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Mine pressure behavior of coal seam and environment management technical research

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ABSTRACT

In deep inclined coal seam entry, mining pressure behavior is intensive and the support is extremely different. Based on continual finite element method, this paper adopts FLAC3D software to simulate rule of liberation seam (coal seam that with no or low shock ground pressure danger) stress and coal seam thickness deformation with physical mechanics parameters and geologic feature of roof and floor strata. It adopts alternate optimized layout in liberated layer according to pressure relief range of liberation seam. And it also studies the effect rule of different coal bed pitch and strata spacing on liberation seam pressure relief. The result shows that pressure relief range of liberated layer is direct ratio to work face length of liberation seam. And top pressure relief shielding angle increases with the increase of coal seam dip angle while bottom pressure relief angle is on the contrary. The bigger interlayer spacing is, the weaker pressure relief effect is. Whereas the smaller interlayer spacing is, the stronger pressure relief effect is. And liberation seam mine pressure behavior rule is applied into 7# coal work face entry. In addition, falling behind of environment management in mine industry affects agriculture and ecological environment heavily. Therefore, coal industry and ecological environmental construction should develop at the same pace.

KEYWORDS

Numerical modeling; Mining of liberation seam; Mine pressure behavior rule; Environmental management technology.

INTRODUCTION

High pressure, temperature, water pressure and intensive mining disturbance induced by deep mining may lead to a series of dynamic disaster. Especially, high ground pressure can increase pressure of surrounding rock in roadway, which will bring difficulty to deep roadway support. In addition, intensive deformation of roadway, big damage area of surrounding rock, serious damage of support system increase the difficulty of roadway maintenance. How to solve difficulty of deep roadway support is a serious challenge to mining system. Liberation seam refers to coal seam that with no or low shock ground pressure danger, which is also termed as protective seam by some scholars. After mining liberation seam, it can produce liberation impact on coal seam that with no or low ground pressure danger and eliminate or reduce shock or outstanding danger in order to preventing outstanding of coal and gas. Deep high stress damage that is studied in this paper can also fundamentally remit the difficulty of deep roadway support.

It is well-known that coal mining is a continuous dynamic process. In the process of mining coal, rock strata will move, deform and relieve pressure. In general liberation seam pressure relief rule[1], adoption of some static analysis results can not fully reflect movement and deformation of overlying strata. That is, movement and deformation of rock strata is a dynamic process. Based on the complicated coal mining, it is difficult to do much site measurement. Therefore, making use of superiority of numerical simulation, this paper fully studies coal pressure behavior rule of mining overlying strata as well as deformation and pressure relief distribution rule of long distance liberated coal seam by lots of experimental comparison. And it also provides technical support for optimized layout of liberated layer entry. However, as non-renewable energy, mass mining and utilization of mine is bound to cause resources shortage and pollution and damage on agriculture and ecological environment. Especially the major disasters such as water and soil erosion, greenhouse effect, ozone depletion, acid rain are all related to coal mining and utilization.

CALCULATION OF COAL PILLAR STABILITY

Calculation of coal pillar yielding width

It is generally recognized that the width of yielding zone is the width between coal pillar boundary and support pressure peak[2]. Suppose coal is continuous homogeneous isotropic elastic body, movement and deformation before coal pillar yield is tiny, yielding zone of coal pillar can be regarded as Eastover, yield zone occurs shear failure and the failure surface is parallel to the coal seam, coal pillar is not affected by horizontal tectonic stress[3], stress of coal pillar is symmetry with neutral surface. In order to calculate width of yielding zone, the formula of coal pillar yielding zone is as follows.

$$r_p = \frac{M\beta}{2\tan\phi_0} \ln \frac{\sigma_{zl} + \frac{C_0}{\tan\phi_0}}{\frac{C_0}{\tan\phi_0} + \frac{p_x}{\beta}} + (\frac{M}{2} - Z)\tan\phi_0 \quad (1)$$

Disturbance factor d can be introduced into the formula if disturbance effect in coal yielding is considered, then the formula changes to:

$$r_p = \frac{Md}{2\tan\phi}\left[\ln(\frac{C + \sigma_{zl}\tan\phi}{C + \frac{P_x}{\beta}\tan\phi})^{\beta} + \tan^2\phi\right] \quad (2)$$

In this formula, β— side pressure coefficient of interface between yielding zone and nuclear zone.

M— height of coal pillar

d — mining disturbance factor

ϕ — internal friction angle of coal

C— cohesion of contact surface of coal seam roof and floor

σ_{zl} — ultimate strength of coal pillar

p_x — lateral restriction of coal wall

According to coal geological parameter, suppose β as 0.47, M as 3.8 m, φ as 30°, C as 2 Mpa, σ_{zl} is 6.714 M p a and p_x is 0. The result is $r_p = 8.1m$. Considering the yielding zone to both sides of coal pillar, the stable width of coal pillar is 16.2 m. Then we can know that stability of coal pillar is good when retaining 20 m of zone[4].

According to the calculation result, top layer zone belong to big pillar, that is, B > 2 L. At this moment, loading in the middle of coal pillar is uniform distributed and is stress of original rock ρH. From boundary to middle, it is plastic zone, elastic zone and original rock stress zone[5].

