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Research Article

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Research on recoverable range of upward mining in room-and-pillar residual mining area

Zihan Yang [1]* Le Xu[2]

[1]College of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo, China, 454003
[2]State Grid Construction Investment Inner Mongolia Energy Co., Ltd, Erdos, China, 017200
Email: 1592618547@qq.com

Abstract In order to study the safety problem of ascending mining in room-and-pillar residual mining area of a mining area in northern Shaanxi, numerical simulation was used to study the influence of ascending mining on the stability of interlayer rock strata and coal pillars in the lower goaf under the change of coal pillars and interlayer spacing in different areas. The results show that the theoretical analysis satisfies the local recoverable condition; upward mining can be carried out in areas where the interlayer spacing is greater than 15 m. In the area with a layer spacing of 10 m, the coal pillar with a coal pillar width of less than 6m * 6m is more likely to be unstable, and it is not recommended to carry out ascending mining. The regional coal pillar with a coal pillar width of more than 6m * 6m has a risk of instability, and corresponding measures should be taken before mining. The area with a layer spacing of 4m cannot be mined up.

Keywords Upward mining; orthogonal analysis ; numerical simulation ; old mine residual mining area

1. Introduction

In order to improve the recovery rate of coal resources and coal production, the major mining areas actively implement the integration of coal resources. It is more suitable to use the ascending order to mine the abandoned coal resources in the residual mining area of some old mines in Shaanxi and Inner Mongolia [1]. Chinese scholars have done a lot of research on the ascending mining of close distance coal seams. Feng Guorui and others [2] systematically analyzed the law of mine pressure appearance and the chain instability mechanism of coal pillar group in the mining of residual coal pillars, summarized the discriminant method of ascending mining, and developed a series of strata control technologies for ascending mining. Zhao Yixin [3] established a specific ascending mining mechanical model for the ascending mining of close distance coal seams, and studied the stress distribution law and fracture distribution characteristics in the coal seam. Wang [4] studied the law of strata behavior and strata movement in the ascending mining of close distance coal seam in Fangezhuang Coal Mine, and evaluated the feasibility of ascending mining. Liang Shaping et al. [5] analyzed the law of mine pressure behavior after upward mining in Hanjiawa Coal Mine from three aspects of stress, plastic zone and displacement through numerical simulation, and determined that the coal seam met the upward mining conditions.

Most of the existing upward mining feasibility studies are aimed at the overall feasibility evaluation of a coal seam. However, for some mining areas integrated by old mines, there are many coal pillars with large width and different sizes in the goaf. At the same time, considering the influence of coal thickness change and mining height difference, these factors have increased great uncertainty for upward mining, and it is difficult to make a unified conclusion on the mining feasibility of the whole coal seam. In this paper, numerical simulation and orthogonal analysis are used to study the migration law of coal and rock mass in different areas under the influence of coal pillar size and interlayer spacing difference in the upward mining of room and pillar residual mining area, which provides a theoretical basis for the division of recoverable areas in the upward mining of room and pillar residual mining area in old mines.

2. Project Profile

Taking a mine in the northern margin of the Loess Plateau in northern Shaanxi as the engineering background, the study area contains a total of seven mineable coal seams, numbered from top to bottom as 3-1,3-2,3-3,4-3,4-4,5-2 upper and 5-2 coal seams. Among them, No.5-2 coal seam is the main mineable coal seam in the mine field, with a thickness of 2.21 ~ 7.04 m, an average of 4.97 m, the shallowest coal seam depth is 175.03 m, and the deepest is 235.68 m ; the 5-2 upper coal seam in the study area is the secondary main coal seam. The thickness of the layer is 0.80 ~ 2.83 m, with an average of 1.91 m. It belongs to the upper bifurcation coal seam of the 5-2 coal seam. The spacing is 2.64 ~ 25.49 m, with an average of 18.97 m'

Through field investigation, it is found that there were 30 small coal mines in the study area, most of which were built in the late 1980 s and early 1990 s. The mining methods are mostly room and pillar mining and manual drilling and blasting. Figure 1 shows that the size of the coal pillar left by the coal pillar exposed during the open-pit stripping treatment of the room-and-pillar goaf of a coal mine in the mine field is extremely irregular, with different sizes and shapes. There are many resources left, and the waste of coal resources is astonishing.

