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Study on the Deformation Law of Surrounding Rock of Middle Bottom Pumping Roadway under the Influence of Close Distance Mining

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Abstract: *The surrounding rock of the middle-bottom drainage roadway experiences extensive crushing and severe deformation due to the combined effects of mining dynamic pressure and dense gas drainage holes, making its control challenging. Based on the engineering background of 3103 middle bottom drainage roadway in Hebi No.9 Coal Mine, the variation law of vertical stress and displacement of roof and side of bottom drainage roadway with dense boreholes under the influence of mining is revealed by means of field investigation, numerical simulation and theoretical analysis, and reasonable roadway support measures are put forward. The results indicate that as the inclined working face progresses, the vertical stress peak in the surrounding rock of the bottom pumping roadway is observed approximately 10 to 15 meters ahead of the mining face. Mining activities induce asymmetric deformation in the middle and lower sections of the roadway. The right side exhibits a maximum deformation 1.21 times greater than the left side, while the roadway's plastic zone transitions from a horseshoe shape to a butterfly shape. Based on the asymmetric deformation and failure characteristics of the surrounding rock in the bottom drainage roadway, a multi-level coupling control scheme was developed, comprising high-strength prestressed bolts (cables), deep and shallow grouting anchorage, and shotcrete. The approach was successfully implemented in the field, effectively mitigating the uncoordinated deformation of the roadway. This study provides valuable insights for enhancing the stability of surrounding rock and extending the service life of bottom pumping roadways under similar conditions.*

Keywords: *Close mining; Middle bottom pumping roadway; Dense drilling; Asymmetric deformation failure; Multi-level coupling control technology*

1. Introduction

The design of the gas floor drainage roadway facilitates early gas extraction from the working face, effectively mitigating the gas threat during coal mining operations. However, constructing dense extraction boreholes typically compromises the structural integrity of the enclosing rock mass in the bottom extraction roadway. Due to the influence of mining-induced dynamic pressure near the working face, the damage to the surrounding rock mass of the roadway is exacerbated, and the bottom extraction roadway is seriously deformed in the upper working face and cannot be used again. If the bottom drainage roadway is preserved, it can be used as the transportation roadway of the next mining area roadway, which greatly saves the construction amount of the project.

In recent years, both domestic and international scholars have made significant progress in studying the stress environment and failure characteristics of surrounding rock in dynamic pressure roadways [1-3] .Considering the asymmetric deformation and failure in dynamic pressure roadways, Ding Ziwei and Chen Shangyuan [4-5] developed a numerical model to investigate the primary causes of such deformation. Xu Youlin et al. [6] selected a roadway affected by dynamic pressure as the test site, proposed the concept of a reconstructed bearing arch, and implemented a combined support system using bolt-shotcrete cable and bolt-grouting. This approach significantly enhanced the overall strength of fractured surrounding rock and effectively controlled roadway deformation. Wu Shaokang and Zhu

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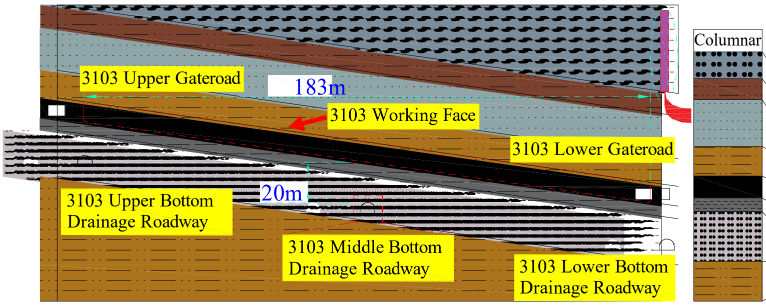
Lei [7-8] proposed the coordinated control technology of "unloading−rotating−solid" and the support concept of multi-level coupling bearing structure for the dynamic pressure failure law caused by coal seam group mining. Yuan Yue et al. [9] developed a mechanical model for circular roadways under a deep dynamic pressure environment and derived the implicit expression for the plastic zone limit, targeting the issues of large deformation instability and control in high-stress mining tunnels. Lu Xiaodong and Ren Xiaoyang et al. [10-11] analyzed the stress evolution law and failure characteristics of surrounding rock in mining roadway through numerical simulation, and obtained the stress change law of surrounding rock under the influence of mining. Through field measurement, combined with theory and numerical calculation, Yang Bo et al. [12] conducted an in-depth study on the deformation mechanism of roadways affected by dynamic pressure superposition and proposed a support system involving "two-side reinforcement and floor reinforcement." However, the surrounding rock damage in the middle bottom drainage roadway is more severe compared to the upper and lower drainage roadways, making support more challenging. Few studies have addressed the combined effects of dynamic pressure and dense drilling on bottom drainage roadways. There is an urgent need to investigate the deformation behavior and reinforcement techniques for middle bottom drainage roadways influenced by dynamic pressure and dense drilling.