Calculation of floor yielding damage depth

According to slip line field theory[6], floor yielding damage depth h is:

$$h = r_0 e^{\alpha \tan \psi_f \cos(\alpha + \frac{\varphi}{2} - \frac{\pi}{4})} \quad (3)$$

$$r_0 = \frac{x_0}{2\cos(\frac{\pi}{4} + \frac{\varphi_f}{2})} \quad (4)$$

Combined with ultimate balance theory, the biggest yielding damage depth of upside stress distribution to floor rock strata can be confirmed:

$$h_\sigma = \frac{M \bullet \cos\varphi_f \ln \frac{kyH + C\cot\varphi}{\xi(p_i + C\cot\varphi)}}{4\xi f\cos(\frac{\pi}{4} + \frac{\varphi_f}{2})} e^{(\frac{\varphi_f}{2} + \frac{\pi}{4})\tan\varphi_f} \quad (5)$$

In this formula, K—stress concentration factor;

γ— average volume weight of up overlying strata;

H— buried depth of coal seam

f — friction coefficient of contact surface between coal seam and roof and floor

ξ— triaxial stress coefficient

pi— resistance of support to buttock

ψf— internal friction angle of floor strata

According to geological conditions, M is valued as 3.8 m, K as 3, ψ as 30°, C as 2 Mpa, H as 100 m, γ as $25 KN/m^3$, f as 0.2, pi as 0 andψf as 33°. Then h is calculated out as 8.6 m. In other words, influence depth of top layer mining on floor by theoretical calculation is 8.6 m[7].

DEFINITIONS OF THE BOUNDARY CONDITIONS FOR THE FINITE ELEMENT ANALYSIS

2444 work face of adjacent mining situation and neighborhood relationships is as follows. Surface part 2442 (external) work face have been stopped (adjacent roadway is also termed as testing roadway 2444 material roadway). Deep part is 7446 goof of coal seam 7# in liberation seam. Bottom of 2442 is goof 7444. Average interlayer spacing of coal seam 2# and 7# is 110 m. Arrangement of 2444 work face in clip river coal mine is shown in Figure 1.

On the basis of production geological conditions of 7446 work face in clip river coal mine and taking all the factors into account, a numerical model whose dip angle is 25° is established according to the horizon relationship of coal 2# and 7# as shown in Figure 1. Size of model is : 310 m×1 m×480 m. Position coordinates of coal 7# work face is x=(90, 230), length of work face is 160 m and the interlayer spacing between 7# and 2# is 110 m[8]. Top boundary of the model is stress boundary. Bottom boundary is vertical fixed displacement. And left and right boundaries are fixed in horizonal level[9].

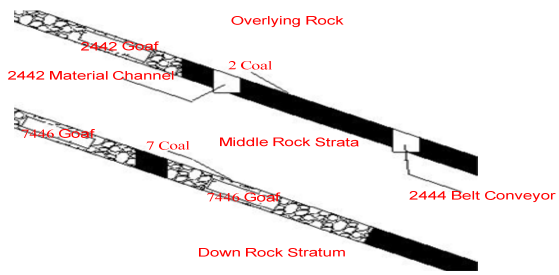


Figure 1 : 2444 Location plan of work face

After mining liberation seam, stress field in stope is redistributed. Distribution of stress field of top and floor in liberation seam is shown in Figure 2. Pressure relief coefficient K_0 is defined to reflect change scope of stress in rock strata. The definition formula is:

$$K_0 = \frac{\delta_0 - \delta}{\delta_0} \times 100\% \quad (6)$$

In this formula, K_0 is pressure relief coefficient of rock strata; δ_0 is stress value of original rock; δ is stress in rock strata after mining low adjacent strata.

