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Study on the Parameters of Roadside Support after the Cantilever Beam of the Basic Roof with Height of Fracture Zone Cut by Deep-Hole Blasting

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Study on the Parameters of Roadside Support after the Cantilever Beam of the Basic Roof with Height of Fracture Zone Cut by Deep-Hole Blasting

Tao Hu[1], Gongyu Hou[1], Zhuhe Li[2] and Jianpeng Chen[3]

1, School of Mechanics and Civil Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China;

2, China Mining Technology Innovation (Beijing) Coal Technology Co., Ltd., Beijing 10083, China;

3, Nanyang Coal mine, Ke Xing Groups of Gaoping County, Gaoping 048440, China)

Abstract. In order to determine the reasonable parameters of roadside support, based on the analysis of the law of surrounding rock activity in gob-side retaining roadway, it is proposed that the relationship between different parameters of roadside support wall and its supporting resistance is calculated and analyzed by using the improved mechanical model after deep-hole blasting roof cutting and improving the external mechanical environment of surrounding rock then. The mechanical equation for calculating the width and strength of supporting wall near roadway is derived. The analytical solution of width and strength value of roadside support under roof cutting condition is obtained, and field application is carried out in 3207 working face of Nanyang Coal Mine. The results show that it is feasible to set the height of the upper-side fissure zone of the goaf beside the roadway as the height of the cutting roof; it is reasonable to calculate the height of the cut roof as the height of the static block; the formula of the width with a certain strength of the roadway support wall obtained in this paper and the redundant safety factor of the parameters of the roadway support wall tried to be adopted are effective. Finally, after improving the external mechanical environment of retained roadway surrounding rock, reasonable parameters of roadside support are the guarantee to ensure the stability and integrity of retained roadway structure along goaf.
Keywords: gob-side entry retaining; roadside support; deep-hole blasting roof cutting; static calculation model

1. Introduction

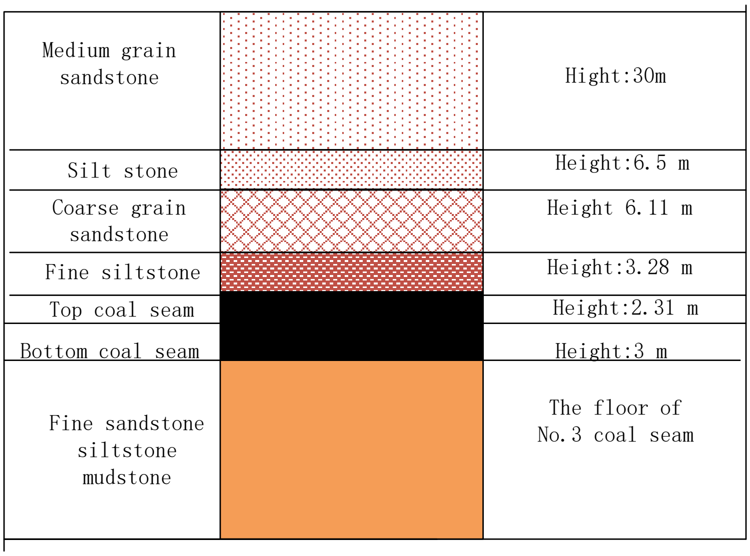
Under certain size of the roadway and the height of coal seam, the parameters of the roadside support wall is an important factor affecting the stability of the roadway structure. Besides, it can also increase the coal recovery rate, reduce the material cost and labor intensity. Therefore, parameters of width and strength of roadside support wall are the key problem in coal mining and a subject that scientists and technicians have been studying all the time.

