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# OPTIMUM SIZE OF COAL PILLAR DIMENSIONS SERVING MECHANISED CAVING LONGWALL FACE IN A THICK SEAM

Guanyu Yang, Cun Zhang, Runlong Yan and Shuai Jia

*Abstract:* Chain Pillars serving longwall face is an important factor influencing the stability of the roadway surrounding rock in the fully mechanised caving longwall face. The reasonable width of the section coal pillar is proposed, combined with the theoretical analysis, numerical simulation and field measurement for the fully mechanised caving longwall face in thick seam in Jinzhuang coal mine. Results of the numerical simulation show that when the width of the section pillar increases to 24 m, there is an 8 m wide elastic zone in the coal pillar and a saddle-shaped vertical stress distribution, which shows that the coal pillar can maintain its stability. So the reasonable width of the coal pillar is 24 m, which is close to the result of theoretical calculation (23 m). The field observations also illustrate that the 30 m wide coal pillars in the first mining face is too large resulting in a waste of resources.

## INTRODUCTION

Chain Pillars serving longwall face is an important factor influencing the stability of a roadway serving the fully -mechanised longwall face caving. Research has been carried out for the design of optimum coal pillar width. The coal pillar design theory and equation proposed by Wilson(1980) is the most widely applied theory, Wang *et al.*, (2002) and Xu *et al.*, (2005) have introduced creep and constitutive relationships and analysed the long-term deformation and stability of the coal pillar, thus establishing the necessary conditions for maintaining coal pillar stability; Bai *et al.*, (2004), using numerical calculations, studied the relationship between the stability of the narrow coal pillar, the width of coal pillar, the mechanical property of coal and rock mass, and provided the indexes to evaluate the stability of the coal pillar from the perspective of materials and structures; Zheng *et al.*, (2012) studied the stress fields distribution rules in the mining process of chain pillars of different widths along the goaf-side entry drive and proposed two influence factors; disturbance influence of roadway driving and advanced mining influence of working face. These two factors were suggested to be considered when deciding the optimum coal pillar width along a goaf-side road entry drive.

Although there are various designs of optimum width of coal pillars, nevertheless they are all limited to the design of coal pillar in the longwall face for certain conditions and there is seldom any field measurement being carried out to verify them.

Based on the engineering background of working faces 8203 and 8204 as the first mining face with super high seams in Jinzhuang coal mine of the Datong mining areas, this paper reports on research methods of combining theoretical analysis, field measurements and numerous simulations, which were used to determine the optimum width of a coal pillar in a fully mechanised first longwall caving face in super high seams and verified its rationalisation by field measurement.

## GEOLOGICAL ASPECTS

The burial depth of the Jinzhuang coal mined seam is 290~340 m, and the dip angle of the coal seam is 3~4°. The working seam is coal seam 3-5# with stable coal layers. The lithological character is shown in Table 1.

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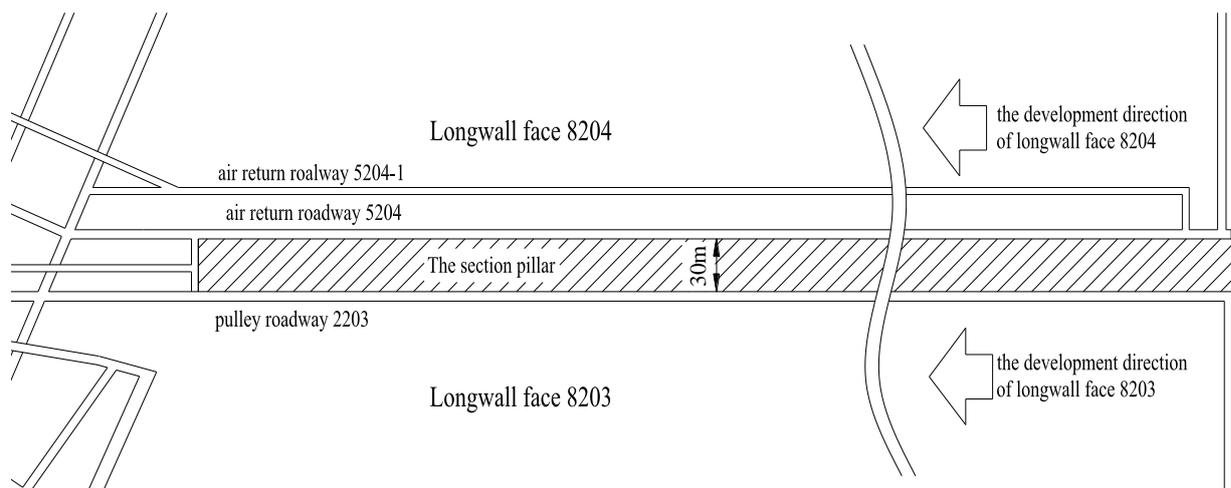
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**Table 1: The Lithological Characters**

