



Research on the Retention of Small Coal Pillars in Goaf Excavation Along the Fully Mechanized Mining Face

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ABSTRACT

In order to solve the problems of coal pillar retention and closure in the fully mechanized mining face, this paper takes the 208 fully mechanized mining face of Daning Coal Mine as the prototype, and studies the width of small coal pillars left in the goaf of the 208 fully mechanized mining face of Daning Coal Mine through a combination of theoretical analysis and numerical simulation. The minimum size of coal pillars in each section is about 2.8-5.0m; By using FLAC 3D numerical simulation software to simulate and analyze the numerical values of different coal pillar settings, it was finally concluded that setting a 6m coal pillar resulted in the most stable bearing structure of the roadway itself.

KEYWORDS

Digging Tunnels Along the Air; Small Coal Pillar; FLAC 3D Numerical Simulation.

1. INTRODUCTION

Coal resources will continue to be the main energy source in China for a considerable period of time. Domestic coal mines generally adopt the method of underground mining. According to statistics, the annual length of excavated tunnels in large and medium-sized state-owned coal mines has reached 21000 km, of which more than 80% are pre mining tunnels. For underground mining, maintaining the stability of the surrounding rock during the service period of the roadway is a prerequisite for achieving safe and efficient production in coal mines[1-2]. The excavation of tunnels and the backfilling of working faces will break the static equilibrium state of the original rock stress in the strata. During the excavation process, most of the tunnels are in a static pressure state in the original stress field. Once affected by the mining of surrounding working faces, the static pressure state in the original rock stress field is changed under various concentrated pressures, and the stress value increases sharply, leading to the re adjustment of the surrounding rock stress of the tunnel again or multiple times[3]. The stable equilibrium of the roadway under the original static pressure state is broken, and the surrounding rock undergoes significant deformation, displacement, and pressure increase. It is necessary to redistribute stress to reach a new equilibrium before the roadway surrounding rock can stabilize again. During this period, accompanied by the phenomenon of large deformation of the roadway surrounding rock, some tunnels are unable to resist concentrated stress due to insufficient support strength, resulting in instability and affecting the normal, safe, and efficient production of the mine[4-5].

In recent years, with the development of small coal pillar excavation technology along the goaf, the coal extraction rate has been greatly improved. China's geological conditions are complex and varied, and the method of retaining coal pillars in mines varies due to the physical and mechanical properties

of the coal rock mass, mining techniques, and roadway support forms [6]. In practical engineering practice, considering the influence of surrounding rock properties and other factors, a reasonable width of small coal pillars should be selected to withstand the pressure caused by mining on the overlying roof, while also isolating the ventilation and gas leakage in the goaf, ensuring safe mining of the working face. Therefore, based on the stress environment in which the coal pillar is located, a coal pillar stability mechanical model is established to theoretically calculate the size of the coal pillar and simulate the support quality of the roadway, in order to achieve the goal of controlling the stability of the surrounding rock of the goaf excavation roadway.

2. PROJECT OVERVIEW

The 208 comprehensive mining face is the 8th mining face in the second mining area, located in the western part of the second mining area. The north-south direction (projection) is 1586.6m long and the east-west direction (projection) is 254.5m wide. The eastern part of the 208 fully mechanized mining face is the 207 working face, the western part is the planned 209 working face, the northern part is the auxiliary roadway of the second mining area, and the southern part is the southern boundary of the mine and the northern part of Songwangzhuang Village. The corresponding ground locations of the work face include Gaozhuangtou Village, Shedidi Village, Houhongtupo Village, and Qianhongtupo Village, all of which have been relocated. The elevation of the coal seam floor in the working face is between +540m and +590m, the elevation of the ground is between +759m and +900m, and the burial depth is between 169 and 360m, which is similar to the terrain trend.

The working face has a low to medium mountain terrain, with the northern part being relatively flat, the middle being higher, and the southern part being lower. The terrain is strongly cut, with developed gullies and only a small amount of exposed bedrock under steep slopes. Except for the central highlands, which are gentle slopes, the rest are mountainous and sloping areas (within the range of 15-45 °) covered by shrubs or weeds, with exposed loess or bedrock. Within the mining area of the working face, there are multiple houses and caves in abandoned villages. There is an orchid coalbed methane transmission pipeline on the northern surface of the working face.

