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Research Article

Deformation Characteristics and Control Technology of Roadway in Water-Rich Soft Rock

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Jurassic soft rocks are the main coal-bearing strata in western mining areas, which are rich in water and high in expansive minerals. The roof and floor of the coal seam are easily muddied and disintegrated when affected by water, and heave floor of roadway in soft rock has become one of the problems that restricts the safety and efficient production of coal mines in western mining areas. It is not ideal for the effect of the traditional roadway control theory on geological soft rock roadway support, and the deformation is difficult to control. Take the tailgate of 11506 working face of a coal mine in the western mining area as the research background. This surrounding rock conditions and the deformation characteristics of the roadway in tailgate of 11506 working face were analyzed systematically, and the optimization design of the support scheme of the water-rich soft rock roadway was carried out by using theoretical analysis and numerical simulation. The application of the support in the tailgate of 11506 working face was carried out. The results show that slip of the two sidewalls, support failure, stress concentration, and floor heave were failure characteristics in water-rich soft rock roadway. The optimization of the roadway section, thin guniting of the roadway surface, optimization of support components, and gradient support could effectively achieve the control of soft rock roadway deformation. The maximum floor heave during the roadway deformation monitoring period was 230 mm, which decreased about 75% compared with original support. The influence range of the advance abutment stress is 0~60 m, of which 0~30 m is the serious influence area. The research results have good engineering practice significance for the control of bottom bulge of the soft rock roadway in this coal mine and western mining area.

1. Introduction

Soft rock roadway support in Jurassic strata is influenced by the stress environment of the roadway, mining range, geological conditions, etc. The surrounding rock of roadway is dominated by muddy rock formations, which are more fragmented and easily disintegrated by water, and is a typical geological soft rock [1]. Mining in soft rock faces great challenges, and the problems caused by soft rock pose great hazards to mine production [2].

Aiming at the treatment of soft rock support in the western mining area, numerous studies and field practices have been conducted by many researchers. Controlling water environment and horizontal stress state in floor is the key to floor control [3]. Wang et al. [4] indicated that the greater the strength of the surrounding rock at the sidewalls, the smaller the amount of floor heave of the roadway, and the floor heave can be controlled by reinforcing the two sidewalls of the roadway; Hou et al. [5] believed that the weak position of the surrounding rock support is the first to be damaged under stress and the inverted arch can effectively control the floor heave; He et al. [6] proposed the surrounding rock synergistic control technology. Bai et al. [7] analyzed the deformation characteristics of the rock layer at the floor of the roadway under the action of mining-induced stress, summarized the stratum movement laws at different depths of the floor, and proposed a control scheme to reinforce the floor of the roadway; Kang et al. [8] used the method which is a combination of theoretical analysis and physical experiments to propose a mathematical expression for the amount of floor heave and unique measures which can prevent and control the floor heave; Wen et al. [9] established the floor heave mechanical model with corresponding floor heave control technology aiming at the technical difficulties of large deformation of soft rock in the district; Xie et al. [10] proposed the technology by using grouting bolt with concrete backfill to control the floor heave technology in deep roadways. The previous research has provided valuable experience for high water expansion weakly cemented soft rock roadway support. Yu et al. [11] investigated a combined optimized support method, which greatly improved the roadway stability and effectively controlled the roadway deformation. MO et al. [12] studied the mechanisms of floor heave by numerical models in roadways. Li et al. [13] considered that the stress field in the surrounding rock is important for the stability of roadway. Yang et al. [14] proposed a combined support to control large deformation of soft rock roadway. Water-rich soft rock in western mining area needs that the anchor cable used in the optimal control scheme has the characteristics of constant resistance and large deformation [15]. Jia and Liu [16] compared the two kinds of support by numerical simulation method and believed that the combined support of "steel mesh + full anchor cable + concrete floor" was effective for water-rich roadway. The support approaches for a water-rich soft rock roadway in tectonic stress areas were studied using UDEC software [17]. The tunnel deformation monitoring and measurement work can be used to grasp the dynamic evolution law of the surrounding rock [18]. Jing et al. [19] considered influence of the immersion softening phenomenon of the roadway floor and the self-supporting structure characteristics of the surrounding rock on the stability of the surrounding rock, and a new concept of the internal and external self-bearing structure was proposed. Aiming at soft rock ground support issues under conditions of high stress and long-term water immersion, Yang et al. [20] believed that the support technology focusing on cutting off the water, strengthening the small structure of the rock and transferring the large structure of the rock was effective. The key of supporting water-rich soft rock roadway is the protection of surrounding rock and the effectiveness of supporting. The meaningful work done by the researchers from the support technology can guide the development of this study.

