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Study on Deformation Characteristics and Support Technology of Surrounding Rock at Deep Roadway Intersection

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Abstract

Aiming at the serious surrounding rock deformation at the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine, a combination of on-site observation, numerical simulation and on-site industrial test was adopted to comprehensively reveal the deformation and failure characteristics of the intersection and propose effective control technologies. The results show that the main reasons for the surrounding rock deformation at the intersection are the large burial depth of the roadway, the superimposed stress caused by the cross distribution of roadways, and the relatively weak surrounding rock. In response, a support scheme of roof anchor cable reinforcement combined with grouting reinforcement is proposed. The on-site industrial test shows that after adopting the roof anchor cable reinforcement combined with grouting reinforcement support scheme, the maximum displacement of the roof and floor of the roadway is 250mm, and the maximum displacement of the two sides is 200mm, ensuring the safe use of the roadway.

Keywords

Intersection; Anchor cable reinforcement; Grouting reinforcement; Superimposed stress.

1. Introduction

Underground roadways are important channels connecting various systems, and their stability is crucial to the safe and efficient production of coal mines. Due to the needs of coal and material transportation, pedestrian passages and ventilation, underground roadways often form intersections or Fork in the road， which are called branch roads, and the positions where they intersect or branch are called roadway intersections[1]. Because the roadway intersection is faced with complex stress fields and multiple excavation disturbances, the surrounding rock of the roadway intersection is often seriously deformed and damaged. Therefore, the roadway intersection is a key part of roadway construction and support. If the design is unreasonable, it will bring great adverse factors to production and safety[2].

In recent years, scholars at home and abroad have conducted a lot of research on the support technology of large-section intersections in deep roadways. Li Zhanjin et al[3] studied the deformation and failure mechanism and deformation mechanical mechanism of the third level track downhill in Hemei No. 5 Mine, summarized the failure reasons of typical Y-shaped intersections, and proposed an anchor net cable + flexible layer truss coupling support scheme with bottom corner bolts to control floor heave for large-section intersections of newly opened roadways. Lu Shoumin et al. [4] carried out experimental research on bolt-net-shotcrete support for class V soft surrounding rock roadways and intersections in Pansan Mine, and proposed a bolt-net-shotcrete support technical scheme suitable for this type of surrounding rock. Through on-site tests, the effectiveness of the support scheme in improving the stability of roadways and intersections was verified, proving that bolt-net-shotcrete support can effectively control the

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deformation of surrounding rock and improve the safety of roadways and intersections. Wang Yinqun[5] conducted in-depth research on the support technology of cross roadways in thick coal seams, and proposed a support scheme suitable for such roadways, including reasonable selection of support materials and structural design. Through practical application, the effectiveness of the support technology in ensuring the stability and safety of roadways was verified, and the support technology can significantly improve the bearing capacity of roadways and reduce roadway deformation; He Manchao et al. [6]studied the corresponding support technology for the intersection of deep soft rock roadways in Xing'an Mine, and proposed an effective support scheme, including the use of high-strength bolts and anchor cables and other support materials. Through practical application, it was verified that the support technology can significantly improve the stability of the intersection and reduce deformation and damage; in-depth research was conducted on the stability of the intersection of deep Tertiary soft rock roadways, the failure mechanism of the intersection was analyzed, and targeted support countermeasures were proposed; He Xiaosheng et al. [7] proposed the use of steel tube concrete supports or composite support technology as solutions for the support of soft rock roadways, especially the support technology of intersections or large-section roadways. Wei Sijiang et al. [8] conducted a simulation study on the creep problem of surrounding rock in large-section broken chambers, and proposed corresponding control technologies, including reasonable support design and construction measures, and then verified the effectiveness of the proposed control technologies in reducing surrounding rock creep and improving chamber stability through simulation analysis. Hou Chaojiong et al. [9,10] in-depth discussed the support principle of deep soft rock roadways in view of the problems such as sharp increase of rock mass stress, increase of ground temperature, deterioration of lithology, and enlargement of surrounding rock plastic zone and broken zone caused by the gradual increase of mining depth, and proposed measures such as reasonable arrangement of roadway space position, improvement of surrounding rock mechanical properties, and increase of support resistance.

This paper takes the roadway support at the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine as the research background, studies the deformation and failure characteristics and influencing factors of the surrounding rock at the intersection, and optimizes the support parameters of the intersection, which is of positive significance for ensuring the stability of the surrounding rock at the intersection and the safe production of the mine.