3. ANALYSIS OF COAL PILLAR RETENTION SIZE

In order to avoid the influence of fixed support pressure or residual support pressure on the roadway, reduce the movement of the surrounding rock of the roadway to maintain stability, and minimize the loss of coal pillars in the section, the width of the protective coal pillars in the section flat roadway should be as small as possible. However, the roadway cannot be arranged in the unloading zone because when using anchor rods to support the section flat roadway, the anchor rods may be installed in the broken surrounding rock due to the rupture of the coal pillars, resulting in a weakened anchoring force of the anchor rods and a reduced support effect. It can be seen that determining the reasonable position of the roadway is also very important, and the minimum width of the coal pillar [7-8] is:

$$B = x_1 + x_2 + x_3 \quad (1)$$

$$x_2 = (30\% \sim 50\%) (x_1 + x_3) \quad (2)$$

In the formula: x_1 is the width of the plastic zone generated in the goaf coal body after mining on the working face, m; x_3 is the effective length of the anchor rod, m; x_2 is the coal pillar stability coefficient increased considering the thickness of the coal seam.

After calculation: $B = x_0 + x_4 + x_3 = 3.8 \sim 5\text{m}$

For safety reasons, the width of the coal pillar should be greater than 3.8~5m.

4. DETERMINATION OF REASONABLE COAL PILLAR WIDTH FOR GOAF EXCAVATION

A numerical simulation model was established based on the comprehensive column chart of the 3# coal seam in Daning Coal Mine and its physical and mechanical parameters of the roof and floor slate. The model rock layers are divided into 18 layers, and the model size is 500m × 87.7m (X × Z). The model constrains x-direction displacement on both sides and z-direction displacement on the bottom; The vertical stress at the upper boundary of the model is considered based on a depth of 300m and a bulk density of 25kN/m³. The original rock stress is 7.5MPa, and a vertical stress of 6.185MPa is applied at the top of the model to simulate the self weight of the overlying rock layer. A monitoring line is set up along the middle of the coal seam on the left side of the 207 working face to monitor the lateral support pressure before and after excavation. The mechanical parameters required for this simulation analysis were obtained by consulting relevant materials, and the stress simulation analysis of the goaf under different coal pillar widths was carried out to preliminarily obtain a reasonable coal pillar width.

4.1. Distribution characteristics of surrounding rock in goaf tunnels under different coal pillar widths

Simulate the distribution and deformation characteristics of the surrounding rock of the roadway under stress disturbance under six different coal pillar widths, including 3m, 4m, 5m, 6m, 7m, and 8m, and compare the simulation results to determine the coal pillar width. The simulation scheme for coal pillar width is shown in Table 1.

Table 1 Coal pillar retention size table

Scheme	I	II	III	IV	V	VI
Coal pillar width/m	3	4	5	6	7	8

From the lateral vertical stress curve of the goaf mentioned above, it can be seen that the width of different coal pillars and the surrounding rock environment at the location of the roadway are different. The roadway along the 3-6m coal pillar is located between the stress reduction zone and the stress peak, while the 7-8m coal pillar is located near the stress peak range. Afterwards, the stress above the coal pillar is lower than the stress peak. According to the above analysis, the roadway along the goaf should be arranged in the area where the stress is lower after the upper goaf is stabilized. Therefore, it is not recommended to leave the 7-8m coal pillar.

4.2. Simulation analysis of stress and deformation of coal pillar surrounding rock during excavation

4.2.1. Analysis of stress distribution law

After the stability of the overlying roof of the 207 working face goaf, the excavation of the 2802 trench was carried out. The excavation activity changed the stress distribution of the surrounding rock, and it was analyzed. After the model calculation was completed, the vertical stress distribution law of the surrounding rock characteristics within a range of 120m laterally adjacent to the goaf was taken.

