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Study on Optimization of Mining Pillar in Isolated Island Working Face of Thick Coal Seam under Complex Conditions

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Abstract. In this paper, a thick coal seam in Shandong Province is used as a prototype, which is located below the upper layer of 6 m residual pillar, and is a typical isolated island coal face based on the mining theory of upper liberation layer. The optimization study on the coal pillar of the island coal pillar working face formed by the over stratification is carried out. When mining the coal face with stratified island pillar, it is easy to be affected by the upper residual coal pillar and the lateral support stress of the two side goaf. The isolated island surface is easy to form high concentration stress, the roof movement is violent, the impact ground pressure is easy to be induced, and the support press frame is easy to be formed. Mining earthquake and other dynamic disasters seriously threaten the safety of working face. Therefore, the reasonable determination of the width of coal pillar is guaranteed. By using UDEC numerical simulation method, this paper studies the mining optimization of the coal face under the influence of the upper stratified residual pillar, which is the important factor of the safe mining of the separated island working face under the thick coal seam, and the optimization of the mining of the coal face under the influence of the upper stratified residual pillar. This paper analyzes the stress distribution and evolution law of coal pillar in lower layer protecting roadway, and determines that it is appropriate to keep 12 m coal pillar in isolated island working face of lower stratified coal pillar, and the internal dislocation is 6 m in the residual pillar of upper stratification, which can reduce its impact risk at this time. It can ensure the safe mining and high recovery rate of coal.

1. Introduction

With the increase of the mining intensity of China's coal resources, plenty of mining areas face the challenges of resources exhaustion and strain replacement in recent years, especially in eastern China, the coal resources with better mining conditions are on the decrease. In addition, the large-scale mechanized production method in those areas lacks the formal mining space, which leaves a quantity of island working faces in the existing mining areas of production. As it is known to all, coal resources are considered as non-renewable energy sources. Therefore, it is necessary to exploit the residual island working face so that coal resources can be efficiently used and its recovery rate can be well improved. However, mine dynamic disasters such as rock burst often occur in the exploitation process,



and the causes are very complicated. Besides, there are also many influencing factors, which leads to serious deformation of the roadway and is detrimental to the safety production of mines.

In regard to this situation, the current mining condition, technical condition and equipment fail to reasonably exploit the island working face of thick and extra-thick coal seam at one time. Therefore, it can be divided into several medium-thick layers for processing [1-5]. The mining of coal seam consist of two types: downward mining [6] and upward mining [7]. A large number of studies have shown that downward mining (the upper layer will be exploited firstly and the lower layer secondly) belongs to the mining of liberation layer, which can change the movement of surrounding rock and its stress distribution, reduce the impact induced by the movement of the overlying roof and play a better protective role for the mining of lower layer [8-12]. Some of the researches mentioned above have only studied the pressure relief and protection effect in the mining of lower layer caused by goaf after the exploitation in the upper layer of thick coal seam. However, they fail to take the influence of the coal pillar in the goaf section into consideration. And others have focused on the impact of the residual coal pillar in the upper layer on the mining of coal seam in the lower layer, without considering the layout characteristics of the working face in lower layer. Therefore, a mine in Shandong Province is selected as the research object in this paper to study the layered mining of thick coal seam, the complex conditions such as the residual pillar in the upper layer and the island characteristics of working face in the lower layer are considered on all sides. Based on the mining theory of upper protective layer, this paper analyzes the mining of the working face of isolated coal pillar in lower layer under complex conditions by means of UDEC numerical simulation software. According to the data of stress distribution and evolution law of chain pillar in the pre-exploitation of working face, the width of coal pillar in island working face in lower layer can be determined, which can reduce the impact risk and ensure the safety mining and higher recovery rate. Besides, this paper will provide references and guidance for the settings of similar coal pillar, as well as for the prediction and prevention of dynamic disasters in the process of coal mining. [13-14].

