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Research on Bolt-grouting Reinforcement Technology of Broken Surrounding Rock in Roof of Multiple Disturbance Bottom Drainage Roadway

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Abstract: The coal seam floor layout bottom drainage roadway is one of the effective means of gas outburst elimination in the working face. However, the roof surrounding rock of the bottom drainage roadway will undergo multiple disturbances such as bottom drainage roadway excavation, drilling excavation, roadway excavation and working face mining, which will easily lead to large deformation of the surrounding rock of the bottom drainage roadway, which will greatly affect the safety and stability of the bottom drainage roadway and the safety of the mine. In this process, the fracture of the borehole wall of the extraction borehole expands, and it is subjected to severe dynamic pressure during roadway excavation and working face mining. At the same time, the redistribution of surrounding rock stress brings secondary damage, which will lead to the increase of roof deformation. Based on the maintenance of the roof surrounding rock of the bottom suction roadway in the 14020 working face of Zhaogu No.2 Coal Mine, aiming at the problems of local large deformation of the roof surrounding rock of the bottom suction roadway and the difficulty in maintaining the roadway caused by the mine pressure appearance, in order to reduce the roof disturbance of the bottom suction roadway and strengthen the roof support, the indoor test, numerical simulation, theoretical analysis and industrial test are used to carry out the research on the deformation law of the roof surrounding rock of the bottom suction roadway and the bolt grouting reinforcement technology. A numerical calculation model of multiple disturbances in the bottom drainage roadway considering the construction of drainage boreholes was established. The causes of deformation and failure of the roof of the bottom drainage roadway were analyzed, and the supporting parameters and techniques were improved. The timing and support scheme of the test roadway support (reinforcement technology) were determined. Under the condition of high strength support, the influence law of bottom pumping roadway excavation, drilling excavation, roadway excavation and working face mining on the deformation degree of roof surrounding rock is revealed. The active reinforcement technology of bolt-grouting for surrounding rock of test roadway is put forward and applied in the field. According to the feedback of the on-site mine pressure monitoring results, the roof deformation degree of the test roadway after excavation and mining is small, and the roadway section meets the production demand, which verifies the feasibility of the bolt-grouting reinforcement technology.

Keywords: Bottom drainage roadway; multiple disturbances; bolting support; numerical simulation.

1. Introduction

The total amount of coal consumption has always occupied the main position of China, and coal mining has gradually shifted to deep mining [1]. With the deepening of mining depth, the number of gas outburst mines increases, and gas outburst accidents and mining replacement tensions are common [2]. For this reason, most mines use the bottom drainage roadway cross-layer extraction method to pre-extract gas from the coal seam of the working face. This method is also widely used in gas mines, which not only greatly reduces the number of mine gas overruns and coal mine gas accidents, but also greatly improves the utilization rate of gas resources and ensures the safe and efficient production of mines [3]. However, the surrounding rock of the bottom drainage roadway roof will undergo multiple disturbances such as bottom drainage roadway excavation, drilling excavation, roadway excavation, and working face mining. In this process, it will lead to large deformation of the roof, reduce the efficiency and cost of gas extraction, and even induce accidents such as roof and gas, which seriously restricts the safe and efficient production of the mine [4]. Therefore, in view of the deformation and failure characteristics of the surrounding rock of the bottom drainage roadway in the process of gas extraction, it is of certain economic and social significance to carry out the maintenance of the surrounding rock of the bottom drainage roadway.