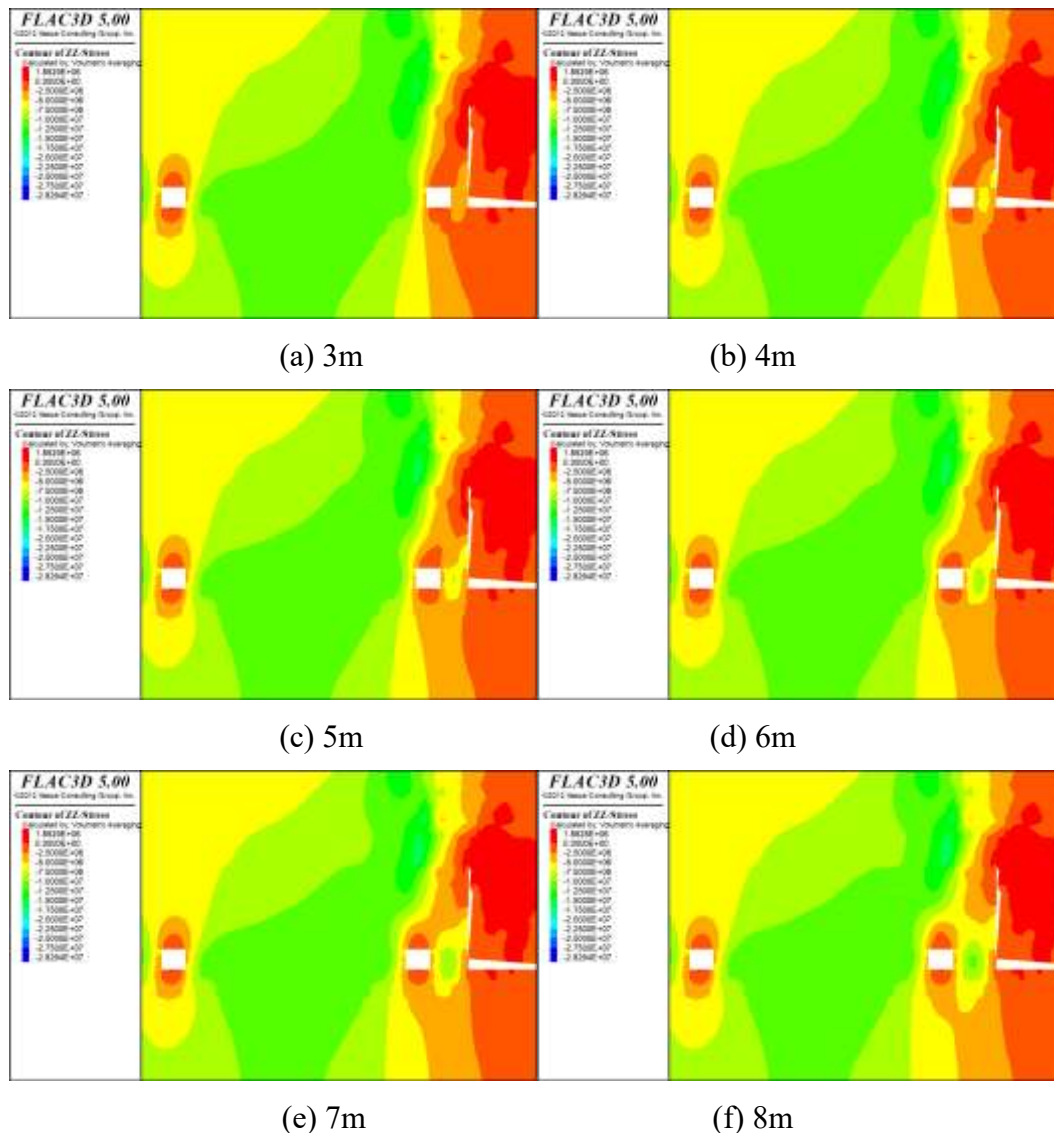
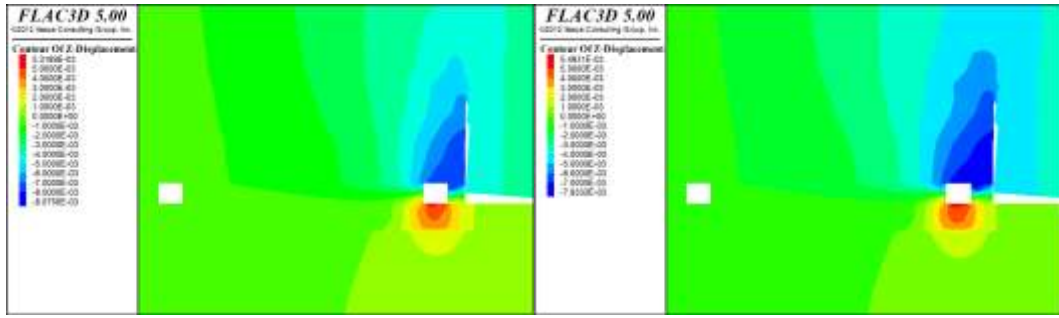


Figure 1 Cloud map of vertical stress distribution in surrounding rock of coal pillars with different widths after excavation along the goaf

The vertical stress distribution cloud map corresponding to different coal pillars during excavation is shown in Figure 1. According to the simulation results, it can be seen that as the width of the coal pillar increases, the horizontal stress of the coal pillar and the vertical stress of the roof gradually increase, while the horizontal stress of the solid coal pillar changes little, and the vertical stress of the bottom plate first decreases and then increases. When the width of the coal pillar is 3m or 4m, the peak stress of the coal pillar is close to the goaf, and the coal body at the edge of the goaf is broken. The overall bearing capacity of the narrow coal pillar is low, and effective bearing cannot be formed; From Figure 1(c) and Figure 1(d), it can be seen that when the width of the coal pillar is 5m and 6m, there is a stress core zone in the middle of the small coal pillar, and the structure is complete and capable of self stabilization.