Zhang Jixiong [1] carried out research on the width of the supporting body around the dense filling roadway; Wang Xiaohu et al [2] calculated the reasonable width of the filling body under the composite roof; Kan Jiaguang et al [3] studied and optimized the width of the supporting body under the hard roof. Zhang Yuanyuan et al [4] optimized and confirmed the influence of different filling body widths on the stability of retaining roadway; Luo Zhong et al [5] studied the filling body width of the large section gob-side entry retaining; Yang Baishun [6] carried out the numerical simulation study on the reasonable width of gob-side roadway filling wall; Chen Yong [7] combined the method of cutting top resistance, determination of support body strength, numerical simulation and field test to obtain reasonable width of roadside support body; Li Yingfu [8] determined the reasonable width of the roadside filling body through the stability criterion of key blocks; Zhang Xinhai [9] studied the influence of different width filling bodies on the deformation characteristics of the roof along the goaf; Wu Jilei [10] studied the reasonable width of the filling body through the "S-R" stability theory and numerical simulation method. But, few research results can be found under such conditions: the falling thinner-direct roof cannot fill up the goaf, and the cantilever beam of thicker basic roof with large length and thickness is formed. In this case, the time spin of the cantilever's rotation and sinking is long, and the damage to the retained roadway is to a large extent. Moreover, practice and research prove that the stability of the "small structure" of the roadway is affected by the "large structure" in which the multiple blocks are hinged after the broken of the lateral basic roof of the goaf, and the support forms can only adapt to the roadway deformation caused by the rotation and sinking of the old top rock layer [11-12]. Only after improving and controlling the external mechanical environment of the surrounding rock, the reasonable parameters of width and strength of the roadside retaining wall are the realistic guarantee for the stability and integrity of retained roadway structure along goaf.

This paper studies the determination of reasonable parameters of roadside support after cutting the cantilever beam roof by the deep hole blasting, and propose that eliminating the rotary extrusion of the cantilever beam roof to the roadway's structure is the main factor to ensure.

2. Project Overview

The No. 3 coal seam mined in Nanyang Coal Mine is 5.31m thick and the stratum is gentle. The direct top is a fine siltstone of 3m thick. The basic roof is coarse sandstone of 6m-thick with simple structure (Fig. 1). The 3207 working face fully mechanized caving face adopts two-in-one Y-type ventilation. The track lane and the belt lane are the air inlet lanes, and the belt lanes are used as the remained gateway along goaf after the mining, as the return air passage connecting the working face and the boundary return air passage (Fig. 2). The designed 3207 fully mechanized caving face has a length of 180m, a design height of 2.8m and a top coal height of 2.51m. The length of the belt lane of 3207 working face fully mechanized caving face is 1868m.