Experts and scholars have carried out a lot of research and made some progress on the deformation and failure law and stability control technology of roof surrounding rock in bottom drainage roadway. The bottom pumping roadway is located in the floor of the working face. For this reason, Qian et al. [5] used the theory of elastic-plastic mechanics and limit analysis, combined with the layered structure of the stratum, and proposed the theory of key strata. It is believed that there is also a solid and stable rock layer in the coal seam floor, which is called the key stratum. Zhang Pingsong et al [6] studied the water flowing fracture of coal seam floor by simulation experiment, and analyzed the dynamic evolution law of floor water inrush with multi-field coupling as the research content. Li Hao et al. [7] used theoretical analysis and numerical calculation to carry out the fault failure law of the floor of the extra-thick coal seam. Based on the problem that the bottom drainage roadway is seriously damaged after being affected by the mining of the working face, the secondary bolt-mesh-cable-spray collaborative support technology is proposed. After the field implementation, the deformation of the bottom drainage roadway is controllable and meets the requirements of safe production. Li Yongen et al. [8] used theoretical analysis and numerical simulation to study the deformation and failure characteristics of surrounding rock in bottom drainage roadway, and put forward the reasonable layout position and surrounding rock control technology of bottom drainage roadway. Jia Fengshuo et al. [9] analyzed the disturbance effect of roadway excavation on bottom drainage roadway by means of numerical simulation and industrial test, and put forward the support scheme of broken surrounding rock in bottom drainage roadway.

The above experts and scholars use theoretical analysis, numerical simulation and industrial test to reveal the deformation and failure law of roof surrounding rock in the process of disturbance of bottom drainage roadway, and provide reference for the layout and stability control of bottom drainage roadway from the aspects of stress and support. However, most experts and scholars ignore the weakening effect of drilling construction on the surrounding rock of the roof of the bottom drainage roadway and the superposition effect under multiple stress disturbances when calculating, and the calculation results have certain errors. Therefore, through the research on the deformation instability and stability control mechanism of surrounding rock in deep roadway, this study puts forward the coordinated control technology of roof bolting and grouting support in bottom drainage roadway, which provides technical guarantee for the safe, stable, safe and efficient production of mine bottom drainage roadway, and has important theoretical significance and practical application value. The research results can provide a certain basis for the stability control of the surrounding rock of the bottom drainage roadway under similar engineering conditions.

2. Engineering Background

The design production capacity of Zhaogu No.2 Mine is 1.8 million t / a, and the main coal seam is No.21 coal seam. The average thickness of coal seam is 6.16 m, the average dip angle of coal seam is 4 °, and the coal seam structure is simple and stable. The 14020 working face is located in the fourth panel, with a buried depth of about 800 m. The average advancing speed of the working face is 3 m / d. The initial weighting step of the working face is 31.9 m, and the periodic weighting step is 18-25 m. The mining engineering plan of 14020 working face and other measures roadway is shown in figure 1.

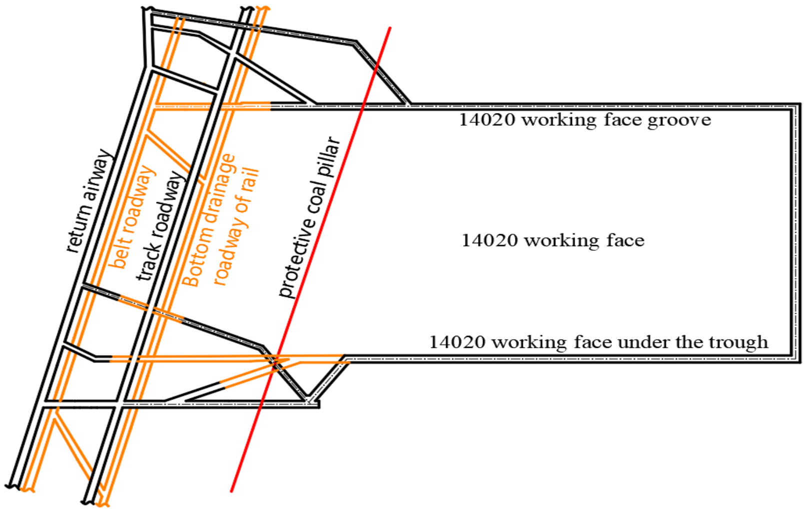


Figure 1. Mining engineering plan of test roadway

The gas problem has long been one of the main factors threatening the safe and efficient production of coal mines and the safety of miners ' lives. Therefore, before the excavation and mining of 14020 working face and lower crossheading, the extraction boreholes are arranged at a distance of 15 m from the bottom plate of 14020 lower crossheading. The diameter of the boreholes is 100 mm, one every 5 °. The extraction boreholes are arranged in a ' fan-shaped ' form to carry out the pre-extraction of gas through the layer.

