Mechanisms and Application of Roadside Soft Medium Connecting the Roof in Gob-side Entry Retaining

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ABSTRACT

For using gob-side entry retaining on the condition of hard limestone roof in thin coal seam, establishing the mechanical model of roadside soft medium connecting the roof, analyzing the mechanisms of roadside soft medium connecting the roof. Based on the above investigations and the geological condition of panel 090101 in Anyi colliery of Jiexiu City, using theoretical calculation to obtain the height range of soft medium, using numerical simulation to analyze the relationship between plastic zone of roadway surrounding rock, the characteristic of roadside support, deformation of surrounding rock and the height of soft medium, which determines that the height of soft medium is 0.2 meters, proposing that soft medium of top roadside support uses high water content material when water-cement ration is 4 and the lower part filling of roadside support uses high water content material when water-cement ration is 1.5. Research results are successfully applied to a field practice.

KEYWORDS: hard roof; gob-side entry retaining; soft medium connecting the roof; numerical simulation

INTRODUCTION

The content of gob-side entry retaining includes the activity law of surrounding rock, the relationship between surrounding rock and support, support in mine gateway, reinforced support and roadside support, etc. Domestic and foreign scholars have carried on a large amount of research around the contents for many years [1,2].

Domestic scholars have studied in the aspects of gob-side entry retaining: Zhang Jixiong [3,4] and others studied the reasonable width of roadside support body of gob-side entry retaining in solid fill mining and the technology of in-situ gob-side entry retaining in fully mechanized solid fill mining; Bai Jianbiao [5] and others put up with the new technology of gob-side entry retaining with roadside cement; Zhang Dongsheng and others [6] studied the stability control of filling body of gob-side entry retaining in fully mechanized top coal caving face, conducted research about surrounding rock deformation characters of gob-side entry retaining; Ma Liqiang and others [7] studied packing body supporting resistance of enter-in packing for in-situ gob-side entry retaining in fully mechanized top coal caving face, and discovered that the surrounding rock stability is closely related with the packing body and the entry support method.

But the previous research lacked to study the stress characteristic and mechanisms of roadside support body, especially in the aspects of soft medium connecting the roof above the filling body. The movement of roof heavily influences the stability of roadside support body in the condition of hard roof and thin coal seam. To make the deformation of roadside support body adapt to the rotation and subsidence of basic roof, we can use the yielding deformation of soft medium connecting the roof above the filling body to protect the filling body, so that to control the deformation of roadway surrounding rock. Based on the geological condition of panel 090101 in Anyi colliery of Jiexiu City, proposing that soft medium of top roadside support uses high water content material when water-cement ration is 4 and the lower part filling of roadside support uses high water content material when water-cement ration is 1.5, establishing the mechanical model of roadside soft medium connecting the roof, analyzing the mechanisms of roadside soft medium connecting the roof, using theoretical calculation and numerical simulation to analyze the control effect of roadway surrounding rock in the different height of soft medium, which eventually determines the reasonable width of soft medium connecting the roof and assesses the roadway maintenance through the deformation of roadway surrounding rock.

ENGINEERING AND SUPPORT CONDITION

The tested roadway is in working panel 090101 of Anyi colliery, the working face is 280 meters in buried depth and the average thickness of coal seam is 1.2 meters, of which the immediate roof is limestone with 7.73 meters thick, the basic roof is fine sandstone with 21.9 meters thick, the direct floor is 10# coal seam with 0.6 meters thick and basic floor is mudstone with 2.68 meters thick. Rock type of roof and floor is as shown in table 1.