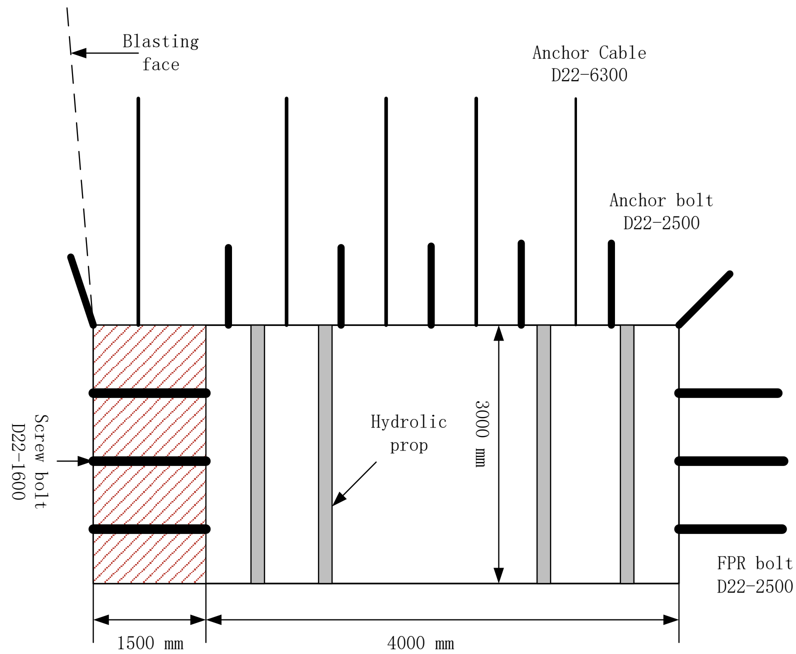


Figure 1. Lithology and retention parameters of the roof layer of 3# coal seam

The laneway is 3207 belt lane with a width of 5500 mm, a height of 3000 mm and a net section of 16.5 m^2. The width of the concrete support wall is 1.5 m. The anchor cable - anchor net - bolt support system is adopted as reinforced retaining. D22mm bolts are arranged in each row at the top of the roadway with spacing of 800mm×900 mm. The D22mm high pre-stressed anchor cable is used and arranged in a row with row spacing of 900mm×1000mm to anchor the roof of the roadway to prevent the top plate from separating; three of FRP bolts are also arranged with a spacing of 1250mm×1000mm in coal body side; deformed screwed steel bar and cross anchor are also used in the support wall to stabilize the width of the wall and keep the wall stable. At the same time, Single hydraulic prop and steel beam (one prop and three columns) are used to temporarily strengthen the support within the area 50 meters ahead of the roadway and the 200m away from the working face (Fig.1).

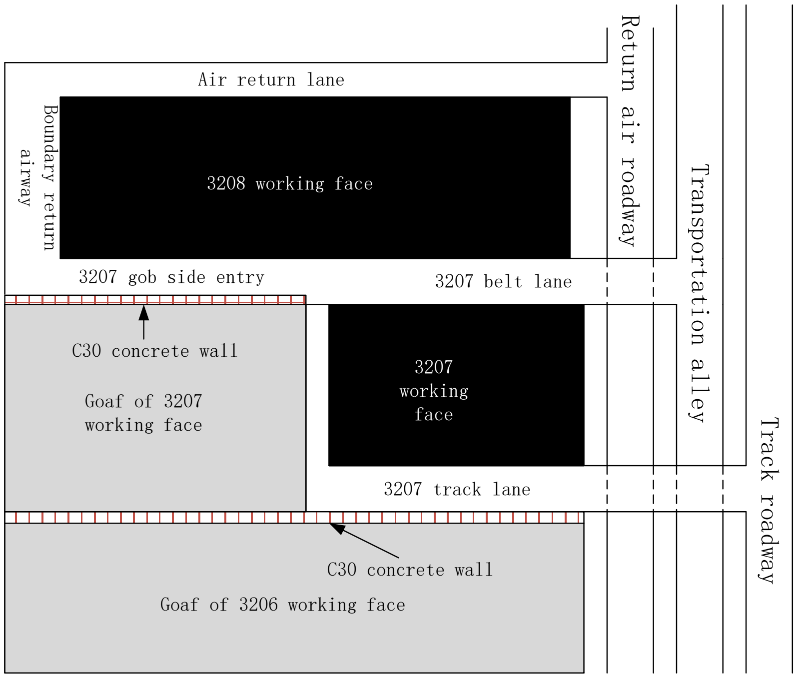


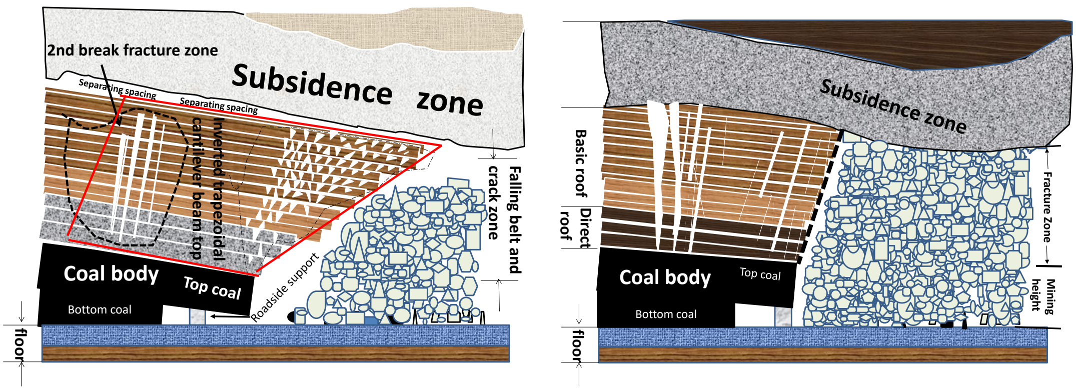
Figure 2. Layout of the stope face and gob-side entry retaining

