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Research on Bolt Support Technology in Soft Coal Seam Roadway

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Abstract

In order to solve the problem of surrounding rock control in soft coal seam roadway, taking the centralized return airway of No. 2 coal seam in Liangdu Coal Industry as the research background, the mechanical conditions of roadway surrounding rock were analyzed by means of field investigation, rock mechanics experiment and numerical simulation. The design principles of roadway support in soft coal seam were put forward: high strength anchor cable support, high preload support and high stiffness support. The bearing capacity of surrounding rock was strengthened by anchor cable support, and the deformation and failure of surrounding rock were effectively controlled. Through the numerical simulation method, the deformation and plastic failure range of roadways under different support schemes are compared and analyzed. The support scheme of centralized transportation roadway is studied and determined, and the field test is carried out, which effectively controls the deformation of surrounding rock of roadway in weak coal seam.

Keywords

Roadway Support, High Preload, High Strength, Bolt Support, Support Design

1. Introduction

In recent years, with the development of coal mine roadway support theory and technology, the proportion of roadway driving along the coal seam is increasing, and the support form of coal seam roadway has changed greatly [1]. The traditional passive metal support, low strength and low preload bolting and shotcreting support can not meet the needs of surrounding rock control in soft coal seam roadway [2] [3] [4].

Many scholars have concluded that the strength of bolt support and its preload are important factors affecting the effect of roadway support [5] [6] [7]. High strength and high pre-tightening bolt support technology has the advantages of timely control, strong shear capacity and large support stiffness for weak coal seam roadway, which can effectively improve the stability of roadway [8] [9] [10]. Therefore, this paper takes the soft coal seam roadway in the concentrated return air roadway of Liangdu Coal Industry as the research object, analyzes the mechanical properties and parameters of the surrounding rock of the roadway, based on the principle of high strength and high preload support, studies and determines the roadway bolt support scheme and parameters, and successfully carries out field tests.

2. Project Summary

The 2 # coal seam of Liangdu Coal Industry is divided into 2 # upper and 2 # lower, which is a stable mineable coal seam. The ground elevation is 880 - 965 m, the underground elevation is 475 - 585 m, and the depth is 305 - 450 m. In order to ensure the normal and safe production of Liangdu Coal Industry, the geological mechanics characteristics and roadway support technology of No. 2 coal seam are studied. Taking the concentrated return air roadway as an example, the concentrated return air roadway serves the concentrated return air roadway of No. 2 coal mining. The excavation section is a rectangular section with a width × height of 5.3 m × 3.3 m, which mainly serves as the return air task of the working face during coal seam mining.

During the excavation of the concentrated return airway, the excavation is carried out along No. 2 coal seam. The average thickness of No. 2 upper coal seam is 0.87 m. The roof mudstone is the main, followed by sandy shale, floor mudstone, fine sandstone, and simple structure. The average thickness of No. 2 lower coal seam is 1.23 m, and the roof gradually changes from sandy shale to sandstone and mudstone from south to north. The bottom plate gradually changes from sandy shale to argillaceous sandstone and mudstone from south to north, and the structure is simple.

3. Test and Analysis of Physical and Mechanical Properties of Surrounding Rock of Roadway

In order to grasp the mechanical properties and parameters of the surrounding rock of No. 2 coal seam roadway in Liangdu Coal Industry, coal samples and roof core samples were obtained from the excavation face and processed into standard cylindrical specimens with a diameter of 50 mm and a height of 100 mm. The uniaxial compressive strength and uniaxial tensile strength tests were carried out by using the rock mechanics test system. Some of the stress-strain curves of coal and rock mass are shown in **Figure 1**. The mechanical properties and parameters of surrounding rock are analyzed, and the mechanical characteristics of surrounding rock of concentrated return airway are obtained:

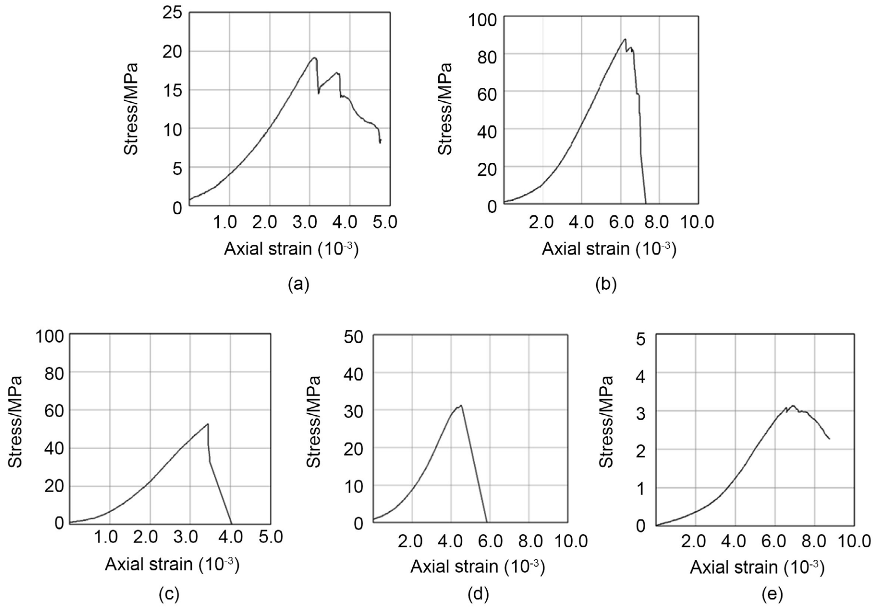


Figure 1. Uniaxial compression stress-strain curve of coal rock mass. (a) Stress-strain curve of mudstone; (b) Stress-strain curve of sandstone; (c) Stress-strain curve of sandy mudstone; (d) Stress-strain curve of sandy shale; (e) Stress-strain curve of No. 2 coal.

1) The mudstone and sandy mudstone in the surrounding rock of roadway roof are weak and easy to deform. The average uniaxial compressive strength of mudstone and sandy mudstone is 14.56 MPa and 26.86 MPa respectively, and the average tensile strength is 1.79 MPa and 1.81 MPa respectively. On the whole, the strength of mudstone and sandy mudstone in roadway surrounding rock is low and the elastic modulus is small. For large-area surrounding rock geological body, due to the influence of bedding, joint and structure, the strength of surrounding rock is lower, and it is more prone to deformation and failure.

2) The average uniaxial compressive strength of sandstone and sandy shale is 82.21 MPa and 41.50 MPa respectively, and the average tensile strength is 5.15 MPa and 2.06 MPa respectively. The roof sandstone has high compressive strength, belongs to hard rock, and has high bearing capacity.

3) The uniaxial compressive strength of the two sides of the roadway is low, and the average uniaxial compressive strength is 4.37 MPa. According to the research on the classification standard of the strength of soft and weak coal body [11], the value is less than 5 MPa, which belongs to soft coal body. The weak surrounding rock of the roadway increases the difficulty of surrounding rock control.

It can be seen from the strength test results of the surrounding rock of the roadway that the two sides of the concentrated return air roadway of No. 2 coal seam are weak, and the roof is basically 20 - 40 MPa medium hard rock except for a small part of hard sandstone.

4. Centralized Return Airway Support Design Principles

Bolt support is a widely used, economical and effective support form in coal mine roadway. The essence of bolt support technology is to provide effective high initial support strength and good resistance increasing performance. Based on the current advanced technology of roadway support and combined with the actual geological and mechanical conditions, the design principle of bolt and anchor cable support in concentrated return airway of No. 2 coal seam is put forward [12] [13] [14]:

1) Using high strength anchor cable support system. The roof strata of the concentrated return airway are relatively weak and thick, and some sections have fault structures. The mining roadways on both sides of the working face are susceptible to mining. The weak coal and rock mass is easy to deform and break or shear dislocation along the weak surface, and the axial force and shear force generated by the anchor cable are large. Therefore, the No. 2 coal seam roadway adopts a high-strength anchor cable support system to ensure that the anchor body has greater stiffness and strength and can withstand greater loads.

