Study on reasonable grouting parameters based on UDEC numerical simulation

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Abstract: In view of the frequent occurrence of roof collapse and chipping accidents in the broken surrounding rock roadway in the goaf, grouting reinforcement is applied to the surrounding rock of the roadway. The field test proves that the selected grouting parameters are reasonable and achieve the purpose of controlling the deformation of the surrounding rock of the roadway.

0 Introduction

China is a large coal mining and utilization country. In recent years, a large number of shallow coal resources have been developed, and a large area of goaf is being formed. Shallow resources are continuously depleted, and deep mining has become a development trend^[1]. With the increase of mining depth, the original stress and tectonic stress will increase, the roadway will be deformed seriously, the maintenance will be difficult, the risk of mine disaster will increase, the production environment will be more complicated and changeable, and the requirements for safe mining of deep coal resources will be higher^[2-4]. For the complex mechanical environment in the deep environment, the complex mechanical properties and deformation failure of “three high one disturbance” have the characteristics of large deformation, high stress and difficult support^[5-8], especially for the lithology of the top and bottom plates. Soft roadways, support, maintenance costs and technical requirements are higher, seriously affecting the safety of mining^[9]. Especially in the excavation of the roadway below the goaf, the support requirements will be higher. If the support effect is not satisfactory, there may be accidents such as roof fall and sheet metal. Some mines do not follow the design specifications when driving in the roadway, and need to pay extra maintenance costs. At present, the most ideal treatment method for the roadway without smooth blasting under the goaf is the grouting filling method, injecting the material with cementing properties into the gap around the roadway to break the surrounding rock, forming a stable high strength. Cement body to play the role of active support^[10].

1 Main street status

As the main road of the mine was excavated by the blasting process, the construction was not carried out according to the requirements of smooth blasting, which led to serious over-excavation of the surrounding rock outside the contour of the roadway. After the roadway excavation, the stress is redistributed, and stress concentration will occur in some places surrounding rock's own resistance strength, the surrounding rock will undergo plastic damage. In the process of roadway support, the workmanship is reduced, the support is not carried out according to the bolts and anchors, and the design of the anchor and anchor cable is chaotic. The active support is not played and the bearing capacity of the surrounding rock is improved, resulting in stable surrounding rock. After adding the roadway to support the roadway, there is a large gap between the support body and the surrounding rock. The support effect of the roadway is not obvious, which eventually leads to the instability of the surrounding rock. After the roadway is put into use, a large-scale roofing accident occurs. Therefore, it is necessary to strengthen the main road to ensure the normal and safe production needs of the mine.

2 Stress numerical analysis

2.1 Numerical model establishment

The failure mechanism of the auxiliary track is analyzed by the combination of theoretical analysis and numerical calculation. According to the actual production and geological conditions, the UDEC numerical calculation software is used to establish the physical model of numerical calculation. The model size is 50×35m (width×height), and a fixed load is applied at the upper boundary. The buried depth is calculated by 120m. The lower boundary of the model applies a fixed load in the vertical direction, and the left and right boundaries apply a fixed load in the

horizontal direction. The established mechanical model and the physical models are shown in figures 1 and figure 2 respectively.

Fig.1. Roadway mechanical model.

Fig. 2. Numerical calculation model of the roadway.

2.2 Determination of mechanical parameters

According to the condition of the top and bottom of the roadway exposed during the roadway excavation, a large number of samples were taken for experimental determination, and the physical and mechanical parameters of each rock layer were obtained, as shown in Table 1.

Table 1. Physical and mechanical parameters of rock formations.

Rock formation	Bulk modulus $K(\text{Pa})$	Shear modulus $G(\text{Pa})$	Friction angle $F(^{\circ})$	Adhesion $C(\text{Pa})$
Mudstone	3.4e9	1.7e9	20	2.3e6
Siltstone	8.2e9	4.9e9	32	2.8e6
Mudstone	3.4e9	1.7e9	20	2.3e6
Coal	3.3e9	1.6e9	19	2.4e6
Mudstone	3.4e9	1.7e9	20	2.3e6
Siltstone	8.2e9	4.9e9	32	2.8e6

2.3 Numerical calculation results

According to the numerical calculation model, after excavation of the roadway under the original rock

condition, the original stress field in equilibrium is replaced by the redistributed stress field. Figure 3 shows the vertical stress contour distribution around the roadway.

Fig. 3. Vertical stress contour map of roadway.

From Fig.3, we can see that the stress concentration at the top of the roadway and the two bottom corners after excavation is obvious. When the pressure at the stress concentration exceeds the strength of the masonry support, the masonry body is destroyed in the stress concentration area, and even the overall support is caused. Invalidation, lost support for the surrounding rock of the roadway, and accidents such as roofing and sheeting will occur.

