SIZE OPTIMIZATION AND CO-OPERATIVE SUPPORT MECHANISM OF COAL PILLAR IN RESIDUAL RESOURCES RECOVERY WORKING FACE

by

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In this paper, a numerical calculation model of the mining face was established to analyze the rational size of coal pillars in the goaf on both sides by using FLAC^{3D} based on the mining geological conditions in the pilot area. Furthermore, the feasibility of co-ordinated reinforcement with steel pipe column was explored, which can be applied to the recycling of residual coal resources like protecting coal pillars and of great value to increase the recovery rate in gobs as well.

Key words*: rational size of coal pillars, co-ordinated reinforcement, residual resources*

Introduction

With the long-term high-intensity mining of coal resources, many mines begin to enter the period of resource exhaustion, so it becomes particularly important to keep the efficient recovery of coal resources like protecting coal pillars and well field corner coal pillars in the mining area, which is of great significance to improve the recovery rate of resource-exhausted mine, to extend the service life of mine and to relieve the employment pressure of personnel. Actually, there are amounts of coal column reserves left in the working face, providing a recoverable resource for exhausted mines. However, due to the irregular resource distribution, complex geological environment and high surrounding rock stress, the stability of the roadway among the protected coal pillars in recovery working face is poor, which means that the wide roadway protection coal pillars are required to be left. On the other hand, the size of the coal column in the transportation roadway vary from the different positions of stop line in each working area, which could lead to plenty of problems such as low resource recovery rate, large surrounding rock deformation, poor economic benefits and so on. Therefore, the size optimization of coal pillars and collaborative control of the surrounding rock under bilateral mining conditions have to be settled urgently.

In view of the problem of protecting pillar resource recovery in gobs, Smart *et al.*[1] obtained the strength values of coal rock specimens from a large number of experiments,

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applied them to pillar strength calculation through certain correction parameters ,and proposed the *Hollad-Gaddy* formula. The Austrian Engineer, Rabcewicz [2] put forward a new construction plan on the basis of summarizing previous construction experience. Its construction principle is: to make full use of the carrying capacity of the surrounding rock itself, to use rock bolts and shotcrete as the main support method, to timely reinforce the surrounding rock, to prevent the destruction of surrounding rock, and finally to achieve the purpose of controlling the stability of surrounding rock. Hui *et al*. [3] conducted the deformation and failure of roadway surrounding rock rules in no support, anchor beam network cable support and bracket support, those three different support forms under the dynamic pressure along the roadway in gods when the coal pillar width is certain. Also he analyzed the deformation under different support means, and built up the exactly support forms suitable for different conditions. Zhai *et al.* [4] analyzed the lithology characteristics of the roof and coal seam and the stress characteristics of the roadway in the pilot area, pointed out the high strength and high pre-tension anchor network cable support system, and designed the support of the roadway along gobs in order to effectively control the deformation of surrounding rock.

In this paper, the influence of coal pillars size to the surrounding rock deformation among roadway in working face was analyzed [5-7], and also the cooperative bearing rule of concrete steel tube column and small coal column in the roadway were discussed. The results show that research has important theoretical value and practical significance to improve the roadway surrounding rock control effect of high stress island pillar working face, to reduce the pillar size, to improve the pillar resource recovery rate, and to ensure the safe and efficient production of resource-exhausted mines.

