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Research on orthogonal experimental design technology based on anchor mesh cable coupling support

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Abstract: *In view of the difficulty in supporting the return air gateway under the goaf of the close coal seam in Xihe Coal Mine, in order to improve the stability of the roadway of the close coal seam group and the supporting effect of the roadway, the orthogonal test method is adopted. Based on seven main influencing factors, such as the length of the anchor bolt, three common variables are set for each factor, and the FLAC^{3D} numerical simulation software is used to simulate and analyze 18 groups of orthogonal tests to obtain the best optimization scheme. Then, the deformation of surrounding rock and the range of shaping zone are compared before and after optimization. Compared with the original support scheme, the optimized support scheme reduces the roadway displacement, reduces the stress release area, improves the bearing capacity of surrounding rock, effectively solves the serious problem of surrounding rock deformation in Xihe Coal Mine, and provides theoretical and technical support for roadway deformation control.*

Keywords: *Close coal seam; Orthogonal test; Support; Numerical simulation*

1. Introduction

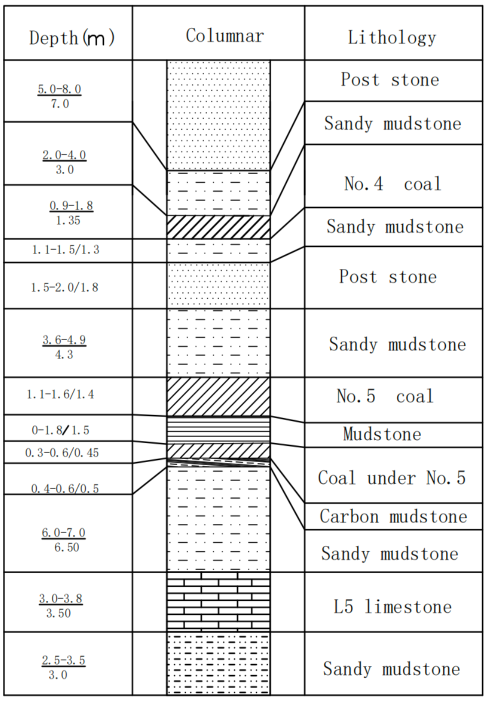

Figure 1: Comprehensive Geological Histogram

Xihe Coal 5205 return air chute is located in the north of the return air lane, directly below the original 4201 return air chute. The return air chute is 5205 long. The return air chute is a semi coal rock roadway, with an average burial depth of 463m, a design length of 608.3m, a width of 4.7m and a height of 2.7m. The average thickness of Coal Seam 5 # is 1.2m, and the nearest 7.4m above the

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working face is 4201 goaf, as shown in Figure 1.

The top and bottom plates of the 5205 return air chute are mainly composed of mudstone and sandy mudstone, which are loose and fragile. The uniaxial compressive strength is below 40 Mpa, and the tensile strength is below 2.0 MPa. Because the compressive hardness of the sandy mudstone in the water absorption state is significantly reduced, it is softened rock, causing the surrounding rock of the top and bottom plates to be easily weathered and broken. The residual coal pillar around the 4 # coal seam above has caused local stress concentration in the 5205 return air gateway. At present, the roadway roof is broken and the surrounding rock is severely deformed and damaged.

2. Analysis of deformation and failure mechanism of close coal seams

The deformation or fracture varies not only with the degree of deformation, but also with the mechanism. There are many reasons that affect the deformation of roadway, including the physical and mechanical properties of surrounding rock mass, ore composition, rock mass structure and the influence of faults, folds, folds and other structural zones. Water, gas, temperature, design, support structure, construction technology and quality all have a certain impact on the roadway. According to the analysis of the geological conditions of the 5205 return air gateway in Xihe Coal Mine, various factors that affect the deformation and damage of its surrounding rock generally include:

(1) Rock strength

The top and bottom plates of the 5205 return air chute are mostly mudstone and sandy mudstone, which are relatively loose, basically below 40Mpa, and the tensile strength is basically below 2.0MPa. Because the compressive hardness of the sandy mudstone in the water absorption state is significantly reduced, it is softened rock, causing the surrounding rock of the top and bottom plates to be easily weathered and broken.