Therefore, drawing on the engineering context of the 3103 middle bottom drainage roadway at Hebi No.9 Coal Mine, this paper employs theoretical analysis and numerical simulation to reveal the vertical stress and displacement variation patterns of the roof and sidewalls of the bottom drainage roadway with dense boreholes under mining influence. Reasonable reinforcement and support measures are proposed and validated through field application. The research findings provide valuable reference for the design of surrounding rock control technologies for bottom pumping roadways.

2. Background of the project

2.1. Geological overview of roadway

The 3103 middle bottom drainage roadway is situated in the middle-lower section of the 3103 working face within the 31 mining area of Hebi No.9 Coal Mine. Its depth ranges from approximately 651.2 to 753.8 meters, with a total length of 548.7 meters, and the distance from the roadway top to the coal seam varies between 10 to 27 meters. The roof strata of 3103 middle-bottom pumping roadway are mainly medium-grained sandstone, and the local roof is divided into gray-black sandy mudstone. The direct bottom is the interbed of medium-grained sandstone with L9 limestone and sandy mudstone, and the direct roof is medium-grained sandstone. The roadway layout and histogram are shown in Figure 1.



Lithology	Thickness/m
Medium Grained Sandstone	7.79
Sandy Mudstone	6.2
Fine-grained Sandstone	13.6
Sandy Mudstone	8.72
Coal Seam	6.4
Mudstone	4
Medium Grained Sandstone	14.54
Sandy Mudstone	11.62

Figure 1: Spatial position relationship between working face and roadway and comprehensive histogram

2.2. Failure characteristics of roadway surrounding rock

During the mining of the inclined working face, significant deformation and failure occurred in the 3103 middle bottom pumping roadway, as illustrated in Figure 2. The maximum roof subsidence of the roadway is 850 mm; there is asymmetric deformation in the side, and the maximum deformation is 310 mm. Roof collapse occurs in the section near the top working face.

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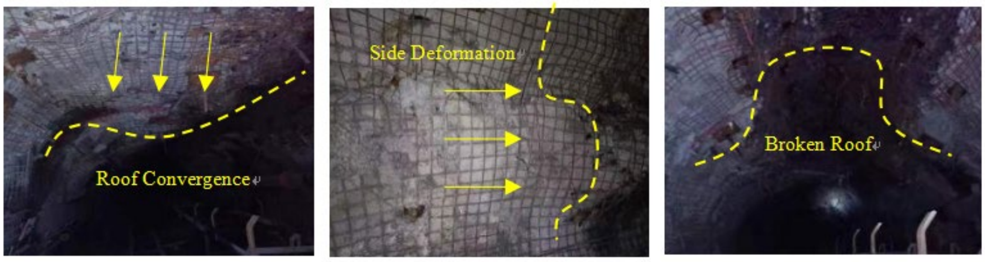