The surrounding rock conditions and the deformation characteristics of the roadway were analyzed, and the optimization design of the water-rich soft rock roadway support scheme was carried out. The key points of roadway support in water-rich soft rock are pointed out. Engineering practice shows that the technology can effectively control the large deformation of the soft rock roadway and meet the requirements of an efficient production of working face.

2. Project Overview and Roadway Failure Characteristics

2.1. Project Overview. The 11506 working face is mining 5 coal seam with an average thickness of 2.62 m. It is a monoclinic structure inclined to the east, with an inclination angle of 6~9°. The surrounding rock of the roadway is soft rock; the lithology is mainly composed of mudstone, siltstone, and fine sandstone; and the rock is soft and easy to swell and become mudded when encountering water, mainly manifested as the floor heave of the roadway. There are no other large faults, folds, magma intrusion, and column collapse in the working face.

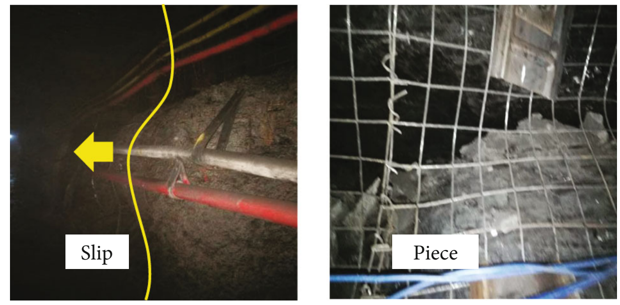


Figure 1: Slip of the sidewalls in site.

The 11506 working face is under the mining area in 2 coal seam and the coarse sandstone aquifer on the roof of the 2 coal seam, which may produce certain recharge to the sandstone aquifer on the roof of the 5 coal seam.

2.2. Roadway Failure Characteristics. According to the analysis of geological data of this coal mine and field observation, there are the following characteristics in the roadway of 11506 working face:

(1) Shallow buried depth and small stress

(2) False roof (mudstone) and immediate roof (siltstone and mudstone interlayer) swollen with water and poor cementation, making the support more difficult

(3) The roadway is drived along the roof, the lower part of the roadway is nearly 1 m high mudstone, and the floor of the roadway is 0.5 m thin coal seam. Due to the large amount of water causing the mudstone of the side to swell and weaken seriously, the mudstone interlayer between the coal seam is prone to weak surface slip when the roadway is loaded by the two sidewalls (Figure 1)

(4) Tailgate of 11506 working face is affected by mining 11502 working face and 12202 working face gob in 2 coal seam, which seriously affects the stability of the roadway bolt-mesh support system

Currently, there are mainly the following problems existing in the support of roadway in water-rich soft rock in the coal mine.

2.2.1. Slip of the Two Sidewalls. The roadway is drived along the roof, there are about 1 m high mudstone in the lower part of the roadway, and the bottom of the roadway is 0.5 m thin coal seam (Figure 2). Due to the large amount of water causing the mudstone of the side to be weakened seriously, the mudstone between the coal seam in sidewalls is prone to weak surface slip leading to the deformation of the sidewalls, affecting the normal work surface mining.

Two sidewall deformation can be divided into two types which are stress "weak face slip" and mudstone "weak face slip."