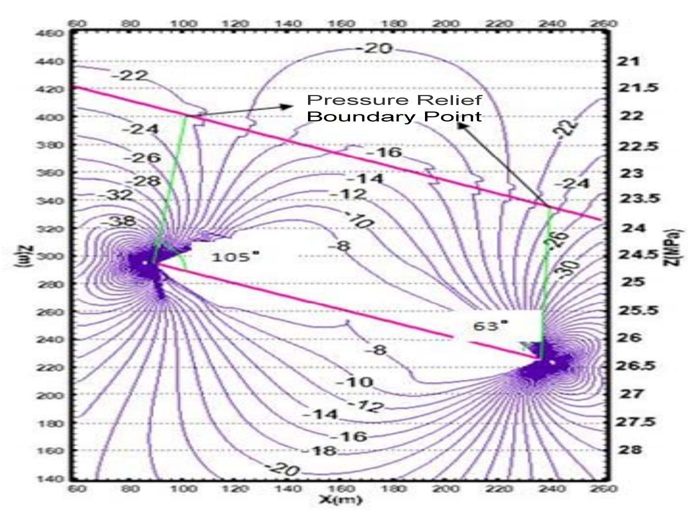


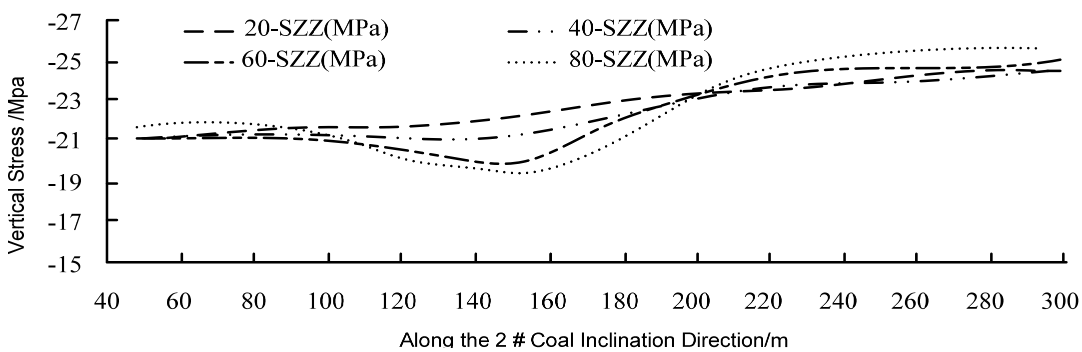
Figure 2 : Contour map of stress field distribution of 7# coal roof and floor when work face length is 160 m

It can be seen from Figure 2 that reduced range of stress in coal 2# is lower than the work face length of 7#. Length of stress-descend area is 153 m which is 95.6% of work face length in coal 7#. However, two sides of stress-descend area along with trend of the coal strata 2# is stress-elevated area. Top and bottom pressure relief boundary point and fall position of 7# coal roof are connected to form a trapeziform. The area within the trapeziform is pressure relief range of coal strata. Ligature between 7# coal strata and pressure relief boundary is effective pressure relief district line. The area within effective pressure relief district line is stress-descend area. Otherwise, it is stress-elevated area. Concentration coefficient is obviously bigger than 1. Angle between the ligature of 7# coal strata and pressure relief boundary is pressure relief shielding angle. Top pressure relief shielding angle is 105° and bottom pressure relief shielding angle is 63°[10].

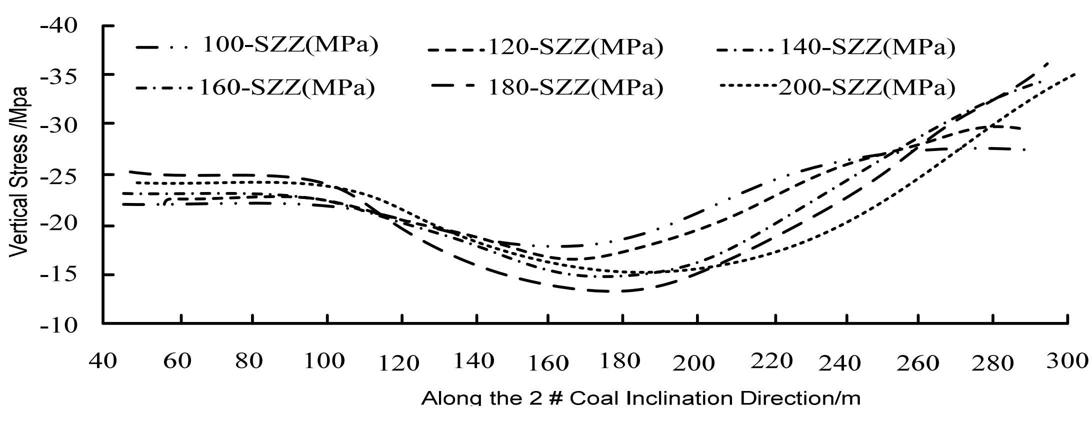
As mentioned above, mining liberation seam leads to stress concentration of perpheral region of two sides of goaf in liberation seam work face. And stress in the middle of goaf is released. Rock strata around coal seam roof move and deform towards goaf by impact of support pressure of coal wall of goaf. As a result, stress of liberation seam 2# elevate[11].

When liberation seam work face length is different, vertical stress distribution curve of 2# coal strata is shown in Figure 3

In order to study the impact of different liberation seam work face length on liberation seam pressure relief.



(1) Work face length of liberation seam is 20~80 m



(2) Work face length of liberation seam is 100~200 m

Figure 3 : Influence of liberation seam work face on coal 2# vertical stress distribution

It can be seen from Figure 3, there is a transformation of developing from nothing of pressure relief effect of 2# when the work face length of liberation seam grow from 20 m to 80 m. And the effect becomes more and more obvious. When the work face length grows from 100 m to 180 m, the pressure relief effect of coal seam 2# continues to develop and stress pressure relief coefficient of coal seam 2# become maximum. When work face length of liberation seam grows from 180 m to 200 m, pressure relief range of coal seam 2# become bigger. At that moment, the vertical stress of coal seam 2# elevates.

Effect of pressure relief shows a tendency of decreasing and be stable in 16~20 Mpa. And pressure relief coefficient tends to be stable[12].

Figure 4 is the change rule of thickness of coal 2# with different work face length of liberation seam. In the figure, vertical coordinates is vertical movement transformation of liberated layer. Horizonal coordinates is the tendency of coal 2# work face[13].