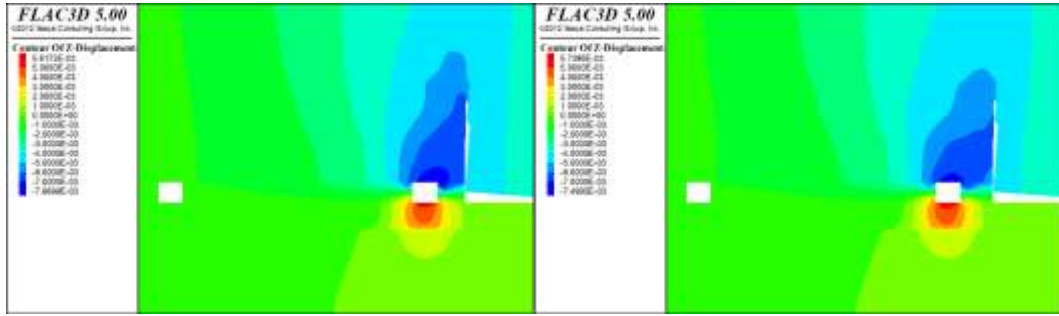
4.2.2. Analysis of Displacement Distribution Law

The vertical and horizontal displacement of the tunnel and the deformation of the surrounding rock during excavation are shown in Figures 2 to 3.



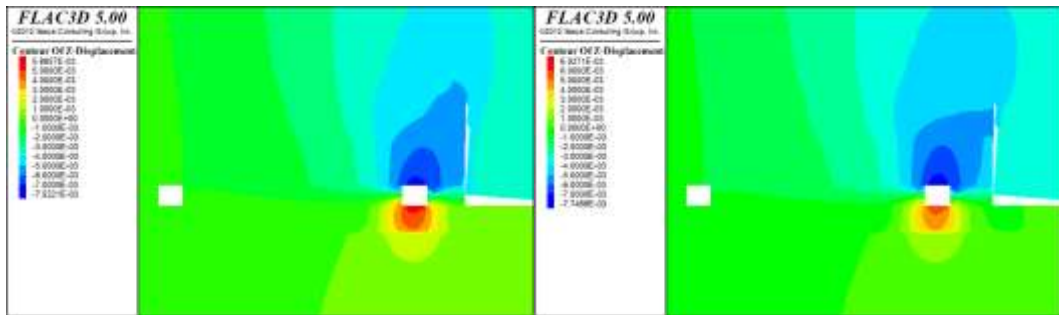
(a) 3m

(b) 4m



(c) 5m

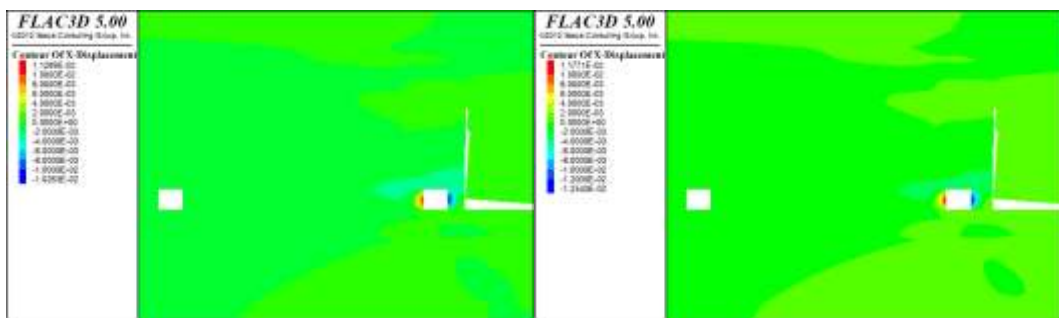
(d) 6m



(e) 6m

(f) 8m

Figure 2 Cloud map of vertical displacement of surrounding rock of coal pillars with different widths after excavation along the goaf