2. Engineering Overview

The S2303 working face of Gucheng Coal Mine is the second working face on the west side of the south No. 2 panel main roadway, with the panel main roadway on the east side, the S2305 working face on the south side, solid coal on the west side, and the S2301 working face on the north side. The floor elevation of the No. 3 coal seam in the working face is +273.0 ~ +340.0m, the surface elevation is +933 ~ +937m, and the burial depth is 603 ~ 647m. The S2303 working face mines the No. 3 coal seam, which is located in the middle and lower part of the Shanxi Formation. According to the working face and surrounding boreholes, the total thickness of the coal seam is 6.87 ~ 7.48m, with an average thickness of 7.2m. The coal seam structure is simple, containing 0 ~ 2 layers of mudstone and carbonaceous mudstone gangue, generally 1 layer. The immediate roof of the coal seam is mudstone and sandy mudstone, locally siltstone, and the floor is sandy mudstone, mudstone, and locally siltstone. The floor elevation of the coal seam in the working face is +273m ~ +340m, and the dip angle of the coal seam is 0° ~ 18°, with an average of 4°.

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3. Analysis of Deformation Factors at the Intersection

At the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine, as shown in Figure 1, there are phenomena of roof subsidence, fracture, and serious surrounding rock deformation, threatening the safe production of the mine.

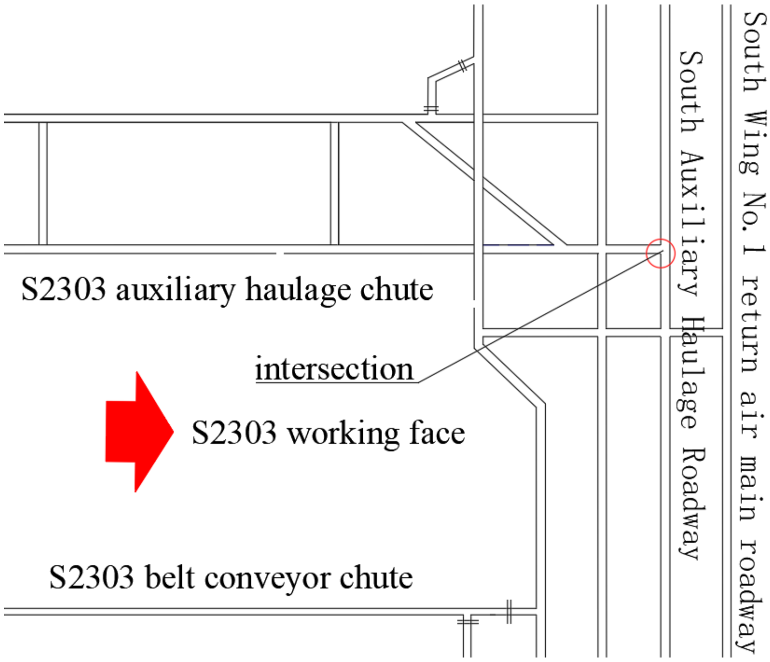

Figure 1. Layout Plan

The main reasons for the deformation of the surrounding rock at the intersection are as follows:

1.Large burial depth of the roadway

The large burial depth of the roadway leads to a high degree of stress concentration in the surrounding rock, resulting in serious shrinkage of the roadway section and large deformation of the surrounding rock. The superposition of in-situ stress and multiple bearing pressures in the stope is the main source of stress evolution causing floor heave. The average burial depth of the S2303 working face in Gucheng Coal Mine is 625m, the roadway burial depth is large, and the horizontal tectonic stress is obvious, causing extrusion deformation of the roadway roof and sides. The original support strength is obviously unable to effectively control the deformation and damage of the shallow surrounding rock of the roadway, resulting in serious fragmentation of the roadway surrounding rock.

2.Superimposed stress caused by cross distribution of roadways

The S2303 auxiliary transport gateway, south wing belt conveyor main roadway, south wing auxiliary transport main roadway, south wing No. 1 return air main roadway, etc. are densely distributed in a cross shape. During the excavation of the roadway, it is easy to generate disturbed stress and superimposed stress, leading to large deformation of the surrounding rock.

3.Relatively weak surrounding rock

According to the histogram of the roof and floor of the S2303 working face in Gucheng Coal Mine, as shown in Figure 2, the lithology of the roadway roof is mudstone and sandy mudstone, etc. Core samples were taken from the borehole at the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine, processed into standard samples, and the physical and mechanical properties of the roadway surrounding rock were tested by RMT-150B rock mechanics servo testing machine. The average tensile strengths of

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mudstone and sandy mudstone are 1.2MPa and 1.5MPa respectively, which are relatively small and easy to be damaged under strong mining action. The roadway roof is mainly composed of weak rock layers such as mudstone and sandy mudstone, which are easy to expand when encountering water. The surrounding rock is relatively weak, with poor bearing capacity, and the roadway is prone to deformation and damage under high stress, making support difficult and requiring high support technology.