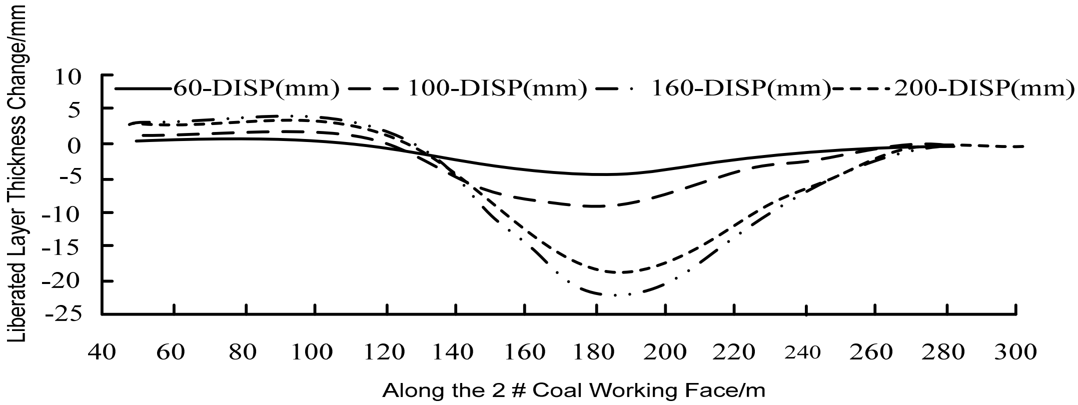


Figure 4 : Change rule of thickness of coal 2# with different work face length of liberation seam

Deformation data in change rule of thickness of coal 2# with different work face length of liberation seam was extracted by tecplot software. The deformation of liberated layer after data integration is shown in Figure 4. It shows that liberated layer is under compression when data is bigger than 1. Otherwise, liberated layer will be dilatant. Analysis comprehensively can work out that:

Work face length of liberation seam is 60 m. Impact of liberation seam on the deformation of liberated layer is small. Expansion area and degree are small and the maximum expansion value is only 4.7 mm. Its expansion rate is 0.235% compared to coal seam 2#. And it is located above the goaf.

This paper studies the effect law of coal seam dip angle on liberation seam mining combining with the basic situation of geography in clip river coal mine. And it also studies profile form rule of dip angle on stress distribution of coal seam. And the evolution rule of different coal seam dip angle on stress pressure relief can be worked out[14].

From formula 4-1, we can know that when $K_0 > 0$, it shows that there is pressure relief effect after mining liberation seam and it is in pressure relief area. If $K_0 < 5\%$, it is stress relief transition area. If $K_0 > 5\%$, it is stress relief active area.

From Figure 5 and Figure 6, we can know that vertical stress distribution can be divided into original rock stress area, stress-elevated area and stress-descend area. However, according to the size of stress pressure relief, it can be divided into stress releasing active area and stress releasing transition area. The middle of coal 2# is stress releasing active area and both sides are stress releasing transition area.

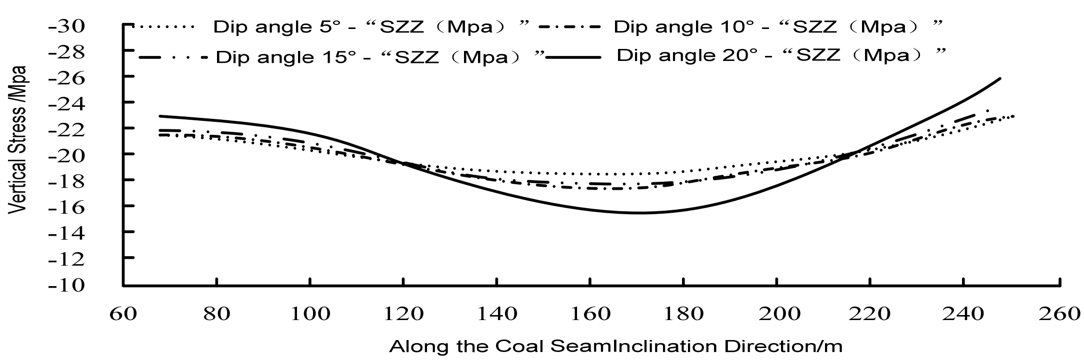


Figure 5 : Curve of coal 7# stress distribution when mining gentle dip liberation seam

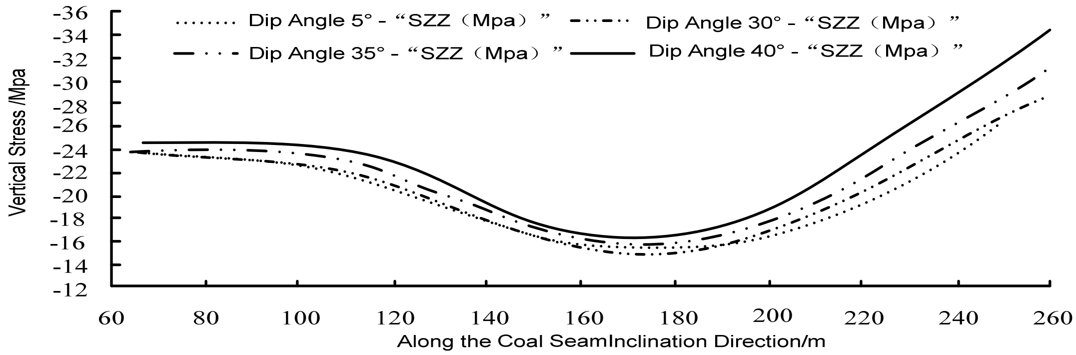


Figure 6 : Stress distribution curve of coal 7# when mining medium dip liberation seam