Table 1: Properties of roof and floor of coal seam in working panel 090101

The name of roof and floor	Rock type	Average thickness /(m)	Description of rock type
Basic roof	Fine sandstone	21.9	Dark grey, surface covered with carbon debris, rich with muscovite
Immediate roof	Limestone	7.73	There is animal fossil, fissure is filled with calcite. Tight hard and not easily collapse
False roof	Mudstone	0.03	Existing with nonexisting, collapsing as mining
Coal seam	Anthracite coal	1.2	Without rock partings. Easy structure and is mainly clarain
Direct floor	10# coal seam	0.6	There is plant fossil
Basic floor	Mudstone	2.68	Black bauxite mudstone

The size of panel 090101 is 3.7 meters wide and 2.6 meters high with a rectangular section. The roof is supported by equal strength thread steel bolt (Φ16mm×1600mm), with an inter-row spacing of 1300mm×1200mm. The two ribs are jointly supported by thread steel bolt, steel joist and plastic net, of which equal strength thread steel bolt (Φ16mm×1600mm) and an inter-row spacing of 1300mm×1200mm is used. The bolt of roof is anchored by resin anchoring agent of CK2340 and K2340 every pore respectively, of which the anchoring agent of CK2340 faces the bottom of the pore. The bolt of ribs is anchored by resin anchoring agent of K2340 every pore. The anchoring pallet uses steel plate with 10mm thick.

To control the deformation of surrounding rock, the solid coal of rib of roadway is reinforced supported before mining. The specific parameters includes that equal strength thread steel bolt of

Φ16mm×2600mm is reinforced with 2 bolts in every row among the original bolts, and the plastic net is covered with the rib. Bolting support sketch after reinforcement is as shown in fig.1.

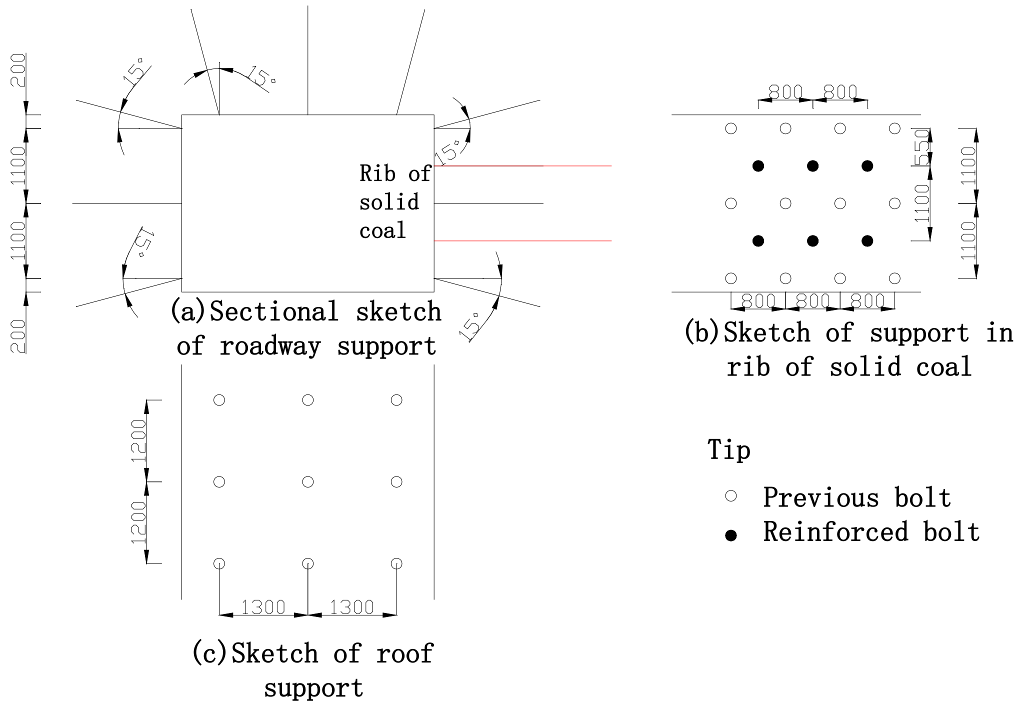


Figure 1: Bolting support sketch after reinforcement (unit: mm)