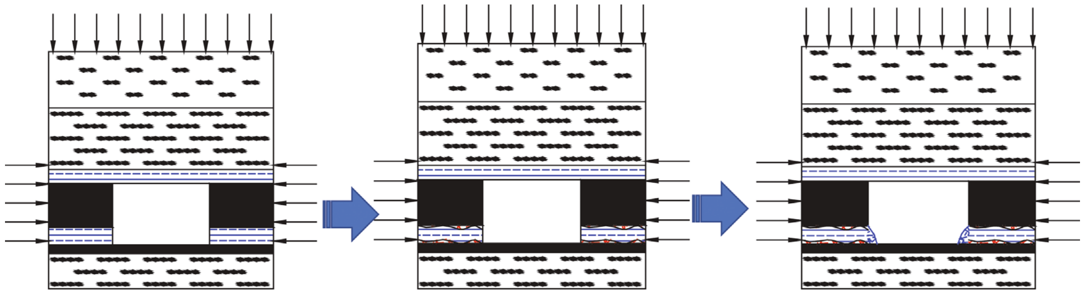


Figure 2: Sidewalls slip process of roadway in 11506 working face.

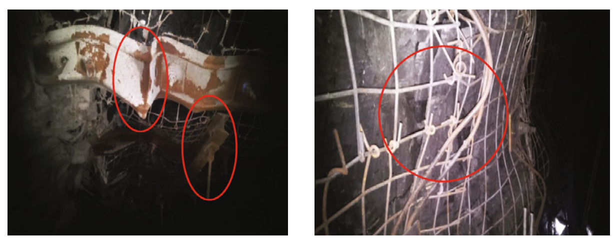


Figure 3: The failure of bolt-cable-mesh support: (a) steel belt bending and shear of anchor cable. (a) Failure of anchor net.

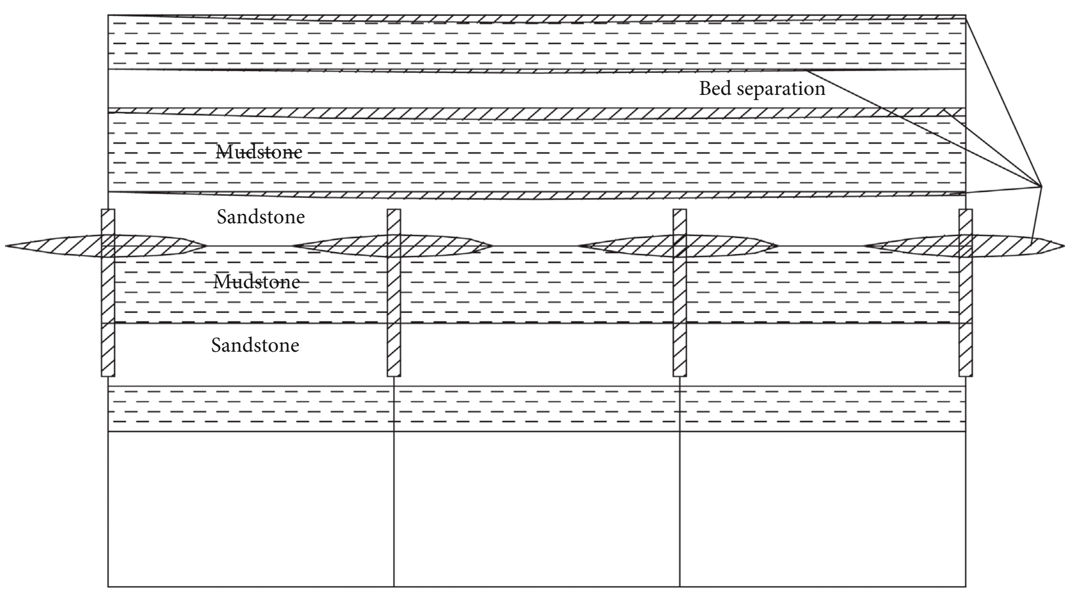


Figure 4: The diagram of composite roof separation.

With the increase of horizontal stress, due to the sliding contact between the mudstone and coal seams, the poor formation of the roadway at the intersection of different lithologies, and the poor control ability of the support to the surrounding rock, the weak surface (red part in Figure 2) is formed under the action of horizontal stress, and the horizontal slip of the two sidewalls occurs with the change of time.

Increasing the friction force at the intersection of coal and rock layers or taking measures to prevent the movement of the sidewalls can effectively control the deformation of the sidewalls. At the same time, undertaking timely surface blocking measures at the drenching place to avoid the contact between the surrounding rock and water will lead to the argillization of the surrounding rock and control the occurrence of the weak surface slip phenomenon.