3. Technology of Gob-Side Entry Retaining by Side Concrete-Wall Support with Deep-Hole Blasting Roof-Cutting

The technology is simple to operate. Firstly, the advanced deep-hole blasting is adopted to pre-crack the basic roof of the goaf next to the roadway to cut off the mechanical connection between the basic roofs. Secondly, in the roadside filling area, the pumping concrete fills the roadside supporting wall. With the working face advance, the roof of the goaf collapsed along the blasting pre-cracked face under the joint effect of the support wall, the anchor bolt reinforcement support and the single prop support to weaken and eliminate the damage of rotation of the roof cantilever beam on the gob-side entry retaining. So the external mechanical environment of the surrounding rock is improved and controlled. At this time, under the condition, the parameters of strength and width of the roadside support is the key to the success of the gob-side entry retaining.

3.1. Design of Blasting Parameters for Deep-Hole Blasting Roof

In coal mining, with the continuous advance of the working face, the goaf is formed in the stope. The direct roof will continue to collapse in the middle. To some extent, the height and length of the top-roof of the inverted trapezoidal cantilever beam will increase continuously. Under the action of overlying load and self-weight, the cantilever roof continuously rotates and sinks to the goaf (fig.3). Experiments and practices have proved that the height of the cantilever top is the height of both the falling zone and the fissure zone below the bending subsidence zone [16]. It has brought tremendous rotational extrusion damage to the structure of gob-side retaining roadway and roadside support.



A, before deep-hole blasting roof cutting B, after deep-hole blasting roof cutting

Figure 3. Structural sketch of cantilever beam in Goaf

So, the rotation and sinking of the cantilever beam roof below the crack zone of the goaf's roof is the main factor affecting the stability of the roadway. Therefore, cutting off the unstable roof below the fracture zone is beneficial to the stability of the roadway.

The roof of the 3207 working face of Nanyang Coal Mine above the height of 18m is the 30m old roof of hard and stable medium sandstone, which belongs to the curved sinking zone of the stope. Below it is unstable fracture zones and fall zones. Therefore, the determined height of deep hole blasting is the height of the fracture zone: 18m. According to experience, the hole-spacing of the blast-hole is set at 2m, the blast-hole angle is set vertical to the roof, and the mud plugging height is 8 meters in a blast-hole. The special explosion-proof two-way shaped energy PVC pipe is used to fill the mining explosives.

After the falling of the top roof plate below the height of the fissure zone of the goaf, the anchored roof of the roadway often separated from the top roof plate above the side coal body, and separated from the upper curved subsidence zone. Therefore, the load on the support wall of the roadside is the weight of the top roof plate of the upper anchorage zone, which is in accordance with the conditions of the static calculation model, and can be used for the mechanical analysis of the wall of the roadway.

According to the observation of mine pressure in Nanyang Coal Mine, the maximum pressure on the end support of fully mechanized mining face is 35 MPa, and the maximum pressure on the press-pillow of side coal wall of goaf is 24 MPa. So, for safety consideration, in this program the strength of the roadside support wall was designed to at least 28MPa.