MECHANICS OF ROADSIDE SOFT MEDIUM CONNECTING THE ROOF

The mechanical model of roadside soft medium connecting the roof

The movement of gob-side roof heavily influences the stability of surrounding rock structure in gob-side entry retaining. The roadside filling body is damaged in the severe movement of roof, especially in the condition of hard thick roof. The roadside filling body must realize the characteristic of constant increasing resistance of full support body and meet the rotation and subsidence of basic roof through the yielding deformation. Normal filling body can hardly meet the requirement. So the paper proposes that we use soft medium to connect the roof above the filling body and protect the integrity and stability of the lower main filling body through the yielding deformation of soft medium. Contrast to the main filling body, the equivalent stiffness of soft medium is lower than main filling material and soft medium has a bigger flexible quantity under pressure. In the paper, the soft medium uses high water content material when water-cement ration is 4 and the main filling body of lower part uses high water content material when water-cement ration is 1.5. Structure of the soft medium connecting the roof [8] is as shown in fig. 2.

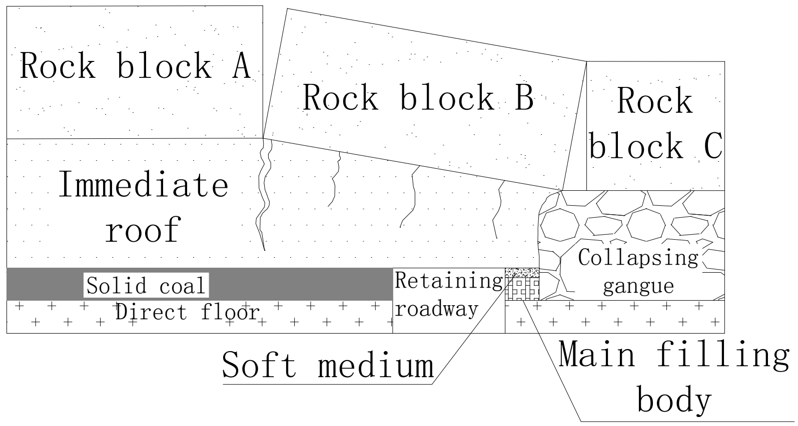


Figure 2: Structure diagram of the soft medium connecting the roof

In the condition of mining for gob-side entry retaining under the hard roof of thin coal seam, the high strength, large thickness, high integrity and simple joint fissure of roof strata lead to the longer time of hanging roof and the bigger deformation of roadway surrounding and the filling body. So the reasonable roadside support is the key to keep the stability of surrounding rock for gob-side entry retaining in the basic roadway support of bolt, joist and plastic net.

The analysis of mechanics of soft medium connecting the roof

The mechanics of soft medium connecting the roof has following features in the movement of surrounding rock of gob-side entry retaining:

The distance of separation between immediate roof and basic roof is increasing when immediate roof subsides behind the working face. Then basic roof rotates along the fracture line, which heavily increases the loading of gob-side support body. The support body must have flexible quantity and enough compressive strength to maintain the integrity and stability of the roof above the support body in order to prevent the support body from being damaged by the rotating and subsidence of key rock block B. Soft medium connecting the roof above the lower main filling body solves the problem perfectly through its characteristic of proper yielding deformation, which constantly increases the resistance of the lower main filling body and protects the integrity of full roadside support body. The hinge structure of rock block A, B and C keeps being constant in the stable condition of roof movement and the deformation velocity of surrounding for gob-side entry retaining, which makes the roadside support body be constantly pressed and makes soft medium be in creep stage. And the deformation velocity of soft medium is faster than that of the lower main filling body, which makes the lower main filling body of high water material not be damaged suddenly, so that to prevent the deformation instability of roadside support body effectively.

We understand the importance about soft medium connecting the roof in the condition of hard roof through analyzing the mechanics of soft medium in gob-side entry retaining. Based on the analysis and the certain roadside filling material and width of filling body, the height of soft medium is the key to ensure the success of gob-side entry retaining in the condition of hard roof under thin coal seam, which enhances the supporting ability and the balance ability of roadside support body.