The 14020 working face and the crossheading are excavated along the roof of the coal seam, and the size of the bottom pumping roadway is 5.1 m (width) × 4.3 m (height). The lithology exposed between the bottom drainage roadway and the coal seam floor is mudstone and limestone, of which mudstone is 14 m and limestone is 2 m.

3. Study on Deformation and Failure Characteristics of Roof Surrounding Rock of Bottom Drainage Roadway Under Multiple Disturbances

In the process of excavation drilling, roadway excavation and working face mining, the stress environment of roof surrounding rock of bottom drainage roadway is changed. In this process, stress concentration occurs, and the stress exceeds the ultimate stress of rock mass, resulting in deformation and failure of roof surrounding rock and deterioration of roadway stability. At the same time, under the influence of multiple superimposed pressures, the causes of surrounding rock failure in the bottom drainage roadway are also more complex. In order to improve the surrounding rock of the bottom pumping roadway and improve the stability of the bottom pumping roadway, it is necessary to study the deformation and failure characteristics of the roof surrounding rock of the multi-disturbance bottom pumping roadway.

3.1. The original support situation of test roadway

The roof of the bottom pumping roadway is supported by full anchor cable. The support scheme is as follows : (1) Roof anchor cable specification : Φ21.6 mm × L4100 mm, row spacing : 800 mm × 1000 mm, along the center line of the roadway to both sides of the average arrangement; (2) The specification of the anchor cable in the side : Φ21.6 mm × L4100 mm, the row spacing : 800 mm × 1000 mm, the first anchor cable in the upper part is 450 mm from the roof of the roadway ; (3) Channel steel beam anchor cable specifications : Φ21.6 mm × L8250 mm, row spacing : 1300 mm × 2000 mm, along the roadway center line to both sides of the average arrangement; (4) Reinforcement grouting anchor cable specification : Φ22 mm × L8300 mm, row spacing : 1600 mm × 2000 mm ; (5) Reinforcement support anchor cable specification : Φ28.6 mm × L8250 mm, row spacing : 1600 mm × 1000 mm ; the metal mesh is welded with Φ6 mm steel bar, the mesh size is 70 mm × 70 mm, and the mesh size is 2090 mm × 1180 mm.

Under this supporting condition, the surrounding rock of the bottom drainage roadway in Zhaogu No.2 Mine is affected by multiple disturbances such as dense upward large-diameter drainage boreholes and mining. The surrounding rock of the roadway roof is prone to weathering, hydration and expansion. According to the field observation, the anchor cable has problems such as anchor withdrawal, fracture, and dripping, accompanied by problems such as roof subsidence and bulging. The specific situation is shown in Figure 2 :

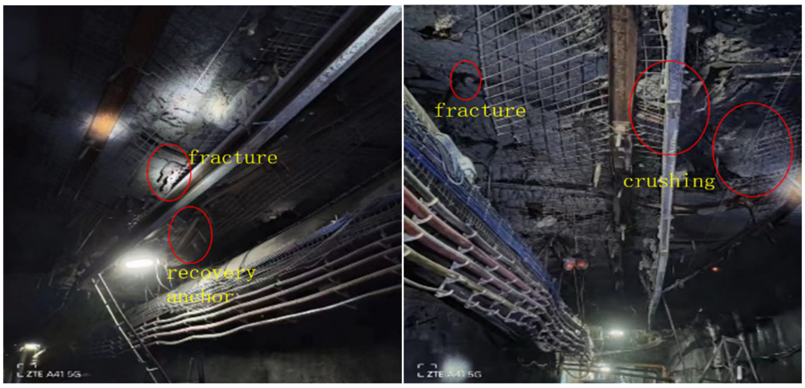


Figure 2. The scene diagram of the bottom drainage roadway

Based on the field observation results, the geological conditions of roadway production and the on-site support conditions, the main reasons for the large deformation of the surrounding rock of the roof of the test roadway are as follows : (1) The roof strength is small ; (2) Insufficient support strength ; (3) Multiple stress superposition disturbance such as mining ; (4) The strength of supporting materials does not match.