Sequence Number	Position	Thickness/m	Lithology	Lithological Characters
1	Overlying rock strata	20	Medium grained sandstone	Layard, medium grained texture, massive structure
2	Upper roof	12	Gritstone containing gravels	Layard, coarse grained texture, massive structure
3	Immediate roof	0.8	Fine sandstone	Layard—grey, fine grained texture, massive structure
4	False roof	0.5	Mudstone	ash black, bedding joint
5	Coal 3#	9	Coal	black, massive structure, pitchy luster, and brownish black striation
6	Dirt band	0.6	Mudstone	ash black, containing a large amount of plant fossil fragment
7	Coal 5#	7	Coal	black, semimonocoque, layer texture, massive structure
8	Director floor	5	Carbone mudstone	black, pelitic texture, massive structure
9	Base floor	15	Silty mudstone	grey—ash black, aleuritic texture—politic texture, massive structure, diagonal structure development

The longwall top coal caving method was used in working faces 8203 and 8204. The mining thickness was 3.9 m and the top coal average thickness was 11.55 m. The ratio of mining height to caving height was 1:2.96. The working face 8203 was mined firstly, followed by the working face 8204. There was 30 m section pillar which ensured the roadway kept stable during mining. The detail is shown in Figure 1.

The main entry roadway 2203 and main return air roadway 5204 were arranged along the floor of the coal seam of 3 to 5, and a second return air roadway 5204-1 roof was excavated along the stable strata of coal seam 3-5# roof.

**Figure 1: Plane figure of the working face layout**

### THEORETICAL ANALYSIS OF REASONABLE WIDTH OF SECTION COAL PILLAR

The front abutment support pressure in front of the coal face can be affected by the mining activity and has a great influence on the deformation of the surrounding roadway rock layers. Therefore, the determination of optimum width of the coal pillar would ensure the stability of the coal pillar and roadway

surrounding rock formation when the working face advances. An optimum coal pillar width left between two roadways is left to ensure the stability of roadways in the service period so as to achieve the regular production of the working face.

Based on the most widely applied coal pillar design theory (Wilson, 1980), researchers in China examined the calculation equation for designing the section coal pillar. The ultimate strength that the coal pillar can bear is:

$$\sigma_s = \left( \frac{2C \cos \varphi}{1 - \sin \varphi} + \frac{1 + \sin \varphi}{1 - \sin \varphi} \lambda \gamma H \right) (a - 0.00492kMH) L \quad (1)$$

The actual ultimate strength that the coal pillar has to withstand is:

$$\sigma_p = \gamma H \left[ a + \frac{b}{2} \left( 2 - \frac{b}{0.6H} \right) \right] L \quad (2)$$

Where;  $a$  is the width of coal pillar (m);  $b$  is the width of working face (m);  $H$  is depth of mining (m);  $\gamma$  is the average volume force of underlying strata ( $\text{kN/m}^3$ );  $C$  is the cohesion of coal body (MPa);  $\varphi$  is the internal friction angle ( $^\circ$ );  $\lambda$  is the factor of stress concentration which is 0.4~0.8. and based on experiments;  $K$  is 0.225~0.25;  $M$  is the mining thickness (m);  $L$  is the length of section coal pillar (m).