THE DETERMINATION OF THE HEIGHT OF SOFT MEDIUM CONNECTING THE ROOF

The stability of surrounding rock in gob-side entry retaining is closely related to the strength and geometrical size of roadside support body. In the condition of the certain roadside filling material and width of filling body, designing the height of soft medium reasonably is important to ensure the success of gob-side entry retaining.

The theoretical calculation of the height range of soft medium connecting the roof

The deformation between basic roof and roadway floor should be known to determine the height of soft medium in gob-side entry retaining. Based on the structure diagram of gob-side entry retaining shown in fig.3, the deformation between basic roof and roadway floor can be obtained as [1,9]:

$$\Delta h = (h - h_p)(l_1 + a + 0.5a_1)/l \quad [10]$$

In the formula: where h is the height between basic roof and coal seam floor (m), h_p is the height between basic roof and coal seam floor after the rotating of basic roof (m), k is the compaction coefficient of fragmented rock, the value range of k is determined by the roof lithology, m is the thickness of coal seam (m), l_1 is the pre-breaking distance of the key rock block (m), a is the width of roadway retaining (m), a_1 is the width of filling body (m), l is the length of breaking rock block (m).

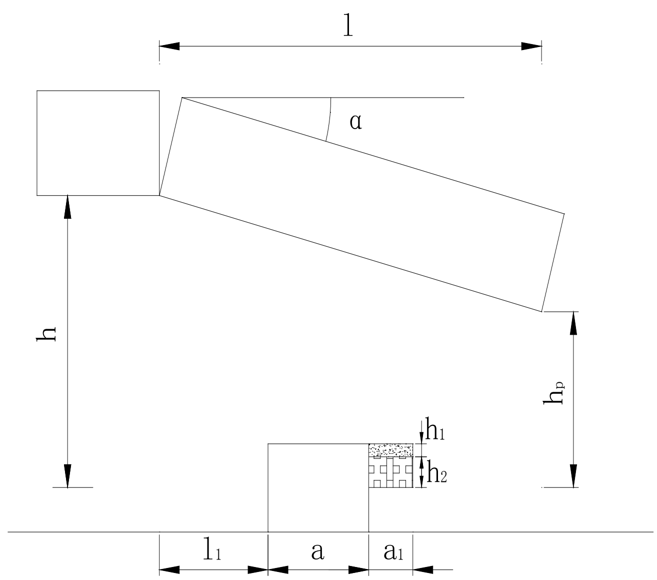


Figure 3: Structure diagram of gob-side entry retaining

According to the factual condition of working panel 090101, m=1.2m, h=8.9m, k=1.1, l_1=4.5m, a=3.7m, a_1=1m, l=20m. Putting these values to the formula, it can obtain Δh=0.187m.

To make the roadside support body adjust to the certain deformation of basic roof structure, the height of soft medium connecting the roof should satisfy as $h_1 \geq \Delta h$. But excessive flexible quantity of soft medium will lead to the instability of roadway roof when h_1 is oversized. So multiple factors need to be considered to determine the reasonable height of soft medium.

The numerical simulation of the height range of soft medium

The establishment of numerical model

The finite difference software's FLAC3D numerical simulation is used to analyze relationships between the characteristic of roadside support body and the deformation of roadway surrounding rock and the different height of soft medium [11-14]. Based on the symmetry principle and the lithology distribution of roof and floor of coal seam in 090101 working face, dividing the model into 6 layers vertically and the model size with 100m×100m×60m is presented. Vertical stress with 6.26MPa is applied to the upper boundary of model and the lateral pressure coefficient is 0.5. Vertical displacement of bottom boundary and horizontal displacement of left and right are fixed. In roadside support body, the soft medium of upper part uses high water content material when water-cement ration is 4 and the main filling body of lower part uses high water content material when water-cement ration is 1.5. The filling work follows the mining of working face closely. The coal seam of model uses strain-softening model and the rest uses Mohr-Coulomb model. Physico-mechanical parameters of roof and floor of coal seam in 090101 working face are defined as follows (table 2).