3.2. Model establishment

In order to reveal the deformation and failure law of the roof surrounding rock of the bottom pumping roadway caused by drilling excavation, roadway excavation and working face mining, the model is excavated sequentially according to the on-site construction process until the calculation is balanced.

According to the relationship between the mining sequence of the bottom drainage roadway and the columnar shape of the coal seam, the Flac3D numerical calculation model of the coal and rock strata of the bottom drainage roadway considering the drilling construction is established as shown in Figure 3. In order to improve the calculation degree of the deformation of the surrounding rock of the roof of the bottom drainage roadway, the surrounding rock of the roof is encrypted.

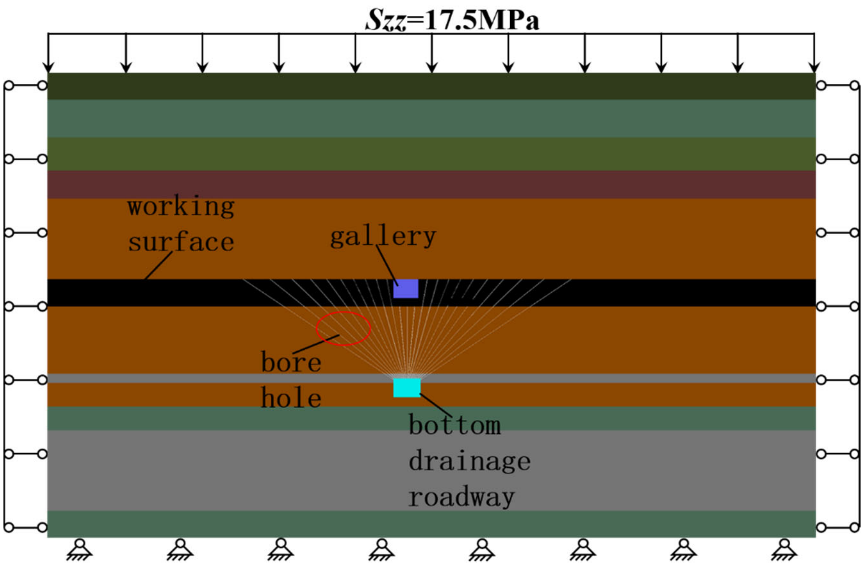


Figure 3. Numerical calculation model of test roadway

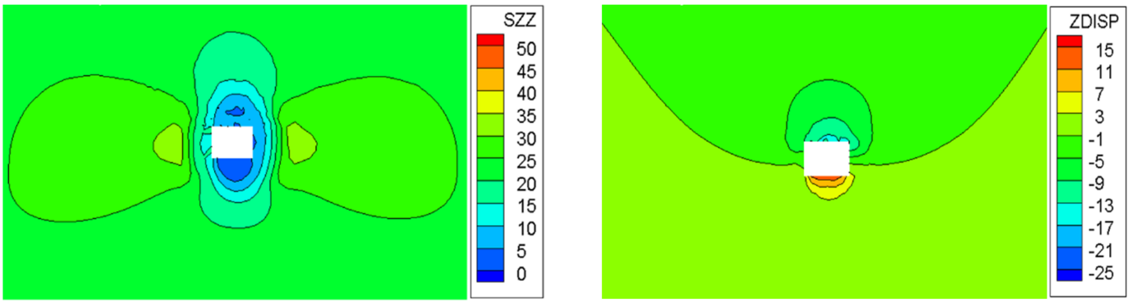
Model length × width × height = 156 m × 5 m × 99 m ; the shape of the drilling hole is octagonal, 21 drilling holes are excavated in the roof of the bottom drainage roadway, and one is excavated in each of the two sides ; the diameter of the borehole is 100 mm, one every 5 °, and it is arranged in the form of ' fan '. The Mohr Coulomb constitutive is assigned to the model globally ; according to the results of ground stress test, the normal displacement of the lower boundary and the surrounding of the model is limited, and the vertical load of 17.5 MPa is applied to the upper boundary.