3.2. Study on the Parameters of the Roadside Retaining Wall

3.2.1. Theoretical Calculation and Analysis. Taking reference from the separation rock method of British scholars [13], this paper takes the height of the fracture zone as the height of the static rock mass, and also uses this height as the cutting height. The curved subsidence zone of the upper boundary and the stationary block on the roadway remain in a separated state. After cutting the basic roof, the roof of the goaf collapses and loses the mechanical connection with the top plate of the roadway. The static support theory can be used to calculate the support parameters of the roadside support wall, and the dynamic pressure coefficient [14-15] is used to calculate the rotational pressure of the roadside support wall from the top plate of the cantilever beam.

A mechanical model is established for calculation, assuming that (1) the rock formation is a horizontal rock formation; (2) the roof of the cantilever beam is fractured at the top corner A (Fig. 4), and at the right side it is a roof cantilever that is not bound by the side roof; (3) the force of the gangue layer in the goaf to the cantilever beam of the roof is zero; (4) the shear angle on both sides of the rock block is the same;

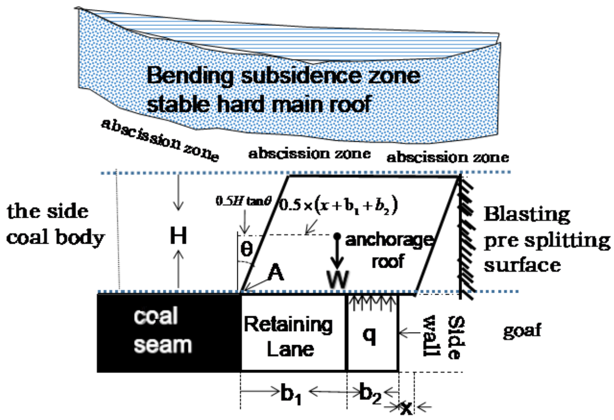


Figure 4. Static pressure calculation model of retaining tunnel

For the convenience of calculation, assuming that the rock formation is a horizontal rock formation, the horizontal component of gravity is zero, and the horizontal component of the supporting resistance of the roadside support wall is also zero. The self-gravity per meter of the roof rock mass is:

$$\mathrm{w} = H\gamma(x + b_1 + b_2) \tag{1}$$

The horizontal arm length of the separated roof slab relative to the apex angle A is:

$$R_1 = 0.5\left(x + b_1 + b_2\right) + 0.5H\tan\theta \tag{2}$$

The force of the supporting wall perpendicular to the top plate is:

$$Q = qb_2 \tag{3}$$

The horizontal force arm R2 of the supporting wall relative to the coal seam apex angle A is:

$$R_2 = b_1 + 0.5b_2 \tag{4}$$

The equation for taking moments at point A is:

$$\sum M_A = 0 \text{ , i.e. } qb_2 \times R_2 - W \times R_1 = 0$$

Under the condition that the dynamic pressure is not considered, the roadside support load is:

$$q = \frac{H\gamma\left(x + b_1 + b_2\right) \times \left[0.5\left(x + b_1 + b_2\right) + 0.5H\tan\theta\right]}{b_2 \times \left(b_1 + 0.5b_2\right)} \tag{5}$$

In the formula, b_1 is the distance from the inner side of the roadway support to the coal, that is, the width of the roadway, is 4.0m; b_2 is the width of the roadside support; the distance of the outer side of the roadside support x takes the value of 0.5m; the bulk density of rock separated from the roof γ takes the value of 24kN/m^3; θ is the shear angle; the cutting height or the height of roof caving H takes the value of 18m.

The relationship between the width of the supporting wall and the bearing pressure is calculated according to formula (Fig. 5). That can also explain the relationship of the width and strength of roadside support wall.