2.2.2. Failure of Support. The main reasons for the failure of the support system are the unreasonable support and low efficiency of bolt and cable support, mainly manifested by

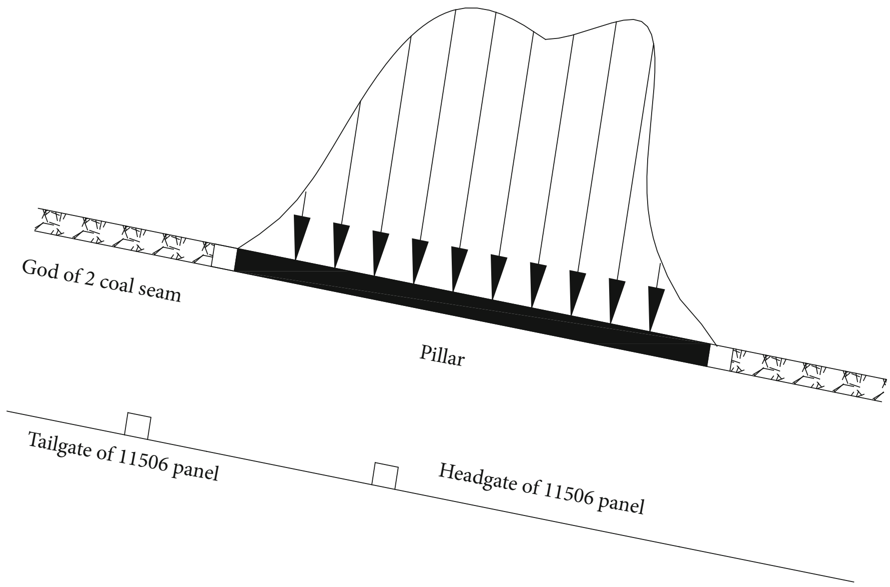


Figure 5: Roadway position relationship and stress field superposition.

the deformation of the steel belt shearing the bolt, the steel ladder obstructing the bolt force transfer, and the bolt beam shearing the anchor cable as shown in Figure 3.

The steel belt is deformed and stretched locally under stress causing the adjacent bolts to shear off, meanwhile, the stress of the steel ladder is linear, which is not conducive to the transmission of bolt preload and working resistance.. When the cable is stressed, the cable beam is twisted and deformed, and this results in the cable shearing off.

Under the condition of composite soft rock roof, there is obvious roof separation fracture distribution in the bolt section as shown in Figure 4, and the roof separation is beyond the control range of the bolt, which makes the bolt-cable support fail.

2.2.3. Stress Concentration. The tailgate of 11506 working face was arranged about 40 m below the coal pillar in the 2-coal mining interval, and the roadway was in the stress concentration area with significantly higher stresses as shown in Figure 5. At the same time, the tailgate of 11506 working face was influenced by mining disturbance by the adjacent working face.

2.2.4. Floor Heave. The floor is deformed and damaged under the influence of the stress of the two sidewalls and the lithology of the rock layer. It is necessary to build inverted arch to keep the roadway meet service requirement. If the design is not reached during the construction, the deformation of the roadway will be very violent. Figure 6 shows the damage of floor heave.

In summary, the overall slip of the two sidewalls of 11506 working face is large, which is nearly 1.5 m in local part. The existing support cannot effectively control the roadway deformation; therefore, the roadway support stability is not effectively guaranteed.

(a) (b)

Figure 6: The damage of floor: (a) floor heave. (b) Stress cracking of floor.

3. Support Design and Optimization Methods

3.1. Methods

3.1.1. Monitoring Measures. The roadway surface convergence monitoring can better judge the movement of surrounding rock and analyze whether the surrounding rock is in a stable state. Roadway surface convergence monitoring includes two sidewalls of the displacement monitoring, roof, and floor displacement monitoring. In site, the cross-point method is used to monitor the surface displacement of roadway, and the monitoring points are arranged on each monitoring section.

The aim of this study is to evaluate the effectiveness of the support scheme by monitoring roadway surface convergence.

3.1.2. Modeling. To simplify the simulation conditions, set the upper boundary as free and apply gravity (10 MPa), and set the remaining boundaries as fixed. The Mohr-Coulomb model was selected to simulate the condition. The rock parameters of main strata in the model are shown in Table 1. In FLAC3D, the cable structure elements are used to model the rock bolts and cables. The mainly mechanical and geometric parameters are listed in Table 2.