The necessary condition of keeping coal pillar stable is:

$$\sigma_p \leq \sigma_s \quad (3)$$

According to the above equation, the width of coal pillar should satisfy conditions in the following:

$$a \geq \frac{\frac{\gamma H b}{2} \left( 2 - \frac{b}{0.6H} \right) + 0.00492kMH \left( \frac{2C \cos \varphi}{1 - \sin \varphi} + \frac{1 + \sin \varphi}{1 - \sin \varphi} \lambda \gamma H \right)}{\left( \frac{2C \cos \varphi}{1 - \sin \varphi} + \frac{1 + \sin \varphi}{1 - \sin \varphi} \lambda \gamma H - \gamma H \right)} \quad (4)$$

According to the practical data of working face 8203:  $b=220$  m,  $\varphi=35^\circ$ ,  $M=16$  m,  $K=0.225$ ,  $\lambda=0.8$ ,  $\gamma=19$   $\text{kN/m}^3$ ,  $H=300$  m,  $C=3.07$  MPa, inserted into equation 4, the width of coal pillar can be calculated at  $a \geq 22.9$  m, say  $>23$  m. Thus for the stated conditions the actual ultimate strength that the coal pillar withstand will not be over its ultimate strength, thus the coal pillar maintains stability.

### THE NUMERICAL CALCULATION OF THE REASONABLE WIDTH OF SECTION COAL PILLAR

The strata of roof and floor in this simulation project adopts the Mohr-Coulomb model, the coal seam adopts a strain-softening model and the goaf adopts a complete elastic model.

Software FLAC3D was used to analyse the evolution rules of coal pillar stress and plastic zone development of the working face on two sides in different mines. In the simulation, the width of the coal pillar has adopted 16, 20, 24 and 30 m, left and right working faces are excavated to 20, 50, 80, 90, 100, 110, 120, 150, 180 and 200 m, the evolution rules of coal pillar stress and plastic zone in 100 m section were analysed. The lengths of the two coal pillar of the working faces were taken the same. Details are shown in Figure 2.

Figure 3 shows changes of plastic stress in the coal pillar. Only the corresponding section of coal pillar is shown and the width of each grid is 1 m. The coal pillar was analysed according to the evolution of plastic zone and stress in coal pillars with the advancing coal face of length 100 m. From Figures 3 to 5, the development of plastic zone is in the left side of in the coal pillar is and the right side is its corresponding stress evolution.