2) Using high preload, high stiffness support, give full play to the bearing capacity of surrounding rock itself. Through high pre-tightening force to achieve real active and timely support, so that each rock layer is locked as a whole, improve the internal friction angle and cohesion of the rock layer within the anchorage range, effectively reduce the early deformation and failure of the surrounding rock, improve the mechanical properties of the surrounding rock, and make full use of the bearing capacity of the surrounding rock. The anchor cable is connected by metal mesh and steel strip to form an overall bearing structure, which can avoid local failure and caving instability of surrounding rock. The supporting structure not only provides high support resistance, but also realizes high stiffness support and can adapt to certain surrounding rock deformation.

3) High pre-tightening force anchor cable strengthening support. The thickness of the weak rock stratum of the roof is large, and the anchor cable has the advantages of large length and high pre-tightening force. It can not only anchor the broken surrounding rock to the stable area of the roof, but also prevent the weak roof from falling and falling due to the large separation outside the anchor bolt. Through the high pre-tightening force of the anchor cable, it can further improve the stress environment of the surrounding rock, improve the strength of the surrounding rock itself, and effectively reduce the deformation of the surrounding rock.

5. Numerical Simulation of Roadway Support Scheme

5.1. The Establishment of Numerical Model and Numerical Simulation Scheme

Taking the concentrated return airway of No. 2 coal seam as the object, according to the geological and mechanical conditions of the roadway and the surrounding rock structure, the numerical model is established by FLAC3D, and the Mohr-Coulomb constitutive model is adopted [15]. The overburden load of 7.5 MPa is applied above the model, and the horizontal displacement constraint and vertical displacement constraint are applied on both sides and bottom of the model. The physical and mechanical parameters of coal strata in the numerical model are shown in **Table 1**. Combined with the experience of roadway support engineering [16] [17] [18], considering the long service life of centralized return airway, four support schemes are designed, among which scheme 1 is no support, and the specific numerical simulation scheme is shown in **Table 2**. By simulating the stability of roadway surrounding rock under different support schemes, the reasonable support scheme is selected by comparative analysis.

5.2. Numerical Simulation Results Analysis

Through numerical simulation, the influence characteristics of different support schemes on the deformation of concentrated return airway are obtained, see **Table 3**; the influence of different support schemes on the deformation of surrounding rock in concentrated return airway is shown in **Figure 2** and **Figure 3**.

Table 1. Physical and mechanical parameters of coal strata in numerical model.

Rock formation	Bulk modulus K/GPa	Shear modulus G/GPa	Density d/N·m^{-3}	Angle of friction f/°	Binding power C/MPa	Tensile strength t/MPa
Sandstone	5.5	3.2	1900	29	2.2	2.5
Mudstone	2.5	1.5	1700	27	1.0	2.0
Medium-grained sandstone	6.0	4.2	2450	33.5	2.6	3.5
Sandy shale	5.4	3.2	2100	29	2.3	3
2 # coal	2.0	1.0	1400	27	1.0	1.5
3 # coal	2.0	1.0	1400	27	1.0	1.5
Sandy mudstone	4.8	2.6	1850	29	1.8	2.0

Table 2. Simulation scheme of support parameters of concentrated return airway.

Scheme	Top bolt	Side bolt	Top anchor rope
Scheme 1	0	0	0
Scheme 2	6 Φ20 × L2000 mm rebar bolt, row spacing 800 × 1000 mm	3 Φ20 × L2000 mm rebar bolt, row spacing 1200 × 1000 mm	3 Φ21.8 × L5300 mm anchor rope, row spacing 1600 × 1000 mm
Scheme 3	6 Φ20 × L2200 mm rebar bolt, row spacing 800 × 1000 mm	3 Φ20 × L2200 mm rebar bolt, row spacing 1200 × 1000 mm	3 Φ21.8 × L6300 mm anchor rope, row spacing 1600 × 1000 mm
Scheme 4	6 Φ20 × L2400 mm rebar bolt, row spacing 800 × 1000 mm	3 Φ20 × L2400 mm rebar bolt, row spacing 1200 × 1000 mm	4 Φ21.8 × L7300 mm anchor rope, row spacing 1200 × 1000 mm