(a) Roof Convergence *(b) Side Deformation* *(c) Broken Roof*

Figure 2: Deformation and failure characteristic of the roadway

3. Surrounding rock deformation law of middle bottom drainage roadway under the influence of mining

3.1. Construction of dense borehole bottom pumping roadway model

To investigate the effect of working face mining on the stability of surrounding rock in a roadway with dense boreholes, a FLAC3D calculation model was developed. The model dimensions are 400 m × 90 m × 100 m. The roadway is positioned directly beneath the coal seam, 15 m below the top working face, with the coal seam thickness being 7.0 m. The cross-section of the 3103 middle-bottom pumping roadway features a straight wall with a semi-circular arch. The roadway has a width of 4.8 m and a height of 3.4 m, as illustrated in Figure 3.The displacements at the left, right, front, rear, and lower boundaries of the model are constrained. A vertical stress of 16.25 MPa is applied at the top, with a lateral pressure coefficient of 1.0.The Mohr-Coulomb criterion is employed for the calculations, and the rock mechanics parameters are listed in Table 1.

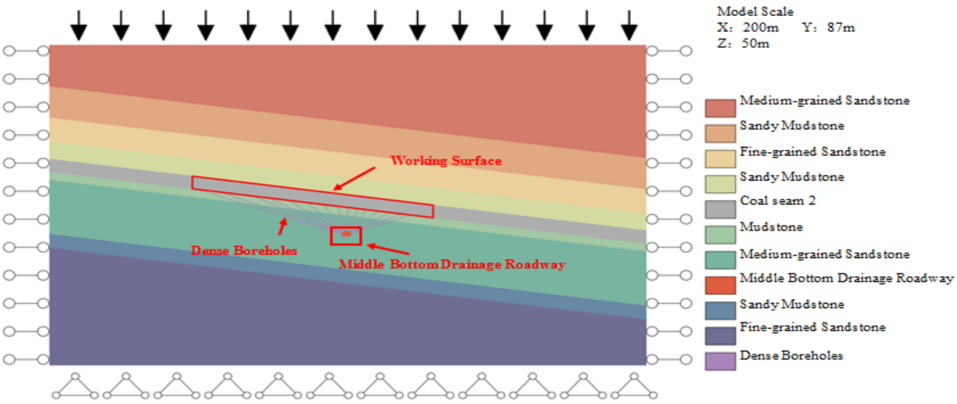

Figure 3: Numerical calculation model

Table 1: Physical and mechanical parameters of rock strata

Lithology	Density/ (kg·m-3)	Bulk Modulus /GPa	Shear Modulus /GPa	Compressive Strength/MPa	Cohesion /Mpa	Internal friction angle/°
Sandy Mudstone	2978	10.43	10.35	1.89	34.9	14.9
Fine-Grained Sandstone	2500	11.75	7.60	4.18	45	35
Medium-Grained Sandstone	2756	16.96	10.14	4.5	51.4	38
Coal Seam 2	1378	0.37	0.73	0.30	14.8	19.5
Mudstone	2462	10.11	4.71	1.18	28.8	16.2

3.2. The influence law of mining disturbance on stress and displacement of surrounding rock in roadway with dense boreholes

The model is sliced in the x-z plane, as illustrated in Figure 4.As the inclined working face above