Table 2: Physico-mechanical parameters of roof and floor of coal seam in 090101 working face

Position	Rock type	Thickness/ (m)	Density/ (kg/m3)	Elastic modulus/ (Gpa)	Poisson ratio	Cohesion/ (Gpa)
Roof	Fine sandstone	21.9	2.55	2.5	0.22	3.5
	Limestone	7.7	2.70	3.2	0.20	4.5
Coal seam	9# coal	1.2	1.43	1.2	0.35	1.9
Floor	10# coal	0.6	1.41	1.1	0.36	1.8
	Mudstone	2.7	2.51	2.4	0.24	3.1
	Lower strata	25.9	2.50	2	0.30	2.3

The size of panel 090101 is 3.7 meters wide and 2.6 meters high with a rectangular section. In order to analyze the control effect of roadway surrounding rock in the different height of soft medium for gob-side entry retaining, setting the width of roadside support body as 1m and the height of soft medium as 0, 0.1m, 0.2m, 0.3m respectively in the condition of other parameters invariable.

The results and analysis of numerical simulation

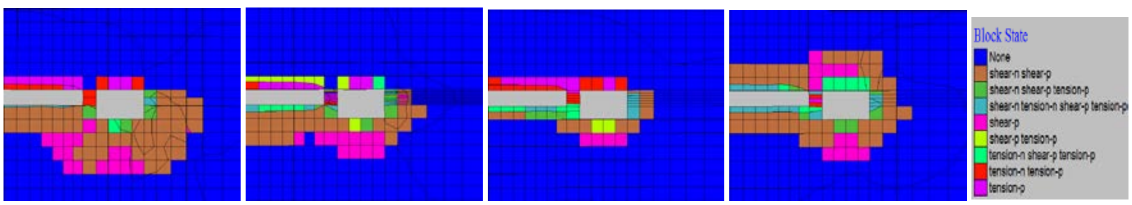
The stress and compressed volume of roadside support body change continuously in different height of soft medium as the mining of working face. The changing curve is as shown in fig.4, fig.5 and fig.6.

We can know from fig.4: The roof begins to lose the stability and plastic zone has been arisen in the roadside support when the mining process has worked for 10m. And plastic zone presents different features in different height of the soft medium, which shows the area of plastic zone is the smallest when the height of the soft medium is 0.2m.

We can see from fig.5: In the condition of the width of roadside support body with 1m, stress has a small decreasing tendency in the different filling body place from gob-side to roadway side (0→1m), because basic roof touches the support body in gob-side first, then gradually compresses the full support body and makes the full support body equably forced in the rotating and subsidence of basic roof. The stress of filling body is biggest without soft medium and the stress decreases first then increases when the height of soft medium increases from 0.1m to 0.3m, which reflects that soft medium absorbs part of load and avoids stress concentration in filling body through the characteristic of yielding, but it cannot play its role when the height of soft medium is excessive.

We can see from fig.6: The compression of soft medium gradually increases and the compression of the main filling body decreases first then increases as the height of soft medium increases, which reflects that soft medium and the main filling body have a compatible deformation in the appropriate height of soft medium, but it cannot decrease the deformation of the main filling body through its characteristic of yielding when the height of soft medium exceeds a certain value.

Thus, plastic zone of roadway surrounding rock, the stress and compression are smallest when the height of soft medium is 0.2m, which shows that the deformation of soft medium adjusts to certain deformation of basic roof and decreases the stress concentration in filling body and protects the integrity of the main filling body.



（a） Without soft medium （b）0.1m （c）0.2m （d）0.3m

Figure 4: Plastic zone of roadway surrounding rock in different height of the soft medium

