanming Li  
Anhui University of Science and Technology

Haifeng MA  
Anhui University of Science and Technology

Research Article

Keywords: Gas drainage, Gas control, Deep well mining, Regional outburst prevention

Posted Date: March 8th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1364288/v1

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Study on upper and lower gas drainage and prevention and control technology in deep mine mining high gas mine

Dongdong Pang$^{1,2}$, Xingang Niu$^{1,3,4}$, Xianchen Wang$^{15}$, Chuanming Li$^{1,2}$, Haifeng MA$^{1,2}$

$^{1}$State Key Laboratory of Mining Response and Disaster Prevention and Control in Deep Coal Mines, Anhui University of Science and Technology, Huainan, Anhui 232001, China;
$^{2}$School of Safety Science and Engineering, Anhui University of Science and Technology, Huainan, Anhui 232001, China;
$^{3}$State Key Laboratory of the Gas Disaster Detecting Preventing and Emergency Controlling, China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400037, China;
$^{4}$Gas Research Branch, China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400037, China.

$^{5}$Zhujixi coal mine, Wanbei Coal Power Co., Ltd, Huainan 232000, China

Correspondence should be addressed to Xingang Niu; 1197807770@qq.com

Abstract: In view of the “three high” problem of deep high gas mine mining, the rapid increase of coal seam permeability coefficient and the continuous reduction of coal and gas outburst risk gradually increase the difficulty of gas control. Taking the occurrence of long-distance outburst coal seams in zhujixi mine as the research background, this paper analyzes the gas occurrence characteristics of 11-2 Coal Seam and the feasibility of 11-2 Coal Seam as the lower protective layer by using the technical methods of theoretical analysis, calculation and numerical simulation, and studies and determines the pressure relief protection range of 11-2 coal seam mining to the overlying 13-1 coal seam; This paper puts forward the regional outburst prevention technology of underground penetrating and bedding borehole pre drainage for the protective layer and the regional outburst prevention technology of pre drainage combined with the mining surface and underground of the protected layer.

Coal seam 11-2 has uneven gas occurrence and poor regularity. There are only high gas areas in some parts, which are greatly affected by geological structure and slate properties of coal seam top and bottom. Coal seam 11-2 is a stress dominated briquette and gas outburst coal seam. Zhujixi mine adopts the regional outburst prevention model of combined pumping up and down the well, that is, coal seam 11-2 with low outburst risk is selected as the protective layer for mining first, and coal seam 13-1 is protected above. At the same time, the gas in the protected layer shall be extracted. 11-2 Coal adopts the gas control mode of "one side with three lanes (one side with five lanes in the first mining face) and surface drilling", so as to realize multi-purpose, joint treatment and continuous mining of one lane. Comprehensive outburst prevention measures are adopted for the tunneling working face through layer drilling pre drainage and the coal mining working face along layer drilling pre drainage area. During the mining period, the surface drilling and top drainage roadway are used to extract the pressure relief gas of 13-1 coal, and the combined upper and lower shaft extraction area technology is adopted. In the underground excavation and mining working face, the gas concentration of return air flow, measured residual gas content and residual gas pressure are measured. The prediction indexes have not exceeded the standard, and there has been no dynamic phenomenon. In the application of outburst prevention technology in the area of up-down combined extraction in zhujixi mine, the proportion of well extraction is 56.7%, and the proportion of underground extraction is 43.3%. The maximum height of the caving zone after mining of coal face 11-2 is 11.6m, and the height of the fracture zone is 34.4~52.2m. The working face of protective layer 13-1 is arranged at the upper part of the fracture zone or the lower part of the bending...
subsidence zone, which can effectively increase the permeability of coal seam 13-1, and has no significant impact on the normal mining of coal face 13-1.

Keywords: Gas drainage; Gas control; Deep well mining; Regional outburst prevention

