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Research Article

Effect of Strong Mining on the Fracture Evolution Law of Trick Rise in the Mining Field and Its Control Technology

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This study investigates the law of stress field and fracture field of the surrounding rock at the trick rise of the mining area affected by strong mining. It is found that as the working face continues to approach, large-scale cracks occur in the surrounding rock on the track rise. In particular, when the working face crosses the track rise, the equivalent stress τ_{oct} concentration area expands, gradually intersecting with the surrounding rock concentration area of the roadway. It indicates that the working face advancement caused a dramatic change in the stress field of the roadway envelope, which will have an immediate adverse effect on the track rise. With comprehensive support costs, economic efficiency, and other factors, the working face will no longer cross the track rise, and the stopping line is roughly controlled at -20 m so that the track rise can serve other working faces for a long time. The reinforcement support scheme of "anchor mesh spray + grouting anchor" is proposed for the key areas such as arch shoulder. Through the analysis of the field monitoring of the roadway surface displacement, the deformation of the roadway surrounding rock showed a change trend of increasing first and then stabilizing with time, which indicates that the support effect was good and greatly improved the stability and safety of the roadway.

1. Introduction

There are many coal-forming periods in China [1], and the occurrence conditions are very complex [2]; among which most of them are mined by shaft, and the roadway is the lifeline of coal mine production [3]. Most of the excavation and preparation roadways in coal mines are arranged in the floor of coal seam [4]. Floor roadway is a kind of very common high stress roadway affected by coal seam strong mining [5]. When such roadways are affected by strong mining, the stress of roadway surrounding rock increases significantly [6], often exceeding or even several times the compressive strength of rocks [7]. This causes serious deformation of the surrounding rock during the service period of the roadway [8], so the roadway needs to be continuously maintained and repaired. The above strong mining and other effects caused by the roadway large deformation, difficult to support [9], not only support costs increased significantly and will cause difficulties in coal mining succession, seriously affecting the normal production of the mine [10]. Therefore, how to solve the support of this kind of roadway is one of the most complex engineering technical problems in the world of underground engineering [11] and also one of the key problems in underground resource exploitation [12].

Coal mining disrupts the original stress balance of the floor roadway [13], causing stress redistribution in the rock strata around the recovery space and transferring to the deep section of the floor [14], resulting in different degrees of damage to the floor [15]. Cheng et al. [16], Lu and Wang [17], and Xu et al. [18] grasp the law of the mining floor by studying the stress distribution and damage characteristics of the mining floor, which is of great significance for

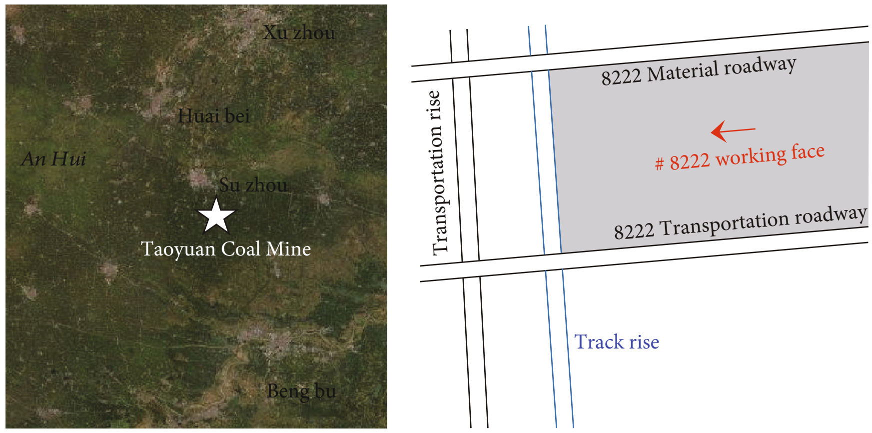

Figure 1: Location of the Taoyuan coal mine and the plane graph of mining face arrangement.

the layout and maintenance of the mining floor roadway [19].