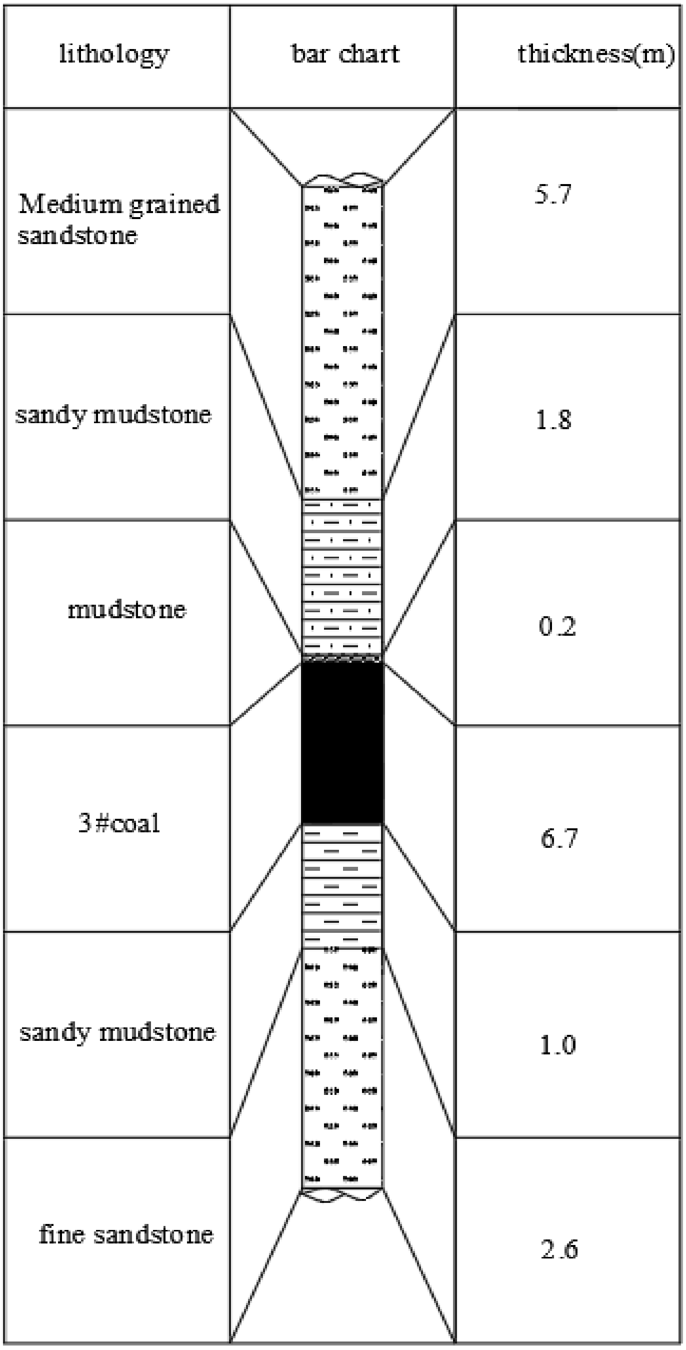

Figure 2. Columnar Diagram of Roof and Floor of S2303 Working Face

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4. Research on Intersection Control Technology

4.1. Intersection Control Strategy

Through the analysis of the deformation factors at the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine, the intersection control strategy is obtained.

(1) The roadway has a large burial depth and high ground stress, and the original support strength is obviously unable to effectively control the deformation and damage of the roadway surrounding rock. The overall stability of the roadway surrounding rock can be increased by reinforcing anchor cables.

(2) The roadway roof contains a large amount of mudstone and sandy mudstone with low strength and easy to expand when encountering water, which generally presents a state of developed fractures and loose cementation. Mudstone and sandy mudstone are mixed and associated. Under high stress, the roadway is prone to deformation and damage. Grouting reinforcement can be used to increase the strength of the roof surrounding rock and ensure the stability of the roadway intersection.

4.2. Research on Intersection Reinforcement Support Technology

Through the analysis of the roadway intersection control strategy, three sets of intersection reinforcement support schemes are proposed, and the optimal support scheme is obtained through numerical simulation research. The intersection reinforcement support schemes are shown in Table 1.