(2) Impact of goaf

About 7.4m above the roadway is the 4201 goaf, and the interaction between coal seams will definitely increase significantly. Coal seam excavation will destroy the stress balance of the original rock, damage the original structure of the excavation area, thus weakening the stability of the surrounding rock itself. The remaining coal pillars around the 4 # coal seam above will cause local stress concentration in the 5205 return air chute, and the roadway will be severely deformed and damaged, as shown in Figure 2.

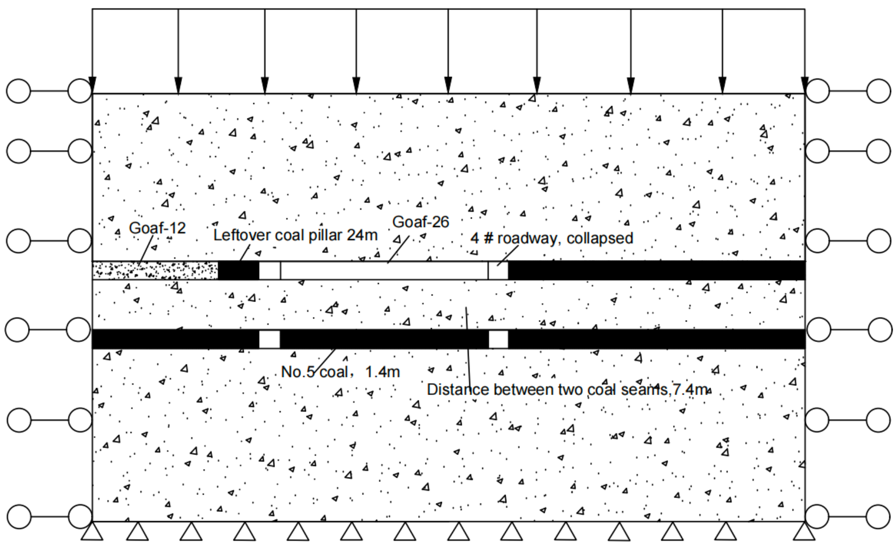

Figure 2: Roadway location and relationship between upper and lower shafts

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3. Orthogonal experimental design based on anchor mesh cable coupling support

3.1 Selection of relevant test parameters

Orthogonal test design is to select some tests from all tests according to orthogonality. This part of tests has the characteristics of uniform dispersion and orderly comparability, and is representative. Therefore, orthogonal test can replace comprehensive test with partial test [1]. The research parameters selected according to the experimental research object include: bolt length, bolt diameter, bolt pre tightening force, anchor cable length, anchor cable diameter, anchor cable pre tightening force, and row spacing between bolts. There are 7 factors in total, and 3 horizontal parameters are taken for each factor. The orthogonal test parameters that should be selected after reviewing the literature are shown in the following table 1.

Table 1: Orthogonal test parameters

Factor level	1	2	3
A Bolt length	2.0m	1.8m	1.6m
B Length of anchor cable	7.3m	6.3m	5.3m
C Anchor rod diameter	20mm	18mm	16mm
D Pre tightening force of anchor cable	260KN	240KN	220KN
E Diameter of anchor cable	19.8mm	21.8mm	23.8mm
F Row spacing between bolts	1.0	0.9	0.8
G Bolt pre tightening force	130KN	110KN	90KN

3.2 Orthogonal test design

Different parameters of each factor in orthogonal test will be combined with different parameters of another factor once to ensure that important tests are not omitted and unnecessary tests are not done. The following table shows 18 groups of orthogonal experimental design combinations generated by 7 factors and 3 levelsL18 (3^7) , as shown in Table 2:

Table 2: Combination Table of Orthogonal Test Design

Test No Column	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2
3	1	3	3	3	3	3	3
4	2	1	1	2	2	3	3
5	2	2	2	3	3	1	1
6	2	3	3	1	1	2	2
7	3	1	2	1	3	2	3
8	3	2	3	2	1	3	1
9	3	3	1	3	2	1	2
10	1	1	3	3	2	2	1
11	1	2	1	1	3	3	2
12	1	3	2	2	1	1	3
13	2	1	2	3	1	3	2
14	2	2	3	1	2	1	3
15	2	3	1	2	3	2	1
16	3	1	3	2	3	1	2
17	3	2	1	3	1	2	3
18	3	3	2	1	2	3	1