In order to reduce the deformation of surrounding rock and ensure the normal use of roadway, a clear analysis of the failure mechanism of roadway surrounding rock is the premise of reasonable and effective support [20]. Many scholars have shown factors such as the lithology of the surrounding rock mass of the roadway, the vertical distance between the roadway and the working face [21], the horizontal distance between the roadway and the end of the working face [22], and the support method of the roadway [23]. Affected by mining, the mine pressure of the roadway appears drastically [24], resulting in the expansion of the range of the plastic zone of the surrounding rock, and the deformation of the surrounding rock is greatly increased [25]. As a result [26], the roadways exhibited large deformations and were difficult to maintain [27, 28]. More seriously, the original support system was seriously damaged, the surrounding rock extrusion was large, and the roadway rib spalling and floor heave were obvious. [29]. Therefore, it is of great theoretical and engineering significance to systematically analyze the rupture and evolution mechanism of the surrounding rock of the working face across the mining floor roadway under the influence of mining and to adopt effective local strengthening support technology [30].

In view of this, taking the track rise in the II2 mining area of Taoyuan coal mine as the engineering background [31], this study investigates the law of stress field and fracture field of the surrounding rock at the floor of the mining area affected by strong mining and proposes the reinforcement technology applicable to the reinforcement of the track rise in the mining area affected by strong mining pressure. This study has important theoretical significance and practical value for the effective control of the strong mining affecting the deformation and damage of the surrounding rock in the track rise of the mining area.

2. Engineering Background

Taoyuan coal mine is located in the southern suburb of Suzhou City, Anhui Province, China. The mine is located at the southeast edge of the Huaibei coalfield, which belongs to the Carboniferous Permian coalfield [32]. The 10# coal is the main mining seam, the thickness of the coal seam is 0~6.67 m, and the average thickness is 2.60 m. II2 mining area arranges four rise lanes, all of which are arranged in the floor of 8# coal and the roof of 10# coal. The four rise lanes, especially the track rise, have been affected by the mining of the lower 10# coal and the upper II8221 working face, resulting in serious deformation of the lanes. Worse still, the mining of the II8222 working face will cause a certain degree of mining impact on the four ascents (Figure 1).

II8222 working face is located in the first stage of the left flank in II2 mining area, the design elevation of the working face is -504.9 m~-604.2 m, and the average coal thickness of the coal seam is 2.0 m. Obviously, the mining of II8222 working face will have a serious impact on the safety of the track rise, so it is necessary to master the law of mine pressure appearing under the influence of mining, as well as the resulting deformation and damage mechanism of the surrounding rock, and put forward effective support countermeasures.

3. Numerical Model

In order to study the variation law of the stress field on the track rise induced by the advancing disturbance of the working face and the impact of the produced the fracture damage, the numerical modelling software ABAQUS (based on finite element method) is used to establish the numerical calculation model of the track rise in this study (Figure 2). The numerical calculation model uses a 64 m × 63 m × 15 m rectangular body, which is divided into 295,568 units. The roadway section is arched, with a width of 3.6 m, a straight wall height of 1.5 m, and a circular arch radius of 1.8 m. The model is simplified to three rock layers: roof strata, coal strata, and floor strata. The boundary conditions of the model are set as follows (in situ stress measurements): the bottom surface is constrained by vertical displacement, the height of the overlying rock layer of the model is 550 m, so it is loaded on the upper boundary of the model in the form of uniform load (14 MPa). The maximum horizontal stress is 17 MPa, along the direction of the roadway;