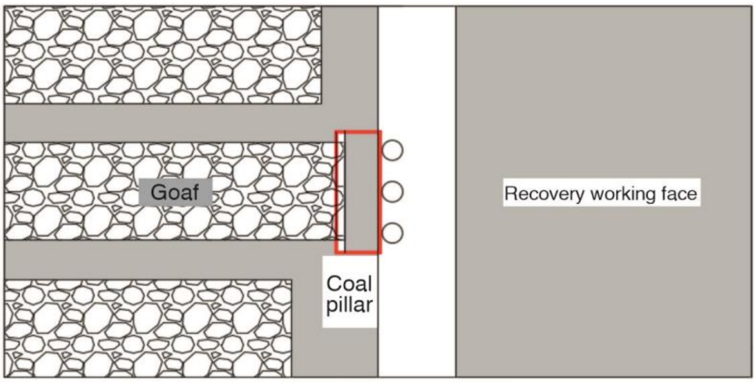


Figure 1. Top view of small coal column

Engineering background

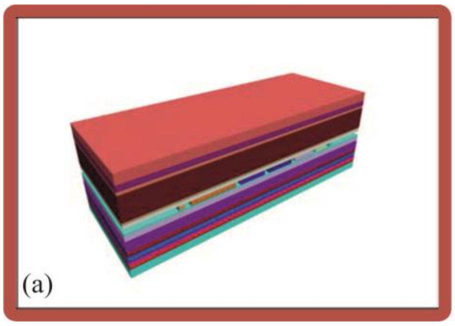
Zhangcun Coal mine where is located in Changzhi City, Shanxi Province was chosen as a pilot site. According to the geological conditions of the protected coal pillar mining face in 25 mining area, the buried depth of No. 3 coal seam in the mining area is 400 m, and the direct top thickness of 5.89 m is composed of sandy mudstone. The average thickness of the old top is 6.0 m, which is made up of medium grain quartz sandstone and siltstone. The bottom plate with a thickness of 9.15 m consists of black mudstone and fine sandstone mainly, followed by sandy mudstone and siltstone. The foundational mechanical properties of each rock formation are shown in tab. 1.

Table 1. Basic mechanical parameters of surrounding rock

Sample	Tensile strength [MPa]	Compressive strength [MPa]
Sandy mudstone	1.54	26.8
siltstone	3.92	54.6
Fine sandstone	2.29	15.4
mudstone	2.61	33.7

Simulation scheme design

The stability analysis model of the small coal pillar roadway was established with the geological conditions of the experimental area, as shown in fig. 2. Thenumerical model sizewas 285 m × 96 m × 76.4 m. The whole model had 256280 units and 269984 nodes. Mohr-Coulomb model was adopted as rock formation configuration, and large deformation mode was used to simulate the deformation. What's more, the roadway size was 3500 mm × 5000 mm, and the surrounding rock was supported by anchor rod. Further, the upper surface of 10 MPa equivalent load was applied, with sliding boundary and fixed boundary at the bottom. Additionally, the calculation model would approximate the rock mass, coal seam and filling area as homogeneous, continuous and isotropic media, which only considered the dead weight stress and ignores the influence of structural stress.



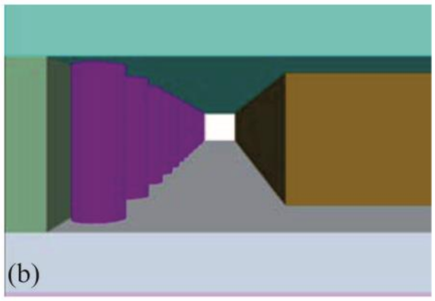


Figure 2. (a) Calculation model of small pillar roadway and (b) calculation model of pillar-steel tube column cooperative support roadway

This model was mainly considered the influence of the pillar size and the steel tube column support on the stability of the roadway in the mining area. Designing three calculation schemes of 5 m, 10 m, and 15 m pillar sizes, the concrete steel tube column with the diameter of 1200 mm was arranged to jointly support the small coal pillar of 5 m. Through the calculation and comparative analysis of the four schemes, the optimal coal pillar size of the roadway in the recovery working face of the isolated island coal pillar was determined. Then the reinforcement mechanism of the small coal pillar under the cooperative support condition of the steel tube column was further investigated.

Stress distribution of surrounding rock in small coal pillar roadway

The stress distribution characteristics of roadway surrounding rock reflects the bearing state of roadway roof, small coal pillar and solid coal gang, and also provides a basis for the stability evaluation of small coal pillar on the recovery face of protective coal pillar in the mining area. By the way, the cloud map of the surrounding rock stress distribution in the small coal pillar roadway in the mining area under the four scheme conditions is exhibited in fig. 3.