Figure 1: Rooms & pillars mining exposure site

In the study area, it is determined that 5-2 coal is the residual mining area such as mining 3 to 3, mining 4 to 5, mining 6 to 7, mining 8 to 8, mining 10 to 15, and the mining height is about 3-5m.In this paper, according to the surrounding rock lithology, working face layout, coal seam spacing and other conditions of 5-2 coal and 5-2 upper coal in coal mine, the key parameters such as roof compressive strength change and plastic zone range of residual mining area in old mine are obtained, and the recoverable range of 5-2 upper coal in ascending fully mechanized mining is analyzed.

3. Theoretical Analysis of Feasibility of Upward Mining

Many studies have shown that [6], the feasibility of ascending mining of close distance coal seam group depends on the stability of the coal pillar in the lower goaf and the integrity of the upper coal seam. Therefore, according to the specific occurrence conditions of 5-2 upper coal seam, the maximum mining height and the minimum coal seam spacing are taken respectively. The stability of the coal pillar left in the integrity of 5-2 upper coal seam are analyzed.

A. Coal Pillar Stability Analysis

Coal pillar stress and coal pillar strength are the determinants of coal pillar stability. The stability of coal pillar is judged by the ratio of coal pillar strength to coal pillar stress. The area with mining width of 6m and 6m in 5-2 coal goaf is selected as the research object. The mining thickness of 5-2 coal is about 3m, the average buried depth is 120m, and the strength of coal pillar is about 20MPa. Due to the extremely complex stress distribution in the coal pillar, only the self-weight stress field of the surrounding rock is considered. It is considered that the weight of the overlying rock above the goaf is all transferred to the coal pillar, which is obtained by multiplying the average stress of the support when the coal pillar is recovered by a certain coefficient. For the residual mining area of 5-2 coal seam, the average bulk density of overlying strata is 2500 kN / m3, the maximum mining depth is 120 m, the width of coal pillar is 6.0 m, the width of coal room is 6.0 m, the length of coal pillar is 6.0 m, and the stress of coal pillar is 12 MPa.

According to the above calculation, the stability coefficient of 5-2 coal pillar is 1.6, and the theoretical analysis of coal pillar stability is relatively safe. However, due to the non-standard mining width during previous mining, the stability coefficient of coal pillars in different regions fluctuates up and down. Therefore, it is necessary to further study the stability of coal pillars in different regions of the mining area.

B. Upper Coal Seam Integrity Determination

The ' three zones ' discriminant method can be used to determine the integrity of the upper coal seam. By analyzing the position relationship between the ' three zones ' of the lower coal seam and the upper coal seam, the integrity of the upper coal seam can be judged.

The calculation shows that the development height of the caving zone after the mining of 5-2 coal is 12 m, and the development height of the fracture zone is 53 m. The 5-2 upper coal is above the caving zone and is within the range of the fracture zone after the mining of the lower working face. The integrity of the coal seam in the fracture zone is not seriously damaged by the mining below. It is necessary to further study the integrity of different areas of the upper coal seam. The area with good integrity can be mined by existing technical means.

4. Upward Mining Numerical Simulation

A. Modelling

Based on the field engineering practice characteristics of long-wall fully mechanized mining above the room and pillar goaf of coal mine, FLAC3 D is used to establish a numerical model to simulate whether the long-wall fully mechanized mining of 5-2 upper coal can be carried out above the room and pillar goaf of 5-2 coal. In the modeling process, combined with the actual situation, the boundary conditions of the calculation model are determined as follows: the four boundaries of the model are constrained by the model to ensure that the boundary will not have horizontal displacement ; the bottom boundary of the model is fixed, so that the displacement of the bottom boundary in the horizontal and vertical directions will not occur. The boundary above the model can move freely. The calculation model and the calculation model of physical and mechanical parameters of rock strata and the physical and mechanical parameters of rock strata are shown in table 1.

