International Journal of Energy
ISSN: 2957-9473 | Vol. 6, No. 1, 2025

Deformation Law and Control Technology of Floor Roadway under Multiple Mining Conditions

Weikun Yang [1, 2, *], Xiangyang Zhang [1, 2], Jun Zhao [3]

[1] National Key Laboratory of Deep Coal Mining and Environmental Protection, Anhui University of Science and Technology, Huainan, Anhui, China
[2] School of Mining Engineering, Anhui University of Science and Technology, Huainan, Anhui, China
[3] Bojiang Haizi Mine, Inner Mongolia Silver Macro Energy Development Co., Ltd., Ordos, Inner Mongolia, China
*** Corresponding author:** Weikun Yang

Abstract: In this study, FLAC3D software was used to establish a numerical simulation model to investigate the deformation characteristics of surrounding rock in the floor roadway of a gangue belt conveyor at a mining area in Gubei Mine. The stress evolution and plastic zone expansion of the surrounding rock under multiple mining-induced disturbances were explored, and an optimized roadway support scheme was proposed. The constant parameters specified before solving the model included the mining layout, geological conditions, material properties, and loading conditions. The stress evolution and plastic zone characteristics were determined through simulation. The stress concentration zone exhibited a "butterfly" shape during mining and disappeared after pressure relief upon mining completion. The plastic zone expansion pattern showed consistency with the stress evolution characteristics, with rapid expansion observed when the distance between the adjacent coal seam working face and the roadway was less than 80 m. Based on the results, an “advanced reinforcement” anchor bolt and cable support scheme was developed, and field experiments demonstrated a significant reduction in roadway deformation. These findings provide practical guidance for roadway surrounding rock control under similar conditions.

Keywords: Multiple Mining; Stress Evolution; Plastic Zone Expansion; Advanced Reinforcement; Roadway Surrounding Rock Control.

1. Introduction

With the continuous increase of mining depth, coal mine roadway is facing more and more complex stress environment, especially for floor roadway, which is often affected by multi working face mining. The support form and parameters of roadway need to be re-examined and studied to meet the needs of mine support in deep horizontal mining.

In view of the deformation and control measures of surrounding rock in floor roadway under the influence of mining, many scholars have carried out relevant research through various methods. In terms of numerical simulation, Yu Guo and Fuqiang Gao [1-2] studied the deformation characteristics and failure mechanism of surrounding rock in soft rock floor roadway through numerical simulation, and put forward corresponding surrounding rock control technology, which effectively guaranteed the long-term stability of surrounding rock in floor roadway. The numerical simulation analysis shows that the size and shape of the plastic zone of the surrounding rock are related to the angle between the roadway and the maximum horizontal principal stress, which directly affects the stability of the surrounding rock of the roadway [3]. In engineering practice, Wenxiang Dai [4] discussed the transfer characteristics of concentrated stress in overlying residual coal pillars based on the research background of 30515 fully mechanized caving face in Tashan Coal Mine. Taking 3104 roadway of Zhaozhuang Coal Industry as the research object, Hu Zhang [5] analyzed the influence of floor strength coefficient and different size coal pillars on floor bearing capacity under different lithologic conditions, and put forward the corresponding roadway optimization scheme. Yexiang Wu [6] studied the space-time evolution law of roadway surrounding rock stress under the condition of repeated mining by taking the 22205-return airway of Shendong Buertai Coal Mine as a case. Heng Ren [7] carried out the mechanical property test, using the three-dimensional constitutive model of rock, through theoretical analysis and stress-strain curve, the damage law of surrounding rock under roadway excavation was obtained.

The above research and analysis mainly focus on the effect of a single coal seam on the surrounding rock of the roadway, and less on the multiple mining effects under complex conditions such as multiple working faces and multiple coal seams. Therefore, in order to improve the production efficiency and safety of the mine, it is particularly important to study the temporal and spatial evolution law and characteristics of roadway deformation under multiple mining conditions. In this paper, the floor roadway of gangue belt conveyor in a mining area of Gubei Coal Mine is taken as the research object. The numerical simulation method is used to analyze the stress field and plastic zone evolution law of surrounding rock deformation of floor roadway under the influence of multiple mining, in order to provide reference for similar engineering conditions.

2. Engineering Background

In the Guobei Coal Mine, located in the Huainan mining area, an upward mining method was adopted for the extraction of a coal seam group in a specific mining district. The 11-2 coal seam was extracted first, with a mining height of 4.2 m and a burial depth of -553.2 m, followed by the 13-1 coal seam, which was mined with a height of 4.5 m and a burial depth of -461.5 m. Due to the distinct geological occurrence characteristics of the two coal seams, the advancing directions of the working faces in each seam were designed differently. A floor roadway for the gangue belt conveyor was excavated 107.1 m below the 13-1 coal seam, along the strike direction of the 1552 (3) working face. The horizontal distance between this roadway and the stop lines of 1332(1) and 1342(1) working faces in the 11-2 coal seam was 40 m. The design section of the roadway is 5.4 m × 4.3 m. The type is semi-circular arch roadway and U-shaped shed support. Under the combined influence of mining activities from the three working faces, the roadway experienced severe floor heave and roof failure.