2. Introduction of the project

The coal left by a mining area of 10304 is regarded as the object, which belongs to the mining of thick coal seam according to its thickness. On account of the interlayer, the occurrence and mining conditions, the coal seam can be divided into the upper layer and the lower layer for its exploitation. Furthermore, after detection, it's found that the whole area of the coal can be mined because it owns simple structure and light variation in thickness. And the thickness of upper layer is 5.64m~7.14m, with an average of 6.29 m, while the lower layer is 2.58m~3.47m, with an average of 3.18 m. The average distance between the two layers is 11.13 M. At present, the coal seam in upper layer has been mined, and a residual coal pillar with the width of 6 m is reserved. Below the residual coal pillar, a working face with adjacent goaf on both sides has been designed and arranged, which is recognized as the typical island working face. As a result, the mining of it in lower layer will be affected by dual influences: the lateral supporting stress of the adjacent goaf on both sides and the residual pillar in the upper layer.

3. Establishment of UDEC numerical model

According to the analysis of the previous literature researches, it can be known that a great number of studies fail to simultaneously take the complex conditions such as the residual coal pillar in the upper layer and the isolated working face in the lower layer into account during the mining of thick coal seam. In view of such mining and geological conditions, the reserve and optimization of the coal pillar in lower layer after the exploitation of the working face in upper layer will be thorny problems. Generally speaking, methods such as mechanical modeling, numerical simulation and similar simulation experiment are often used to handle the optimization problem of coal pillar [15]. However, the method of mechanical modeling needs to consider more precise mechanical influence factors, which is difficult to establish the accurate models. The similar simulation test requires a long operation period, as well as many physical and financial resources. And the numerical simulation has strong

controllability and short operation period, which can meet the research needs. Therefore, the method of numerical simulation is utilized in this paper to optimize the island working face mining of coal pillar in the lower layer under the consideration of the complex conditions such as the residual coal pillar in the upper layer and the island characteristics of working face in the lower layer.

This paper attempts to adopt the method of UDEC numerical simulation (two-dimensional discrete element) to vividly reflect the movement characteristics of overlying strata after the mining of upper layer. The simulation software of UDEC is a two-dimensional discrete element program based on Lagrangian Algorithm to deal with discontinuous media, which is often used to simulate the response of the media under static or dynamic loads. On basis of analysis above, UDEC is adopted in this paper to simulate the width setting of the coal pillar for the safty mining of island working face in lower liberation layer, and the width from the perspective of stress distribution and evolution law of coal pillar is optimized. Then the deformation and large displacement of the block system will be well simulated. And in this section, the stress of working face and coal pillar will be studied and analyzed [16].

Based on the histogram of borehole 60 in the study area, the numerical model with the length of 750m and the height of 110m is established, as shown in Figure 1. According to the exploitation situation of the mine, the island working face of coal pillar formed after the mining of upper and lower layers is presented in the dotted box, while the working face of the upper and lower layer presented outside the dotted box has been mined. The island working face of coal pillar in upper layer will be firstly mined, as shown in Fig. 1, and the residual coal pillar with a width of 6m is formed in the upper layer. Then the island working face with 150m wide of coal pillar in lower layer will be mined, which belongs to the lower mining in the upper liberation layer. Therefore, before the mining of island working face of coal pillar in the lower layer under the liberation layer, the mining situation of coal seam is shown in Figure 1. And the physical and mechanical parameters of coal seam and the roof and floor are shown in Table 1.