Table 1: Main rock parameters of main strata in the model.

Strata	Tensile strength (MPa)	Shear modulus (GPa)	Bulk modulus (GPa)	Cohesion (MPa)	Friction angle (°)
Overlying strata	0.55	3.66	5.31	1.43	41
Medium-fine sandstone	0.85	3.55	5.32	2.7	43
5 coal seam	0.23	1.45	4.97	0.68	24
Argillaceous siltstone	0.31	1.52	3.38	1.5	27
Fine sandstone	0.75	3.46	5.11	3.08	33

Table 2: Mechanical parameters of the blots [21].

Type	E (GPa)	C_g (N/m)	K_g (N/m)	ρ_g (m)	A (m^2)	F_t (N)
Rock bolt	200	4.7e5	5.6e9	8.79e-2	3.14e-4	1.6e5
Anchor cable	195	4.7e5	4.2e9	8.79e-2	2.49e-4	2.5e5
Introduction	Young's modulus	Grout cohesive strength per unit length	Grout stiffness per unit length	Grout exposed Perimeter	Cross-sectional area	Tensile yield strength

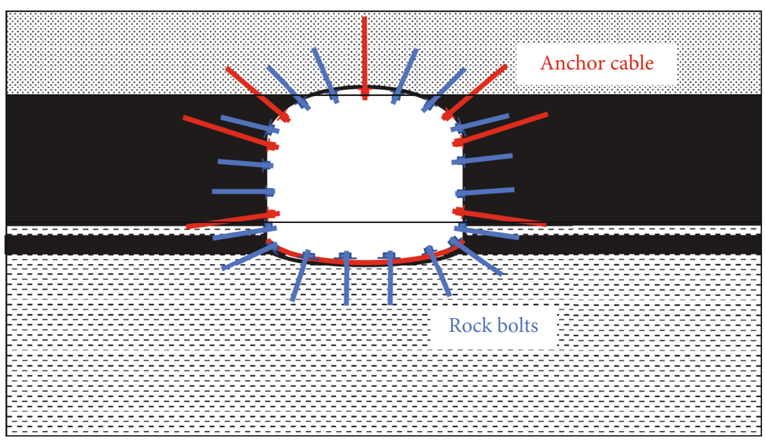
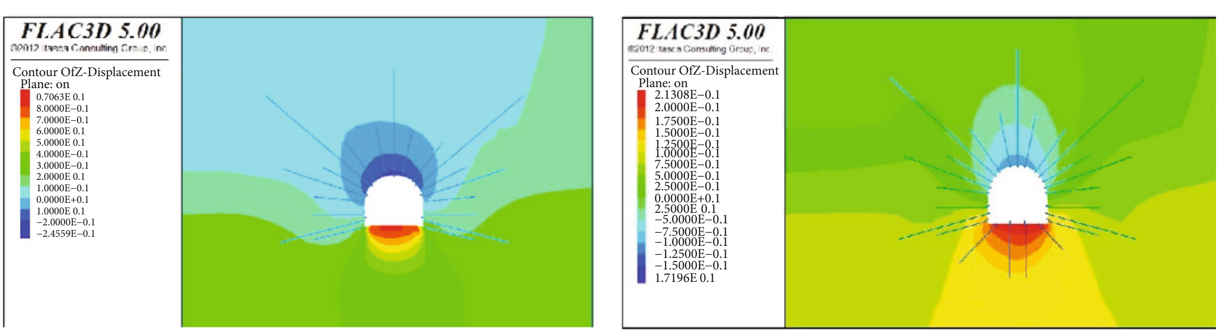


Figure 7: The diagram of cross-section support.



(a) Condition without floor bolts

(b) Condition with floor bolts

Figure 8: Numerical results of floor reinforcement.

3.2. Support Design and Optimization Principles and Scheme. In view of the problems in original support and the failure characteristics of roadway, the following supporting design and optimization principles were proposed..