Based on field investigations, the primary causes of severe deformation in the floor roadway are as follows:

(a)The complex stress environment resulting from the combined effects of high original rock stress and superimposed mining-induced stress. This has led to large-scale, non-stationary, and nonlinear deformation and failure of the surrounding rock in the roadway. The 11-2 coal seam exhibits low coal strength, and the overlying strata include multiple layers of hard sandstone roofs. These conditions result in a wide and intense influence zone of abutment pressure, with significant manifestations of mining-induced stress in the roadway.

(b)The inability of the existing conventional low-efficiency support technologies to adapt to the complex engineering environment characterized by strong mining-induced disturbances. Under the influence of multiple mining activities, severe deformation occurs in the U-shaped steel supports, including extensive leg deformation and twisting or fracturing of the beams [8].

3. Scheme of Numerical Simulation

In order to explore the deformation law of surrounding rock of floor roadway under the influence of multiple mining, based on the drilling data of Gubei Coal Mine, the comprehensive geological histogram and the physical and mechanical parameters of coal and rock measured in the laboratory, a FLAC3D three-dimensional numerical model [9] was established to analyze the dynamic evolution process of mining stress and the expansion law of plastic zone. The model size and boundary conditions are shown in Fig.1, and the physical and mechanical parameters of each rock layer are shown in Table 1.

Fish language is used to excavate the roadway step by step, each step is 3 m, and the cycle is 2000 steps. The working faces of 1332(1), 1342(1) and 1552(3) are excavated step by step, each step is 10 m, and the cycle is 2000 steps.

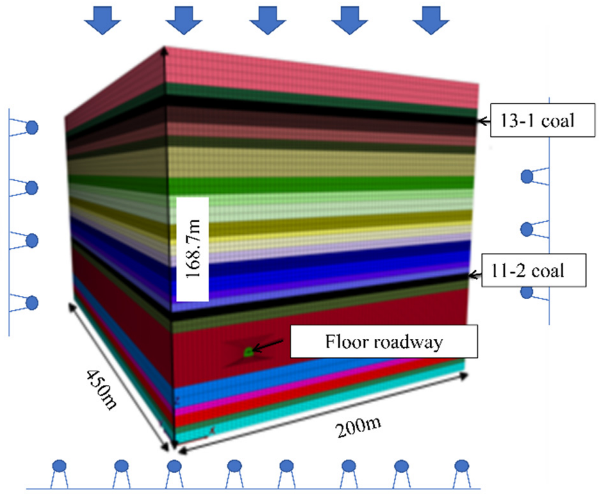

Fig 1. Overall schematic diagram of the numerical model

Table 1. Physical and mechanical parameters of each rock layer in the model

Layer Number	Rock Type	Density (kg/m³)	Compressive Strength (MPa)	Tensile Strength (MPa)	Cohesion (MPa)	Friction Angle (°)	Bulk Modulus (GPa)	Shear Modulus (GPa)
1#	Fine Sandstone	2650	74.5	4.72	4.30	35	19.72	16.98
2#	Sandy Mudstone	2385	18.67	1.44	2.5	27	5.48	3.15
3#	13-1 Coal Seam	1374	8.25	0.87	0.78	25	1.72	0.87
4#	Siltstone	2635	55.73	3.95	4.10	33	13.77	6.30
5#	Medium Sandstone	2750	60.21	3.13	7.98	34	11.98	9.42
6#	11-2 Coal Seam	1400	8.81	0.99	0.82	25	1.76	0.90

4. Analysis of Effect

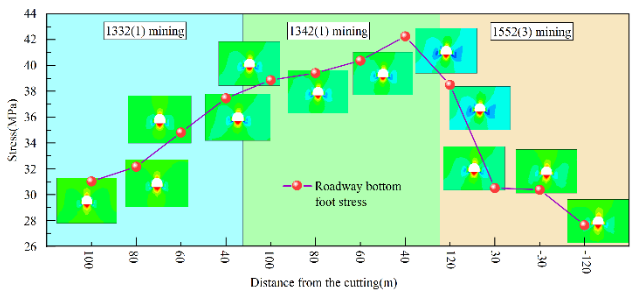

Fig 2. Evolution law of vertical stress of roadway surrounding rock in different mining stages