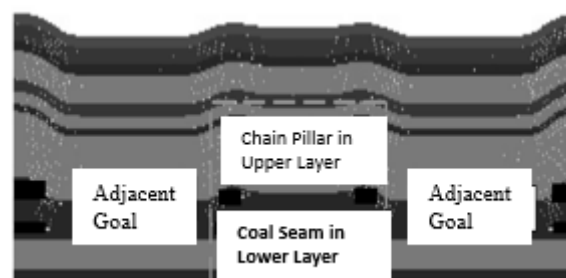


Fig 1. Coal seam mining situation

Table 1. Coal seam and its top and bottom plate parameters

Rock Formation	Thickness/m	Density /kg.m ⁻³	Bulk Modulus /GPa	Shear Modulus /GPa	Cohesion /MPa	Internal Friction Angle /°	Tensile Strength /MPa
Gritsandstone	4.5	2600	7.87	3.38	2.26	25	1.19
Clay	7	2360	2.17	1	1.3	38	1.15
Medium Sandstone/ Gritsandstone	25.5	2700	7.87	3.38	3.26	28	2.19
Fine Sandstone	7	2700	7.87	3.38	3.26	28	2.19
Medium Sandstone	11	2700	7.87	3.38	3.26	28	2.19
Mediun Sandstone	11	2700	7.87	3.38	3.26	28	2.19
Siltstone	2.5	2750	8.82	4.84	3.3	30	2.47
3 _上 Coal	6.5	1350	5.35	5.47	1.1	20	1.5
Siltstone	9.5	2750	8.82	4.84	3.3	30	2.47
3 _下 Coal	3.5	1350	5.35	5.47	1.1	20	1.5
Siltstone	3	2750	8.82	4.84	3.3	30	2.4
Fine Sandstone	19	2700	7.87	3.38	3.26	28	2.19

The boundary conditions of the calculation model are as follows:

- (1) The horizontal constraint is exerted around the model. In other words, the horizontal displacement of the boundary is zero;
- (2) The bottom boundary of the model is fixed. In other words, the horizontal and vertical displacements of the bottom boundary are all zero;
- (3) The top of the model is free boundary. A 9.5 MPa stress of overlying strata is imposed to the top, and the horizontal stress is 4.25 MPa.

$$\sigma_z = \gamma h = 25 \times 380 \text{ KPa} = 9.5 \text{ MPa} \quad (3-1)$$

In the formula: γ refers to the average bulk density of the rock mass, which shows 25 KN/m^3 ;
 h Refers to the thickness of the rock formation that is simulated, which shows 380 m ;

4. Layout optimization of coal pillar working face under liberation layer

4.1. Stress distribution of coal pillar

When optimizing the working face of coal pillar in lower coal seam, it is necessary to notice that the roadway of the working face in lower layer is affected by the residual chain pillar. According to the pillar face, the width of the chain pillar on both sides will be set to 2m, 4m, 6m, 8m, 10m, 12m, 14m, 16m and 18m, respectively. The stress intensity and distribution can be observed in Fig. 3.