3.2.1. Roadway Cross-Section Optimization. It is easy to cause stress concentration in the shoulder of the roadway with rectangular or trapezoidal shape, while the roadway driving forming effect is poor, which is not conducive to

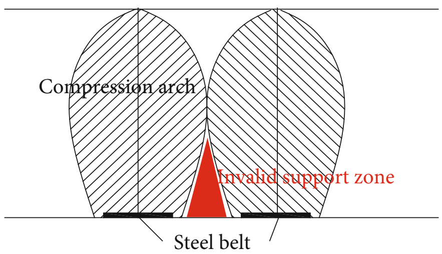


FIGURE 9: The relationship between bolt and surface support.

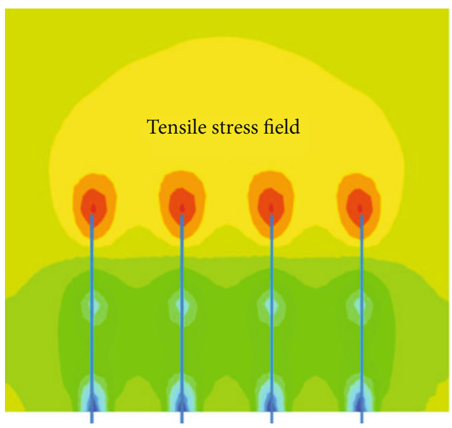


FIGURE 10: Bolt tensile stress field.

the construction of bolt-mesh-cable support and the effect of the role. Therefore, the shape of the roadway was changed to straight wall arch with three-centered arch bottom section as shown in Figure 7, and the construction of the floor bolt was carried out along with the floor water impermeability treatment simultaneously.

Figure 8 shows the displacement of the floor with or without floor bolt support. The floor bolt support makes the laminated floor rock form a combined rock beam, which strengthens the integrity of the floor; meanwhile, it prevents the soft rock expansion, swelling, and the generation of new fissures.

3.2.2. Thin Guniting of Surrounding Rock. The purpose of thin guniting is to increase the surface sealing effect and slurry guniting speed while reducing the comprehensive cost of surface sealing. Effectively seal the spillage of harmful gases in the coal body, and isolate the mine air to produce oxidation to the coal body with the aim of providing fireproof, impermeable, anti-weathering, and anti-rusting function. The material has an elongation of 30%~50%, which can better adapt to the deformation of the roadway caused by mining.

3.2.3. Optimization of Surface Support. The surface support should not only have a certain surface area, but also have a certain strength and toughness. Surface support is to provide a certain compressive stress to the roadway surface through the tension of the bolt to the surface support body and to protect the surface (Figure 9).

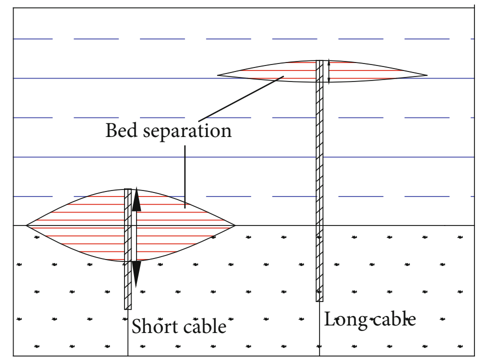


FIGURE 11: The diagram of "long+short cables" support.

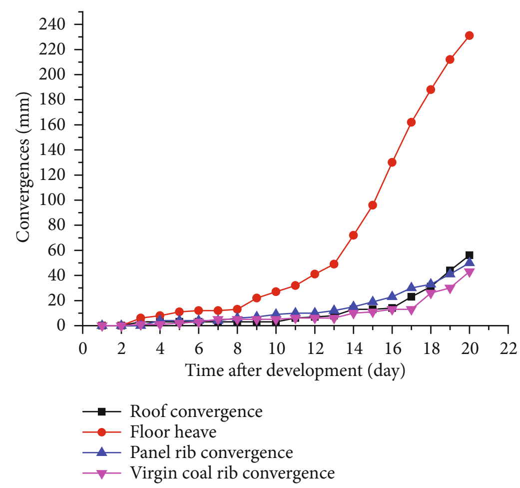


FIGURE 12: The relation between convergences and time.