0 Introduction

Coal is the main energy in China. China is one of the countries with the most serious gas disasters in the world. The endowment of coal resources and long-term strong demand lead to the rapid transfer of China's coal development to the deep at the speed of 10-25m per year. The gas problem faced by deep coal mining is more serious. Considering the three aspects of safety, energy and environmental protection, it is necessary to strengthen the co mining of coal and gas in deep coal seams [1-3]. The safe and efficient mining of kilometer deep wells faces technical problems such as high ground stress, high gas and high low temperature [4-6]. The task of preventing gas disasters is still very arduous. With the increase of mining depth, the deep coal seam is in the complex environment of "three highs", and the gas problem faced by the development of coal resources will be more serious [7]. When the coal seam is mined more and more downward, the coupling relationship between gas pressure and content becomes more and more unclear, and the dynamic phenomenon dominated by in-situ stress will become more and more obvious, and gradually develop into the key to cause outburst. Especially in deep roadway mining, the surrounding rock characteristics of the stope have changed dramatically, the underground working environment has changed dramatically, and coal and gas outburst still occurs when the gas content and gas pressure do not exceed the critical value [8], resulting in hidden dangers in safety production. With the continuous improvement of coal mining depth, the permeability of coal seams will become worse and worse. This is a very unfavorable condition for the prevention and control of gas disasters, and it also has certain limitations for the safety production of coal mines. Coal seam strengthening is an effective way to improve gas drainage, and the key is to change the coal structure [9-11]. Protective layer mining technology can increase the micro cracks of coal body and release in-situ stress, so as to improve the permeability of coal seam, produce "pressure relief and flow increase effect" and realize effective gas drainage [12-16]. For outburst coal seam without protective layer, it can reduce the external stress of coal seam and change the physical and mechanical properties of coal, A variety of anti reflection technologies of the coal seam have been tested and applied, including large-diameter drilling, cross drilling and deep hole, dredging blasting, hydraulic anti reflection and gas explosion anti reflection. Taking the mining coal seam of zhujixi mine as the research object, this paper investigates the occurrence and gas geological data of 11-2 Coal Seam in zhujixi mine, studies and analyzes the gas storage characteristics and outburst risk degree of 11-2 Coal Seam, and explores the key technology of long-distance coal seam group up and down combined pumping and outburst prevention, which lays a foundation for the continuity of mine wat control and mining, and has guiding significance for mine safety production.

1 Analysis of coal seam gas occurrence characteristics

1.1 Coal seam gas occurrence

The sedimentary environment of coal bearing rock series in the mine is stable, and the thickness of each coal bearing section, coal seam spacing and coal seam thickness are relatively stable. The spacing between 11-2 and 13-1 coal seams is 67.08~86.30m, with an average spacing of 74.36m. Coal seam 13-1 is mainly distributed in the deep part of line 35 to line 37, with a thickness of 2.18~5.29M and an average of 4.0m. It is dominated by thick coal. The coal seam minability index is 1.00 and the coefficient of variation is 24%. It is a stable coal seam. The roof is mudstone, a few points are sandstone, and the floor is mudstone and carbonaceous mudstone. The lower part of coal seam 13-1 is 74.36m away from coal seam 11-2.
Coal seam 11-2: the thickness is 0.77~1.80m, with an average of 1.55m, the coal seam minability index is 1.00, and the coefficient of variation is 19%. The roof is mainly composed of mudstone and siltstone, with light gray fine sandstone in the middle and lower part, and interbedded with siltstone and fine sandstone in some parts; The floor is dominated by mudstone, and the middle and lower part is siltstone and fine sandstone. The mudstone of the roof and floor belongs to soft rock ~ semi hard rock, the siltstone belongs to semi hard rock, and the fine sandstone belongs to hard rock. During the development preparation period, the measured maximum gas pressure of coal seam 11-2 in the first mining of the mine is 1.2MPa, and the gas content is 2.23 ~ 8.63m$^3$/t; The maximum gas pressure of 13-1 coal seam is 1.36mpa and the gas content is 3.93 ~ 8.48m$^3$/t.

1.2 Influencing factors of coal seam gas occurrence

The buried depth of coal seam is the main factor affecting gas content [17-19]. With the increase of coal seam buried depth, the overlying strata make the coal seam and roadway surrounding rock from loose to dense under the action of self weight pressure. The average buried depth of coal seam 11-2 is more than 900m, the overlying thickness is 340 ~ 600m, and the tertiary and quaternary new strata are covered. The linear regression relationship between geological exploration gas content and buried depth is shown in Figure 1.

![Fig. 1 11-2 Linear regression relationship diagram between geological exploration gas content and buried depth.](image)

According to the regression analysis, there is a positive correlation between the two on the whole, that is, the gas content in coal seam increases with the increase of buried depth, but the increasing trend is not obvious, and the correlation coefficient is only 0.1421 , indicating that the gas occurrence in coal seam 11-2 is less affected by buried depth.

The influence of geological structure on gas storage is influenced by the structural form. For example, closed geological structures such as compression and torsion faults are favorable for gas storage, so the gas content is large; Open geological structures such as tensile faults can accelerate gas release and have low gas content. Under normal conditions, the axis and inclined end of gentle fold can promote the storage of gas, and the gas content is large; For example, the gas content in the axis of the anticline is greater than that in the two wings. If the tensile fractures in the axis are developed and denuded, the gas will easily escape, which is unfavorable for the storage of gas; In addition, the axial stress of syncline is mainly compression, and the fracture is not developed, which is easy to produce gas enrichment, and its content will also become higher [20, 21].