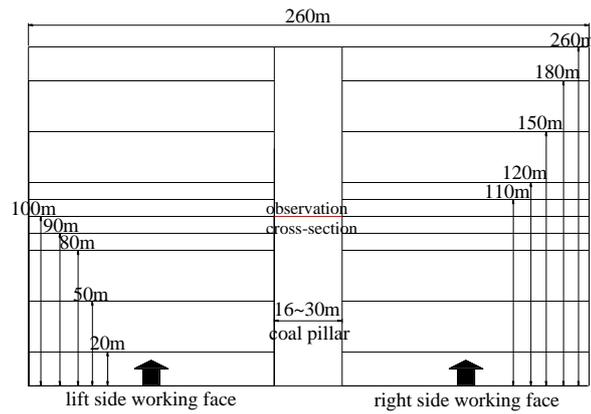


Figure 2: The schematic diagram of simulation project

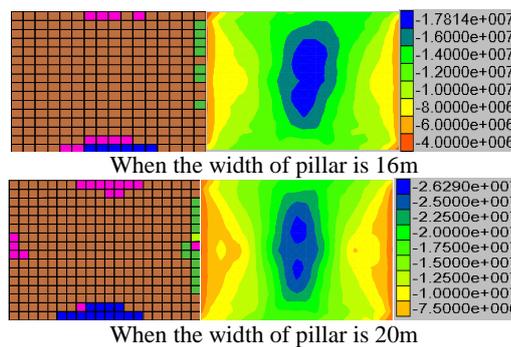


Figure 3: The changes of plastic stress in 16 m and 20 m wide coal pillar

When the width of the coal pillar increases from 16 m to 20 m, the bearing capacity will increase, causing pillar failure during the mining process. From the perspective of stress, the peak stress value on 20 m wide, coal pillar will be relatively smaller than that of 16 m coal pillar width. Note that the overall residual strength of 20 m failed coal pillar is also larger than that of 16 m coal pillar.

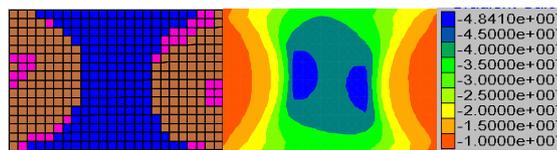


Figure 4: The changes of plastic stress in 24 m wide coal pillar

As is shown in Figure 3 and Figure 4, when the width of coal pillar increases from 20m to 24m, the development of plastic zone and the stress in coal pillar are quite different from the previous situation. In the advancing working face, the plastic zone of coal pillar, that is continuously being developed, does not spread all over the coal pillar. In terms of stress, the stress peak value will increase gradually and continuously move inwards, however, the left and right peak points do not overlap. The result clearly indicates that there is an elastic zone with small stress between the two peak point, so the final distribution of stress in the coal pillar is saddle-shaped with the two sides of the coal pillar will be destroyed as the stress in the middle part of the coal pillar increase. This, however, will be an elastic zone with the coal pillar maintains its stability.

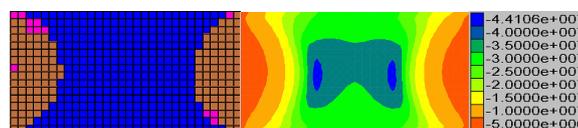


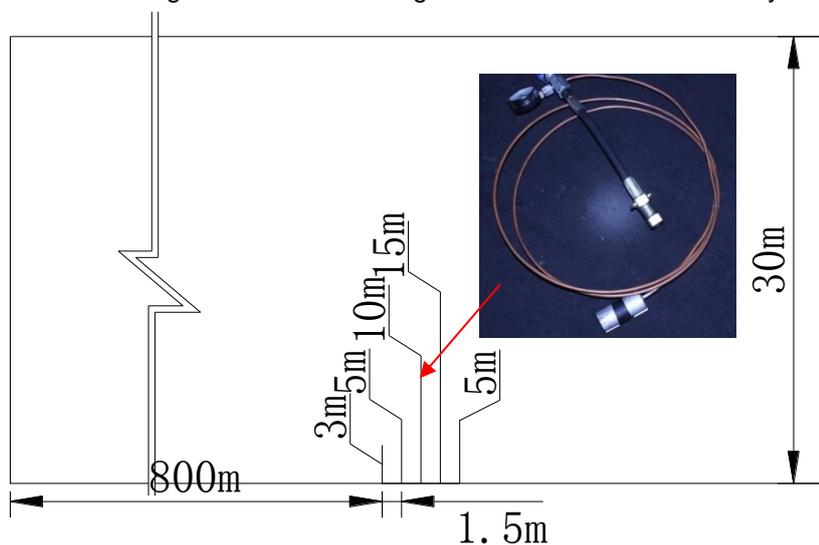
Figure 5: The changes of plastic stress in coal pillar of 30 m in width

As is shown in Figure 5, when the working face finishes there remains a 17 m wide elastic zone in the coal pillar core and the stress distribution is roughly "saddle-shaped". Therefore, it is clear that the 30 m wide coal pillar is better, which seldom loses stability.