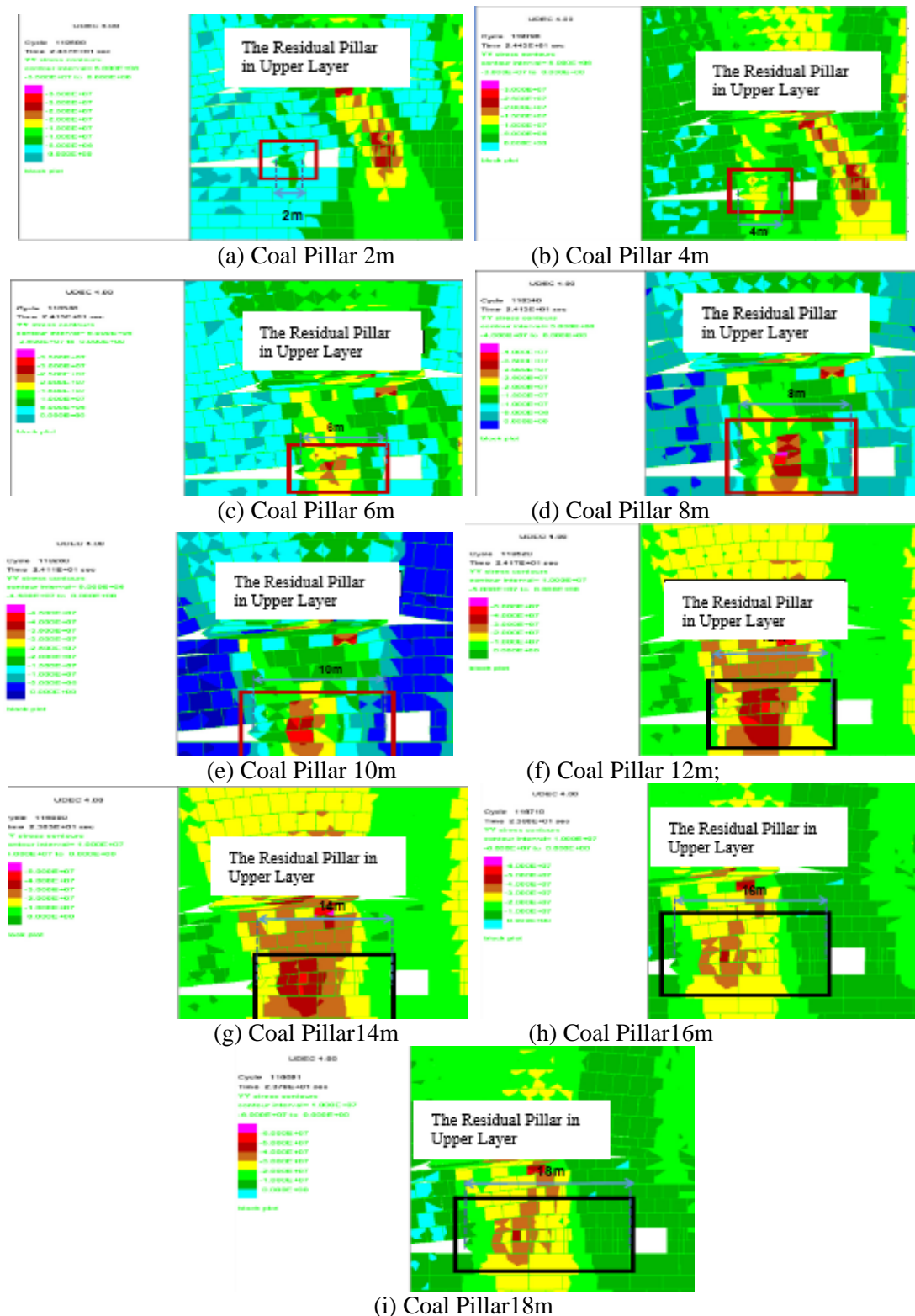


Fig. 2 Stress distribution of coal pillar and its top and bottom plate in different width coal pillar

According to the stress distribution of coal pillar in different widths in Fig. 2 (a) and (b), it is easy to know that the residual coal body (protective coal pillar) of the island working face is affected by the

superposition influence which is from the lateral support pressure of the adjacent goaf when the widths of the protective pillar are 2m and 4m, respectively. As a result, the compressive strength of the coal body reaches its own strength limit, and the coal with narrow pillar is strongly pressed so that it lost the original bearing capacity, which has no protective effect to the roadway. What's more, dynamic disasters such as rock burst will break out because a large amount of elastic potential energy accumulated in the coal body is suddenly released. As shown in Figure 2(c), (d), e), (f), when the widths of protective coal pillar are set to 6m, 8m, 10m and 12m respectively, the stress concentration factor of coal pillar in the lower layer under the influence of the residual chain pillar is still larger, although the protective coal pillar gets wider. In addition, under the action of the lateral stress superposition of the goaf on both sides, the pillar can not support the pressure from the overlying strata and the roadway also lacks stability. At this time, dynamic disasters are so easy to occur that it is unfavorable for the layout of roadway. On the contrary, as the protective coal pillar in lower layer gets wider, it's succeed to supporting the pressure from the residual coal pillar in upper layer when the widths are set to 14m, 16m, and 18m, as shown in Figures 2 (g), (h), and (i). And as the coal pillars in lower layer becomes wider, the affect of the coal pillar in upper layer on the roadway is gradually reduced. Meanwhile, the surrounding rock stress of the lateral adjacent goaf on both sides exerts weaker superposition influence on the roadway, and the elastic potential energy in protective coal pillar will be stable to maintain its plasticity. At this point, the roadway is so stable that it can be perfectly laied out.

4.2. Stress evolution law of coal pillar

When the widths of coal pillar are set to 2m, 4m, 6m, 8m, 10m, 12m, 14m, 16m, 18m, 20m, 22m, 24m, 26m, 28m, 30m, 32m, 34m and 36m respectively, the change curve is shown in Fig. 3.