(a) 3m

(b) 4m

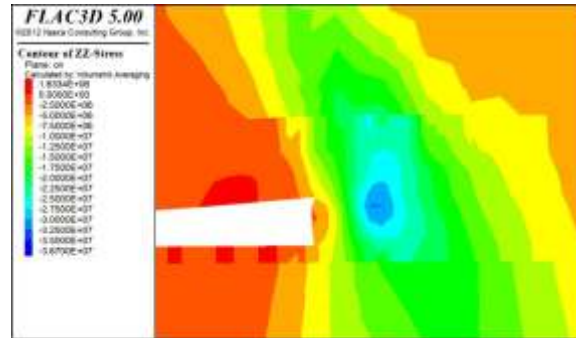


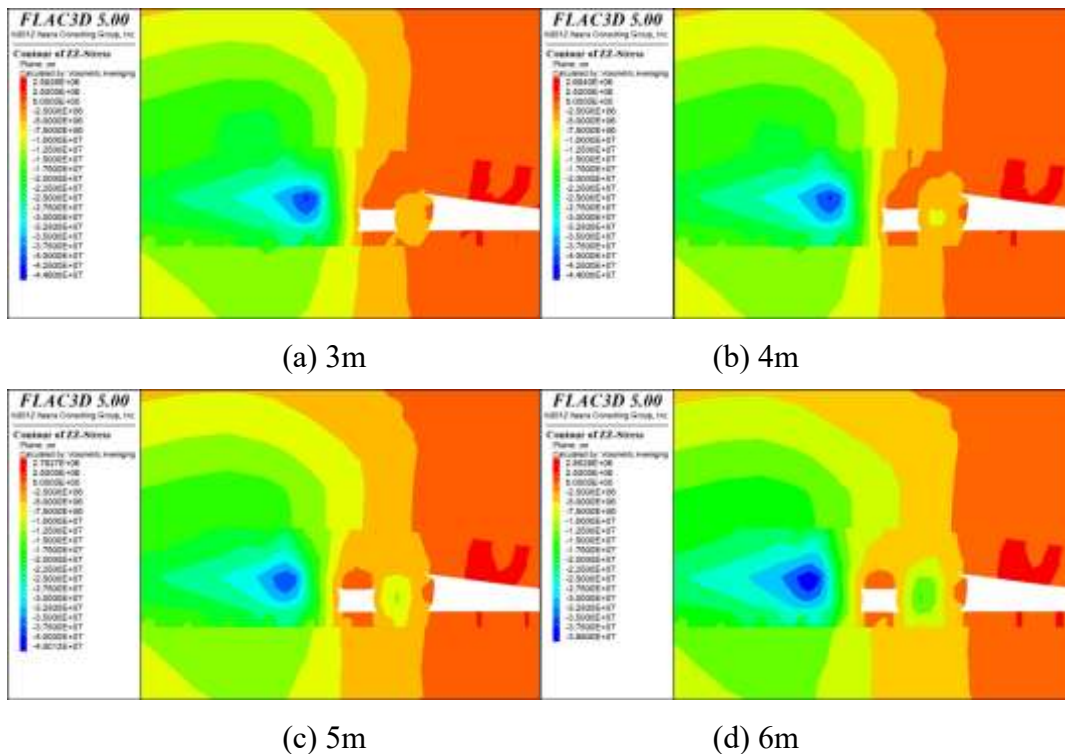
Figure 4 Vertical stress cloud map of advanced working face

Figure 4 shows the vertical stress cloud map of the advanced working face. It can be seen from the figure that: ① During the mining process, due to the twisting deformation of the overlying roof, a stress peak with a magnitude of 36.7 MPa appeared at a position about 6 meters away from the working face; ② The leading stress first increases to the peak stress, and then gradually recovers to the original rock stress at a distance of about 30m from the leading working face. ③ At a distance of 20m from the working face, the leading vertical stress is 13.4MPa, which is about 1.79 times the original rock stress. Advance support is carried out within 20m of the working face to ensure the safety of the operation.

In order to reflect the stress of coal pillars and the deformation of surrounding rock during the backfilling of the lower working face as much as possible, a section 6 meters ahead of the working face was taken for analysis. The analysis results are as follows:

(1) Analysis of stress distribution law

According to the above analysis of the advanced vertical stress, it can be concluded that the peak of the advanced support pressure is reached 6 meters ahead of the mining face. During the mining period of the 208 working face, the peak of the advanced support pressure is located 6 meters ahead of the mining face. Afterwards, under the condition of leaving coal pillars, this position is used as the research object to analyze the stress distribution of the surrounding rock of the roadway, as shown in Figure 5.