The measured gas content near the structure of 11501 working face in zhujixi mine is relatively large, which is 5.96 ~ 8.38m$^3$/t. The measured gas content of 11051 working face is affected by the structure. In the area near the fault and fold, the gas content is generally 5.90 ~ 8.39m$^3$/t, in the area without geological structure, the gas content is 3.71 ~ 5.21m$^3$/t, and the gas content in the geological structure zone is relatively high.
1.3 Analysis of gas occurrence law

It can be seen from table 1 that \( \text{N}_2 : \text{CO}_2 : \text{CH}_4 = 3.51\%~68.87\%:1.29\%~20.17\%:27.15\%~94.13\% \) in the natural gas composition of coal seam 11-2. The \( \text{CH}_4 \) composition tested by only three boreholes is greater than 80%. The thickness of tertiary ~Quaternary loose layer of coal measure stratum of the mine is 340 ~ 600m. After calculation, the depth of gas weathering zone is 810 ~ 1070m, and the buried depth of coal seam 11-2 is 960 ~1080m. Therefore, most areas of coal seam 11-2 are located in \( \text{N}_2-\text{CH}_4 \) zone. According to the measured gas content during the development and mining of coal seam 11-2, the elevation of -923.8 ~ -1059.4m is selected, and a maximum value is selected from the elevation drop of every 10m to construct the linear regression relationship between the gas content of coal seam and the buried depth of coal seam, as shown in Figure 3.

Table 1  Gas content and composition test results of 11-2 coal seam in the first mining area during geological prospecting period

<table>
<thead>
<tr>
<th>Number</th>
<th>Natural composition of gas /%</th>
<th>Floor elevation/m</th>
<th>Gas content/m³/t</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \text{N}_2 )</td>
<td>( \text{CO}_2 )</td>
<td>( \text{CH}_4 )</td>
<td>( \text{C}_2\text{H}_6 )</td>
</tr>
<tr>
<td>34-1</td>
<td>17.07</td>
<td>11.79</td>
<td>71.14</td>
<td></td>
</tr>
<tr>
<td>34-2</td>
<td>30.62</td>
<td>7.02</td>
<td>61.52</td>
<td>0.69</td>
</tr>
<tr>
<td>34-3</td>
<td>37.35</td>
<td>14.12</td>
<td>47.83</td>
<td>0.10</td>
</tr>
<tr>
<td>34-4</td>
<td>3.51</td>
<td>6.34</td>
<td>87.33</td>
<td>1.97</td>
</tr>
<tr>
<td>35-1</td>
<td>51.49</td>
<td>16.46</td>
<td>32.05</td>
<td></td>
</tr>
<tr>
<td>35-2</td>
<td>3.79</td>
<td>94.13</td>
<td>1.84</td>
<td>1.05</td>
</tr>
<tr>
<td>35-3</td>
<td>8.59</td>
<td>2.59</td>
<td>87.96</td>
<td>0.78</td>
</tr>
<tr>
<td>36-1</td>
<td>15.25</td>
<td>6.48</td>
<td>78.27</td>
<td></td>
</tr>
<tr>
<td>36-2</td>
<td>29.73</td>
<td>16.54</td>
<td>52.17</td>
<td>1.02</td>
</tr>
<tr>
<td>36-3</td>
<td>53.88</td>
<td>8.09</td>
<td>38.03</td>
<td></td>
</tr>
<tr>
<td>36-4</td>
<td>13.81</td>
<td>9.16</td>
<td>76.18</td>
<td>0.66</td>
</tr>
<tr>
<td>37-4</td>
<td>45.77</td>
<td>3.20</td>
<td>50.61</td>
<td>0.33</td>
</tr>
<tr>
<td>38-1</td>
<td>30.48</td>
<td>41.16</td>
<td>27.56</td>
<td></td>
</tr>
<tr>
<td>38-2</td>
<td>52.68</td>
<td>20.17</td>
<td>27.15</td>
<td></td>
</tr>
<tr>
<td>38-4</td>
<td>68.87</td>
<td>1.29</td>
<td>29.84</td>
<td></td>
</tr>
</tbody>
</table>
It can be seen from Figure 2 that the gas content of coal seam 11-2 is 2.23 ~ 8.6324 m$^3$ t, with an average of 5.48 m$^3$ t. According to the fitting regression analysis, the correlation coefficient between gas content and coal seam buried depth is only 0.1729. The law of gas content increasing with the increase of coal seam buried depth is not obvious, and the distribution of gas content is discrete. At the same time, through the statistical analysis of the measured gas content of coal seam 11-2, there are 4 groups with gas content $w \geq 8$ m$^3$ t, the maximum is 8.63 m$^3$ t, and they are all in the abnormal area of coal seam and geological structure area. 83% of the 18 groups with $7$ m$^3$ t $\leq w < 8$ m$^3$ t are in the abnormal area of coal seam and geological structure area, and the rest are less than 7 m$^3$ t. To sum up, the gas content generally increases with the increase of coal seam buried depth, but the law is not obvious, the gas occurrence is uneven, and the gas content is generally low compared with typical outburst coal seams.