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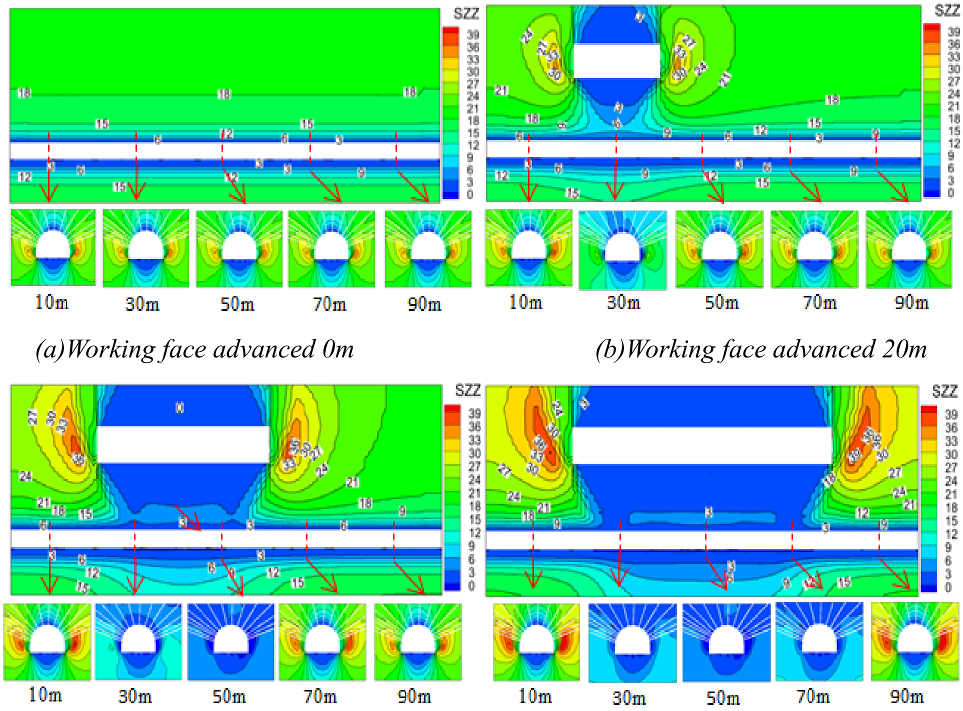
the bottom pumping roadway advances, stress unloading occurs in the goaf. The middle bottom pumping roadway, located beneath the working face, lies in the vertical stress unloading zone, where the surrounding stress is relatively low. Mining activities cause stress redistribution in the rock strata around the working face, leading to continuous adjustment and transmission of the original rock stress. Advance abutment pressure forms around the working face, intensifying stress concentration on the left and right sides of the middle-bottom pumping roadway in the front and rear sections of the goaf. This severely impacts the stability of the floor roadway within the goaf.



(a)Working face advanced 0m *(b)Working face advanced 20m*

(c)Working face advanced 40m *(d)Working face advanced 60m*

Figure 4: Evolution law of vertical stress of surrounding rock of roadway affected by mining

As shown in Figure 5, vertical stress monitoring of the roof and sides of the bottom pumping roadway reveals that when the working face advances 20 m, a stress concentration area forms in front of and behind the working face. Under dynamic pressure, the peak roof stress of the bottom pumping roadway reaches 0.6 MPa, while the peak stresses on the left and right sides reach 11.1 MPa and 12.3 MPa, respectively. When the working face advances 40 m, the roof stress peak appears 50 m from the roadway, reaching 0.75 MPa. The peak stresses on the left and right sides decrease to 9.9 MPa and 11.2 MPa, respectively. At an advancing distance of 60 m, the roof peak stress of the roadway stabilizes at 0.76 MPa, while the left and right side peak stresses further decrease to 9.2 MPa and 10.8 MPa, respectively. These observations indicate that as the working face advances, the vertical stress peak of the roadway roof initially increases before stabilizing, while the peak side stresses decrease progressively.

Figure 6 illustrates the displacement curve of the 3103 middle-bottom drainage roadway during different mining stages. When the working face is advanced to 20 m, the maximum displacement occurs at 30 m of roadway roof and side. When the working face is advanced to 40 m, the maximum displacement occurs at 40 m of roadway roof and side. When the working face is advanced to 60 m, the maximum displacement occurs at 50 m of roadway roof and side. It is concluded that after the working face is advanced, the deformation of the roadway is the most serious at the bottom drainage roadway below the middle point of the goaf.

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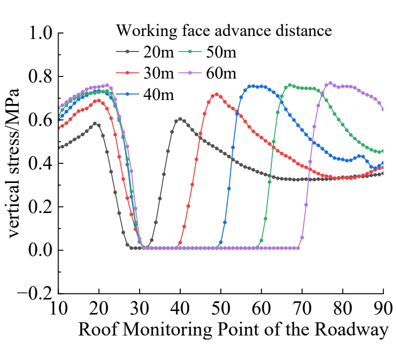
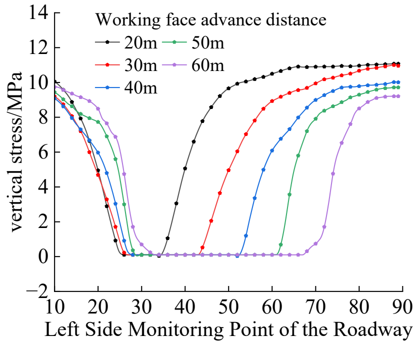
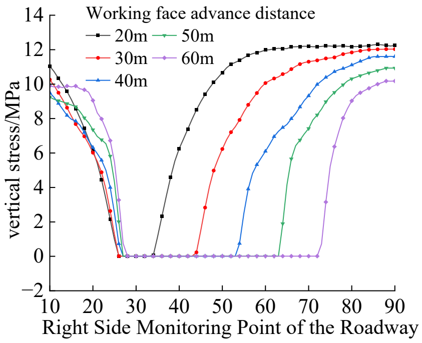