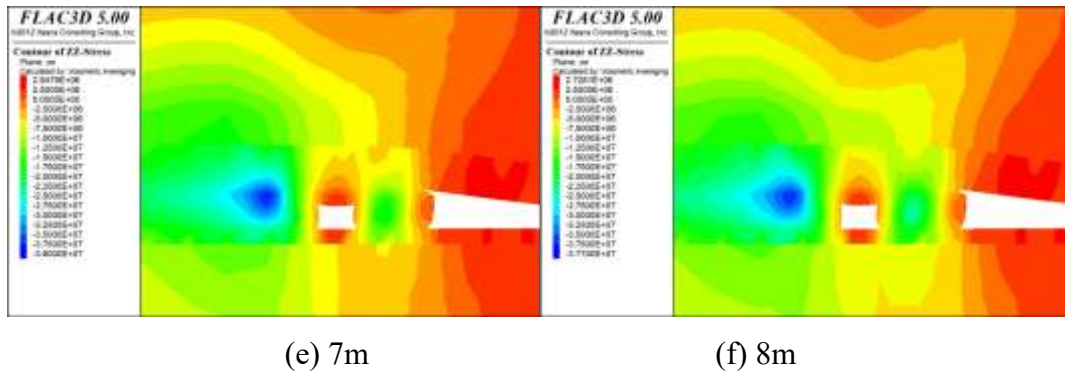


Figure 5 Stress distribution of surrounding rock of coal pillars with different widths along the goaf during the mining period

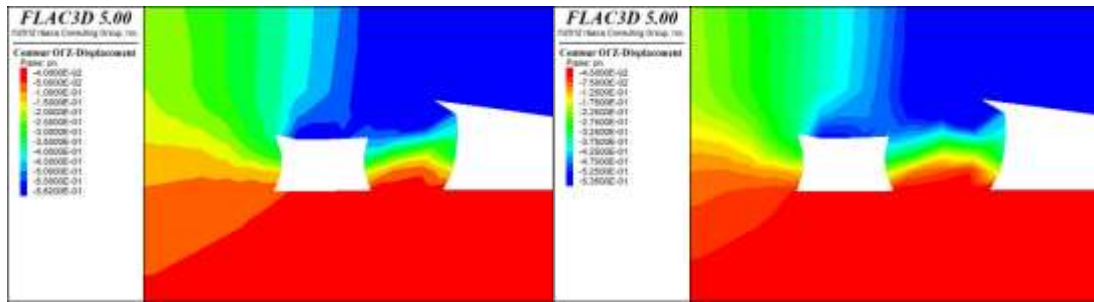
Table 2 Comparison of Stress in Different Coal Pillar Width during Mining Period

Coal pillar width/m	Peak stress of small coal pillar/MPa	Stress concentration factor	Peak stress on the solid coal side/MPa
3	10	1.8	44.6
4	14	2.5	44
5	16.8	3	40
6	21.1	3.8	38.9
7	31.2	5.6	39
8	36.1	6.5	37.7

Analyzing the peak stress above coal pillars of different widths and the stress on the solid coal side during the mining period of the working face, as shown in Figure 5:

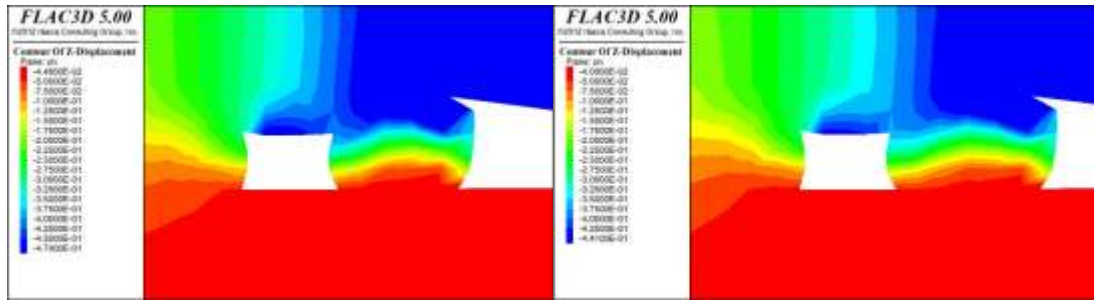
- ① As the width of the coal pillar increases, the support capacity of the coal pillar for the overlying rock layer gradually increases, and the stress above the narrow coal pillar gradually increases. The peak stress position gradually shifts to the roadway side, while the stress on the solid coal side gradually decreases, with the peak stress increasing from 10MPa for a 3m coal pillar to 36.1MPa for an 8m coal pillar, and the stress concentration factor increasing from 1.8 to 6.5;
- ② Leave a 3-6m coal pillar, and the peak stress of the coal pillar shows a uniform upward trend. The stress magnitude increases from 10MPa to around 21.1MPa, and the stress concentration factor increases from 1.8 to 3.83. The overall stress distribution of the coal pillar is relatively even; When the width of the coal pillar is 3m, the vertical stress inside the coal pillar does not change relative to the excavation stage. This is because the coal pillar at the peak of the advanced support stress is subjected to high stress, and the bearing capacity is damaged, reducing the roof support capacity; When the width of the coal pillar is 4m and 5m, a smaller stress core is formed at the center of the coal pillar, with stress concentration factors of 2.54 and 3; When the width of the coal pillar increases to 7m, the peak stress of the coal pillar increases significantly, reaching 31.2MPa, which is 5.67 times the original rock stress. The stress above the 8m coal pillar is even greater, and the stress environment of the surrounding rock of the roadway is poor, making support difficult.
- ③ On the solid coal side, as the width of the small coal pillar increases, the support effect of the coal pillar on the overlying roof increases, and the stress on the solid coal side transfers, gradually decreasing.