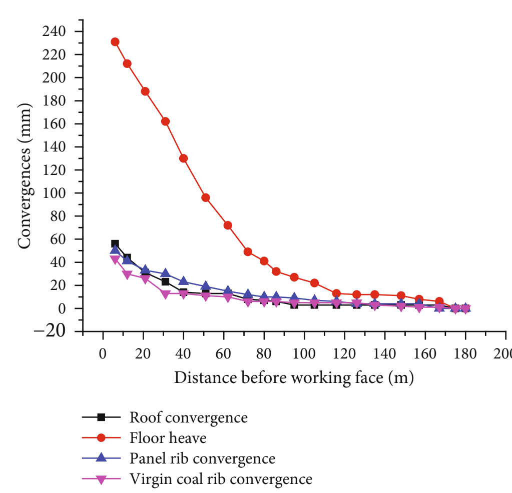


FIGURE 13: The relation between convergences and distance before working face.

3.2.4. Gradient Support. When the cables work, the bolting section and above a certain range of cables bolt is tensile stress (Figure 10). The composite soft rock roof interfacial bonding is poor, so the tensile stress area is very easy to make roof separation.

Figure 14: The result of roadway support optimization.

Therefore, the “long + short cables” are arranged alternately to strengthen the effective control of the composite soft rock roof slab in a targeted manner as shown in Figure 11.

4. Application and Result Analyses

The tailgate of 11506 working face was supported according to the support optimization design. Q500 high strength and high prestress bolts with snake shaped were used to reinforce the floor corner of the roadway. Blots for the floor corner are 20 mm in diameter and 2800 mm in length and that of the cables are 17.8 mm and 7000 mm. The size of steel belt guard is 450×280×4.75 mm (length×width×thickness) and that of the top bolt plate is 1 50×150×10 mm. The thin guniting be carried out with a thickness of 2~5 mm..

Four measuring points are arranged at 180 m in the advanced mining face, and the interval between the measuring points is 15 m. Typical measuring points are selected to analyze the relationship between surrounding rock deformation with time and mining distance. The relationship of the deformation of the surrounding rock ranging between the time and the pushing distance is analyzed in Figures 12 and 13, respectively.

The result shows that the deformation of the roadway is mainly floor heave. During the observation period, the maximum floor heave was 230 mm, and the roadway integrity was well (Figure 14). Compared to the maximum floor heave of 900 mm with origin support, the floor heave was reduced by about 75% after optimization.

After all the collected data were analyzed, it was concluded that the advanced abutment stress influence range of 11506 tailgate was 0~60 m, among which 0~30 m was the serious area.

5. Conclusion

(1) The failure in the tailgate of the 11506 working face is mainly the overall slip of the two sidewalls, the failure of the support system, the superposition of mining stress, and the floor heave

(2) The optimal support design methods of roadway deformation include “optimization of roadway section shape,” “rapid thin guniting of surrounding rock,” “improvement of surface support structure,” and “gradient support” in the water-rich soft rock roadway

(3) The deformation of the roadway is mainly floor heave. The maximum floor heave is 230 mm with the optimal support, which is reduced by about 75% compared with origin support. The advanced abutment stress influence range of 11506 tailgate was 0~60 m, among which 0~30 m was the serious area

The optimized support design avoids roadway reworking effectively, improves driving efficiency, reduces labor intensity, alleviates mining drifting, and achieves good social and economic benefits.

Data Availability

The tables, some figures, and data used to support the findings of this study are currently under embargo, while the research findings are commercialized. Requests for data six months after the publication of this article will be considered by the corresponding author.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

[1] B. T. Shen, “Coal mine roadway stability in soft rock: a case study,” *Rock Mechanics and Rock Engineering*, vol. 47, no. 6, pp. 2225–2238, 2014.

[2] J. L. Cai, *Research on deformation and instability mechanism and application research for Jurassic weak-cemented soft rock roadways*, Anhui University of Science and Technology, 2020.

[3] Yuyang Wang, Yong Liu, Chen Wang, Lianchang Han, and Guanghai Leng, “Mechanics of bottom bulge and control technology in deep mine soft rock roadway,” *Chinese Journal of Underground Space and Engineering*, vol. 17, no. S1, pp. 411–418, 2021.

[4] W. J. Wang and T. Feng, "Study on mechanism of reinforcing sides to control floor heave of extraction opening," *Chinese Journal of Rock Mechanics and Engineering*, vol. 24, no. 5, pp. 808–811, 2005.