In conclusion, as the width of coal pillar increases from 24 m to 30 m, the stress in the coal pillar does not change significantly, which demonstrates that further increase in coal pillar width >24 m, the increase of coal pillar width has less effect on the bearing capacity of the coal pillar, therefore, 24 m wide coal pillar can meet the project requirements. Leaving large pillars will lead to sterilisation of the mineable coal which is an uneconomic endeavour.

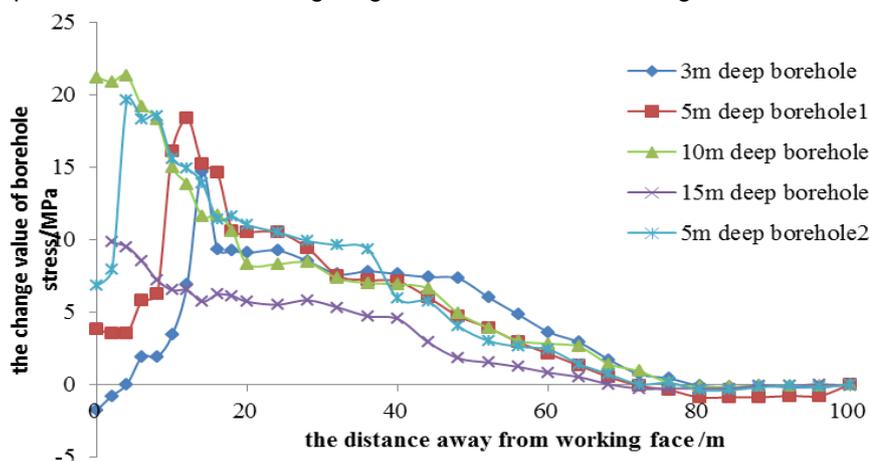
**FIELD MEASUREMENTS OF THE STRESS AND DESTRUCTION OF COAL PILLAR**

Borehole stressmeters, particularly borehole hydraulic pressure cells were used to monitor coal pillar stress and the advancing support pressure of the working face. The coal pillar width between longwall faces 8203 and 8204 was 30 m, the length of working face was 220 m and the longwall panel advance length was 1450 m. Borehole stressmeters were installed at the locations commencing 800 m away from the longwall face. The stress meters were installed at 1.5 m, 3 m, 5 m, 10 m, 15 m and 5 m along the pillar length as shown in Figure 6 and at the height of 1.6m above the roadway floor.



**Figure 6: The layout of borehole stress meter**

The working face was actually advanced about 700 m when the borehole stressmeter installation arrangement was completed, and with the borehole stress meter of 3 m being some 100m away from the working face. With the advance of the working face, changes in stress levels in each location with respect to their positions from the working longwall face are shown in Figure 7.



**Figure 7: The rule of actual measured change of each borehole stress meter**

As is shown in Figure 7, after the borehole stress meters were installed, the stress begins to decline slightly; this is because of the initial stress plug oil compressibility. When the working face was 80 m away from borehole stress meter, the stress begins to increase slowly; when the working face is about 60 m away from the measured zone (the measured zone starts with the borehole of 3 m in depth), the borehole stress rises linearly which indicates the advanced support pressure of the working face has already influenced the observation area and also proves that it is reasonable for the two roadways in the working face to be supported for 50 m in advance. When the working face is about 16 m away from observation borehole, the borehole stress increases rapidly, when this distance reduces to 14 m, the increasing amount of the stress is the largest, which indicates that the approaching support pressure reached the peak value in this place. The field measurement and analysis demonstrated that the numerical simulating results were correct and a 30 m wide a coal pillar in coal mine is larger, thus sterilising more coal in the pillar.

### CONCLUSIONS

The stability rules of coal pillar in an operating mining roadway are studied experimentally, theoretically as well as by numerical simulation. It was found that the minimum pillar width that maintained a stable working environment was 24 m. This minimum pillar width allowed an elastic zone in the pillar core sufficient to maintain stable working conditions. Thus, the use of 30 m wide pillars sterilises a significant amount of coal in the pillar unnecessarily.

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