(2) Analysis of Displacement Distribution Law



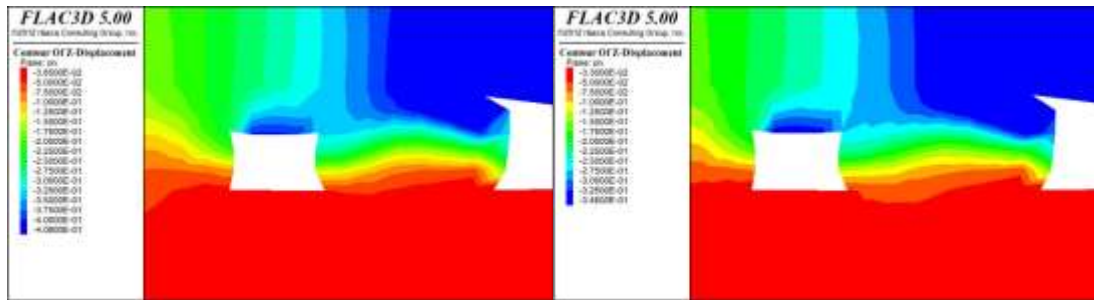
(a) 3m

(b) 4m



(c) 5m

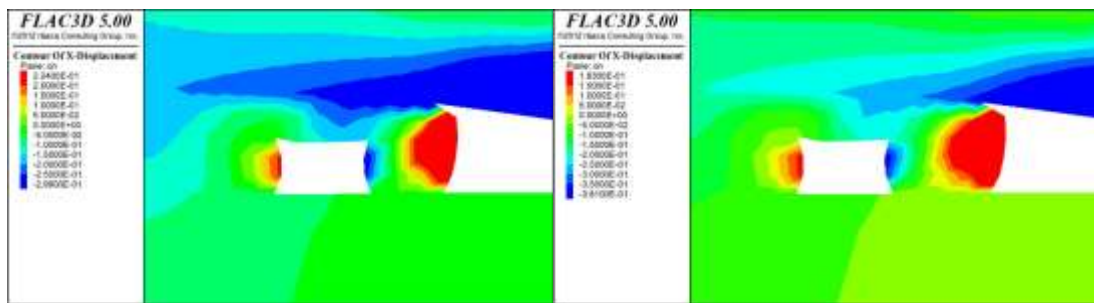
(d) 6m



(e) 7m

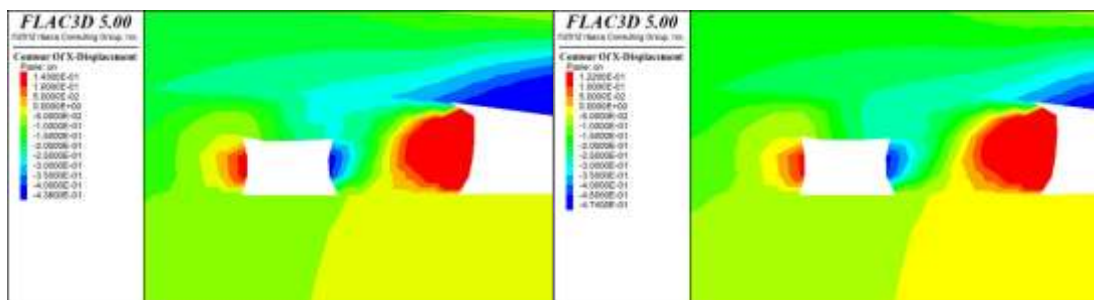
(f) 8m

Figure 6 Cloud map of vertical displacement of coal pillars with different widths during the mining period