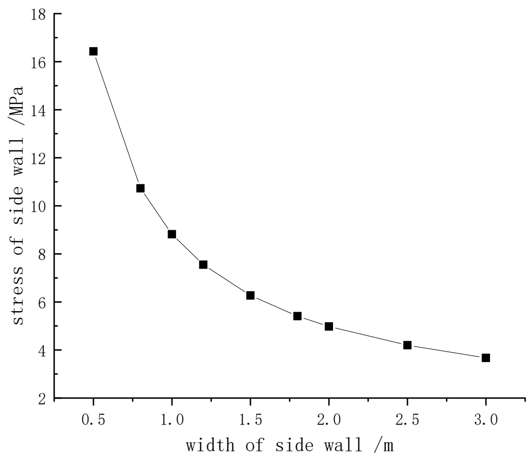


Figure 5. Correlation curve of the width of the roadside retaining wall and its bearing pressure

It can be seen in Figure 4 that the vertical stress of the retaining wall decreases as the wall width increases. When the wall is more than 1m wide and the wall is subjected to a press less than 10 MPa, the decreasing trend is slowed slowly down with the increase of the width of the wall. When the support thickness is 1.5m, the stress of the roadside support is $q = 6.27$ MPa, that is, the load per meter of the support body is only $Q_1 = 9405$ kN/m.

The dynamic pressure caused by the rotation of the old top-roof on the direct top has been difficult to determine. The traditional view is to measure the so-called dynamic load coefficient. According to the comprehensive mining experience data [14-15] in general, the value of η is 1~3, and the value of maximum width takes the value of 3 when designing the roadside support along the roadway, and the maximum load of 1.5m wide wall on the roadside support is 28215 (kN/m), the maximum pressure is 28 MPa, which meets the design requirements. According to the principle of maximum value, and minimum cost but meet the safe demand, the suitable parameters for this case are those: width of the wall is 1.5m, the strength of the wall should be larger than 28MPa.

3.2.2. Theoretical calculation of the parameters of the roadside retaining wall under no any cantilever beam roof. Assuming that the roof cutting is complete, the cantilever beam roof outside the roadside support wall is completely cut off. Suspending roof length, $x = 0$ and the maximum load of the wall is designed to 28MPa according to the above analysis, then: $q = 28000$ kN/m, other conditions remain unchanged. The formula for calculating the width related to its strength of the side wall retaining wall by formula (5) is:

$$0.5\left(q - H\gamma\right)b_2^{\,2} + \left(qb_1 - H\gamma b_1 - 0.5H^2\gamma tg\theta\right)b_2 = 0.5H^2\gamma b_1 tg\theta + 0.5H\gamma b_1^{\,2} \tag{6}$$

Calculation results of the roadside support wall: $b_2 \approx 1.25\ m$

According to the above analysis, due to the fact that we cannot completely cut the cantilever beam on the outer side of the retaining wall, and considering the influence of the dynamic pressure of the old roof, the safety redundancy factor is taken as 1.2 according to the engineering practice experience, then

$$1.2 \times b_2 = 1.25 \times 1.2 = 1.5 \text{ m}$$

After testing the strength of C30 concrete wall after masonry in realistic mining production, the results of concrete strength with setting time are as follows:

Table 1. The compress strength of the C30 concrete wall along its setting time

Time/day	1	3	7	28
Compress strengths/MPa	6.0	12	18	30

After 28 days, the strength of C30 concrete exceed our strength demand, it can satisfy our safety demand. From above analysis, the parameters of the roadside support wall under basic roof cut beside goaf are those: the width of 1.5m and the ultimate compress strength of 28MPa made of C30 concrete material in this study of the paper.

4. Field Application

The 18 m deep hole blasting was used in the 3207 working face in Nanyang Coal Mine and C30 concrete was adopted as the filling material to build a 1.5 m wide roadside supporting wall to carry out the industrial experiment along the goaf, and monitor the deformation of roadway surrounding rock timely.