Table 1. Intersection Reinforcement Support Schemes

Scheme1 Strengthening anchor cablesφ22mm×L3300mm,Row spacing1500mm×1500mm
Scheme2 Strengthening anchor cablesφ22mm×L6300mm, Row spacing 1500mm×1500mm
Scheme3 Strengthening anchor cablesφ22mm×L6300mm, Row spacing1500mm×1500mm, Roof grouting reinforcement

According to the geological report of Gucheng Coal Mine and the results of rock mechanics experiments, the corresponding mechanical parameters of the rock mass are obtained by reduction. The mechanical parameters of the rock mass are shown in Table 2. The FLAC3D numerical simulation software is used to establish the numerical model of reinforcement support, and the structure of the calculation model is shown in Figure 3 below.

Table 2. Reduced Rock Mass Mechanical Parameters

parameter / rock character	Bulk modulus /GPa	Shear modulus /Gpa	Tensile strength /MPa	Cohesion /MPa	Internal friction angle /。	Density /kg/m^3
3#coal	1.3	1.22	0.63	0.84	28.5	1345
Mudstone	2.3	2.22	0.82	1.1	36	2400
Fine sandstone	3.2	6.9	1.06	1.11	36	2560
Sandy mudstone	3.6	6.8	1.05	1.16	32	2610

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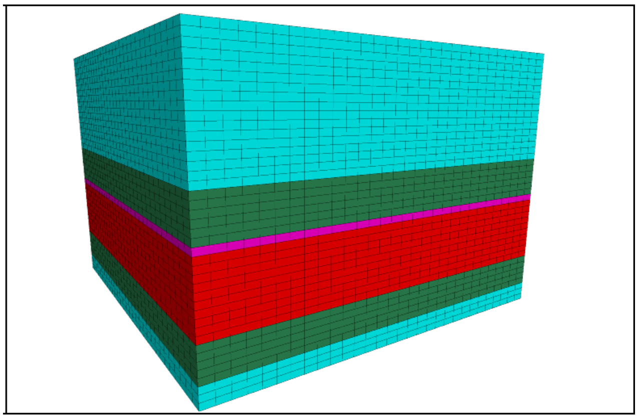

Figure 3. Numerical Calculation Model

Through the simulation analysis of different intersection reinforcement support schemes, as shown in Figure 4, the following conclusions are drawn:

Scheme 1 and Scheme 2 only adopt anchor cable reinforcement measures without grouting reinforcement. In this case, the anchor cables are mainly anchored in the plastic zone with poor stability. Due to the low strength of the rock in the plastic zone, it is easy to deform, so the anchor cables cannot well limit the expansion of the plastic zone and the deformation of the floor, resulting in large floor deformation. Scheme 3 adopts the roof anchor cable reinforcement combined with grouting reinforcement support scheme. Grouting reinforcement can effectively fill the fractures and voids in the rock, improving the integrity and stability of the roof. At the same time, the anchor cables are anchored into the stable rock layer, and together with grouting reinforcement, they improve the overall bearing capacity of the shallow and deep rock mass of the roof, effectively controlling the deformation of the roof; after adopting Scheme 3, the roadway roof subsidence is reduced to 193mm. Through the comparative analysis of different schemes, Scheme 3 is selected, that is, the roof anchor cable reinforcement combined with grouting reinforcement support scheme.