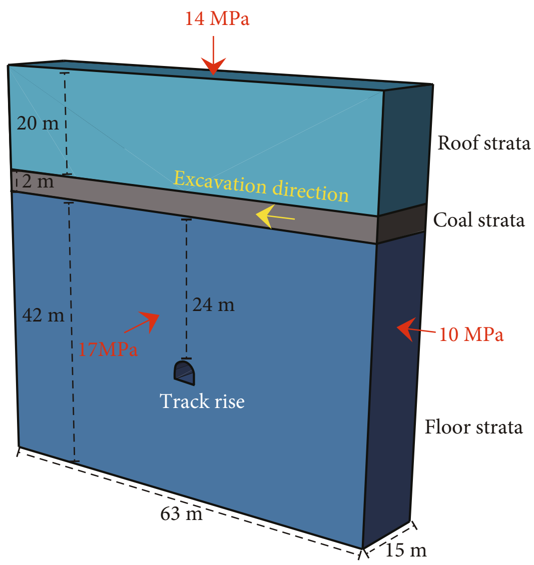

Figure 2: Numerical calculation model.

the minimum horizontal stress is 10 MPa, perpendicular to the direction of the roadway.

Based on the fact that natural rocks contain a large number of microdefects such as randomly distributed microfractures [33], a numerical model of rock damage rupture evolution with random distribution is developed using the secondary development subroutine USDFLD [34]. The total percentage of damaged units is n_0, and their basic mechanical parameters are about 1/2 of the intact units [35]. The Mogi-Coulomb strength criterion [36] is used to determine whether the unit is damaged or not, and the stiffness of the rock damage unit is degraded to 1/10~1/100 of the original initial stiffness [37]. The physical and mechanical parameters of each rock formation are shown in Table 1.

Figure 3 shows the rupture evolution law of the surrounding rock on the track rise during the working face advancement. When the working face advances to the horizontal distance of -20 m from the track rise (all the following are horizontal distance), the track rise has been affected by the previous excavation itself to appear fracture circle, and its rupture characteristics are consistent with the research results of other scholars [38]. As the working face continues to advance, the surrounding rocks of the track rise are gradually affected by the disturbance of the working face, and the rupture zone gradually appears to intersect. For example, when the working face is -12 m from the track rise, the local fissures in the surrounding rock appear to be conductive (similar to a fissure zone) because the surrounding rock adopts random damage distribution characteristics. The law is very obvious when the working face is -5 m from the track rise. The fracture zone is mainly generated by the fracture zone conduction near the two arched shoulders of the track rise and the floor of the working face. When the working face is 3 m away from the track rise, i.e., the working face crosses the track rise, the fracture area near its surrounding rock expands. It indicates that the track rise is strongly affected by the working face advancement and needs to be considered in the aspects of working face advancement and track rise support design.

Figure 4 shows the distribution characteristics of the support pressure coefficient of the track rise and the floor during the working face advancement. The maximum oversupport pressure coefficient of the floor is mostly 2.2, while 2.9 appears locally. The oversupport pressure of the surrounding rock in the two gangs of the track rise is higher, and the support pressure of the surrounding rock near the roof and floor is smaller (about 0.9). This provides the basis for further analysis of the influence of dynamic load on the track rise below.

4. Fracture Evolution Law of Track Rise under the Influence of Dynamic Loading

In the above text, the mining field advancement as a continuous process is simplified to 5 m working face advancement in each analysis time step, which is artificially divided by the actual engineering continuous excavation (infinitely small advancement distance in each analysis step) advancement process, which differs from the actual engineering. In order to further accurately analyze the evolution law of the fracture of the surrounding rock on the track under the influence of continuous mining, it is simplified to a mechanical model of the superposition of uniform load and triangular load (Figure 5) by combining the characteristics of the change law of oversupport pressure during the advance of the working face in the above paper. With the continuous advance [39] of the working face, the dynamic load changes accordingly.

As shown in Figure 5, according to the load distribution characteristics, the essence of the dynamic load change in the mechanical model is that the uniform load q remains unchanged, and the triangular load moves with the working face. The range of support pressure is ab (= $ac + cb$); o is the peak point of support pressure (kq, k is the maximum support pressure coefficient). Based on the above results, the maximum support pressure coefficient is $k = 2.9$. The basic dimensions and parameters of the model are shown in Table 2, and the physical and mechanical parameters of the floor rock are consistent with Table 1.