Table 1: physical and mechanical parameters of coal strata

lithologic characters	Layer thickness (m)	Elastic modulus (Pa)	Bulk modulus (Pa)	Shear modulus (Pa)	Internal friction angle (°)	Cohesion (Pa)	Tensile strength (Pa)
siltstone	8	6.38 e9	2.87 e9	2.82 e9	33.2	1.18 e7	2.3 e6
fine sandstone	4	5.69 e9	2.50 e9	2.54 e9	35.8	1.21e7	2.4 e6
siltstone	10	6.28 e9	2.83 e9	2.78 e9	30.2	1.12e7	3.3 e6
5-2 Upper coal	2	3.78 e9	2.86 e9	1.48 e9	27.1	9.5e6	1.11 e6
siltstone	10	7.38 e9	3.24 e9	3.29 e9	31.3	1.05e7	3.3 e6
5-2 coal	3	3.92 e9	2.61 e9	1.57 e9	28.5	9.8e6	1.05e6
siltstone	10	8.05 e9	3.44 e9	3.63 e9	33.6	1.03e7	3.7 e6

The common rectangular coordinate system is selected to establish the model of 5-2 coal. The xoy plane is taken as the horizontal plane, the z axis is the vertical direction, and the upward direction is the positive direction of the z axis. It is stipulated that the x-axis is the direction of the coal seam, the tendency of the coal seam is the y-axis, and the direction of gravity is the z-axis in the vertical direction. The coal seam is considered according to the horizontal coal seam. The model of the room and pillar goaf is 300 m in strike and 150 m in inclination. In addition, 50 m coal pillars are left in each direction of the mining range to eliminate the influence of boundary effect. According to the simulation scheme, a numerical model is established. It is assumed that the thickness of the coal seam is 6m, the width of the coal pillar is 6m, and the width of the roadway is 6m. A total of 5 rows of coal pillars are retained, and the vertical load p = 1.6MPa (equivalent to 80m thick rock strata) is applied to the roof of the goaf. The size of the whole numerical simulation model is 400m × 250m × 100m. The model is divided into 65748 units and 72892 nodes, as shown in Fig.2.

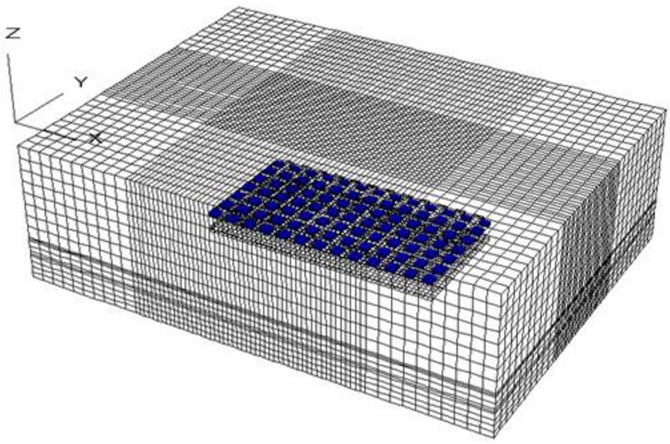
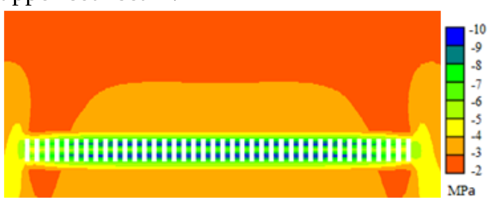


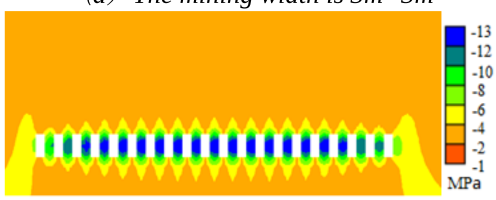
Figure 2: Numerical calculation model diagram