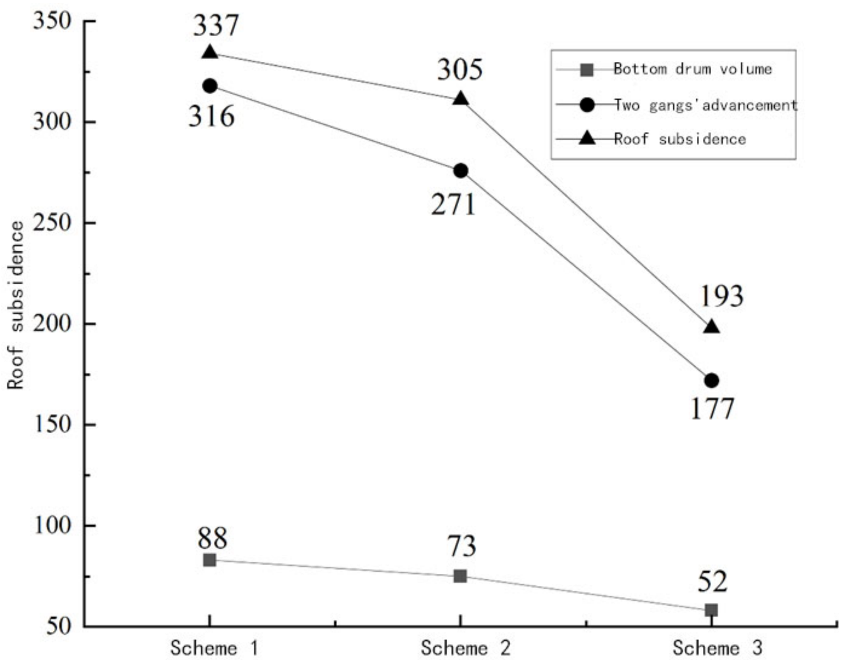

Figure 4. Roadway Deformation Trends of Different Support Schemes

5. Industrial Test

According to the proposed roof anchor cable reinforcement combined with grouting reinforcement support scheme, it was implemented at the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine. The anchor cables used are φ22mm×L6300mm with a spacing and row spacing of 1500mm×1500mm. The roof adopted Weigu No. 2 ultra-fine grouting material independently developed by Shanxi Zhongke Saide Energy Technology Co., Ltd., with a grouting pressure of 5MPa. A 2ZBQS25/6 grouting pump was used, equipped with a conjoined mixing bucket. This pump has dual independent cylinders, and the two suction and discharge ports can suck and discharge slurry simultaneously, allowing the slurry to be mixed at a ratio of 1:1. The working pressure of the grouting pump is adjustable within 0~11MPa, and the flow rate is uniform.

After adopting the proposed roof anchor cable reinforcement combined with grouting reinforcement support scheme, roadway surface displacement monitoring was carried out for 30 days using the "cross" point arrangement method on the roadway surface, as shown in Figure 5. Within the first 12 days, the deformation rates of the roof-floor surrounding rock and the two-side surrounding rock of the roadway reached their maximum values. The maximum displacement of the roadway roof and floor was 250mm, and the maximum displacement of the two sides was 200mm. After 12 days, the roadway deformation continued to increase, but the overall deformation rate slowed down. After 21 days, the deformation rates of the roadway roof-floor and two sides gradually stabilized, and there was basically no significant change in the deformation of the roadway surrounding rock.

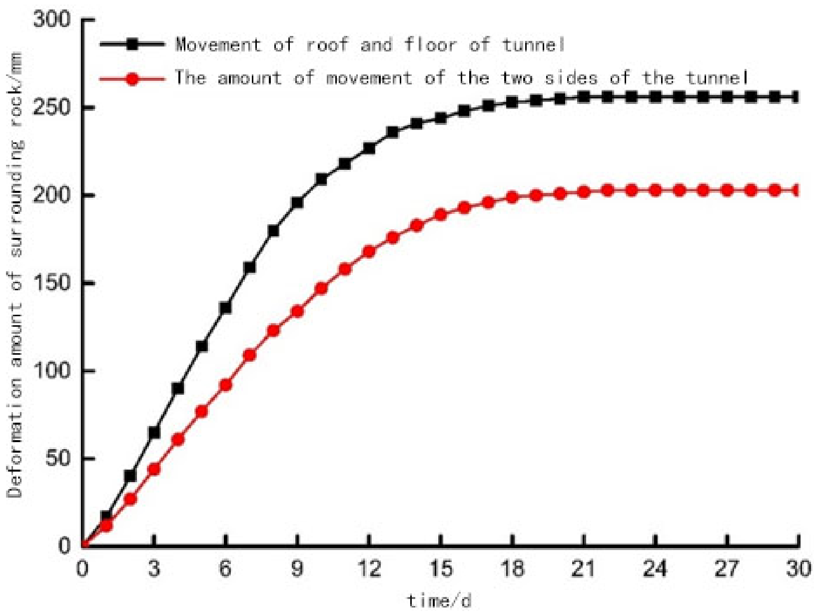

Figure 5. Roadway Surface Displacement Monitoring

6. Conclusions

(1) Through the analysis of deformation factors at the T-junction of S2303 auxiliary entry and south wing auxiliary transport main roadway in Gucheng Coal Mine, it is found that the main reasons for the surrounding rock deformation are the large burial depth of the roadway, the superimposed stress caused by the cross distribution of roadways, and the relatively weak surrounding rock.

(2) Numerical simulation was used to study the intersection reinforcement support schemes, and the results showed that the roadway deformation was the smallest when the roof anchor

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cable reinforcement combined with grouting reinforcement support scheme was adopted. The specific scheme is as follows: anchor cables of φ22mm×L6300mm with a spacing and row spacing of 1500mm×1500mm, and roof grouting reinforcement.

(3) The on-site industrial test showed that after adopting the roof anchor cable reinforcement combined with grouting reinforcement support scheme, the maximum displacement of the roadway roof and floor was 250mm, and the maximum displacement of the two sides was 200mm. After 21 days, the deformation rates of the roadway roof-floor and two sides gradually stabilized, ensuring the safe use of the roadway.

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