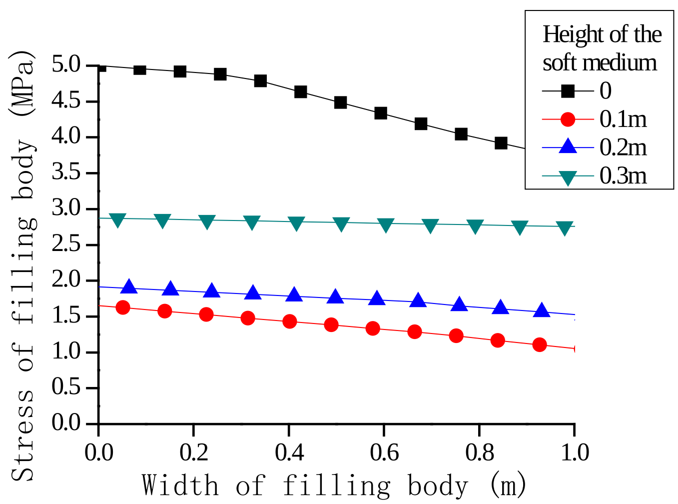


Figure 5: Backfill stress with different height of the soft medium

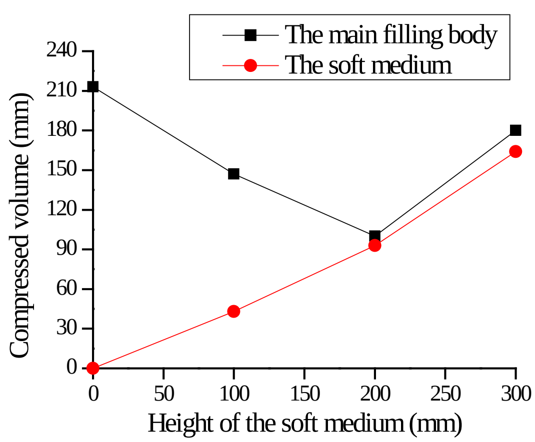
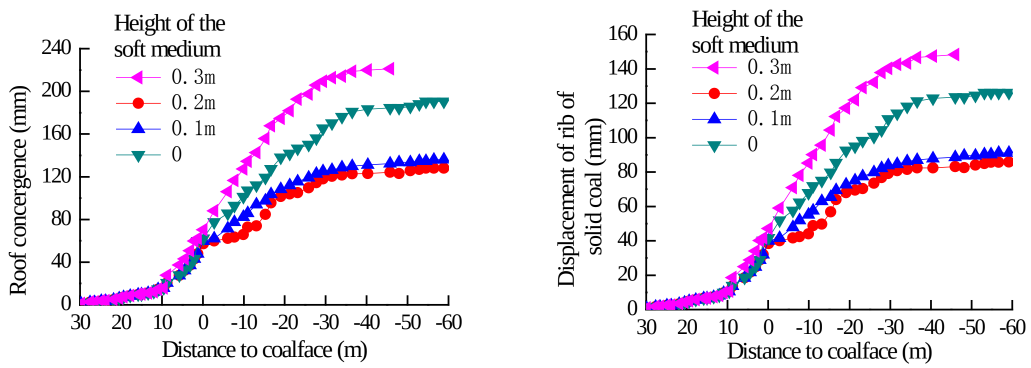


Figure 6: The relationship between compressed volume and height of the soft medium

The deformation of roadway surrounding rock shows some features in different height of the soft medium connecting the roof behind the mining of 090101 working face. The deformation feature of roadway surface displacement is as shown in fig.7.



（a） Roof convergence （b） Displacement of rib of solid coal

Figure 7: Deformation curves with different height of the soft medium

It can be analyzed from fig.7 that the deformation feature of panel 090101 surrounding rock with different height of the soft medium are shown as follows.

(1)The deformation of roadway surrounding rock gradually decreases as the height of the soft medium increases when the height range of the soft medium varies from 0 to 0.2m. The deformation of roadway surrounding rock increases suddenly when the height of the soft medium exceeds 0.2m, and the deformation quantity is bigger than it without the soft medium.

(2) The deformation of roadway surrounding rock keeps invariable behind the working face 40m, of which the deformation is the smallest when the height of the soft medium is 0.2m.

In a word, different height of the soft medium heavily influences the deformation of roadway surrounding rock. The roof subsidence and the displacement of solid coal are the smallest when the height of the soft medium is 0.2m, and the deformation has inflection point at the height of 0.2m, which reflects that the deformation of roadway surrounding rock will increase heavily as the height of the soft medium increases.