Figure 6 shows the characteristics of support pressure distribution and the law of large vertical deformation near the whole track rise surrounding rock affected by the advance of working face. The large vertical deformation contour is roughly circular in shape, and the specific shape characteristics are influenced by the support pressure coefficient and the action range [40].

Figure 7 shows the evolution of the rupture pattern of the track rise during the advance of the working face. When the working face is -30 m away from the track rise, the fracture circle of the track rise has been affected by the previous excavation itself, which is consistent with the above results; the working face advancement has not affected the surrounding rock of the roadway. When the working face is -20 m away from the track rise, the fracture circle of the surrounding rock on the track rise gradually expands. The rupture area of the surrounding rock of its right arch shoulder

Table 1: Numerical model parameters.

Parameters	Roof strata	Coal strata	Floor strata
Young's modulus, E	20 GPa	10 GPa	18 GPa
Poisson's ratio, μ	0.3	0.33	0.3
Internal cohesion, c	4.7 MPa	3.5 MPa	4.6 MPa
Internal frictional angle, φ	37°	28°	35°
The proportion of damaged elements, n_0	20%	25%	20%

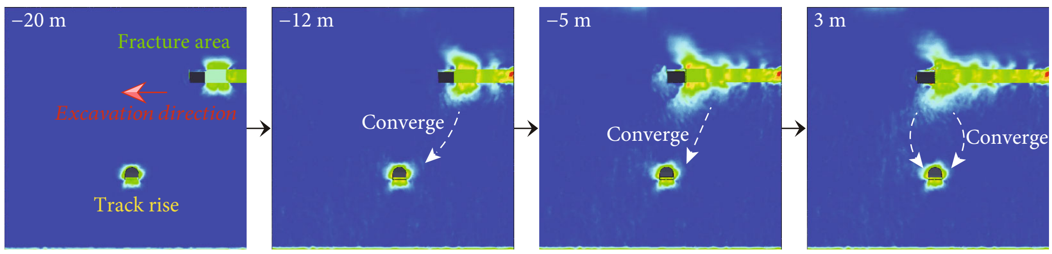

Figure 3: Variation pattern of fracture zone with the advance of working face.

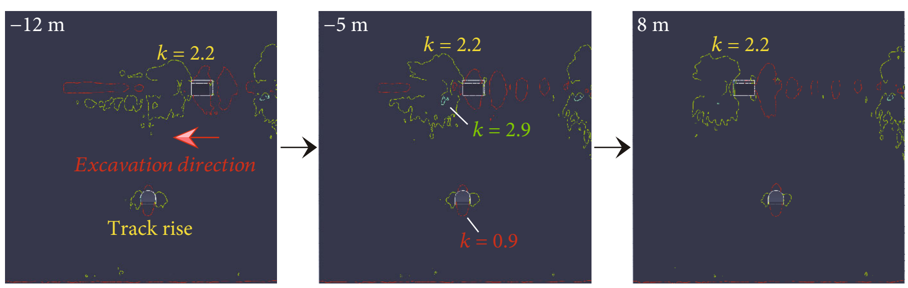

Figure 4: Contour of support pressure.

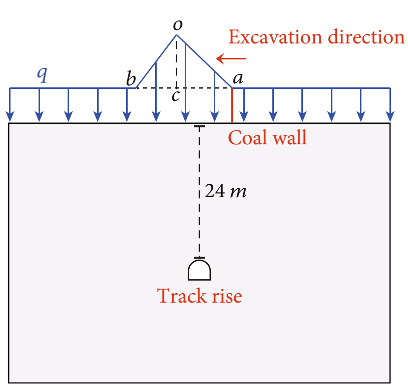

Figure 5: Numerical calculation model.

Table 2: Basic parameters of the numerical model.

Parameters	Values
Length of ac, L_{ac}	2.9 m
Length of cb, L_{cb}	3.2 m
Uniform load, q	14 MPa
Maximum support pressure coefficient, k	2.9

gradually has the tendency to expand to the rupture area of the floor, which indicates that the track rise starts to be obviously affected by the advance of the working face. When the working face is -8 m away from the track rise, the surrounding rock appears a large area of fracture and intersects with the fracture area of the floor. When the working face crossed the track hill 7 m, the whole floor and the surrounding rock of the track rise appeared a wide scale fracture area. It means that the track rise is greatly affected by the working face advance.