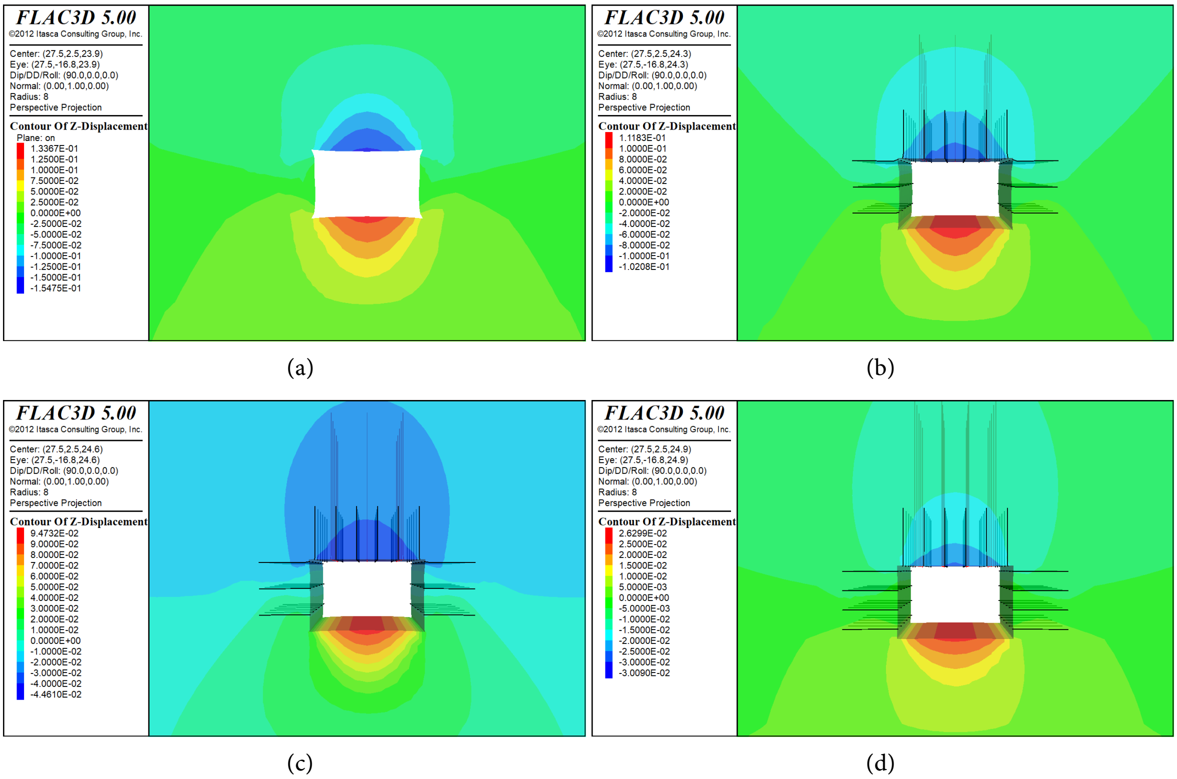


Figure 2. Vertical displacement cloud diagram of different schemes of concentrated return airway. (a) sheme 1; (b) sheme 2; (c) sheme 3; (d) sheme 4.