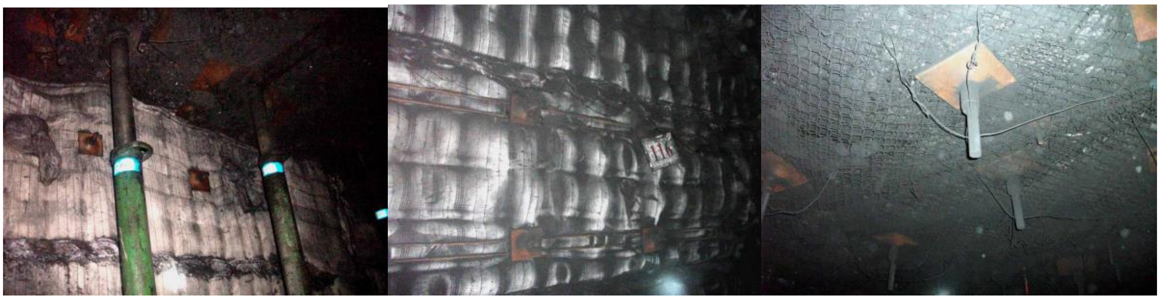
4.1. Layout of Observation Station

Gob-side entry stage: the first station is arranged from the working face, and the following stations are arranged at intervals of 25 m in the area of the roadway. The law of mine pressure in the roadway area is monitored. The instrument stations in the roadway stage mainly monitor the deformation of surrounding rock.

4.2. Analysis of Monitoring Results

The results show that the horizontal deformation of coal band in retaining roadway stage is 30-120 mm, the vertical deformation of the roof is 80-350 mm, the vertical deformation of bottom sill is 10-30 mm, and the horizontal deformation of the wall is 15-80 mm. Within 250 m away from the working face, the section width of the retaining roadway is basically maintained at 3.5-3.8 m, the height is more than 2.5 m, and the effective ventilation section is larger than 9.7 m^2, which satisfies the traffic demand and air-ventilating demand of the working face. The monomer is removed from more than 250m away from the working face, and the surrounding rock remains stable under the support of the roadside supporting wall, as shown in Figure 6.

The field experiment shows that under the condition of deep hole blasting and cutting-roof, the 28MPa of strength and the 1.5m of width of roadside supporting wall is applied to meet the safety requirements of mining, and the structure of the gob-side entry retaining is complete and stable, which explains that after improving and controlling the external mechanical environment of the surrounding rock, the reasonable parameters of the roadside retaining wall are the true guarantee for the stability and integrity of the roadway retaining structure.



A, Effect of roadside support and single hydraulic prop support in early stage of retaining roadway

B, Wall Effect Diagram of Removing Temporary Single Hydraulic Pillar Support in Late Stage of Retaining Roadway

C, roof Effect Diagram of Removing Temporary Single Hydraulic Pillar Support in Late Stage of Retaining Roadway

Figure 6. Filling wall and roof of gob-side entry retaining by deep-hole blasting

5. Conclusion

Field application of deep-hole blasting gob-side entry retaining is carried out in 3207 working face of Nanyang Coal Mine.

1) It is feasible to set the height of the fracture zone of the goaf beside the roadway as the height of the cutting- roof;

2) It is reasonable to calculate the height of the cutting-roof as the height of the static block; the statics model and the formula of the width of the roadway support wall obtained in this paper are proved to be applicable and reasonable.

Finally, after improving the external mechanical environment of retained roadway surrounding rock, reasonable parameters of roadside support wall are the guarantee to ensure the stability and integrity of retained roadway structure along goaf.

3) The results of surrounding rock deformation monitoring indicate that 1.5 m wide roadside supporting wall made of C30 concrete material used in the construction of gob-side entry retaining of Nanyang Coal Mine has met safety and mining requirements, which proves that the redundant safety factor of the width of the roadway support wall tried to be adopted is effective.

4) The determination of reasonable parameters of roadside support wall after cutting the cantilever beam roof by the deep hole blasting cutting-roof on the outside of the roadside support wall, and that eliminating the rotary extrusion of the cantilever beam roof to the roadway structure are the guarantee to ensure the stability and integrity of retained roadway structure along goaf.

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