Because the roadway is disturbed by multiple stages, in order to facilitate construction and ensure good maintenance during the working process of the roadway, after the excavation of the bottom pumping roadway, the roof of the bottom pumping roadway is directly supported with high strength, so as to enhance the anti-disturbance effect of the bottom pumping roadway and control the deformation of the surrounding rock of the bottom pumping roadway within a reasonable range.

After calculating the balance, the deformation data of the surrounding rock in the middle line of the bottom pumping roadway are extracted respectively. After the roof of the bottom pumping roadway is supported, the vertical displacement law of the surrounding rock under different disturbance conditions is obtained, and the deformation and failure characteristics of the surrounding rock of the bottom pumping roadway are analyzed and compared to verify the supporting effect.

3.3. Effect of bottom pumping roadway excavation on deformation and failure of roof surrounding rock

After the excavation of the bottom drainage roadway, the support scheme of the roadway roof is taken immediately to maintain the stability of the roadway, so as to facilitate the safe gas drainage, cover the roadway excavation above and the mining of the working face in the later stage. The calculation results of the vertical displacement of the roof after the excavation of the bottom drainage roadway are shown in figure 4.



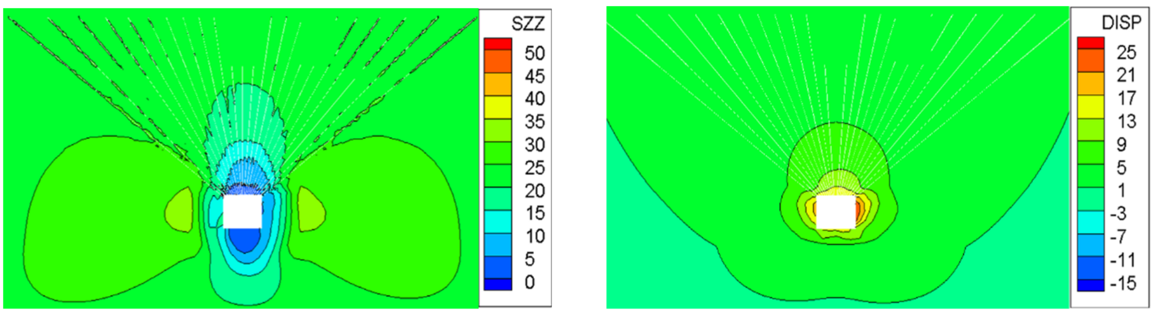
(a) Vertical stress cloud diagram (b) Vertical displacement cloud map

Figure 4. Calculation cloud diagram of surrounding rock deformation law of roadway roof in bottom pumping roadway

It can be seen from Fig.4 that the excavation of the bottom pumping roadway changed the initial stress state of the rock mass, the stress of the surrounding rock of the roadway was redistributed, and the stress concentration occurred in the two sides of the roadway, and the peak stress reached 33 MPa. After the anchor cable support is carried out in the bottom pumping roadway, the maximum deformation of the surrounding rock of the roadway roof reaches 190 mm, indicating that the surrounding rock of the roadway roof is maintained and the roof deformation is effectively controlled after the support.

3.4. The influence of drainage borehole excavation on the deformation and failure of the roof surrounding rock of the bottom drainage roadway

Zhaogu No.2 Mine is a high gas mine. After the excavation of the bottom drainage roadway, it is necessary to excavate the borehole to extract the gas. The calculation results of the vertical displacement of the roadway roof after the excavation of the borehole are shown in Figure 5.



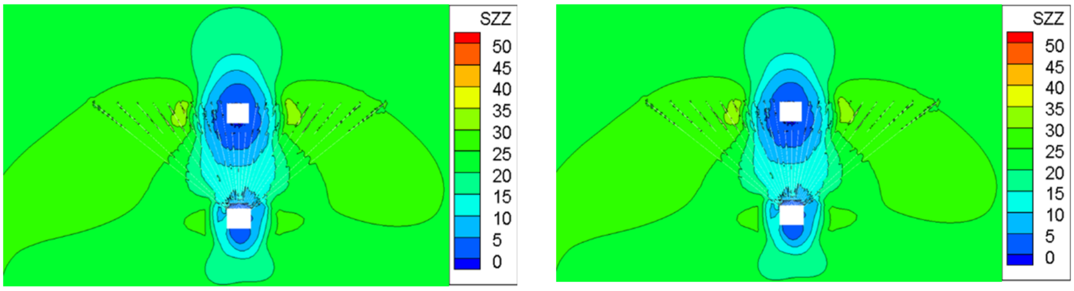
(a) Vertical stress cloud diagram (b) Vertical displacement cloud map