2 Theoretical analysis on the feasibility of protective layer mining

2.1 Analysis of mining height and interlayer distance of protective layer

According to the detailed rules for the prevention and control of coal and gas outburst, when the expansion deformation of the protected layer is greater than 3 $\%$, the mining of the protected layer can effectively protect the protected layer. When the buried depth of 11-2 Coal Seam in 11501 working face of zhujixi mine is 960~1080 m and the cutting width of the working face is 220 m, the minimum effective mining thickness of the protective layer is 0.9 m. The design mining thickness of 11501 working face is 2 m, so the mining thickness of the protective layer meets the requirements. The maximum effective protection vertical distance between the protective layer and the protected layer can be determined according to formula (1):

$$S_x = \dot{S}_x \beta_1 \beta_2$$

Where:
- $S_x$-Theoretical effective spacing of lower protective layer, m;
- $\beta_1$-Influence coefficient of protective layer mining, when $M \leq M_0$, $\beta_1=M/M_0$, when $M > M_0$, $\beta_1=1$;
- $M$-Mining thickness of protective layer, m;
- $M_0$-Minimum effective thickness of protective layer, m;
- $\beta_2$-Proportion coefficient of hard rock (fine sandstone, siltstone, etc.) in rock stratum, Percentage of hard rock in rock stratum $\eta$ express, when $\eta \geq 50$, $\beta_2=1-0.4\eta/100$, when $\eta <$
50%, $\beta_2=1$.

The mining height of 11501 working face is 2m, the cutting width is $L = 220m$, and the mining depth is $h = 983 \sim 1083m$, which is determined by the detailed rules for the prevention and control of coal and gas outburst, $S_x=114\sim122m$, $\beta_1=1$, $\beta_2=1$. According to formula (1): $S_x=114\sim122m$. The maximum interval between 11-2 Coal Seam and overlying 13-1 coal seam in 11501 working face is 73m, which is less than the maximum protection vertical distance. Therefore, 11-2 Coal seam can be used as the lower protection layer of 13-1 coal seam.

At the same time, according to the detailed rules for the prevention and control of coal and gas outburst, the resources of the upper adjacent layer shall not be damaged when mining the lower protective layer, and the minimum interlayer distance between the protective layer and the protected layer can be determined according to formula (2):

\[ H = K \cos \alpha \]

Where:
- $H$: Minimum allowable layer spacing, m;
- $\alpha$: Coal seam dip, 5°;
- $K$: Roof management coefficient. When the roof of goaf is managed by caving method, $K=10$.

According to the occurrence conditions of coal seam in 11501 working face, $H = 9.96m$ can be calculated from formula (2), which is far less than the spacing between the two coal seams. Therefore, coal seam 11-2 can be used as the lower protective layer of coal seam 13-1.

### 2.2 Theoretical calculation of "three zones" height of 11-2 Coal Seam

Coal seam mining is easy to cause the movement, deformation and damage of surrounding rock in the goaf. Under the interaction of self weight stress and surrounding rock, the roof rock stratum produces a violent instability and rebalancing process, forming the "upper three zones" above the goaf as shown in Figure 5. Generally, it will not damage the integrity of the adjacent coal seam roof in the high fracture zone and low bending subsidence zone, Its mining will not be affected, but due to the pressure relief of the coal seam, the permeability becomes stronger, which is beneficial to gas drainage and can eliminate or reduce the outburst risk.

![Zonation model of “upper three zones”](image)

According to the different lithology of coal seam overburden, the height of caving zone $H_m$ and fracture zone $H_f$ can be calculated.