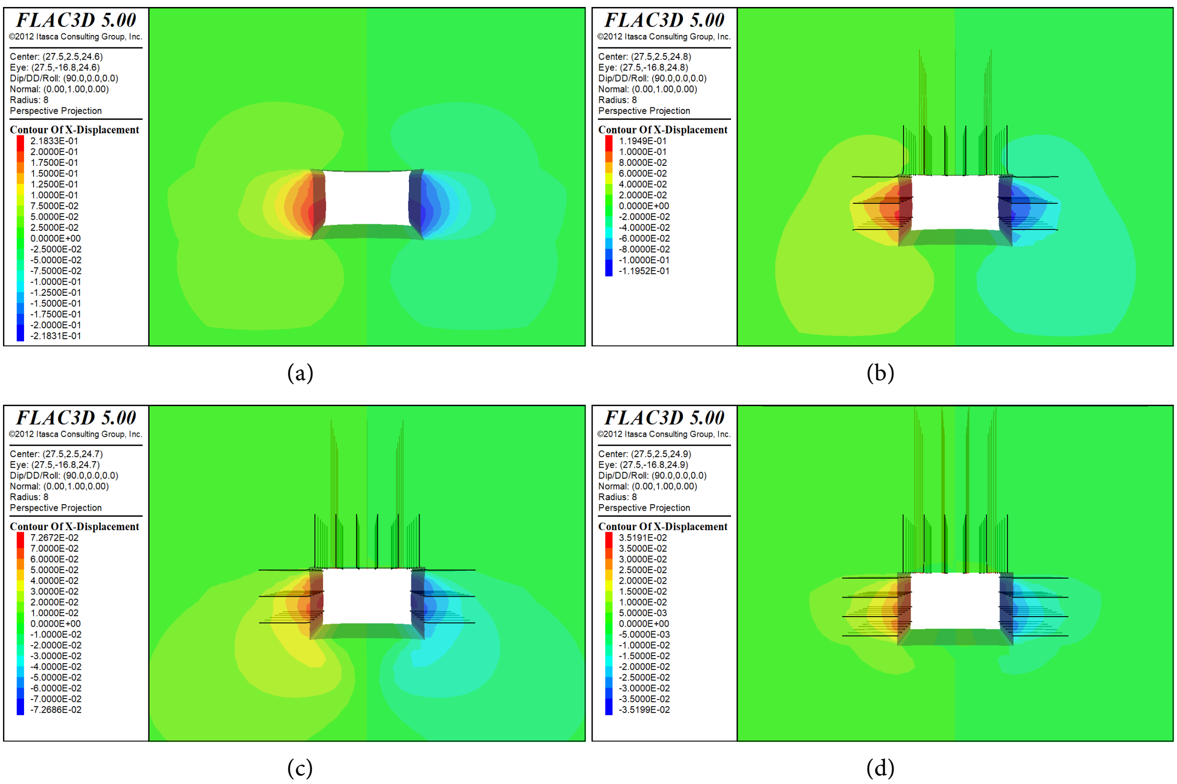


Figure 3. Horizontal displacement cloud diagram of different schemes of concentrated return airway. (a) sheme 1; (b) sheme 2; (c) sheme 3; (d) sheme 4.

Table 3. Roadway deformation under different support schemes.

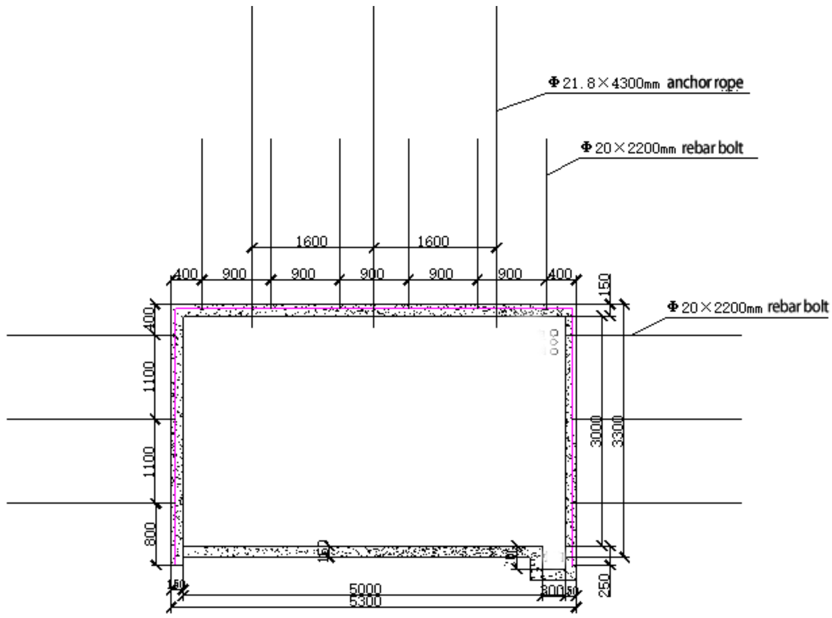
Scheme	Roof subsidence/mm	Floor heave/mm	Relative displacement of two sides/mm
1	154	134	436
2	102	112	238
3	45	95	146
4	30	26	70