(a) Roof Stress Measurement of the Roadway

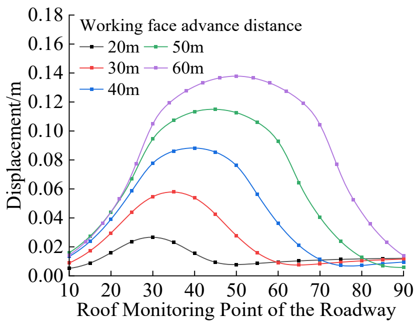


(b) Stress Measurement of the Left Side of the Roadway

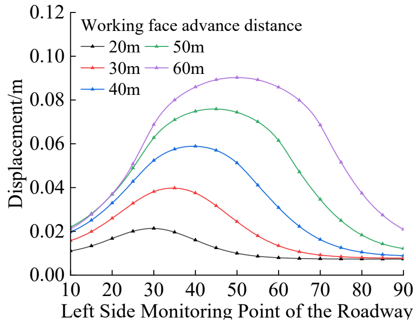


(c) Stress Measurement of the Right Side of the Roadway

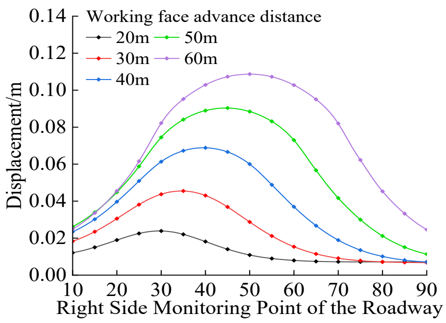
Figure 5: Stress distribution curve of roadway surrounding rock after mining influence



(a) Roof Displacement Measurement of the Roadway



(b) Left Side Displacement Measurement of the Roadway



(c) Right Side Displacement Measurement of the Roadway

Figure 6: Displacement change curve of roadway surrounding rock after mining influence

3.3. Influence of mining disturbance on the plastic zone of surrounding rock in a roadway with dense boreholes

The stability of the surrounding rock of the roadway is closely related to the plastic zone. It can be seen from Figure 7 that after the excavation of the roadway, the horseshoe-shaped plastic zone is generated around the bottom drainage roadway. As the inclined top working face advances to 30 m, the

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stress is gradually released. The failure position of the surrounding rock of the roadway in the non-uniform stress field is concentrated on the arch shoulder, and the butterfly-shaped plastic zone at the top of the roadway is initially apparent. As the inclined working face advances to 50 m, the butterfly leaf part with the characteristics of butterfly plastic zone develops to the deep surrounding rock, forming a complete butterfly shape. When the working face is advanced to 60 m, the plastic zone effect of rock mass in the plastic zone is stronger than that in the horseshoe-shaped plastic zone, especially in the butterfly leaf position, which is more sensitive to the plastic expansion caused by stress concentration, and the surrounding rock is destroyed in a large area, and the roadway is seriously deformed. The numerical simulation results show that the mining stress caused by the mining of the top coal seam has a great influence on the stability of the bottom roadway. With the mining of the top working face, the plastic zone of the middle bottom pumping roadway gradually changes from a semi-circular arch to a butterfly shape, and the shape remains unchanged and the range increases after it becomes a butterfly plastic zone.