According to Figure 7, top and bottom pressure relief shielding angle is nearly the same when coal seam dip angle is small. And with increasing of coal seam dip angle, there is a linear relation between pressure relief shielding angle and coal seam dip angle. Top pressure relief shielding angle increases linearly while bottom pressure relief shielding angle decreases linearly. That will lead to discrepancy of space structure of overlying rock when mining inclined coal seam and horizonal coal seam. Stress form of inclined coal seam mining form an unsymmetrical shell structure. Stress form of horizonal coal seam mining will show a symmetrical shell structure. When dip angle is bigger than 30°, space form is more complex. There is a common feature to mining liberation seam of inclined coal. That is, top pressure relief shielding angle is bigger than bottom pressure relief shade angle.

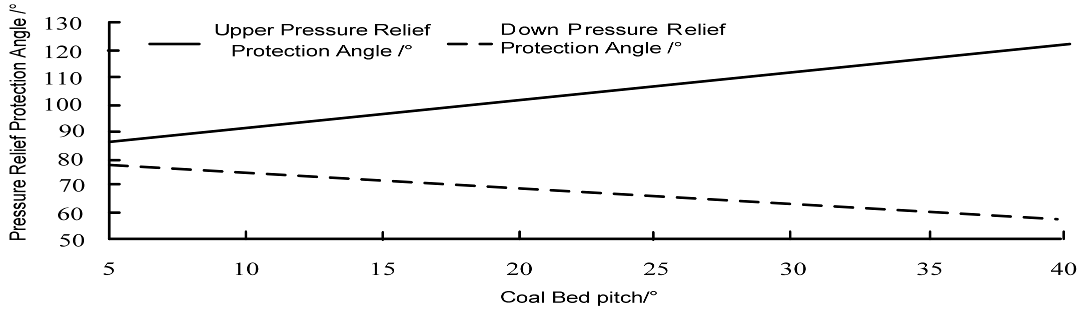


Figure 7 : Relation between dip angle and pressure relief shade angle

It can be seen from Figure 8 that effective pressure relief range and dip angle of coal 2# show a proportional relationship. With the increase of dip angle, effective pressure relief range of coal 2# gradually increase. When the dip angle is 25°, length of effective pressure relief range of coal 2# is 153 m. Projection of pressure relief range in horizonal position is inside coal 7# work face. Therefore, when rationally arrange coal 2# entry, high stress concentration area should be avoided. Adopt alternate method to optimized arrange coal 2# work face entry and make it easy to maintain stability in stress pressure relief area.

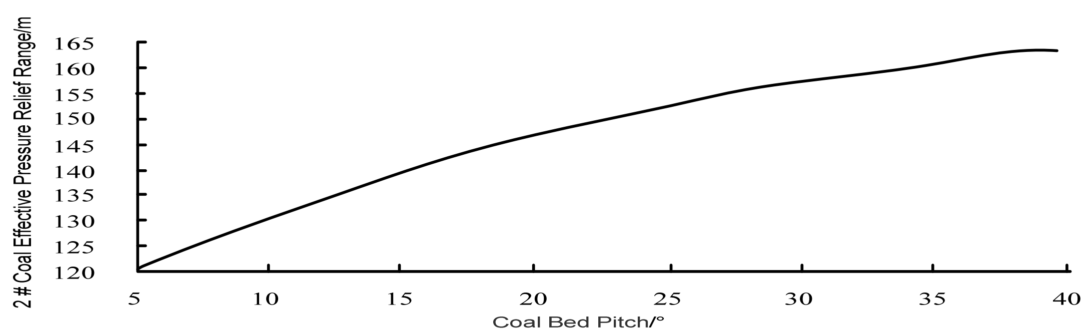


Figure 8 : Relation of coal seam dip angle and effective pressure relief range of coal 2#

Research shows that pressure relief impact of liberation seam will decrease with the increasing of vertical interval under certain condition of geology and mining. When it reaches a critical distance, pressure relief impact will disappear. Height of damage zone of top overlying rock strata caused by mining bottom coal seam is limited. And sufficient interlayer spacing can balance the impact of balance destruction. The bigger interlayer spacing is, the weaker pressure relief effect is. Otherwise, the smaller interlayer spacing is, the stronger pressure relief effect is.