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3.3 Analysis of test results

Table 3: Orthogonal test approach scale

Number	1	2	3	4	5	6	7	8	9
Δz	18.313	18.265	18.395	18.449	19.049	18.516	18.6	18.22	18.931
Δx	9.7589	9.7622	9.7742	9.7751	9.775	9.7802	9.7843	9.7669	9.779
Number	10	11	12	13	14	15	16	17	18
Δz	18.706	18.102	19.504	19.421	19.303	19.638	19.169	18.812	18.12
Δx	9.7848	9.7715	9.7629	9.7749	9.775	9.7723	9.77	9.7793	9.7745

(1) Carry out numerical simulation according to the schemes in the orthogonal experiment table in Table 3, calculate and analyze the drift of roadway roof and floor Δz and drift side approach Δx. The simulation results are as follows:

(2) Range analysis

The most intuitionistic evaluation of the influence of support parameters on the supporting effect of surrounding rock of roadway is the roadway deformation. Because the difference between the wall displacement and the floor displacement is small, the analysis focuses on the roof and floor displacement Δz。 The range analysis method is used to compare the test results, that is, the difference between the maximum mean value and the minimum mean value of each factor is calculated to determine the importance of the factor impact, so as to select the optimal level scheme [2], as shown in Figure 3.

Table 4: Top and bottom plate displacement Δz Analysis table

Factor	A	B	C	D	E	F	G
1Δz(mean value)	18.548	18.776	18.708	18.592	18.798	19.045	18.674
2Δz(mean value)	18.863	18.625	18.827	18.874	18.629	18.756	18.734
3Δz(mean value)	18.642	18.851	18.718	18.886	18.826	18.451	18.844
Δz(range)	0.315	0.226	0.119	0.294	0.197	0.594	0.17
Optimal	A1	B2	C1	D1	E2	F3	G1

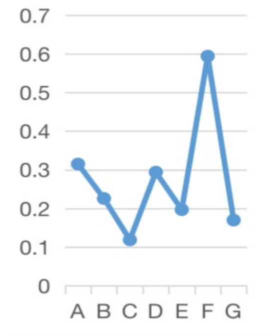

Figure 3: Range Distribution of Roof Subsidence

According to Table 4, the factors that affect the top and bottom slab proximity are FADBEGC in order of primary and secondary order, in which the row spacing between anchor bolts, anchor bolt length, and anchor cable preload have the greatest impact on the top and bottom slab deformation, with the range of more than 0.2, while the anchor bolt diameter, anchor bolt prestress, and anchor cable diameter have little impact, with the range of less than 0.2. The way to judge whether a parameter is optimal is whether the corresponding deformation is the minimum when the parameter is used. It can be concluded that the best scheme for controlling the deformation of surrounding rock is F3A1D1B2E2G1C1, that is, the length of anchor bolt is 2.0m, the length of anchor cable is 6.3m, the preload of anchor cable is 260KN, and the row spacing between anchor bolts is 800mm × 800mm, anchor rod pre tightening force is 130KN, anchor cable diameter is 21.8mm, anchor rod diameter is 20mm.

(3) Determine orthogonal optimization scheme

The original protection mode of 5205 return air chute is bolt support, which has limited support capacity, causing serious roof crushing and surrounding rock deformation. The existing protection mode of roadway is mainly the coupling protection of anchor, mesh and cable, which can produce a

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better joint effect with the original anchor.

Roof bolt of roadway for the ϕ 20 * 2000mm threaded steel anchor bolt, Q235 steel is used as the anchor bolt tray, and the specification is 150 * 150 * 10mm square bracket. The anchor bolt spacing is 800mm, and the row spacing is 800mm; Due to the structural size, the side anchor bolt is ϕ The row spacing between 20 * 2000mm threaded steel anchor bolts is 900 * 800mm [3].