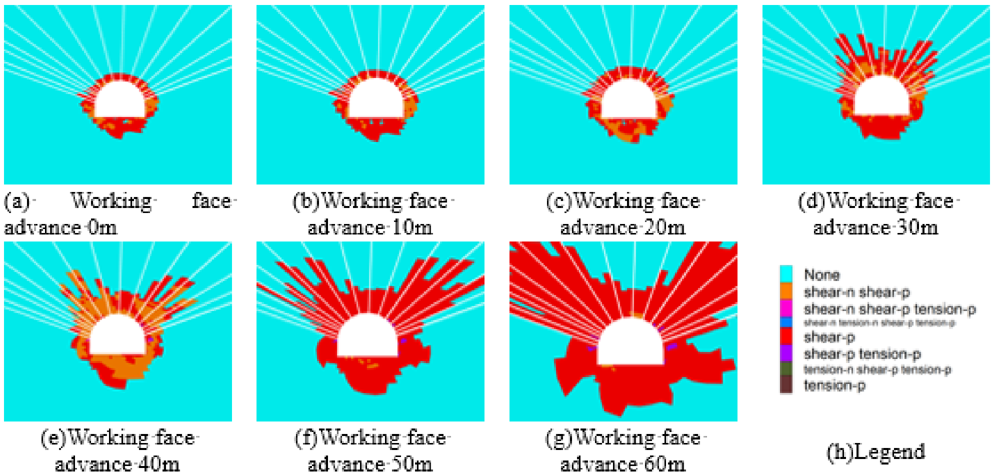

Figure 7: Working face mining plastic zone change diagram

4. Design of surrounding rock control scheme for bottom drainage roadway

Considering the damage to the 3103 middle-bottom drainage roadway and integrating the numerical simulation results with the control principles of roadway surrounding rock [13–14], a tailored support design for the middle-bottom drainage roadway is proposed. The design of the roadway support section is illustrated in Figure 8.The detailed parameters for support reinforcement are as follows:

1) Roadway roof support parameters: The roadway roof is supported by grouting bolt and cable. The grouting bolt is arranged with a row spacing of 1600 × 1600 mm. The reinforcing anchor cable is arranged in ' one or two ' type. The right roof is arranged with φ22 × 8000 mm steel strand anchor cable. The top and left roof are arranged with φ22 × 8300 mm grouting anchor cable. The end of the anchor cable is anchored and the anchoring force is not less than 156 kN. The grouting pressure of the grouting anchor cable is not less than 6MPa, and the row spacing is 1800 mm × 3000 mm.

2) Support parameters of roadway side: It can be seen from the above cloud map and stress curve that the stress on the right side is higher than that on the left side. According to the numerical simulation and actual deformation, the reinforcement design of grouting bolt with different spacing is selected to support the right side. The grouting bolt on the right side is arranged with a spacing of 800 mm. The spacing of grouting bolt on the left side is set to 1600 mm, and the grouting pressure of grouting bolt is not less than 3MPa.

3) After the roadway is exposed, 20mm of thin layer concrete is sprayed in time to find the surrounding rock and seal the jointed rock. After the high-strength anchor rod is set up, the secondary concrete injection is carried out, with a thickness of 30 mm, which is used to seal the surrounding rock, and the grouting is carried out, and the steel mesh and anchor plate are required to be covered. After the grouting is completed, the final spray is carried out with a thickness of 50 mm.