It can be seen from **Table 3** and **Figure 2** and **Figure 3** that with the increase of the length of the roof and the two sides of the bolt, the length of the roof anchor cable and the decrease of the row spacing between the bolt and the anchor cable, the deformation of the roadway decreases continuously from the support scheme 1 to the support scheme 4. Scheme 1 is a non-support scheme, and the roadway has serious deformation. The roof subsidence, the two sides of the roadway and the floor heave are 154 mm, 436 mm and 134 mm respectively. It can be seen that the two sides of the concentrated return air roadway are weak coal, and the relative displacement of the two sides of the roadway is the largest. With the increase of support strength, the deformation of roadway becomes smaller and smaller. When scheme 3 is adopted, the roof subsidence decreases from 154 mm to 45 mm, the two-side convergence decreases from 436 mm to 146 mm, and the floor heave decreases from 134 mm to 95 mm. It can be seen from different support schemes that with the increase of the support strength of the roof and the two sides, the range of surrounding rock deformation gradually decreases, and the amount of floor heave has also been effectively controlled, indicating that the strengthened support of the roof and the two sides is helpful to the control of floor heave. When the support strength continues to increase from scheme 3 to scheme 4, the reduction of roadway deformation and displacement is small. Therefore, through comparative analysis, considering the factors such as supporting effect, economic benefit and convenient construction, the supporting scheme 3 is adopted for the centralized return airway.

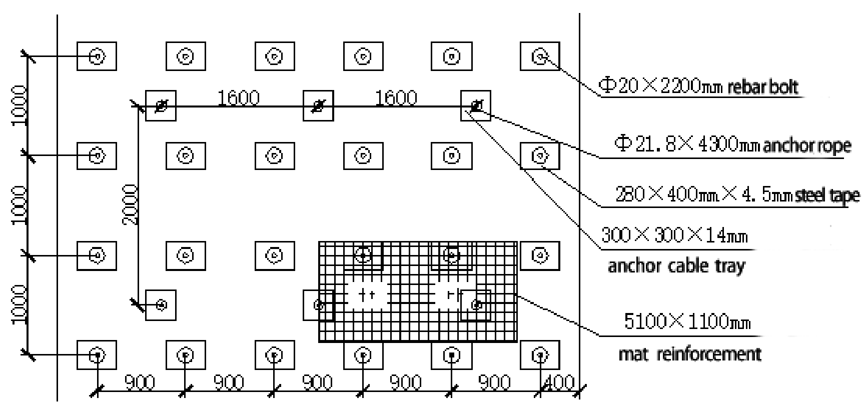
5.3. Roadway Support Design Scheme

Based on the geomechanical conditions of the surrounding rock of the roadway, through the above numerical simulation research, it is determined that the concentrated return airway is supported by "anchor net spray" with high strength and high pre-tightening force. The roadway support section is shown in **Figure 4**, and the specific support design parameters are as follows:

The excavation section of the concentrated return airway is rectangular, the width × height of the excavation section is 5.3 m × 3.3 m, and the width × height of the net section is 5.0 m × 3.0 m. The active support method of "anchor net spray" with high strength and high pre-tightening force is adopted. Each row of the roof is arranged with six rebar bolts with Φ20 mm, L2200 mm and yield strength of 500 MPa, and the spacing between rows is 900 × 1000 mm. The roof is equipped with 5300 mm × 1100 mm hexagonal metal mesh and 320 mm × 5200 mm × 4.5 mm high strength W steel strip. Each row of the roof adopts three Φ21.8 mm and L6300 mm high-strength anchor cables with 300 mm × 300 mm × 14 mm adjustable arch-shaped high-strength trays, and the row spacing between anchor cables is 1600 × 2000 mm. Six Φ20 mm, L2200 m, 500 MPa yield strength rebar anchors were arranged in each row of the rib side. The row spacing was 1100 × 1000 mm, with 3600 × 1100 mm metal mesh and 320 mm × 400 mm × 4.5 mm high strength W steel strip. The roof and two sides of the bolt were anchored with 2 volumes of MSK2355 resin anchoring agent, and the preload torque was 300 N.m. The roof anchor cable was anchored with 3 volumes of MSK2355 resin anchoring agent, and the pre-tightening force of the anchor cable was 200 kN. After the anchor cable support, C25 shotcrete is used for shotcrete support, and the shotcrete thickness is 150 mm.



(a)



(b)

Figure 4. Centralized return airway support section diagram.

6. Support Effect Analysis

The field application was carried out by using the support design scheme of the concentrated return airway of No. 2 coal seam, and the surface displacement and roof separation of the roadway were observed.

The "cross measurement method" was used to observe the surface displacement of the roadway. The laser range finder is used to measure the distance between the roof and floor of the roadway and the two sides of the roadway, and the reading is accurate to 1 mm [19] [20] [21]. After roadway excavation, when the roadway deformation is fast, 3 to 5 times a week are observed. After the roadway deformation tends to be stable, 1 to 2 times a week are observed. The observation results show that the deformation of the concentrated return airway is small after the support of high strength and high pre-tightening force anchor cable, and it tends to be stable after 25 - 30 days after the roadway is excavated. The roof subsidence is 50 - 70 mm, the relative displacement of the two sides is 100 - 120 mm, and the floor heave is 60 - 70 mm.

The "roof separation instrument" is used to observe the roof separation of the roadway. The displacement depth of the deep base point of the separation instrument is 7 m, and the displacement depth of the shallow base point is 2 m. The installation spacing of roof separation instrument is not more than 50 m. The roof separation instrument is installed in time with the head to ensure that the roof separation can be provided at any time. The observation results show that after the roof deformation is stable, the roof separation amount of the roadway is small, and the total separation amount is 35 mm, indicating that the stability of the surrounding rock of the roadway is good, and the scheme can effectively control the deformation of the surrounding rock.

7. Conclusions and Discussions

1) During the excavation process of the centralized transportation roadway, the No. 2 coal seam is excavated along the No. 2 coal seam. The two sides of the No. 2 coal seam centralized return air roadway are weak. The roof is mainly composed of 20 - 40 MPa medium hard rock layer and weak argillaceous rock below 20 MPa except for a small part of hard sandstone.

2) For weak coal seam roadway, the essence of bolt support technology is to provide a higher initial support strength, and has good resistance performance. Combined with the current advanced technology of roadway support, the design principle of bolt support in concentrated return airway of No. 2 coal seam is put forward: using high strength bolt and anchor cable support system; high preload and high stiffness support are adopted to give full play to the bearing capacity of surrounding rock. High preload anchor cable strengthening support.

3) After the implementation of high strength and high preload strong support in the concentrated return airway, the deformation of the roadway is effectively controlled, and the support scheme can meet the requirements of production safety.

Although this paper has preliminarily studied the bolt support technology of soft rock roadway, which has certain guiding significance for practical engineering, the research content is not comprehensive, and some work still needs to be further discussed:

1) In the case study of roadway engineering application, typical roadways with different geological conditions can be selected for support design and application to obtain more engineering support.

2) In the design of support scheme, there is still room for improvement in the support scheme proposed in this paper. Therefore, in order to further improve the support efficiency of bolt support scheme in soft rock roadway, it is necessary to optimize the support structure.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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