As shown in Figure 9 and Figure 10, according to the data of stress pressure relief and coal seam deformation extracted by value calculation, we can know that pressure relief coefficient and dilatancy curve of middle rock strata in liberation seam work face decrease with the increase of interlayer distance. It is consistent with the research result of former scholars. Its formula is:

$$\varepsilon_e = \varepsilon_{e_0} \times e^{-bh} \quad (7)$$

In this formula, ε_e refers to pressure relief coefficient and dilatancy value of liberated layer h away from liberation seam; h refers to vertical distance from liberation seam to liberated layer. ε_{e_0} And b refer to constant.

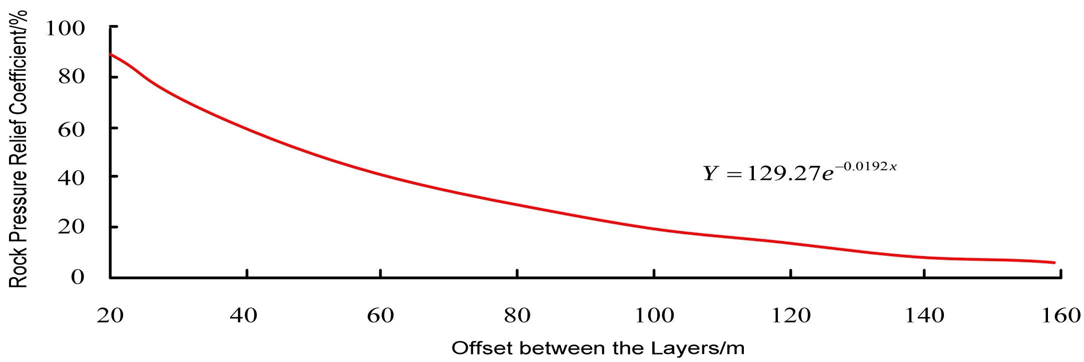


Figure 9 : Pressure relief coefficient curve of middle of liberated layer with different vertical distance from liberation seam

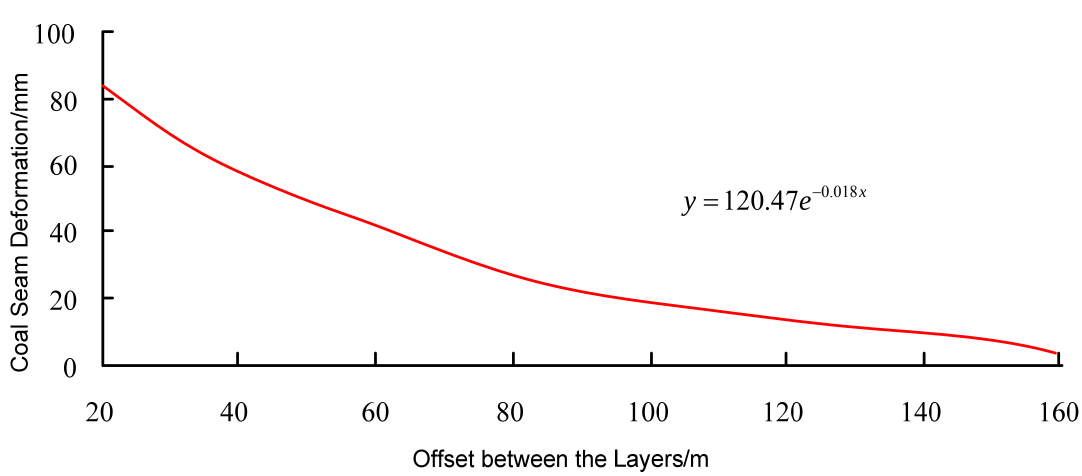


Figure 10 : Dilatancy curve of middle of liberated layer with different vertical distance from liberation seam

So far, according to the maintenance of roadway in clip river coal mine, 100 m of interlayer distance can play an impact of liberation under the condition of inclined coal seam. And theoretical analysis and value calculation show that 100 m of interlayer is not critical distance of pressure relief. Engineering application makes a site inspection experiment on the entry of liberated layer work face in order to comparatively verify numeral simulation result. Dynamic system design method is adopted to confirm the support coefficient of rock bolt in pressure relief wok face entry.

Roof and two sides of roadway adopt high-strength grain steel anchor whose diameter is 22 mm and length is 2400 mm. Interrow spacing of high side anchor is 550 mm×700 mm. Interrow spacing of roof and low side is 700 mm×700 mm. Diameter of roof anchor line is 18.9 mm, length is 7.25 m and interrow spacing is 900 mm×1400 mm. Initial torque of installed bolt is 150 N•m～200 N•m. Second fastening torque is 250 N•m～300 N•m. Tensile anchor can reach design prestress by 120 kN～140 kN.

(1) Roof support parameter

Roadway roof adopts eight high-strength yielding bolts coordination with steel ladder beam and metal mesh support. And anchor is used for strengthening support. Support parameter of top bolt is: diameter Φ22 mm, length 2400 mm. Every top bolt adopts an ultrafast resin cartridge CK2370 and a medium speed resin cartridge Z2370 lengthen anchor. Length of anchor id 1.4 m, interval is 700 mm and interrow distance is 700 mm. Roadway roof is made of steel ladder beam welded by round steel whose diameter is Φ12 mm.