According to the occurrence conditions of coal strata in the test area, the coal seams 11-2 and 13-1 are mainly siltstone, fine sandstone and mudstone, with unidirectional compressive strength of 55.99mpa (45.8~79.6mpa), 78.06mpa (60.8~119.9mpa) and 37.08mpa (22~69.3mpa) respectively.
The interlayer lithology is mainly hard rock, and the calculation formula of collapse zone height is:

\[ H_m = \frac{100 \sum M}{2.1 \sum M + 16} \pm 2.5 \]  

(3)

The average thickness of coal seam 11-2 is 1.6m. The mining technology of full height mining at one time is adopted. After calculation, the height of collapse zone of coal seam 11-2 is \( H_m = 6.6 - 11.6m \).

The calculation formula of fracture zone height is:

\[ H_L = \frac{100 \sum M}{1.2 \sum M + 2.0} \pm 8.9 \]  

(4)

After calculation, the height of fracture zone of coal seam 11-2 is \( H_L = 34.4 - 52.2m \).

After the mining of 11-2 Coal Seam, the protected 13-1 coal seam is in the high fracture zone or low bending subsidence zone. The continuity of 13-1 coal seam will not cause destructive impact, which can greatly increase the permeability of 11-2 Coal seam. To sum up, through the analysis of the reasonable layer spacing and the development height of collapse zone and fracture zone of 11-2 Coal Seam as protective layer, it can be seen that 11-2 Coal seam can be used as the protective layer under 13-1 coal seam.

### 3 Outburst prevention technology in underground pumping area

When the protective layer is mined, under the action of self weight and overburden pressure, the overlying coal layer in the goaf will move to the goaf, producing bedding and through cracks, which greatly increases the permeability of the coal layer and obtains a good channel for the migration of coal seam gas. For underground coal and gas outburst prevention and control, protective layer mining is the most economical and effective regional outburst prevention measure. Therefore, for determining the pressure relief range and protection effect of the protected layer, it is of great significance to study the vertical stress distribution law and deformation characteristics of the roof and floor strata after the mining of the protected layer. Due to the complexity of the mining effect of coal seam roof and floor, if we only use the theories of elastic-plastic mechanics and material mechanics to study, we can not accurately calculate the stress distribution in the overlying rock after the mining of the protective layer. Under the background of the rapid development of computer industry, numerical simulation method makes modeling and transformation of physical field more convenient and fast. Mining models under different conditions can be established according to actual needs, and its unique advantages can be demonstrated at the same time.

In this paper, the combination of numerical simulation and field investigation is used to study the pressure relief protection effect of 11-2 Coal Seam on overlying 13-1 coal seam after mining.

#### 3.1 Establishment of numerical model

According to the occurrence of 11501 working face and overlying coal strata of 11-2 Coal Seam, FLAC3D software is used to establish a model with a dip length of 320m (x direction), a strike length of 380m (Y direction) and a height of 190m (z direction). The mining thickness of 11501 working face is 2m, the average thickness of 13-1 coal seam is 3.8m, and the average interval between the two coal seams is 70m. In order to reduce the influence of coal seam mining on the whole model, 80m coal pillars are reserved along the strike and inclination of the coal seam. The upper boundary of the model is free boundary, and the bottom boundary and left and right boundaries
adopt zero displacement boundary, because the thickness of the overlying strata of the simulated mining coal seam has a certain range, the lateral pressure coefficient is 1.0, and the horizontal stress is applied to the front, back, left and right of the model. The numerical simulation model is shown in Figure 4, and the material physical and mechanical parameters of the model are shown in Table 2.

Mohr Coulomb plastic constitutive model and Mohr Coulomb yield criterion are adopted for calculation, namely:

\[ f_s = \sigma_1 - \frac{\sigma_3 (1 + \sin \varphi)}{1 - \sin \varphi} + 2c \sqrt{\frac{1 + \sin \varphi}{1 - \sin \varphi}} \]  

\[ f_t = \sigma_3 - \sigma_1 \]  

Where: \( \sigma_1, \sigma_3 \) - Maximum and minimum principal stresses, MPa; 
C - Cohesion of rock stratum, MPa; \( \varphi \) is the internal friction angle of rock stratum; 
\( \Sigma \) - Tensile strength of rock stratum, MPa; when \( f_s = 0 \), shear failure of rock mass; when \( f_t = 0 \), tensile failure of rock mass.