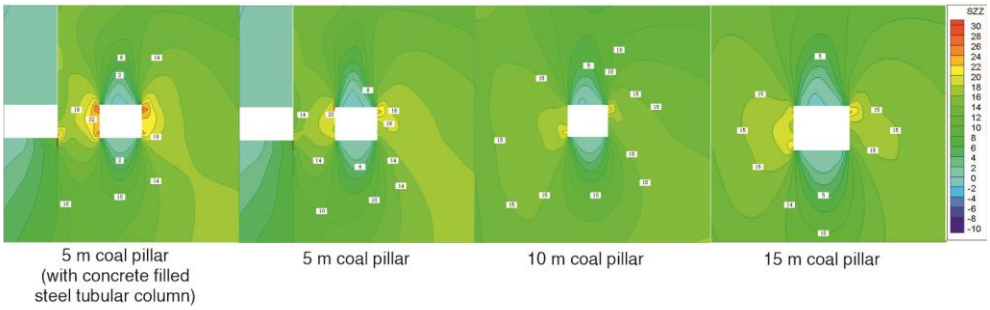


Figure 3. Vertical stress cloud diagram of the small coal pillar roadway

As can be seen from fig. 3, the stress concentration of the small pillar roadway mainly occurs in the top corner, bottom corner of the roadway and inside the small pillar. The maximum vertical stress of the pillar gang is significantly higher than that of the solid coal gang, and the distribution range of the internal stress rise area of the small pillar is greater than that of the solid coal gang. When the pillar width is greater than 5 m, the maximum vertical stress in the width of the pillar decreases. At 10 m and 15 m pillar width conditions, the maximum vertical pressure of the pillar help is 17.1 MPa and 16.4 MPa, respectively. When the width of the pillar is 5 m, the large additional load of the roof causes the pull-shear damage inside the pillar, which reduces the carrying capacity of the pillar, and then causes the damage and instability of the small pillar. What's more, the concrete steel tube column is used to jointly support the 5 m small coal pillar, the distribution range of the stress rise area of the coal pillar is significantly larger than when the concrete steel tube column is not used, and the distribution uniformity of the stress inside the coal pillar is better.

In order to further analyze the change law of the internal stress with the size of the pillar, take the horizontal measurement line of the vertical direction of the pillar and draw the change curve of the vertical stress with the width of the pillar, fig. 4.

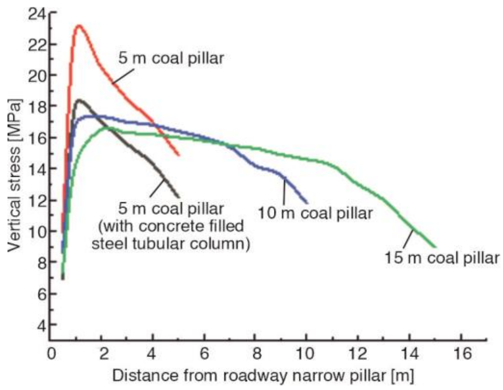


Figure 4. Vertical stress curve of coal pillar

The shallow stress on both sides of the coal pillar shows a decreasing trend, and the stress in the central elastic nuclear area is large. In the range of 5~15 m, the maximum stress inside the pillar increases with the decrease of the pillar width. The maximum vertical stress in 5 m coal pillar increases sharply. When the width of coal pillar increases from 10 m to 15 m, the maximum vertical stress does not decrease significantly. In addition, when the width of coal pillar is 10 m and 15 m, there is a wide range of elastic nuclei in the coal pillar. When the width of coal pillar is less than 10 m, increasing the width of coal pillar has a significant effect on the optimization of the stress distribution of coal pillar. While the width of coal pillar is larger than 10 m, increasing the width has no significant effect on improving the stability of coal pillar. Therefore, under the condition that concrete steel tube column are not used for collaborative support, the reasonable width of coal pillar in the recovery working face of protective coal pillar in the mining area is 10 m.

Under the condition of cooperative support of 5 m small coal pillars by using concrete filled steel tube columns, the maximum vertical stress in the coal pillar decreases from 22.8 MPa to 18.3 MPa (19.7% reduction), which is basically equal to the maximum vertical stress at 10 m and 15 m. Concrete-filled steel tube column plays a good synergistic support role for the roof plate, and the maximum vertical stress in the small coal pillar falls back to a reasonable level. This shows that the stability of 5 m small coal pillar is good under the synergistic support action of concrete filled steel tube column.

Deformation law of surrounding rock in small coal pillar roadway

The deformation law of small pillar roadway can directly reflect the surrounding rock control effect of the mining area, and is also an important basis for evaluating the stability of small pillar roadway. Figure 5 illustrates the vertical displacement of cloud around the roadway in the mining area.