The reasonable height of the soft medium connecting the roof

Based on the above research, theoretical calculation of soft medium in upper roadside support body of panel 090101 is used to obtain the height range of soft medium that need to exceed 0.187m. Numerical simulation is used to analyze the relationship between the characteristic of roadside support and deformation of surrounding rock and the height of soft medium, which shows that the stress, compression of the filling body and the deformation of surrounding rock are the smallest within the engineering permissible range when the height of soft medium is 0.2m. For the reason that using the soft medium to connect the roof in side of panel 090101 is still an exploratory technology, considering factors of the deformation of roadside support body under hard roof and height variation of the coal seam, based on theoretical calculation and numerical simulation of the height of the soft medium, which eventually determines that the reasonable height of the soft medium is 0.2m.

ENGINEERING APPLICATION

Based on the above research, high water content material is tested as roadside filling material in panel 090101 for gob-side entry retaining. Soft medium of top roadside support uses high water content material when water-cement ration is 4 and the lower part filling of roadside support uses high water content material when water-cement ration is 1.5. The height of connecting the roof is 0.2m and the size of roadside support body is 3.0m×1m×1.2m.

The relationship (shown in fig.8) between the deformation of roadway surrounding rock and the distance to coalface is obtained through observing roadway surface displacement in the mining of 090101 working face.

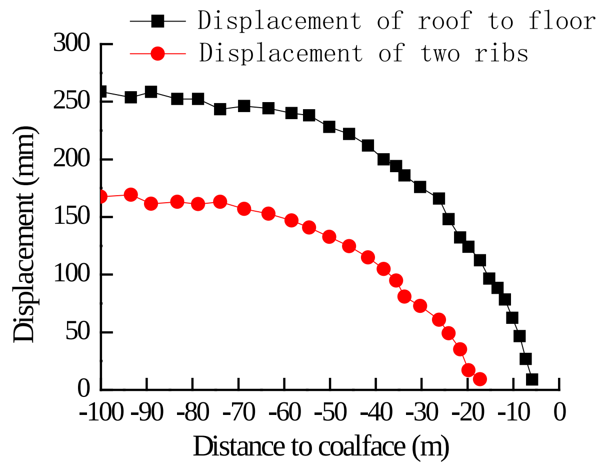


Figure 8: Relationship between displacement of surrounding rock and distance of working face

We can analyze from fig.8 that the deformation of roadway surrounding rock behind the working face increases first then decreases as the mining work goes on. The stable displacement of roof to floor is 264mm and the displacement of two ribs is 171mm, which are in engineering permissible range. It is not difficult for roadway maintenance, which provides a good condition for second mining work.

Second, though the deformation of surrounding rock increases fast behind the working face, it becomes stable after a while. The roadway should be reinforced support behind the working face 30m to 40m for the roadway stability.

Above all, the deformation of roadway surrounding rock is small when retaining roadway is in stable stage, which shows the reasonable height of the soft medium. The yielding characteristic of the soft medium protects the integrity of lower main filling body and protects the stability of retaining roadway.

CONCLUSIONS

For using gob-side entry retaining on the condition of hard limestone roof in thin coal seam, establishing the mechanical model of roadside soft medium connecting the roof, analyzing the mechanisms of roadside soft medium connecting the roof. Its characteristic of proper yielding deformation constantly increases the resistance of the lower main filling body and protects the integrity of full roadside support body. The deformation velocity of soft medium is faster than that of the lower main filling body, which makes the lower main filling body of high water material not be damaged suddenly. When the deformation of the soft medium reaches its limit, the higher strength of the main filling body meets the requirements of the retaining roadway. This is where we can know that the key to use gob-side entry retaining is to determine the height of the soft medium.

Based on the geological condition of panel 090101, using theoretical calculation to obtain the height range of soft medium, using numerical simulation to analyze the relationship between plastic zone of roadway surrounding rock, the characteristic of roadside support, deformation of surrounding rock and the height of soft medium, which determines that the height of soft medium is 0.2 meters.