Figure 5. The calculation cloud diagram of the deformation law of the roof surrounding rock of the bottom pumping roadway by drilling excavation

It can be seen from Fig.5 that after the excavation of the extraction borehole, it is affected by the disturbance of the drilling construction. In this process, the pores of the extraction borehole expand, which has a certain pressure relief effect on the bottom extraction roadway, and the maximum stress of the two sides of the roadway is reduced to 32 MPa. However, it also leads to the breakage of the roof and the decrease of the stability. The deformation of the surrounding rock of the bottom pumping roadway is further increased. The maximum deformation of the roadway roof is about 208 mm, with an increase of 9.5 %, and the deformation of the surrounding rock is small.

3.5. Effect of roadway excavation on deformation and failure of surrounding rock of roof in floor drainage roadway

After the excavation of the upper roadway, the calculation results of the vertical displacement of the roof of the bottom pumping roadway are shown in Fig.6.



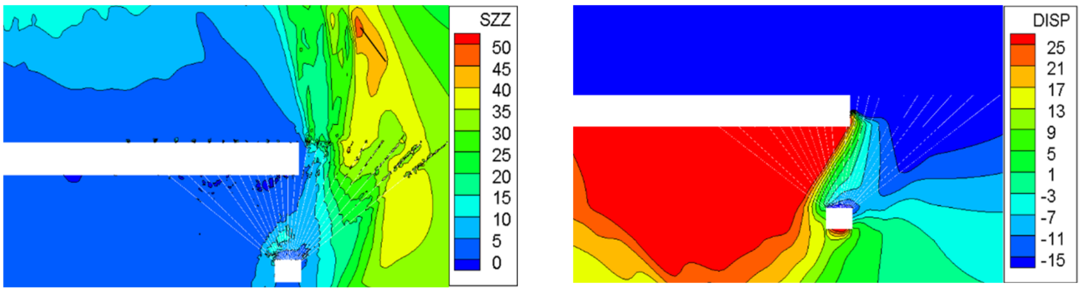
(a) Vertical stress cloud diagram (b) Vertical displacement cloud map

Figure 6. The calculation cloud diagram of the deformation law of the roof surrounding rock of the bottom pumping roadway during roadway excavation

It can be seen from Fig.6 that after the excavation of the upper roadway, the deformation of the surrounding rock of the bottom pumping roadway is greatly affected. After the excavation of the upper roadway, the stress is redistributed, and the stress concentration occurs on both sides of the roadway. The maximum stress is reduced to 26.5 MPa, but the maximum deformation of the roof of the bottom pumping roadway reaches 213 mm, with an increase of 2.4 %, and the deformation of the roof is very small. It shows that the excavation of the upper roadway blocks the downward propagation path of stress, and has a certain pressure relief effect on the bottom pumping roadway. The stress shifts to a deeper depth, and the roof subsidence tends to be stable.

3.6. The influence of working face mining on the deformation and failure of the roof surrounding rock of the bottom pumping roadway

After the roadway excavation, the working face is mined, and the calculation results of the vertical displacement of the roof of the bottom pumping roadway under the supporting conditions are shown in Fig.7.



(a) Vertical stress cloud diagram (b) Vertical displacement cloud map

Figure 7. The calculation cloud diagram of the deformation law of the roof surrounding rock of the bottom pumping roadway in the mining of the working face

From figure 7, it can be seen that with the completion of the mining of 14020 working face, the advanced support force generated by it moves forward, and the stress concentration is large, up to 48 MPa, and the stress near the bottom suction roadway is very small. However, the cracks in the surrounding rock of the roof develop and the degree of fragmentation increases, resulting in the maximum displacement of the surrounding rock of the bottom pumping roadway increasing to about 347 mm, with an increase of about 62.9 %. The roof is damaged greatly, indicating that the mining of the working face has the greatest disturbance to the surrounding rock of the bottom pumping roadway.