(a) 3m

(b) 4m



(c) 5m

(d) 6m

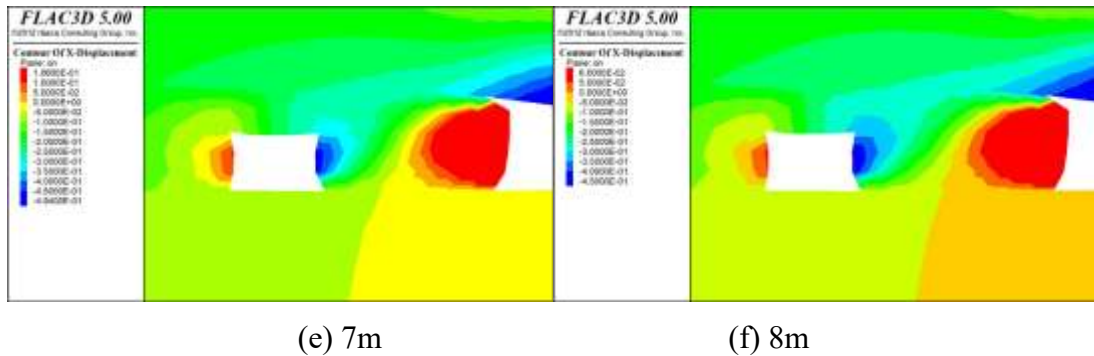


Figure 7 Horizontal displacement cloud map of coal pillars with different widths during the mining period

Due to the lateral residual stress in the goaf and the dynamic pressure of the mining face, the deformation of the surrounding rock in the roadway has significantly increased compared to the excavation period, and the degree of roadway damage is more severe.

According to the horizontal and vertical displacement maps under the condition of leaving different sizes of coal pillars during the mining period, it can be seen that leaving 3m coal pillars during the mining period increases the subsidence of the roadway roof to 355mm, the deformation of the roadway on the goaf side is 317mm, the deformation of the roadway on the solid coal side increases by 0.6m, and the displacement of the left and right sides significantly increases; When leaving 4m, the subsidence of the roof and the lateral displacement of the solid coal decrease compared to 3m, while the displacement of the narrow coal pillar is basically the same. The overall deformation of the 6m coal pillar is not much different from that of the 5m coal pillar. When the width of the coal pillar is 7-8m, it is in the peak range of lateral stress and is affected by the leading peak stress. The deformation of the roadway slightly increases, but the increase is not significant. The bearing capacity of the coal pillar on the overlying roof will gradually increase with the increase of the width of the coal pillar, and the coal pillar will be affected by high stress, which is not conducive to the stability of the surrounding rock structure.

From the displacement cloud map above, it can be seen that when the width of the coal pillar is within the range of 3-4m, the width of the coal pillar is small, and the overall deformation of the roadway is large. At the same time, combined with the 2.4m anchor rod currently used by the mining party, there may be anchor rod penetration during construction, and it is not recommended to use it; When the width of the coal pillar is 5-6m, the displacement of the coal pillar between different layers varies, but the overall stability of narrow coal pillars is good, which is conducive to the anchoring effect of anchor rods and has a good inhibitory effect on tunnel deformation.

Based on the analysis of the stress distribution and deformation of the surrounding rock of the roadway after excavation in the 2802 trench and during mining in the 208 working face under different coal pillar widths mentioned above, when a 6m coal pillar is left, the overall effect of the stress and deformation of the roadway on the coal pillar is better than other coal pillar widths. According to the above theoretical calculation of the coal pillar width range, leaving a narrow coal pillar width of 6m has obvious economic and technical advantages for the mine.

5. CONCLUSION

Due to the special geological conditions of Daning Coal Mine, this article conducted theoretical analysis and numerical simulation research on the determination of reasonable coal pillar width under the condition of excavating tunnels along small coal pillars. The main research conclusions are as follows:

(1)Through theoretical analysis, it is found that the reasonable size of small coal pillars for goaf excavation is 3.8-5m. However, numerical simulation results show that the stress reduction zone ranges from 0-6m, which is basically consistent with the theoretical calculation range.

(2)According to the numerical simulation results of the stress distribution and deformation of the surrounding rock after excavation of small coal pillars along the goaf under different coal pillar widths, it is believed that leaving a coal pillar with a width of 5m can meet the requirements, and the overall effect of the stress and deformation of the roadway on the coal pillar is better than that of other coal pillar widths. Considering that there may be issues with sheet support during the excavation of small coal pillar tunnels, the width of the coal pillar for the 2802 trench is determined to be 6m.

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