Practical application shows that soft medium of top roadside support uses high water content material when water-cement ration is 4 and the lower part filling of roadside support uses high water content material when water-cement ration is 1.5 in the basic roadway support of bolt, joist, plastic net and anchor cable, which adjusts to the movement of roof rock. The stable displacement of roof to floor is 264mm and the displacement of two ribs is 171mm, which shows that the deformation of roadway surrounding rock is effectively controlled and the roadway can be served for the safe mining of next working face.

REFERENCES

1. Sun Henghu, Zhao Bingli (1993) “The theory and practice of gob-side entry retaining [M].” *Beijing: China Coal Industry Publishing House*, 1993.
2. Hua Xinzhu (2006) “Development status and improved proposals on gob-side entry retaining support technology in China [J].” *Coal Science and Technology*, 2006, 34(12):78–81.
3. Zhang Jixiong, Jiang Haiqiang, Miao Xiexing (2013) “The rational width of the support body of gob-side entry in fully mechanized backfill mining [J].” *Journal of Mining & Safety Engineering*, 2013, 30(2):159-164.
4. Huang Yanli, Zhang Jixiong, Zhang Qiang (2011) “Technology of gob-side entry retaining on its original position in fully mechanized coalface with solid material backfilling [J].” *Journal of China Coal Society*, 2011, 36(10):1624-1628.
5. Bai Jianbiao, Zhou Huaqiang, Hou Chaojiong (2004) “Development of support technology beside roadway in gob-side entry retaining for next sublevel [J].” *Journal of China University of Mining & Technology*, 2004, 33(2):59-62.
6. Zhang Dongsheng, Mao Xianbiao, Ma Wending (2002) “Testing study on deformation features of surrounding rocks of gob-side entry retaining in fully-mechanized coal face with top-coal caving [J].” *Chinese Journal of Rock Mechanics and Engineering*, 2002, 21(3):331-334.
7. Ma Liqiang, Zhang Dongsheng, Chen Tao (2007) “Study on packing body supporting resistance of enter-in packing for in-situ gob-side entry retaining in fully mechanized top-coal caving mining face [J].” *Chinese Journal of Rock Mechanics and Engineering*, 2007, 26(3):544-550.
8. Zhou Baojing (2012) “Study on coordinate deformation mechanism of backfill-surrounding rock and technology of gob-side entry retaining [D].” *China University of Mining and Technology*, 2012.
9. Wang Xianglong, Yao Jianguo (1999) “New progress and development trend of longwall mining technology [J].” *Coal Mining*, 1999, (4).
10. Zhang Dongsheng, Miao Xiexing, Feng Guangming (2003) “Stability control of packing body for gob-side entry retaining in fully-mechanized coalfaces with top-coal caving [J].” *Journal of China University of Mining & Technology*, 2003, 32(3) : 232-235.

11. Fan Kegong, Liang Hongguang, Ma Chishuai (2014) "Non-harmonious deformation controlling of gob-side entry in thin coal seam under dynamic pressure [J]." *Journal of Rock Mechanics and Geotechnical Engineering*, 2014(6):269-274.

12. Yantao Chen, Ying Xu, Yewen Feng (2015) "Interaction Mechanism between Surrounding Rock and Roadside Pack for Gob-side Entry Retaining in Thin Coal Seam" [J]. *The Electronic Journal of Geotechnical Engineering*, Vol. 20, Bund. 20(12):4719-4734.

13. Hu Yong-zhong, Liu Chang-you, Li Jian-wei (2015) "Fractal Analysis of Cracks Due to Mixed Mining of Coal Seam Group." *The Electronic Journal of Geotechnical Engineering*, Vol. 20, Bund. 20(17):9749-9760.

14. Ying Chen, Longchen Duan, Yubei Lu, and Ye Wu "Drilling Efficiency and Cost for Different Drill Technology in Loose Stratum." *The Electronic Journal of Geotechnical Engineering*, Vol. 20(9):3999-4010.

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