![Numerical model diagram](image)

**Table 2** Table of physical and mechanical parameters of numerical simulation strata

<table>
<thead>
<tr>
<th>lithology</th>
<th>Lithology /kg/m³</th>
<th>Bulk modulus/GPa</th>
<th>shear modulus/GPa</th>
<th>tensile strength/MPa</th>
<th>Cohesion /MPa</th>
<th>internal friction angle/°</th>
<th>Bulk modulus /GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>mudstone</td>
<td>2461</td>
<td>6.08</td>
<td>3.47</td>
<td>1.0</td>
<td>1.2</td>
<td>30</td>
<td>6.08</td>
</tr>
<tr>
<td>fine sandstone</td>
<td>2873</td>
<td>20.01</td>
<td>13.52</td>
<td>2.9</td>
<td>3.2</td>
<td>42</td>
<td>20.01</td>
</tr>
<tr>
<td>Siltstone</td>
<td>2460</td>
<td>10.83</td>
<td>8.13</td>
<td>2.6</td>
<td>2.75</td>
<td>38</td>
<td>10.83</td>
</tr>
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<td>2461</td>
<td>6.08</td>
<td>3.47</td>
<td>1.0</td>
<td>1.2</td>
<td>30</td>
<td>6.08</td>
</tr>
<tr>
<td>13-1 coal</td>
<td>1350</td>
<td>4.91</td>
<td>2.01</td>
<td>0.9</td>
<td>1.25</td>
<td>32</td>
<td>4.91</td>
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<td>6.08</td>
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<tr>
<td>11-2 coal</td>
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<td>2.01</td>
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<td>1.25</td>
<td>32</td>
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<td>2.6</td>
<td>2.75</td>
<td>38</td>
<td>10.83</td>
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</tbody>
</table>
3.2 Analysis of numerical simulation results

3.2.1 Analysis of vertical stress variation of overlying 13-1 coal seam after mining 11-2 Coal Seam

In this simulation, the width of 11501 working face is 220m and the mining length is 160m. The model is mined along the tendency and the excavation step is 20m. Due to the limitation of FLAC3D post-processing project, Tecplot software is used for graphic processing. The vertical stress contour at the position of 20m, 40m, 80m, 100m, 120m, 140m and 160m, y = 190m in the working face is shown in Figure 5.

Fig. 5 Contour map of vertical stress along the inclined direction at different distances in 11501 working face
According to the vertical stress distribution along the dip direction at different mining distances of the working face of the protective layer in Figure 5, when the working face is mined for 20m, the vertical stress of the coal strata around the goaf does not change significantly, only the stress of the roof and floor strata decreases significantly within a certain range. The stress of the roof and floor strata decreases the most in the middle of the goaf, and the vertical stress is distributed in an arch shape, and the degree of reduction decreases gradually with the increase of the distance from the goaf. There is obvious stress concentration behind and in front of the cutting hole of the working face, and the stress distribution is symmetrically distributed along the middle of the mining length. As shown in Figure 5 (b), after 40m of working face mining, the vertical stress of the coal layer overlying the goaf at the same layer is significantly reduced compared with that at 20m of mining, and the reduction range of vertical stress in the horizontal direction gradually increases, indicating that the pressure relief degree of the coal layer overlying the goaf gradually increases, while the vertical stress at the arch foot gradually increases, but with the increasing range of goaf, under the influence of self weight and other effects, the roof rock stratum gradually moves to the goaf, the caving gangue fills the goaf, compacts it continuously, and the vertical stress recovers. As shown in Figure 5 (d), after 80m mining of the working face, the vertical stress of the coal stratum overlying the goaf changes slightly, and the vertical stress contour changes from arch distribution to camel distribution. As shown in Figure 5 (g), after the working face is mined for 140m, the vertical stress of the coal stratum in the vertical direction will no longer increase with the increase of the mining length of the working face, and the range of the vertical stress contour in the horizontal direction will gradually increase with the increase of the mining length.

In order to study the dynamic change process of the stress of coal seam 13-1 when coal seam 11-2 is pushed for different distances, observation points are arranged on the floor of coal seam 13-1, the stress data of each observation point are recorded, and the change curve of the vertical stress of the protected layer with the mining of the protected layer is obtained, as shown in Figure 6.

