Research of mechanical characteristics and roadway support in two-soft and one-hard coal seam

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Abstract. This paper is concerned with a solution to difficulties, such as a closer convergence between the ribs, a greater floor deformation and a more challenging roadway support, as occurs in fully mechanized panel 21203 return airway of Yunmei Number one coal mine. The research builded on the data derived from field measurement and was combined with the law underlying the movement of overlying strata, caving characteristics, and the law governing the distribution of initial support pressure, as is typical of the coal seam, known as “two-soft and one-hard” in the mine. The study features a horse-shoe arch U type steel support form developed from the currently-used roadway support form—a support form of rectangular cross section comprised of bolt, anchor cable, anchor net, and the FLAC3D numerical simulation based on experiment parameters behind uniaxial compression of surrounding rocks. The results demonstrate that the improved support form may enable an effective change in the roadway stress behavior. The field application shows that the horse-shoe U-type steel support form may provide a more effective control of the extent to which there occur the convergence between the two ribs and floor heave; and a better solution to a greater deformation occurring in return airways.

1. Introduction

The soft coal, soft floor, and hard roof are defined as two-soft and one-hard coal seams, they are difficult geological conditions problem to be solved in the coal face and drift development[1-2]. The fully mechanized panel 21203 return airway in Yunmei Number one coal mine, that belongs to a typical two-soft and one-hard coal seams[3], the panel return airway ribs and floor had large deformation, the large deformation caused support difficultly. According to the observation results of the mine pressure and deformation characteristics in the return airway, the improved support design was carried out, the new support design has obvious effect in two-soft and one-hard coal seams, and provides a theoretical basis and engineering solution for the same roadway construction in the mine.

2. Engineering Introduction

2.1. Coal seam occurrence condition

The coal seam structure is simple. The coal seam Prussian Hardness Coefficient is below 0.37 and inclination angle is 14-17° with an average of 15°. The return airway is driven along the roof of the coal
The thickness range of the seam is 1.7 - 3.1 m and the average thickness is 2.4 m. The average thickness of the coal seam roof is 11.45 m. Most of them are thick and hard intermediate quartz sandstone, partially post stone, black mudstones, and sandy mudstone. The average thickness of immediate floor and floor is 5.6 m. The immediate floor consists of peat, sandy mudstone and siltstone. However, the floor consists of limestone.

2.2. Experimental data
Engineering rocks were sampled and processed, we used Φ50mm×100mm samples as uniaxial and triaxial compression strength test, and used Φ50mm×25mm~50mm samples as Brazilian split test. In addition, mudstone and sandy mudstone were processed into 70 mm×100 mm as cylindrical uniaxial compression test and 70 mm×50 mm samples as cylindrical Brazilian splitting test. All sample require that the sample end face was less than 0.1 mm, and the sample length deviation was less than 0.2 mm, and the sample axial deviation was less than 0.3°, the each group number of uniaxial test samples and triaxial samples should not be less than 3 and 5. The prepared samples are shown in Figure 1.

We used the RMT-150B rock mechanics test system and UA2001A ultrasonic test mechanics to determine the data of coal seam surrounding rock, equipments shown in Figure 2.

Rock compressive strength experiments were conducted under computer control using a displacement rate of 0.005 mm/s displacement, rock uniaxial and triaxial compression test results shown in Figure 3 and Table 1. As can be seen from Figure 3, the uniaxial compression failure characteristics samples are relatively complex. The samples are dominated by shear-tensile failure, the triaxial compression failures are relatively simple, and most of them are shear failure.
a. Immediate roof samples uniaxial and triaxial destructional forms
b. Roof samples uniaxial and triaxial destructional forms
c. Immediate floor samples uniaxial and triaxial destructional forms
d. Floor samples uniaxial and triaxial destructional forms

Figure 3. Rock samples destructional forms

Table 1. Coal seam roof and floor condition

| Rock name       | Longitudinal wave velocity | Tensile strength | Compression strength | Modulus of elasticity | Modulus of deformation | Poisson's ratio | Rock hardness | Rock adhesion | Internal friction angle |
|-----------------|---------------------------|-----------------|----------------------|-----------------------|------------------------|----------------|--------------|---------------|------------------------|
| Roof            | 3841m.s⁻¹                 | 10.48MPa        | 131.77MPa            | 31.92GPa              | 23.76GPa               | 0.15μ          | 13.2         | 25.39GPa      | 45.0°                   |
| Immediate roof  | 3722m.s⁻¹                 | 9.74MPa         | 139.38MPa            | 33.03GPa              | 21.02Gpa               | 0.18μ          | 13.9         | 38.31GPa      | 36.1°                   |
| Immediate floor | 2640m.s⁻¹                 | 3.20MPa         | 34.14MPa             | 8.00GPa               | 5.33Gpa                | 0.23μ          | 4.2          | 48.58GPa      | 35.5°                   |
| Floor           | 5115m.s⁻¹                 | 4.55MPa         | 60.52MPa             | 45.20GPa              | 35.36Gpa               | 0.17μ          | 17.4         | 48.58GPa      | 35.5°                   |

The determination of the rock longitudinal wave velocity shows that there are large differences in several types rock. The immediate floor wave speed is relatively low, the dispersion degree is larger than others, and the immediate roof dispersion is smaller than others. The rock wave velocity shows that the immediate roof integrity is better and the immediate floor integrity is poorer.