Support parameter of roof anchor is: diameter Φ18.9 mm, length 7250 mm. Every anchor adopts an ultrafast resin cartridge CK2370 and two medium speed resin cartridge Z2370 anchor. Height of anchor is 2.1 m and space between top anchors is 900 mm and interrow distance is 1400 mm. Melt net is kind of rhombus melt net made of ≥10# iron wire.

(2) Two side support parameter

High side of 2444 material roadway is supported by seven high-strength yielding anchors and high side is supported by three high-strength yielding anchors. Support parameter of side anchor is: diameter Φ22 mm, length 2400 mm. Every side anchor adopts an ultrafast resin cartridge CK2370 and a medium speed resin cartridge Z2370 lengthen anchor. Length of anchor is 1.4 m. Space between high side anchors is 550 m and interrow distance is 700 mm. Space between low side anchors is 700 mm and interrow distance is 700 mm. Two sides all lay rhombuses melt net and use steel ladder beam that is made of Φ12 mm round steel, as shown in Figure 11.

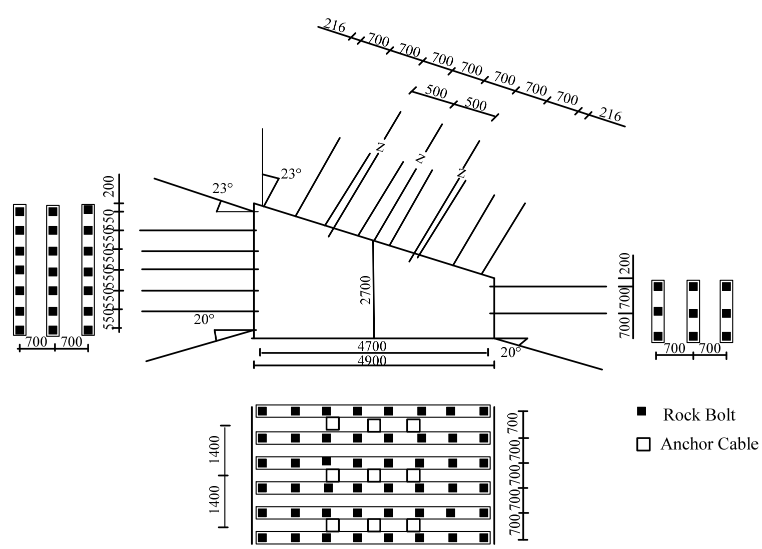


Figure 11 : Arrangement plan of anchor and cable in experimental roadway

In order to make comparative verification of value simulation result, a site inspection experiment is done on deep displacement of 2444 material roadway of liberated layer in simulation area.

(1) Surface displacement of roadway

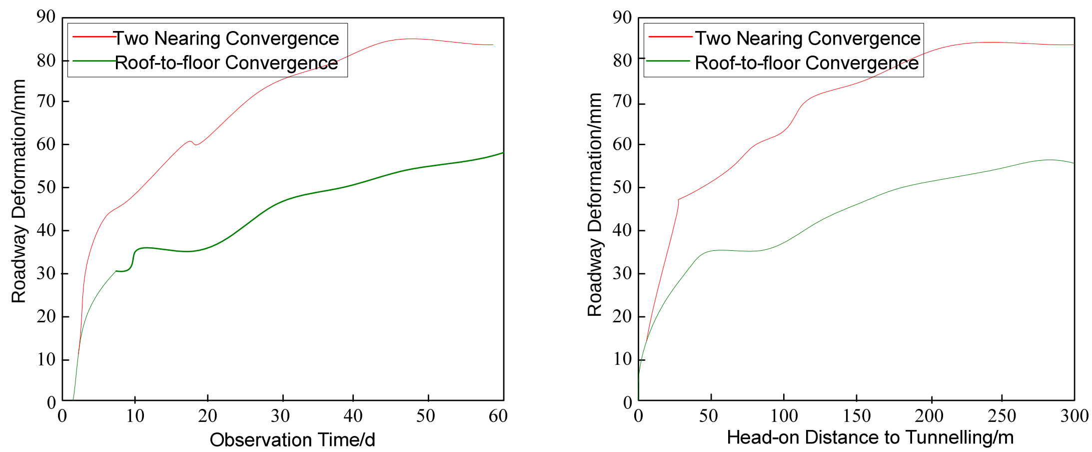


Figure 12 : Monitoring curve of displacement of material roadway surface

Monitoring of displacement of material roadway surface is shown in Figure 12. It can be seen from the figure that 2444 work face material roadway surface displacement has the following rule: after digging the roadway, surface displacement monitoring curve increase quickly. And lasting time is 10 d. Average displacement speed of roof and floor is 3.7 mm/d. Average displacement speed of two sides is 4.9 mm/d. The reason is that after digging roadway, elastic energy accumulated in deep rock suddenly releases and carry capacity goes down; surface crack of surrounding rock expand constantly to the deep side and form a certain range of broken zone. After the rock broke, it expands and surface displacement of roadway increase quickly. Deformation speed of surrounding rock decrease with away from driving work face. When the distance is 225 m, deformation of surrounding tends to be stable. Influence period of driving is about 45 d. That is because different forms of energy dissipation such as plastication lost by plasticity deformation and energy consumed by secondary crack expansion will occur for physics and mechanical effect have nature of nonlinearity and irreversibility. In addition, support component system can absorb some energy in time. When roadway is stable, deformation speed of surrounding rock is below 0.15 mm/d, displacement of two sides is 84 mm, displacement of roof and floor is 57 mm, and control effect of surrounding rock is good.