![Fig. 6 The vertical stress change trend diagram of the 13-1 coal seam along the inclined direction when the 11501 working face is mined at different distances](image)

It can be seen from Fig. 6 that when working face 11501 is stopped for 20m, the minimum vertical stress of coal seam 13-1 overlying the goaf is 23.25mpa, which is 24.13mpa relative to the original rock stress, and the stress reduction rate is 3.64%. The stress concentration in the front of the work and at the cutting hole is not obvious, indicating that coal seam 13-1 is less affected by the mining of underlying coal seam 11-2 at this time; With the increase of the mining length of the working face, the vertical stress of the overlying 13-1 coal seam gradually decreases and the pressure relief range gradually increases. For example, when the working face is mining 40m, 60m, 80m,
100m, 120m, 140m and 160m, the vertical stress of the 13-1 coal seam directly above the middle of the goaf is 21.16mpa, 18.41mpa, 15.55mpa, 12.43mpa, 10.15mpa, 8.64mpa and 8.06mpa respectively, and the stress reduction rates are 12.31% and 23.70% respectively 35.56%, 48.48%, 57.94%, 64.19% and 66.59%. The decline range of vertical stress first increases, then decreases and finally tends to be stable, indicating that the pressure relief degree of coal seam 13-1 gradually increases with the increase of working face distance. After mining to 140m, the goaf should be continuously filled and compacted, resulting in stress recovery, and the pressure relief degree of coal seam 13-1 tends to be stable. The pressure relief range increases with the increase of the working face length.

According to the numerical simulation results, Tecplot software is used to obtain the vertical stress isolines at x = 90m, 100m, 110m, 120m, 130m, 140m, 150m and 160m at different mining distances in the strike direction, as shown in Figure 7.
Fig. 7 Contour map of vertical stress along strike direction at different distances in 11501 working face

It can be seen from Figure 7 that under the occurrence condition of near horizontal coal seam, the vertical stress distribution and variation law of overlying coal strata in goaf are basically the same with the increase of mining length of working face in the strike and dip direction of coal seam. The research shows that when the stress reduction rate of the protected layer is more than 50%, the coal seam is fully relieved and the air permeability is enhanced. The mining of coal seam 11-2 in the protected layer is effective for the pressure relief protection of coal seam 13-1 in the protected layer.

3.2.2 Analysis of vertical displacement change of overlying 13-1 coal seam in 11-2 Coal Seam Mining

The vertical displacement contour at the position of 20m, 40m, 80m, 100m, 120m, 140m and 160m, \( y = 190m \) is shown in Figure 8.
Fig. 8 Contour map of vertical displacement along strike direction at different distances of 11501

It can be seen from figure 8 that after the mining of the working face, the original rock stress balance state of the surrounding rock strata is broken, and the coal seam roof and floor move towards the goaf under the action of the initial in-situ stress field. With the increase of the mining distance of the working face, the displacement of the coal strata in the same layer above or below the goaf gradually increases. The horizontal square lines are symmetrically distributed along the middle of the goaf. Under the conditions of different mining lengths, the movement and deformation laws of coal and rock strata are basically the same.

In order to study the expansion deformation of the overlying 13-1 coal seam at different mining distances of 11501 working face of 11-2 Coal Seam, the measuring points are arranged along the inclination at the top and floor of 13-1 coal seam respectively, and the displacement of the top and floor of 13-1 coal seam during the mining of 11-2 Coal Seam is recorded by Tecplot software. After calculation, the variation trend of the displacement of the top and floor of 13-1 coal seam with the mining length of the working face is shown in Figure 9.

Fig.9  Change trend of 13-1 coal seam roof and floor approaching amount at different distances in 11501 working face

When 11501 working face is advanced to 40m, there is no expansion trend in 13-1 coal seam, and the expansion curve is displayed as a straight line, indicating that the mining of 11-2 Coal Seam has basically no impact on the deformation of overlying 13-1 coal seam; When 11501 working face advances to 60m, the deformation of overlying 13-1 coal seam begins to change, the area and degree of expansion begin to change are still small, and the maximum expansion area appears directly above the goaf.

In conclusion, with the increase of the mining length of the working face of coal seam 11-2, the stress of the overlying coal seam 13-1 in the goaf decreases greatly, and the expansion deformation rate of the coal seam is greater than 3 ‰, which is 4.25 ‰, indicating that the mining of coal seam
11-2 is effective in the pressure relief protection of overlying coal seam 13-1.

3.3 Field practice analysis

Based on the on-site construction conditions of 11501 roof roadway, 100m ahead of the working face of the protective layer was determined, a deep base point displacement meter was installed, and the relative displacement of the roof and floor of the protected coal seam during the mining process of the working face of the protective layer was continuously observed. The variation trend of roof and floor approaching amount of coal seam 13-1 before and after mining of coal seam 11-2 of protective layer is shown in Figure 10.

![Field practice analysis](image)

Fig. 10 The 13-1 coal seam roof and floor displacement changes with the advancement of the protective layer

Through the test of the movement of the roof and floor of coal seam 13-1 during the mining of coal seam 11-2 of the protective layer, according to the calculation formula of the expansion deformation of coal seam, the maximum expansion deformation of coal seam 13-1 at different positions after the mining of coal seam 11-2 is shown in Table 3.