[5] C. J. Hou and L. H. Hou, "Reinforcing sidewalls and corners of gateway to control floor heave," *Journal of China Coal Society*, vol. 20, no. 3, pp. 229–234, 1995.

[6] M. C. He, "Mechanics mechanism of soft rock deformation and supporting countermeasures in coal mine," *Hydrogeology Engineering Geology*, vol. 24, no. 2, pp. 12–16, 1997.

[7] J. B. Bai, W. F. Li, X. Y. Wang, Y. Xu, and L. J. Huo, "Mechanism of floor heave and control technology of roadway induced by mining," *Journal of Mining and Safety Engineering*, vol. 28, no. 1, pp. 1–5, 2011.

[8] H. P. Kang, *Mechanism of soft rock roadway floor heave and its prevention*, China Coal Industry Press, 1993.

[9] Z. J. Wen, J. Y. Lu, and Q. H. Xiao, "Failure mechanism of floor heave and supporting technology of soft rock roadway," *Journal of China Coal Society*, vol. 44, no. 7, pp. 1991–1999, 2019.

[10] G. X. Xie and J. C. Chang, "Study on overcutting-bolting & grouting-backfilling concrete to control the floor heave of deep mine roadway," *Journal of China Coal Society*, vol. 35, no. 8, pp. 1242–1246, 2010.

[11] K. P. Yu, F. Y. Ren, R. Puscasu, P. Lin, and Q. Meng, "Optimization of combined support in soft-rock roadway," *Tunnelling and Underground Space Technology*, vol. 103, article 103502, 2020.

[12] S. Mo, P. Sheffield, P. Corbett et al., "A numerical investigation into floor buckling mechanisms in underground coal mine roadways," *Tunnelling and Underground Space Technology*, vol. 103, article 103497, 2020.

[13] L. P. Li, C. S. Shang, K. W. Chu et al., "Large-scale geomechanical model tests for stability assessment of super-large cross-section tunnel," *Tunnelling and Underground Space Technology*, vol. 109, article 103756, 2021.

[14] S. Q. Yang, M. Chen, H. W. Jing, K. F. Chen, and B. Meng, "A case study on large deformation failure mechanism of deep soft rock roadway in Xin'An coal mine, China," *Engineering Geology*, vol. 217, pp. 89–101, 2017.

[15] T. B. Zhao, M. L. Xing, W. Y. Guo, C. W. Wang, and B. Wang, "Anchoring effect and energy-absorbing support mechanism of large deformation bolt," *Journal of Central South University*, vol. 28, no. 2, pp. 572–581, 2021.

[16] H. C. Jia and Y. Liu, "Analysis on deformation and failure characteristics of surrounding rock in water-rich roadway and weakly cemented soft rock," *China Energy and Environmental Protection*, vol. 44, no. 2, pp. 303–310, 2022.

[17] G. Z. Xue, C. Gu, X. Q. Fang, and T. Wei, "A case study on large deformation failure mechanism and control techniques for soft rock roadways in tectonic stress areas," *China Energy and Environmental Protection*, vol. 11, no. 13, p. 3510, 2019.

[18] F. L. Chen, K. H. Zeng, X. J. Li, M. Xu, and H. Dai, "Construction monitoring and numerical simulation of water-rich tuff soft rock tunnel," *IOP Conference Series-Earth and Environmental Science*, vol. 455, 2020.

[19] W. Jing, X. Wang, P. W. Hao, L. Jing, and W. Xue, "Instability mechanism and key control technology of deep soft rock roadway under long-term water immersion," *Advances In Civil Engineering*, vol. 2021, Article ID 6670379, 13 pages, 2021.

[20] R. S. Yang, Y. L. Li, D. M. Guo, L. Yao, T. Yang, and T. Li, "Failure mechanism and control technology of water-immersed roadway in high-stress and soft rock in a deep mine," *International Journal of Mining Science and Technology*, vol. 27, no. 2, pp. 245–252, 2017.

[21] K. Zhang, G. M. Zhang, R. B. Hou, Y. Wu, and H. Zhou, "Stress evolution in roadway rock bolts during mining in a fully mechanized longwall face, and an evaluation of rock bolt support design," *Rock Mechanics and Rock Engineering*, vol. 48, pp. 333–344, 2015.