B. Goaf Stability Analysis

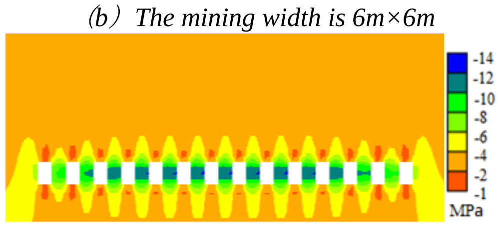
The distribution of stress field and displacement field after room-and-pillar mining of coal seam is shown in the figure. After the mining of the lower coal seam, the stress concentration phenomenon is mainly manifested in the roof and coal pillars of the goaf and their corresponding overlying strata. When the mining width increases from 3m × 3m to 9m × 9m, the maximum stress of coal pillar increases from 9.6MPa to 13.8MPa, which is lower than the ultimate strength of coal pillar, indicating that there is no plastic zone in coal pillar and the whole is in a stable state. The vertical displacement of the upper coal seam increased from 0.014 m to 0.023 m, and the vertical displacement of the coal seam was small, indicating that the integrity of the upper coal seam was better after the lower coal seam was mined. Therefore, the three kinds of mining width can meet the stability of coal pillar in goaf and the integrity of upper coal seam.



(a) The mining width is 3m×3m



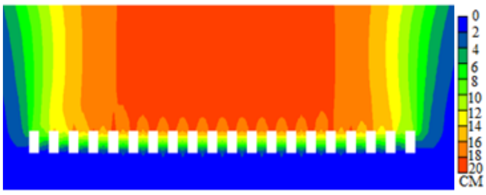
(b) The mining width is 6m×6m



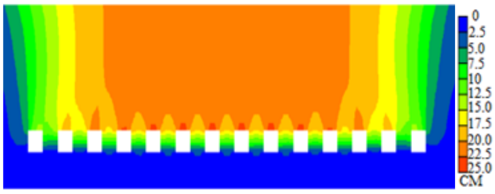
(c) The mining width is 9m×9m

Figure 3: Vertical stress distribution cloud diagram of coal pillar

(a) The mining width is 3m×3m



(b) The mining width is 6m×6m



(c) The mining width is 9m×9m

Figure 4: Vertical stress distribution cloud diagram of coal pillar

B. Analysis of The Influence of Interlayer Spacing

The influence of interlayer spacing on coal pillar in goaf is studied when the mining width is 6m * 6m. In the case of different interlayer spacing, the distribution of stress field and plastic zone in the upper coal seam after fully mechanized mining is shown in the figure. The analysis shows that the boundary support pressure of the upper working face in the upward mining process generates stress superposition through the floor and the lower goaf coal pillar, which is the root cause of the failure of the upper coal seam floor and the lower goaf coal pillar. When the interlayer spacing is 4m, the rock mass of the 5-2 upper coal floor has a penetrating plastic zone, and the upward mining cannot be carried out at this time. When the interlayer spacing is 10 m, the rock mass of the 5-2 upper coal floor has a maximum stress distribution area, and the physical and mechanical properties of the surrounding rock have changed. There may be cracks in the rock mass, which is easy to cause the plastic change of the rock mass. Therefore, it is necessary to analyze the stress state of coal pillars with different widths when the interlayer spacing is 10 m. When the interlayer spacing is 15 m and 20 m, the 5-2 upper coal is basically not affected by mining, and upward mining can be carried out at this time.

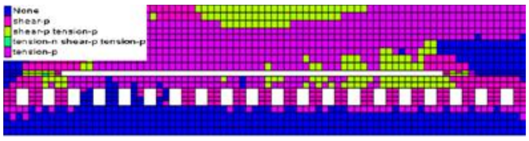
(a) The layer spacing is 4m.

(b) The layer spacing is 10m

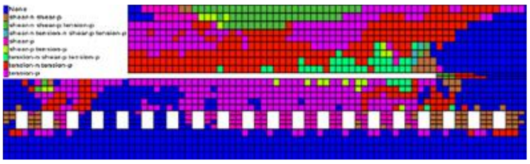
(c) The layer spacing is 15m

(d）The layer spacing is 20m

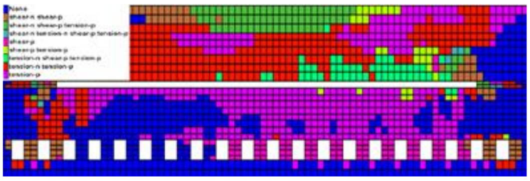
Figure 5: Vertical stress distribution cloud diagram of coal pillar