Deep surrounding rock displacement

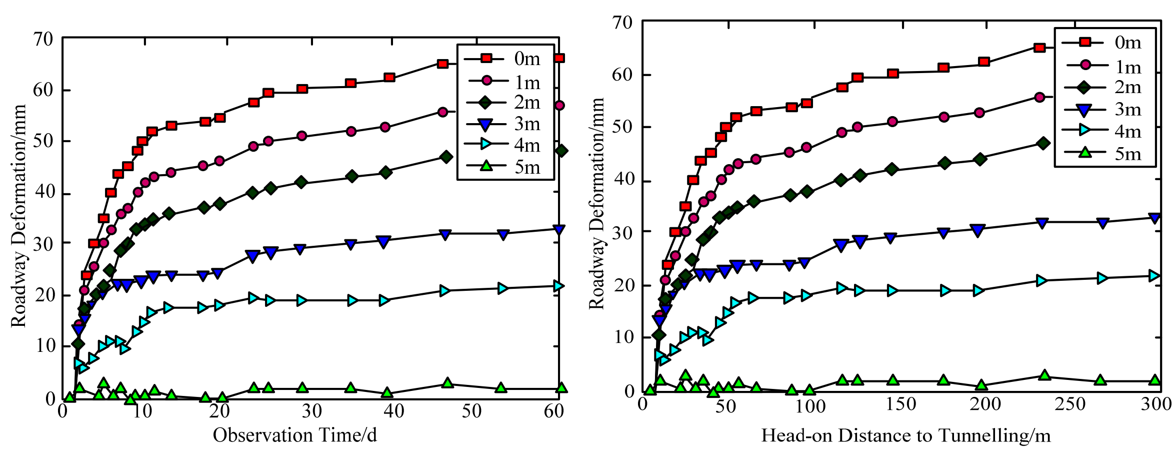


Figure 13 : 2444 Monitoring curve of deep surrounding rock displacement in material roadway

Monitoring of deep surrounding rock displacement is shown in Figure 13. It can be seen from the figure that deep surrounding rock displacement of 2444 work face material roadway roof has the following rule: range of roof moving towards roadway is 5 m. Maximum displacement of surrounding rock towards roadway beyond 5 m is 3 mm and generally it is 0~2 mm; deep surrounding rock is stable and maximum displacement of surrounding rock is 18 mm within 0~2 m anchorage zone of roadway surface. Rock bolt shoulder a big tension force. However, maximum displacement of anchoring zone is much lower than ultimate strain value; surrounding rock activity is acute when depth of surrounding rock is 2~3 m and maximum value is 16 mm. The activity difference of surrounding rock is biggest when the depth of roof is 4~5 m and the maximum value is 20 mm. However, the maximum value is lower than roof boundary reference value and roof is relatively safe. Displacement of deep surrounding rock tends to be stable when away from driving work face. When the distance with driving heading is 120 m, deformation of deep surrounding rock is basically stable.

As mentioned above, two side displacement of 2444 work face material roadway is 84 mm. Displacement of roof and floor is 57 mm. Maximum value of separation layer inside and outside roof anchorage zone is 20 mm but is lower than roof separation layer boundary reference value. Roof is relatively safe and anchor and cable have big carrying space. High prestress rock belt support effectively control deformation of surrounding rock and the effect is good.

CONCLUSION

(1) After mining liberation seam, liberated layer occurs dilatancy, which makes liberated layer occurs pressure relief. Distribution of liberated layer along tendency is compressive deformation area, expansion deformation area and stable area; size of stress pressure relief along liberated layer tendency can be divided into stress releasing active area, stress releasing transition area.

(2) With certain range, pressure relief range and effect of liberated layer become more and more obvious with increasing of work face length of liberation seam. When work face length of liberation seam is up to a certain degree, pressure relief coefficient of rock strata do not rise obviously and pressure relief coefficient decrease.

(3) When coal seam is horizonal, top and bottom pressure relief shielding angle is the same and range of pressure relief is symmetrical shell structure; with increasing of coal seam dip angle, top pressure relief shielding angle increases linearly while bottom pressure relief shielding angle decreases linearly. It leads to a large discrepancy of stress distribution space structure compared with mining horizonal coal seam. Stress form of inclined coal seam mining form an unsymmetrical shell structure and top pressure relief shielding angle is bigger than bottom pressure relief shade angle.

(4) Compared to site inspection result, pressure relief range and rule of liberation seam confirmed by value simulation result adopts alternate arrangement of liberation seam entry. According to the maintenance of roadway in coal mine of clip river, mining of liberation seam can effectively control deformation of surrounding rock. It shows that 110 m of interlayer vertical distance is not critical distance.

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