Roof anchor cable ϕ 21.8 * 6300mm steel strand with row spacing of 1600 * 800mm; The anchor cable tray is made of 270 mm * 270 mm * 16 mm steel plate, and the left and right side anchor cables are made of ϕ 21.8 * 6300mm steel strand with row spacing of 1800 * 800mm, as shown in Figure 4.

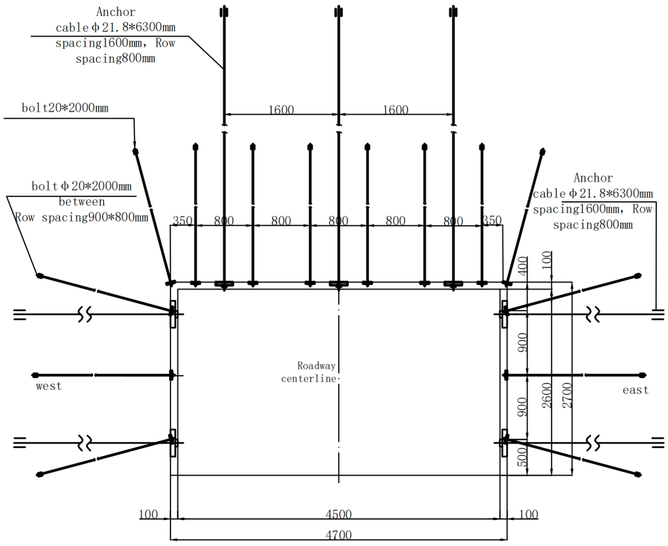

Figure 4: Cross Section of Orthogonal Optimization Support Design

4. Analysis of orthogonal test results based on FLAC3D

4.1 Original support scheme

The anchor rod at the top of the return air chute is ϕ For 18 * 1800mm threaded steel anchor bolt, the anchor bolt tray is a 150×150×10mm square supporting piece, the anchor bolt spacing is 900mm, and the row spacing is 800mm; Due to the structural size, the side anchor bolt is the row spacing between ϕ 18 * 1800mm threaded steel anchor bolts is 900 * 900mm. Roof anchor cable ϕ 19.8 * 5300mm steel strand, the row spacing is 1800 * 800mm, and there is no anchor cable at the upper part [4], as shown in Figure 5.

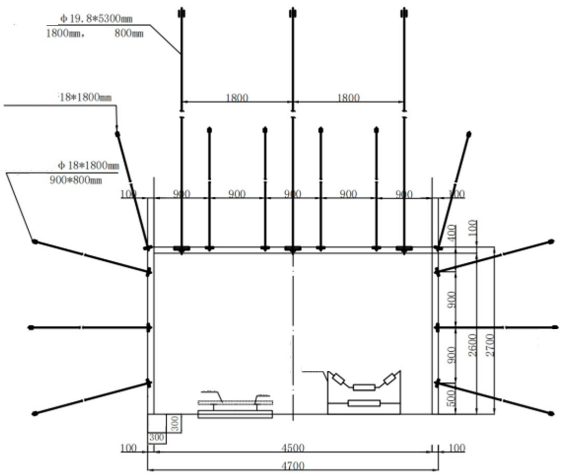

Figure 5: Original Support Design of Roadway

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4.2 Simulation scheme

In order to determine the support effect of the optimization scheme, FLAC^{3D} numerical simulation software is used for simulation, and the model is long×wide × high=259.4m×80m×35.4m, using the Mohr Coulomb constitutive model and the double yield model to confirm the feasibility of the scheme. In this paper, the simulation comparison between the original support design roadway and the anchor mesh cable coupling support design roadway is carried out, and the comparative analysis is carried out on the roadway roof subsidence, the two side displacement and the vertical stress [5] , as shown in Figure 6.