Fig.2 shows the variation law of stress field of roadway surrounding rock and stress at the bottom foot under different advancing distances of working face. In the process of advancing 1332(1) working faces, the vertical stress of surrounding rock of roadway is gradually concentrated, and its influence range is expanding, showing the distribution characteristics of “butterfly”. In the mining stage of 1342(1) working face, due to the superposition of mining stress, the “butterfly” shaped stress concentration area in the roadway develops rapidly, and the stress value at the bottom foot reaches the peak value, up to 42.25 MPa. After the mining of the 1552(3) working face is completed, the surrounding rock of the roadway enters the pressure relief state, the stress concentration degree decreases rapidly, and the “butterfly” stress concentration area disappears. Finally, the stress concentration coefficient of the surrounding rock of the roadway decreases to 1.96 after the mining is completed.

In addition, during the mining process of 1332(1) and 1342(1) working faces, the peak stress of roadway surrounding rock shows a trend of "slow increase first and then rapid increase" Specifically, when the horizontal distance between the working face and the roadway exceeds 80 m, the increase of the peak stress of the surrounding rock is relatively gentle ; when the working face is advanced to a horizontal distance of less than 80 m from the roadway, the peak stress of the surrounding rock shows a significant rapid growth trend.

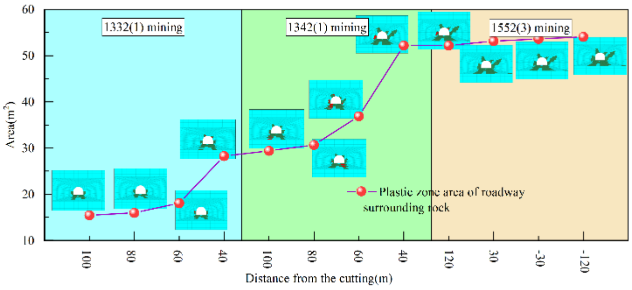

Fig 3. Evolution law of plastic zone of roadway surrounding rock in different mining stages

Fig.3 shows the variation law of plastic zone of roadway surrounding rock under different advancing distances of working face. During the mining process of 1332(1) working face, shear failure occurred in the surrounding rock of the roadway, and the failure depth of the floor gradually increased by 1.5 times. The failure range of the two sides changed little, and the failure mode was close to a small X shape of "both sides of the roof were slightly smaller and both sides of the floor were slightly longer", and the plastic zone area was expanded by 1.83 times. Before the working face of 1342(1) was mined to 80 m away from the roadway, the mining had little effect on the roadway, the depth and range of surrounding rock failure increased by no more than 5 %, and the plastic zone area of the roadway with an average working face advancing 1 m increased by 0.5 m^2. When the working face is 1552(3), the stress of the surrounding rock of the roadway is suddenly released, resulting in shear failure of the two sides, but the range of the plastic zone does not change much.

5. Optimization of Roadway Support Scheme

From the above analysis, it can be seen that in the mining process of 11-2 coal seam, the stress of roadway floor increases rapidly after the working face is 80 m away from the roadway level, and the stress concentration coefficient can reach 3.0. At the same time, the plastic zone area of roadway surrounding rock increases by 1.77 times and 1.70 times respectively after 1332(1) and 1342(1) working faces advance 80 m. Therefore, when 11-2 coal is mined to 80 m away from the roadway level, local reinforcement of roadway is carried out in advance.

The bolt-cable cooperative reinforcement scheme was designed, in which the bolt specification was Φ22×2500 mm, the row spacing was 1000×900 mm, and each bolt was anchored with 2 volumes of Z2560 resin anchoring agent. The anchor cable is arranged longitudinally according to "3-3". The anchor cable specification is Φ22×6200 mm, and the row spacing is 1.6 m×0.9 m. Each anchor cable uses 3 volumes of Z2560 resin anchoring agent. The size of the steel mesh is Φ6-1030×2130 mm, and the mesh is 100 mm. The U-shaped shed was re-strengthened, and the 29 U-shaped shed was adopted. Specification: net width×net height = 5400×3830 mm, shed distance 600 mm. After the net and shed support, the repaired roadway is sprayed, the concrete strength is C20, and the thickness is 100 mm.

Based on the cross-measuring point method, the laser range finder is used to monitor the displacement of the roof and floor of the roadway and the two sides during the mining of the working face, the monitoring results are shown in the figure. 4.