Since the computational model uses the Mogi-Coulomb intensity criterion, its calculation equation [41] is

$$\tau_{oct} = a + b\sigma_{m,2}, \tag{1}$$

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}, \tag{2}$$

$$\sigma_{m,2} = \frac{\sigma_1 + \sigma_3}{2}. \tag{3}$$

Among them, the magnitude of the equivalent stress τ_{oct} has important directional significance for judging the rupture trend of the unit. Therefore, the equivalent stresses τ_{oct} are used in this study to quantify the fracture trend

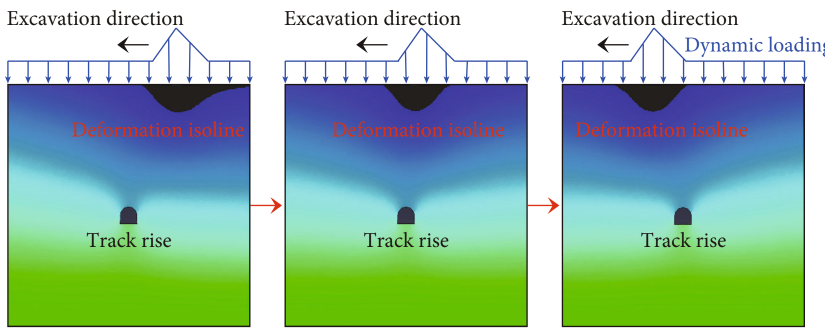

Figure 6: Regional characteristics of large vertical deformation.

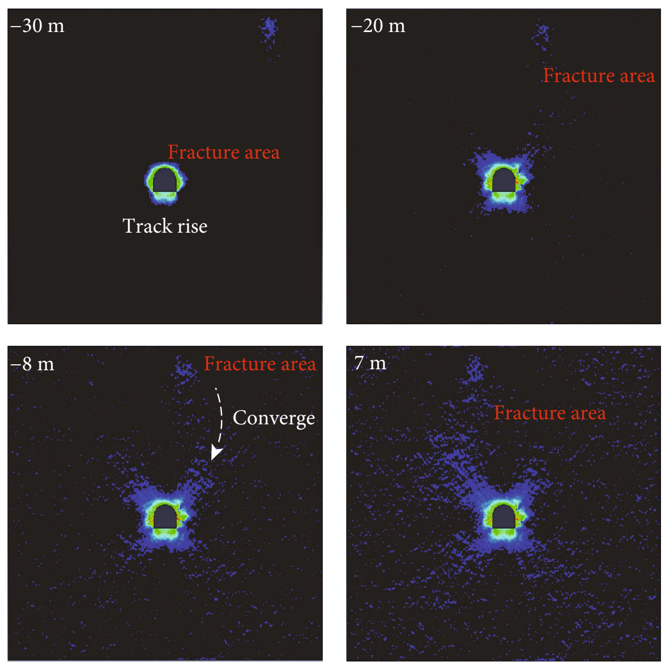

Figure 7: Variation pattern of fracture zone with the advance of working face.

triggered by the workface advancement process, as shown in Figure 8. When the working face is -30 m away from the track rise, the equivalent stress distribution is mainly concentrated near the working face and in the shallow surrounding rock area of the roadway, indicating that the working face has no impact on the roadway. As the working face continues to advance, the range of equivalent force concentration area expands and gradually intersects with the concentration area of the roadway surrounding rock. It indicates that the working face has a substantial impact on the roadway surrounding rock, resulting in a dramatic change in the stress field near its surrounding rock. In particular, in the process of -8 m~7 m from the working face to the track rise, a "waterfall-type" concentration area is formed near the arch shoulder of the track rise. This indicates that the track rise is affected by the disturbance of the working face, which also confirms the crack evolution law of the surrounding rock of the roadway in Figure 7. Therefore, with comprehensive support costs and economic benefits, the working face will no longer cross the track rise, and the stopping line is roughly controlled at -20 m so that the track rise can serve other stopes for a long time.