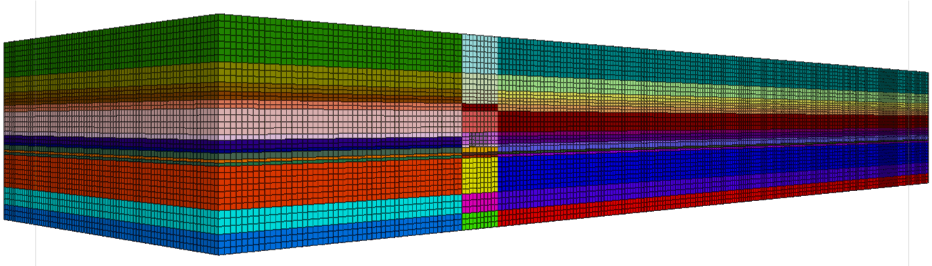

Figure 6: Rock Strata Distribution Map

(1) Roadway deformation

Figure 7: Original Support Scheme and Optimized Scheme x Approach Amount

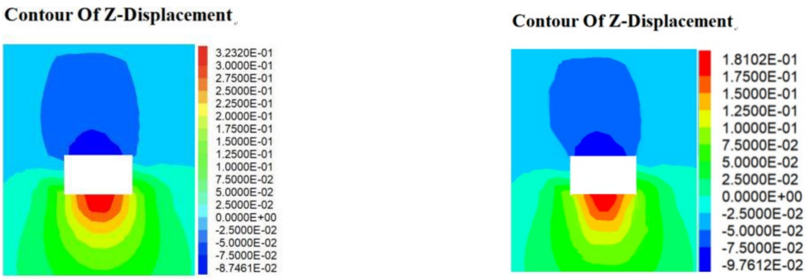

Figure 8: Z-shift of original support scheme and optimized scheme

According to the above simulation, the x-shift amount of the optimized scheme obtained from the orthogonal test is 9.2862cm, the z-shift amount is 18.102cm, the x-shift amount of the original support scheme is 19.421cm, the y-shift amount is 32.320cm, and the deformation amount of the original scheme is almost twice that of the optimized scheme. It can be concluded that when the optimized anchor mesh cable coupling support method is used, the tunnel approach can be significantly reduced, the surrounding rock deformation of the tunnel is small and the stability is good, and the support effect can be strengthened. This support scheme is correct, as shown in Figure 7 and Figure 8.

(2) Stress analysis

The cloud diagram of vertical stress distribution around the roadway under the two schemes is shown in the figure 9. It can be seen from the figure that the support body increases the stress of surrounding rock, reduces the stress release area, and improves the bearing capacity of surrounding rock, which has a positive impact on the stability of the roadway. From the simulation results, it can be seen that the surrounding rock deformation of the roadway using the orthogonal optimized anchor mesh cable coupling support method is significantly less than the initial support scheme, which can better protect the surrounding rock of the roadway from deformation and damage.

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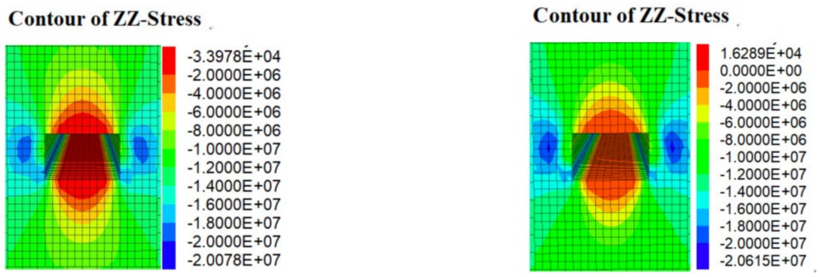

Figure 9: Stress Diagram of Anchor Cable with or without Grouting

5. Summary

The support of the mining roadway under the close coal seam has always been a difficult problem in mining production, especially for the safe mining of the close coal seam. Based on the analysis of the deformation and failure mechanism of the close coal seam, this paper proposes specific control measures, uses 18 groups of orthogonal tests to obtain the optimized support mode, and uses FLAC^{3D} numerical simulation to analyze the support effect. The results show that the bearing capacity of the anchor cable in the support scheme plays a good role, can effectively control the deformation and failure of the surrounding rock of the roadway, can improve the bearing capacity of the surrounding rock, and has good stability. It has good effect on surrounding rock control, ensures the safety of working face mining, improves the mining speed of working face, and realizes the goal of safety and efficiency. It has certain guiding significance for the support design of near seam roadway in the future.

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