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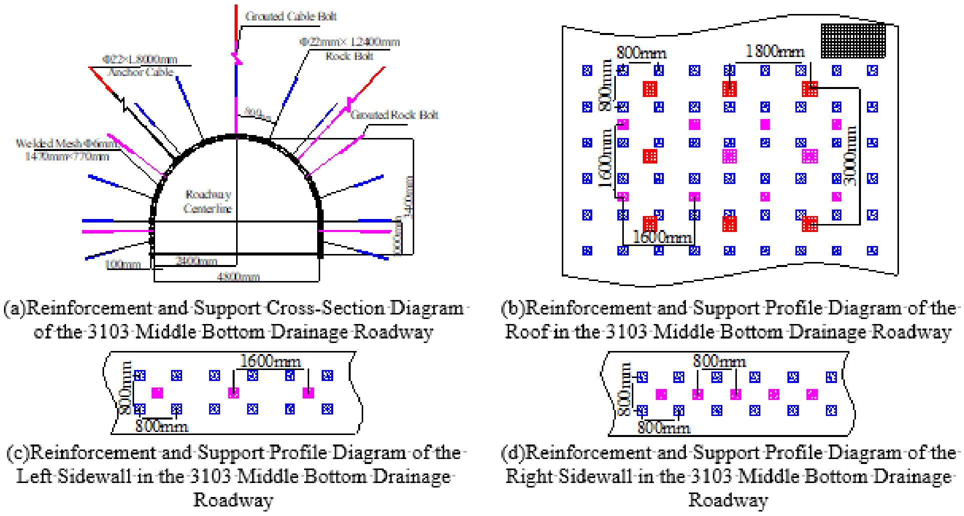

(a)Reinforcement and Support Cross-Section Diagram of the 3103 Middle Bottom Drainage Roadway

(b)Reinforcement and Support Profile Diagram of the Roof in the 3103 Middle Bottom Drainage Roadway

(c)Reinforcement and Support Profile Diagram of the Left Sidewall in the 3103 Middle Bottom Drainage Roadway

(d)Reinforcement and Support Profile Diagram of the Right Sidewall in the 3103 Middle Bottom Drainage Roadway

Figure 8: Reinforcement support section diagram and support parameters

5. Field Application Results

To validate the effectiveness of the multi-level coupling control technology comprising high-strength anchor cables, anchor cable grouting, and shotcrete, the surrounding rock deformation of the reinforced roadway was monitored, with the results presented in Figure 9.

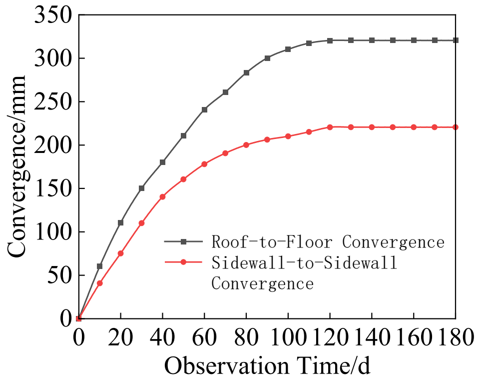

Figure 9: The surface displacement of roadway under reinforcement support

Following the reinforcement of the 3103 middle-bottom pumping roadway, the surrounding rock deformation initially progressed rapidly before slowing down. After 120 days, the roadway convergence stabilized. Monitoring data indicate that the roof-to-floor convergence is less than 320 mm, while the side-to-side convergence is less than 220 mm. The overall control of roadway deformation has improved, ensuring good stability of the surrounding rock.

6. Conclusion

(1) During the working face mining process, the peak vertical stress in the surrounding rock of the middle bottom pumping roadway occurs approximately 10–15 meters ahead of the mining face.The bottom roadway experiences asymmetric deformation due to the mining activities in the top inclined working face. The maximum deformation on the right side is 1.21 times greater than that on the left, with the most severe deformation observed in the bottom pumping roadway beneath the midpoint of the goaf.

(2) The mining stress induced by the top working face significantly affects the stability of the bottom roadway. As the top working face is mined, the plastic zone of the middle bottom pumping roadway evolves from a semi-circular arch to a butterfly shape. Once the butterfly shape forms, its structure remains stable while the zone's range expands.

ISSN 2663-1563 Vol. 6, Issue 4: 137-144, DOI: 10.25236/AJAGE.2024.060420

(3) According to the non-uniform deformation characteristics of 3103 medium-bottom drainage roadway, the multi-level coupling control technology of ' high-strength anchor net cable + anchor cable grouting + shotcrete ' is adopted to reinforce the roadway section. Six months post-mining of the working face, the roof-to-floor convergence of the roadway was reduced to less than 320 mm, and the side-to-side convergence to less than 220 mm, ensuring the long-term stability of the bottom drainage roadway.

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