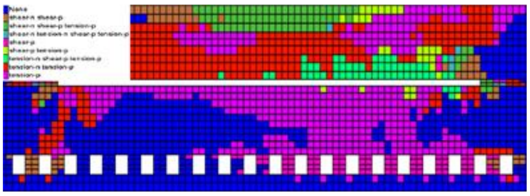
(a）The layer spacing is 4m



(b）The layer spacing is 10m



(c）The layer spacing is 15m



(d）The layer spacing is 20m

Figure 6: Vertical stress distribution cloud diagram of coal pillar

C. Influence Analysis of Coal Pillar Width

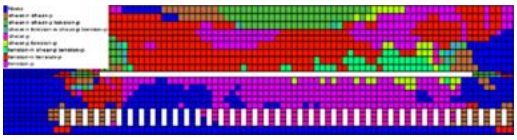
The basic form of stress distribution under different mining width is consistent, and there are different degrees of stress concentration in coal pillar and roof. When the mining width is 9m * 9m, the vertical stress of coal pillar is larger. When the coal pillar is arranged according to 3m * 3m, the plastic distribution range of the coal pillar is further increased, almost throughout the whole coal pillar, and the roof of the lower coal seam is almost plastic distribution, and the stability of the coal pillar is destroyed. When the coal pillar is arranged according to 6m * 6m, the plastic range of the coal pillar also almost runs through the whole coal pillar, which is prone to large-area instability risk. When the coal pillar is arranged according to the mining 9m * 9m, the plastic distribution of the coal pillar only increases slightly on the two sides of the coal pillar, the plastic distribution of the coal pillar roof changes little, and the stability of the coal pillar is the best.

(a）The mining width is 3m×3m

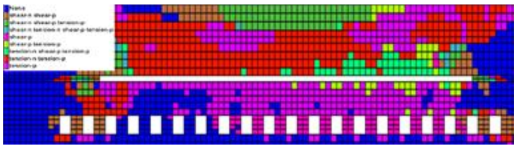
(b) The mining width is 6m×6m

(c) The mining width is 9m×9m

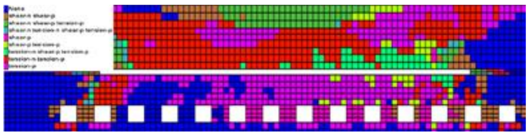
Figure 7: Vertical stress distribution cloud diagram of coal pillar



(a) The mining width is 3m×3m



(b) The mining width is 6m×6m



(c) The mining width is 9m×9m

Figure 8: Vertical stress distribution cloud diagram of coal pillar

Conclusion

1) The stability coefficient of the lower coal pillar is calculated to be 1.6. Using the ' three zones ' discriminant method, it is calculated that the upper coal seam is located on the caving zone of the lower coal seam and within the fracture zone. The upper coal seam is locally recoverable in theory.
2) When the coal pillar width is 3m * 3m, 6m * 6m and 9m * 9m after the simulation of the lower coal seam room and pillar mining, the goaf of the lower coal seam is in a stable state, the roof subsidence is small, and the integrity of the upper coal seam is good ; the coal pillar in the goaf of the lower coal seam is simulated as ascending mining under the condition of 6m * 6m.When the interlayer spacing is greater than 15m, the mining influence has little effect on the coal pillar in the goaf of the lower coal seam, and the coal pillar can be ascendingly mined. When the interlayer spacing is less than 4m, the coal pillar is unstable and destroyed, and the upper coal seam floor is plastically connected, and the ascending mining cannot be carried out. When the interlayer spacing is 10m, the coal pillar in the goaf of the lower coal seam can still maintain stability when the width is 9m * 9m.When the width is 6m * 6m, a large area of instability risk may occur.
3) In summary, for the mining area of the upper and lower coal seam spacing is greater than 15 m area can be carried out on the uplink mining ; for the area with a layer spacing of 10 m, the regional coal pillar with a coal pillar width of less than 6m * 6m is more likely to be unstable, and upward mining is not recommended. There is still a risk of instability in the regional coal pillar with a coal pillar width of more than 6m * 6m, and corresponding measures need to be taken before upward mining can be carried out. For the area with a layer spacing of 4m, upward mining is not recommended.

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