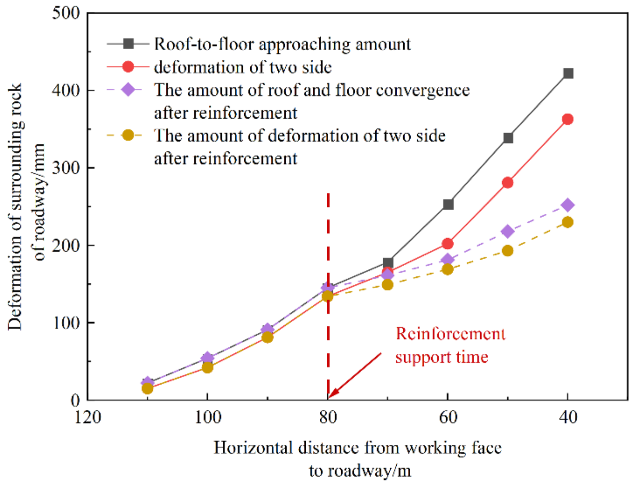

Fig 4. The change of roadway surface displacement in mining stage

Figure. 4 illustrates the deformation behavior of the surrounding rock in the roadway during the mining process of the working face. Following the implementation of the advanced reinforcement support scheme, the displacement of the roof and floor, as well as the two sides of the roadway, decreased by 40.28% and 36.64%, respectively. While the roof experiences some deformation, it remains intact without structural failure. The deformation of the two sides is minimal, and the overall integrity of the roadway is well-preserved.

6. Conclusion

In this paper, FLAC3D software is used to study the stress evolution and plastic zone expansion law of floor roadway under the influence of multiple mining in a mining area of Gubei Coal Mine, and the following conclusions are obtained:

(a) During the mining process of 1332(1) and 1342(1), the floor roadway is in a high stress non-isopressure field, and the stress shows a trend of "slow increase-rapid increase-stability" with the advancement of the working face. The mining of multiple working faces leads to the superposition of supporting stress, so that the stress distribution of the roadway presents a "butterfly" shape with more significant stress concentration on the side near the goaf. The overlying coal seam mining has a pressure relief effect on the roadway, reduces the stress concentration coefficient and distribution range, and inhibits the further development of the plastic zone.

(b) The plastic zone failure of surrounding rock is mainly shearing failure, and the failure range is concentrated on the floor and two sides. When the working face is close to the stop line, the plastic zone of roof expands rapidly and presents an "X" shape.

(c)According to the evolution characteristics of the surrounding rock stress and plastic zone of the floor roadway, the support scheme of “bolt + anchor cable + U-shaped shed + shotcrete” based on the concept of “advanced reinforcement” is designed. The practice results show that when the distance between the working face of the adjacent coal seam and the roadway is 80 m, the implementation of collaborative reinforcement support, the movement of the roof and floor and the two sides is reduced by 40.28 % and 36.64 % respectively, and the expected effect is achieved.

References

[1] Yu Guo, Xigui Zheng, Gangye Guo, Qifeng Zhao, Wei Zhou, Tieliang An, “Study on deformation and failure control of surrounding rock in short-span soft rock roadway”, Journal of Mining and Safety Engineering, 2018, Vol. 35 (06), p1142-1149.

[2] Fuqiang Gao, Xinfeng Gao, Hongpu Kang, “FLAC analysis of mechanical response of deep tunnel surrounding rock under dynamic disturbance”, Journal of Underground Space and Engineering, 2009, Vol. 5 (04), p680-685.

[3] Yufu Sun, “Affects of in-situ horizontal stress on stability of surrounding rock roadway”, Journal of China Coal Society, 2010, Vol. 35 (06), p891-895.

[4] Wenxiang Dai, Weidong Pan, Meng Li, Jian Zhang. “Study on layout and support technology of roadway with strong disturbance in close coal seam”, Coal Science and Technology, 2020, Vol. 48 (12), p61-67.

[5] Hu Zhang, Peilin Gong, Mingjiang Shi, Ye Tian, “Effect of coal pillar width on tunnel floor drum under different floor lithology conditions”, Coal Technology, 2023, Vol. 42 (05), p46-50.

[6] Xiangye Wu, Hongtao Liu, Jianwei Li, et al. “Spacetime evolutionary regularity of plastic zone and stability control in repetitive mining roadway”, Journal of China Coal Society, 2020, Vol. 45 (10), p3389-3400.

[7] Heng Ren, Yongjian Zhu, Pingping Wang, Xiaofei Guo, Kun, Lv, “Evolution rules and experimental study of damage to surrounding rock under the effect of tunnel excavation”, Journal of Underground Space and Engineering, 2022, Vol. 18 (05), p1615-1622.

[8] Shuai Ren, Yong Luo, Diancai Xiao, Guofeng Yu, Xiang Gao, Wei Hu, “Study on the evolution law of mining stress field and reasonable layout of roadway in coal seam group in Huainan mining area”, Mining Technology, 2024, Vol. 24, (5), p69-74.

[9] Hang Lin, Taoying Liu, Jiangteng Li, Ping Cao, “A simple generation technique of complex geotechnical computational model”, Mathematical Problems in Engineering, 2013.1 (2013): 863104.