The results of rock uniaxial compression tests show that the compressive strengths of several types rock are quite different, the immediate roof and roof strength are relatively high, and they belong to hard rock, the immediate floor compressive strength is relatively low, and it belongs to soft rocks, the roof compressive strength is moderate, and it belongs to moderately strong rocks. The Brazilian splitting test results show that all of rocks have better tensile strength.

3. Roadway support design

3.1 Support design

According to the specific geological conditions of the coal mine return airway, and the rectangular section support design parameters in the coal seam return airway[3-5], the horse-shoe U-type roadway supporting form was proposed and the design parameters were given[6-8]. At present, the roadway support form for the return airway at the site is a rectangular of bolting with wire mesh, with a section width 4.3m, and height 2.8m, and section area 12.04m², as shown in Figure 4a. The horseshoe-shaped support method, with a section width 4.3m, and height 3.3m, and section area 12.4m², as shown in Figure 4b.
3.2 Support stress numerical simulation

The numerical constitutive model used the Mohr-Coulomb to determine rock damage. In the Mohr-Coulomb plasticity model, B and S were determined from the Poisson's ratio $\nu$ and elastic modulus $E$ of the rock, and the relationship between the elastic modulus and Poisson's ratio is:

$$S = \frac{E}{3(1-2\nu)} \quad B = \frac{E}{2(1+2\nu)}$$

The FLAC3D software was used to numerically simulate the stress distribution of the surrounding rock under the two support types. The simulation results are shown in Figure 5.

Fig. 5a shows the simulation results. The stress concentration was greatest at the ribs and floor of the rectangular support return airway, the maximum stress reaches 37.3MPa, and the minimum stress value is 0.59MPa in the roof of the return airway.

Fig. 5b shows the simulation results. The maximum stress reaches 38.1MPa at the roof and floor of horse-shoe arch U-type support return airway, the maximum stress is consistent with the maximum stress under the rectangular support return airway, but the horse-shoe arch U-type steel support effectively transfers the stress from the ribs and the floor to the roof, the transfer stress is beneficial to the ribs of control. At the same time, the horse-shoe arch U-type support avoids the direction perpendicular to the structural stress, and it is beneficial to increase its bearing capacity.
4. Field applications

4.1 Support effect monitoring
Since the station is 1050m away from the working face, the impact of the station can be ignored. Two stations were arranged within 100m range of the project, the two monitoring stations distance between 20m to 25m. The measuring points are located in the position where the roof was stable, the supports and ribs were in good condition, and the base plate was flat and firm for long time observation. Two monitoring points that spacing is 1m were arranged for each station. A survey-meter was used to detect the changes in the sectional area of the roadway every day, and the average number of station data in the form of support for the same section was taken to reduce the error.

4.2 Result analysis
Two types of roadway support were constructed in the coal seam return airway, and the pressure observation was carried out in six months among. The results are shown in Figure 4.

![Figure 6. Roadway deformation](image)

Fig. 6 shows the monitored results. There were less than 100mm roof subsidence with the two support types, and with no obvious change. Rectangular supporting roadway had large subsidence in ribs with the change value was between 100mm to 600mm. However, the Horse-shoe U-type roadway subsidence was significantly reduced, the change value was between 20mm to 100mm, and the approach amount was reduced by 83.3% in the sixth month. The floor heave of the rectangular support roadway was severe, the amount was between 60mm to 400mm. The floor heave of the horse-shoe U-type support roadway was obviously reduced, the amount was between 20mm to 100mm, the approach amount was reduced by 75.0.% in the sixth month.

5. Conclusion
The numerical simulation result shows that the horse-shoe U-type steel support effectively controls return airway deformation. The new support method effectively transfers the stress concentration zone from the airway ribs and the airway floor to the airway floor, this stress change improves the bearing capacity of the return airway.

The field application monitored results showed that the ribs and the floor heave of the return airway deformation were effectively controlled with the horse-shoe U-type steel support method. The new support methods compared the rectangular bolting with wire mesh support methods, the amount of has decreased by 83.3%, and the amount of floor heave has decreased by 75%.

The numerical simulations and field tests all reflect that the horse-shoe U-type steel support method is beneficial to two-soft and one-hard coal seam roadways. The goal is to provide a theoretical foundation for solving the coal similar roadway.

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