3 Analysis of grouting reinforcement parameters

Grouting reinforcement technology is relatively mature, but the geological conditions around the surrounding rock are complex and versatile, which makes it difficult to determine the parameters of grouting reinforcement. At present, the design of grouting parameters is generally based on theoretical calculations, and adjusted in real time according to the actual situation of grouting on site.

3.1 Slurry diffusion radius

The flow state of the slurry is closely related to the grouting material and the water-cement ratio, and the broken surrounding rock around the roadway not only requires the slurry to have good fluidity and permeability, but also has high strength after coagulation. Since the Mag formula does not take into account the viscosity of the slurry viscosity, in order to determine the diffusion radius of the slurry, we established a seepage diffusion model considering the denaturation of the slurry^[12], and assumed :

- ①The slurry is incompressible and homogeneous and homogenous;
- ②The slurry flow pattern is unchanged during grouting;
- ③The slurry diffuses in a spherical shape in the fractured rock mass;

④The slurry flow pattern is Newtonian.

Mag formula for Newtonian fluid can be obtained:

$$L = 3 \sqrt{\frac{3k_p T \Delta P l_0}{\beta \phi}} \quad (1)$$

The rock on site was measured and the quick setting grouting material was selected. The type of slurry was Newtonian. The results of related parameters are shown in Table 2.

Table 2. Grouting related parameters.

Porosity (%)	Permeability coefficient $k_p(\text{cm/s})$	Viscosity index k	Slurry diffusion radius(m)
0.4	0.011	0.018	2.3

3.2 Grouting pressure

According to the literature^[13], the relationship between grouting pressure and grouting time can be obtained:

$$p_c = \frac{3qA}{8\pi b^3 B} \left[t^B - \left(\frac{2\pi b r_0^2}{q} \right)^B \right] + \frac{3\tau_0}{2b} \left(\sqrt{\frac{qt}{2\pi b}} - r_0 \right) + p_w \quad (2)$$

The relationship between grouting pressure and grouting diffusion radius is:

$$p_c = \frac{3qA}{8\pi b^3 B} \left(\frac{2\pi b}{q} \right)^B (r_i^{2B} - r_0^{2B}) + \frac{3\tau_0}{2b} (r_i - r_0) + p_w \quad (3)$$

According to the above analysis results, and combined with the actual field conditions, the grouting pressure is determined to be 2 ~ 3MPa.

3.3 Water to cement ratio

From the perspective of economic benefits and actual conditions of the mine, the grouting material consists of CaO, sulphoaluminate cement clinker, gypsum and composite additives. On the basis of the test, the types and proportions of the main and auxiliary materials were determined. Finally, the water-cement ratio was determined to be 5:1.

3.4 Arrangement of grouting holes

The arrangement of grouting holes should be considered to cover all broken surrounding rock areas and reduce economic costs. On the basis of determining the grouting radius, the drilling distance is reasonably determined. According to the above calculation results and the site conditions, it is determined that the grouting holes are arranged equidistantly, and the spacing and spacing are taken to be 1.5 m. The grouting pipe is made of steel pipe with a diameter of 20mm. The length of the grouting pipe is 2.5m, the inner diameter is 15mm, and the grouting sealing length is 1.5m. The most ideal result of grouting is to make the slurry fully penetrate into the broken rock mass and form a large influence range. Therefore, it is required that the grouting borehole must penetrate

into the top plate, three rows per row, one top of the roadway, and two One shoulder angle. As shown in Fig.4.

Fig.4. Grouting hole layout.

3.5 Grouting effect

According to the theoretical calculation results of grouting pressure, the final grouting pressure is determined after multiple tests in the field. Through the grouting drilling distance and the grouting hole penetration overlapping range are adjusted, the variation range of single hole grouting volume in different parts is grasped, which is adopted flexibly. The alternate grouting method between the rows is repeated as many times as possible to increase the strength of the surrounding rock. The mine pressure observation of the roof and the two gangs is carried out regularly, and the development law of the subsidence of the roof and the displacement of the two gangs is analyzed to determine whether the control effect of the grouting on the deformation of the surrounding rock reaches the expected target.

4 Conclusion

After the tunneling of the lower part of the goaf, there are many problems with roofing and sheeting. The UDEC simulation software is used to study the stress distribution law of the roadway. The contour map of the roadway stress distribution is obtained. The stress at the top of the roadway and the two corners is large.

The joint support method of “filling + grouting + anchor rod” is proposed. The theoretical analysis and experimental research on grouting reinforcement parameters are carried out, and reasonable parameters such as grouting pressure, diffusion radius and water-

cement ratio are obtained.

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