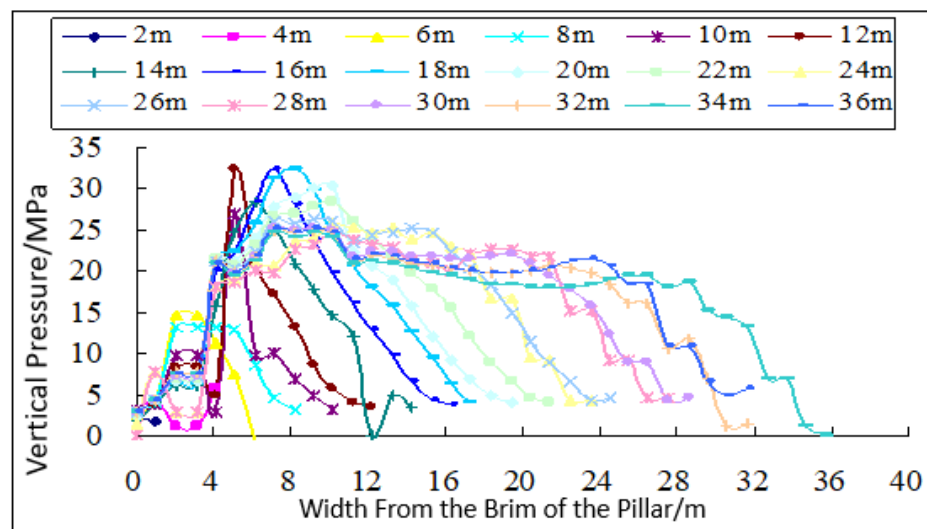


Fig. 3 Peak variation Curve of Vertical stress in Coal Pillar with different widths

According to Fig. 2 and Fig. 3, it can be found that if the width of protective pillar is less than 6m in the mining of the island working face in lower layer, its bearing capacity will be too weak to support the pressure from the residual pillar in upper layer. Then the plasticity of the coal body will be damaged and rock burst will break out. When the widths of protective pillar are expanded to 8m, 10m and 12m, the protective pillar in lower layer is greatly affected by the residual pillar in upper layer, and it's still stay in the high stress concentration area. As shown in the figure, the peak stress curve increases rapidly and continues to climb. When the widths of protective pillar in the lower layer are expanded to 14m, 16m and 18m, the peak stress curve in the protective coal pillar changes lightly as

the pillar gets wider, which indicates that the roadway holds higher stability and is not affected by the residual pillar in the upper layer and the adjacent goaf.

From the perspective of anti-shock, the narrower the coal pillar is, the better the scour prevention is. Impact risk is low because coal in the narrow pillar will almost be "crushed" (be strongly pressed) and at this time, there is no elastic potential energy, not to mention its reserve. However, the width of coal pillar in the section can not be set at will. On one hand, the coal pillar will be easily broken or collapsed by the influence of tensile stress of the top plate on both sides if it is too small, which fails to protect the roadway. On the other hand, if the large coal pillar whose width is at least 50m, serious loss of coal resources will be a problem. Based on the analyses, it can be observed that it is easy to support the chain pillar with smaller width, and at the same time, coal resources can be saved. According to the relevant literature and production experience [14,16], it is appropriate to select the chain pillar with the width of over 12m of the island working face under the liberation layer. However, considering the coal loss and recovery rate, the pillar with the width of 12m should be selected. At this time, the distance between the roadway of the coal pillar working face in upper layer and the goaf of coal pillar working face in lower layer is 6 m.

5. Conclusion

(1) In this paper, UDEC simulation is used to study the optimization problem of the working face of island coal pillar under liberation layer, and the stress distribution and peak evolution law of coal pillar under different widths are also analyzed. It is concluded that the chain pillar with the width of over 12m is properly be selected. However, considering the loss and recovery rate of coal resources, the pillar with 12m wide will be selected. At this time, the distance between the roadway of the coal pillar working face in upper layer and the goaf of the coal pillar working face in lower layer is 6 m.

(2) The layout of the working face of island coal pillar under liberation layer is optimized, which can reduce its impact risk. Both the coal recovery rate and safety production can be guaranteed at the same time.

(3) A variety of anti-shock measures are taken during the mining of the island working face in lower layer to strengthen the monitoring and support of the roadway in this area in order to ensure the safe operation of the working face.

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