With the progress of different working stages, the roof deformation of the bottom suction roadway shows an increasing trend. The main reason is that the roof is affected by multiple pressure superposition under the influence of different disturbances. The variation of roof deformation with different stages is shown in figure 8.

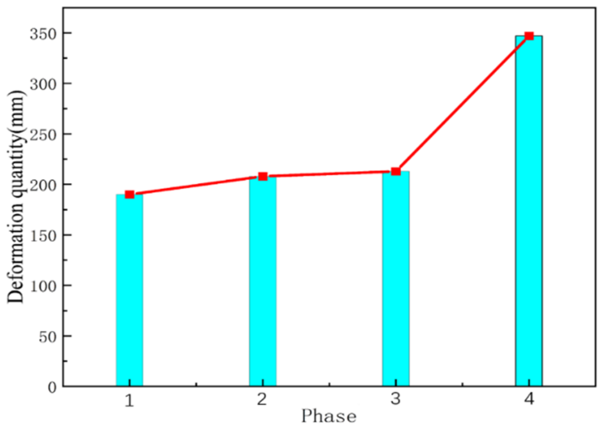


Figure 8. The variation of roof deformation in different stages

It can be seen from the figure that with the process of bottom pumping roadway excavation, drilling excavation, roadway excavation and working face mining, the disturbance of bottom pumping roadway is gradually enhanced. However, due to the high strength of primary support, the displacement and deformation of roof surrounding rock of bottom pumping roadway are effectively controlled in the process of bottom pumping roadway excavation, drilling excavation and roadway excavation. However, after the mining of the working face, the disturbance to the bottom pumping roadway is extremely strong, the deformation of the surrounding rock increases significantly, the plastic deformation of the surrounding rock of the bottom pumping roadway occurs, the surrounding rock expands and breaks, and there is a risk of local roof fall. It shows that the high-strength support strength given for the first time is insufficient, that is, it is difficult to maintain the stability of the roadway under the original support conditions. Therefore, it is necessary to solve the problem by strengthening the support strength of the roadway to ensure the safe and efficient production of the working face.

4. Study on Bolting and Grouting Support Technology of Roof Surrounding Rock in Bottom Drainage Roadway Under Multiple Disturbances

4.1. Primary support

The roadway is supported by full anchor cable. The specifications of anchor cable are as follows : (1) Roof anchor cable specifications : Φ28.6 mm × L4100 mm, row spacing : 800 mm × 1000 mm, along the center line of the roadway to both sides of the average arrangement (3 roots on each side), the roadway at the shoulder angle of 15 ° inclined anchor cable ; (2) Specification of anti-impact yield steel belt anchor cable : Φ28.6 mm × L8250 mm, row spacing : 1600 mm × 1000 mm ; (3)Strengthening anti-scour and yielding steel belt anchor cable specifications : Φ28.6 mm × L 8250 mm, row spacing : 1600 mm × 1000 mm ; (4)the metal mesh is welded by Φ6 mm steel bar, and the grid is 70 mm × 70 mm, The net width is 2090 mm × 1180 mm.

4.2. Secondary support

Because the bottom pumping roadway serves two working faces at the same time, in order to meet the normal work of the next working face, the bottom pumping roadway needs to be well maintained, so the roof surrounding rock of the bottom pumping roadway should be reinforced again. The roof of the bottom pumping roadway is seriously broken. Considering the loosening and failure of the surrounding rock of the test roadway and the development of joint fissures, the bolt-grouting support is considered to strengthen the support. Therefore, while increasing the strength of the roof support, the bearing capacity of the surrounding rock can be fully mobilized by means of artificial grouting, so as to improve the integrity of the roof surrounding rock and control the deformation degree of the roof surrounding rock of the bottom pumping roadway.