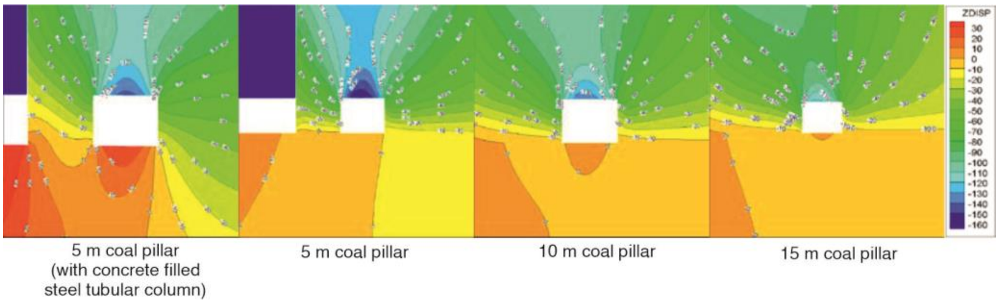


Figure 5. Cloud image of vertical displacement of roadway surrounding rock

From fig. 5, as the pillar width increases from 5 m to 15 m, the subsidence of the roof gradually appears within 3.44 m away, with the increase of the pillar width, the deformation of the roadway roof decreases significantly. It exerts that increasing pillar width affects the deformation control of high stress island working surface. Contrast different vertical displacement under the width of the cloud map can be seen:the vertical displacement contour distribution of 5 m small pillar is dense, which refers to acute vertical deformation of 5 m small pillar because of the additional load and rotation effect by hanging top roof in the goaf. In other words, it intensified the pillar side roof sinking, which lead to the surface of the roadway roof sinking curve presents significant asymmetry. Nevertheless, under the condition of using concrete filled steel tube pillar to jointly support the 5 m small coal pillar, the roof surface and deep base point sink decrease significantly, and the asymmetry of deformation is weaken. It is verified that the combined structure of *5 m small coal pillar + concrete steel tube column* plays a good supporting role in the vertical direction of the mined side of the roadway.

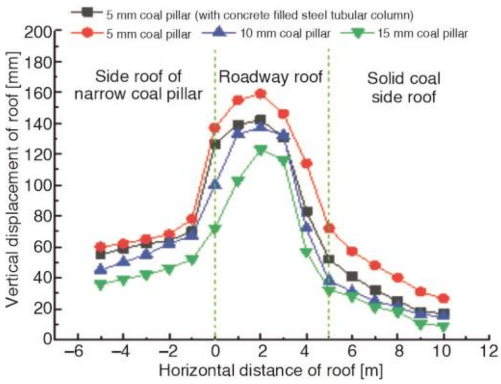


Figure 6. Subsidence curve of the roof

The curves in fig. 6 exhibits the subsidence curve of the roadway roof of the protected coal pillar recovery working face in the mining area. The sinking amount of the pillar roof is significantly greater than the solid coal cap. The sinking amount of the solid coal roof is only about 53% of the coal pillar cap, and the maximum sinking amount of the roof is located at the small pillar side in the middle of the roadway. Under the coal pillar width of 5 m, 10 m, and 15 m, the maximum subsidence of roadway roof is 162 mm, 133 mm, and 122 mm, respectively, tab. 2. Under the condition of using concrete filled steel tube column to jointly support the 5 m small coal pillar, the maximum sinking amount of the roadway roof is 136 mm, which is basically equal to the roof sinking amount of the 10 m coal pillar width and reduced by 16% compared with the 5 m coal pillar.

Table 2. Maximum vertical displacement of roof

Sample	Maximum vertical displacement [mm]
5 m coal pillar (with concrete filled steeltubular column)	136
5 m coal pillar	162
10 m coal pillar	133
15 m coal pillar	122

The smaller pillar width has a significant effect on improving the recovery rate of coal resources in the mining area. Also, it is crucial to extend the service life of resource-exhausted mines and improve the economic efficiency. So, a smaller coal pillar size should be adopted under the premise of meeting the surrounding rock safety control requirements of the high stress island surface roadway. Using concrete filled steel tube column and small coal pillar to support the roof is in favor of the stability of small coal pillar roadway on high stress island surface and will greatly reduce the coal pillar width of high stress roadway.

Conclusion

When the roadway along small coal pillars in the protecting coal pillar recovery-working face suffers from the action of superimposed load in double side goaf, it is very significant to effectthe roadway deformation by controlling thewidth of the coal pillar. When the pillar width is greater than 10 m, it's able to basically meet the requirements of surrounding rock control for pressure relief roadway. On the other hand, when the pillar width is 5 m, it raises the risk of large deformation which happens to the roadway. The combined support structure of *5m small coal pillar + concrete filled steel tube column* not onlyimproves the surrounding rock stress distribution of high stress of small coal pillar roadway, but also controls the convergence deformation of roadwayeffectively. What's more, it improves the stability of small coal pillar as well. In generally, the combined support structure plays an important role in reducing the size of coal pillar recovery working face in the mining area in deed, improving the recovery rate of residual resources and ensuring the safety of high stress roadway. This paper provesthe feasibility of the combined support structure of *5m small coal pillar + concrete filled steel tube column* in the roadway maintenance of high stress island working surface. However, the optimization of the column diameter, filling material strength and column spacing is not involved, and the analysis of relevant parameters should be carried out in the further study.

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