Table 3 11-2 Different drill holes after coal seam 13-1 maximum swelling deformation of coal seam

<table>
<thead>
<tr>
<th>Number</th>
<th>Relative displacement/mm</th>
<th>Coal hole section length/m</th>
<th>Expansion deformation/‰</th>
<th>remarks</th>
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</thead>
<tbody>
<tr>
<td>BX1-1</td>
<td>35</td>
<td>4.8</td>
<td>7.29</td>
<td>Tendency direction</td>
</tr>
<tr>
<td>BX1-2</td>
<td>22</td>
<td>4.3</td>
<td>5.12</td>
<td></td>
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<td>BX1-3</td>
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<td>2.88</td>
<td></td>
</tr>
<tr>
<td>BX1-4</td>
<td>5</td>
<td>5.0</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>BX2-1</td>
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<td>7.7</td>
<td>-0.52</td>
<td></td>
</tr>
<tr>
<td>BX2-2</td>
<td>10</td>
<td>6.1</td>
<td>1.14</td>
<td>Strike direction</td>
</tr>
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</tr>
<tr>
<td>BX2-4</td>
<td>122</td>
<td>5.2</td>
<td>23.46</td>
<td></td>
</tr>
</tbody>
</table>
Table 3 shows that the relative deformation of coal seams corresponding to borehole bx1-1 and bx1-2 in the dip direction is greater than 3 ‰, which is within the effective pressure relief range; According to the relative deformation of coal seams measured by bx1-1, bx1-2, bx1-3 and bx1-4 boreholes, the pressure relief angle in the dip direction is 63.7, the pressure relief angle in the strike direction is 80.8, and the pressure relief line corresponds to the stoping line of the working face of the protective layer with an internal error of 37.2m.

4 conclusion

Taking the occurrence of long-distance outburst coal seams in zhujixi coal mine as the research background, using the combination of theoretical analysis, calculation, numerical simulation and field practice, this paper analyzes the gas occurrence characteristics of 11-2 Coal Seam and the feasibility of 11-2 Coal Seam as the lower protective layer, and studies and determines the pressure relief protection range of 11-2 Coal Seam Mining to the overlying 13-1 coal seam; This paper puts forward the regional outburst prevention technology of underground penetrating and bedding borehole pre drainage for the protective layer and the regional outburst prevention technology of pre drainage combined with the mining surface and underground of the protected layer. The conclusions are as follows:

(1) Coal seam 11-2 has uneven gas occurrence and poor regularity. There are only high gas areas in some parts, which are greatly affected by geological structure and slate properties of coal seam top and bottom. Coal seam 11-2 is a stress dominated briquette and gas outburst coal seam. The height of the "upper three zones" during the mining of 11-2 Coal seam is theoretically calculated, and the feasibility of protective layer mining is demonstrated through numerical simulation, which provides a basis for the layout of the working face of the protected layer.

(2) Adopts the regional outburst prevention mode of combined pumping up and down the well, that is, 11-2 Coal with low outburst risk is selected as the protective layer for mining first, 13-1 coal is protected above, and the gas of the protected layer is pumped at the same time. 11-2 Coal adopts the gas control mode of "one side with three lanes (one side with five lanes in the first mining face) + surface drilling", so as to realize multi-purpose, joint treatment and continuous mining of one lane. The tunneling working face adopts cross layer drilling and pre pumping, and the coal mining working face adopts the comprehensive outburst prevention measures of bedding drilling and pre pumping area. During the mining period, the ground drilling and top drainage roadway are used to extract the pressure relief gas of 13-1 coal.

(3) Using the technology of up-down combined pumping area, the underground excavation and mining face, the gas concentration of return air flow, the measured residual gas content and residual gas pressure, and the prediction indexes have not exceeded the standard, and there has been no dynamic phenomenon. In the application of up-down combined pumping area outburst prevention technology in zhujixi mine, the proportion of up-down pumping is 56.7%, and the proportion of down-hole pumping is 43.3%, Both are indispensable.

Data Availability

The data used for conducting classifications are available from the corresponding author authors upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.
Acknowledgments

This work was supported by the National Natural Science Foundation of China (no. 52174103); Natural Science Foundation of Anhui Provincial Natural Science Foundation (no. 2008085ME147); Special project of science and technology innovation and entrepreneurship fund of Tiandi Technology Co., Ltd (no. 2021-2-TD-ZD008) and State Key Laboratory Open Fund Project (no. SKLMRDPC20KF01).

Reference


https://doi.org/10.1002/ese3.642