For the broken surrounding rock of the bottom pumping roadway, ' grouting anchor cable + grouting ' is used to jointly reinforce the roadway. In addition, according to the deformation and failure range and degree of the floor of the bottom pumping roadway in 14020 working face, the floor is closed and reinforced in time to realize the strengthening support of the whole section and jointly control the large deformation of the surrounding rock of the roadway. Reinforcement grouting anchor cable specifications are as follows : Φ29 mm × L 8250 mm, row spacing : 1600 mm × 1000 mm, using ' 212 ' layout. After grouting, the grouting effect should be observed in time through the borehole peeping technology at the middle line of the roadway roof. When the grouting effect is not ideal, the grouting anchor cable should be added and re-grouting should be carried out in time at the middle line of the roadway.

After the secondary support is constructed, the on-site strengthening support of the bottom drainage roadway is shown in figure 9. It is obviously seen that the integrity of the surrounding rock of the roadway is well maintained, and the roof deformation is significantly controlled, which provides a strong guarantee for safe production.

Figure 9. Field diagram of strengthening support in bottom drainage roadway

5. Industrial Test

The roof of the bottom pumping roadway is supported by full anchor cable. By analyzing the stress state and displacement of the surrounding rock of the bottom pumping roadway under different disturbances, the support technology and parameters during the roadway excavation are reasonably determined, and the support and reinforcement scheme of the roof surrounding rock of the bottom pumping roadway is optimized, so as to develop the stability control and active support technology of the soft and broken surrounding rock of the deep roadway.

Therefore, in order to increase the strength of support and roof surrounding rock, the coordinated control technology of bolting and grouting support is implemented on the roof of the test roadway before the mining of the working face.

After the application of the new technology, the relative displacement of the roof and floor of the test roadway is measured by the cross point distribution method, and the displacement curve shown in Fig.10 is obtained. It can be seen from the figure that the implementation of the cooperative control technology of bolt-grouting support effectively controls the deformation degree of the roof surrounding rock of the bottom pumping roadway. The roof displacement is effectively controlled and tends to be stable, and the roadway section can meet the needs of on-site production.

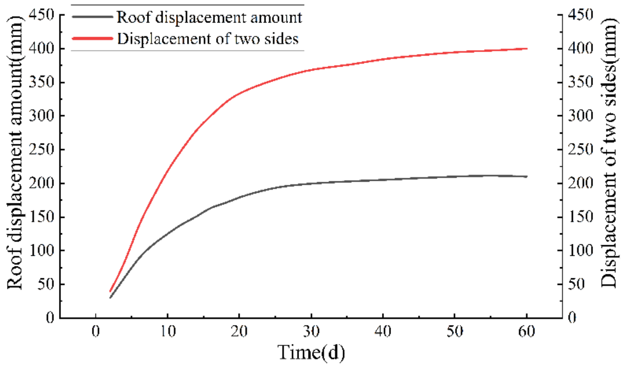


Figure 10. Surrounding rock deformation of test roadway

6. Conclusion

(1) The cross-layer extraction model of bottom drainage roadway is established, and the vertical displacement of bottom drainage roadway under the superposition of different disturbance conditions is compared by using Flac3 D numerical simulation software. The deformation and failure law of roof surrounding rock of bottom drainage roadway under multiple disturbances is revealed, and the deformation and instability mechanism of surrounding rock of bottom drainage roadway is obtained.

(2) Taking the support strength as the variable, the deformation and failure characteristics of the overlying strata under different support parameters and surrounding rock strength characteristic parameters are compared, and the key parameters to control the stability of the overlying strata in the bottom drainage roadway are obtained. The key support technical parameters such as row spacing and grouting strength between bolt (cable) support are optimized, and the stability control technology of the surrounding rock in the bottom drainage roadway is proposed.

(3) The stability control technology of the surrounding rock of the bottom pumping roadway is applied to the test roadway. At the same time, the subsidence and fracture development characteristics of the surrounding rock of the bottom pumping roadway are monitored by means of cross point distribution method, and the deformation and failure law of the surrounding rock after the application of the new technology is analyzed. The results of mine pressure monitoring show that after the application of the new technology, the roof deformation of the test roadway is controlled within a certain range, which ensures the stability and safety of the roadway.

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