5. Surrounding Rock Control Technology

According to the rupture evolution characteristics of the track rise, it can be seen that the influence of the mining of II8222 working face is that the surrounding rock on the track rise is gradually destabilized and fractured. Unless effective support control is obtained, the roadway will be significantly deformed, resulting in destabilization of the track rise. Combined with the analysis of the previous study, the deformation and damage in the track rise are relatively heavy, and the key areas such as the arch shoulder are reinforced. The design adopts "anchor net and cable spray + -grouting anchor" reinforcement support scheme. The specific scheme is as follows (Figure 9).

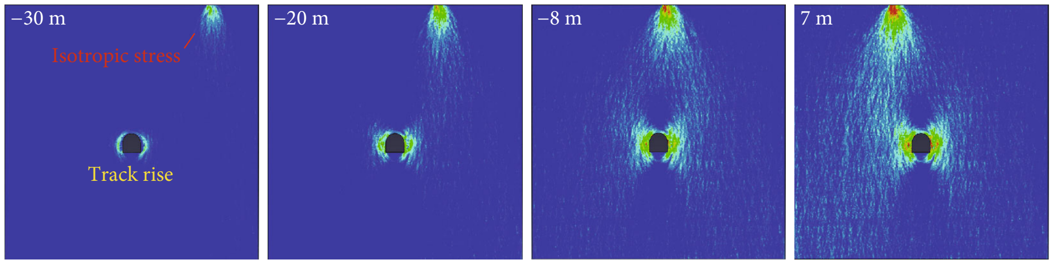

Figure 8: The variation pattern of the equivalent stress with the advance of the working face.

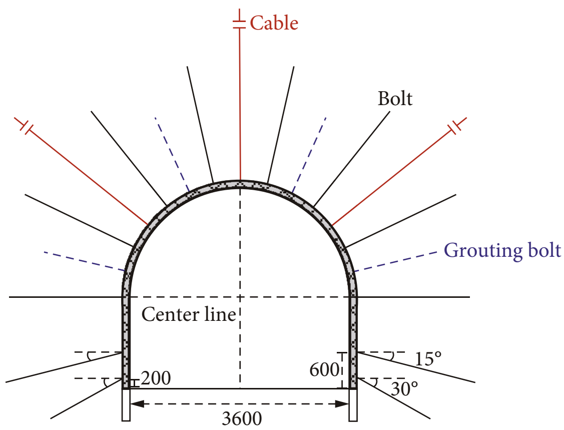

Figure 9: Supporting design of track rise.

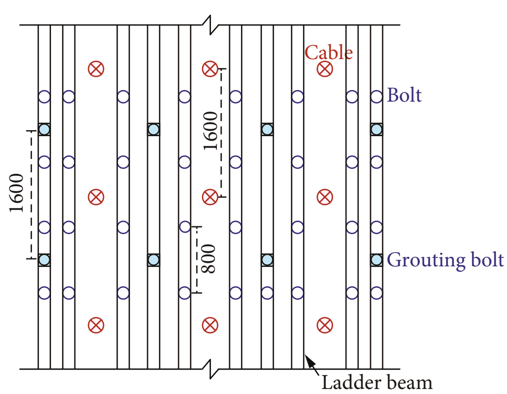

Figure 10: Arrangement of bolts and cables in the track rise.

The rebar bolts are GM22/3000-490 left-handed rebarless rebar anchor with equivalent strength. The interrow distance is 800 × 800 mm, 10 rows in a row, connected by ladder beam along the direction of the roadway. Hollow rebar grouting anchor rods with specifications $\Phi25 \times 2500$ mm, interrow distance 1600 × 1600 mm, 6 pieces in a row, connected by ladder beam along the direction of the roadway (Figure 10).

The surface displacement observation section was set up in the anchor injection reinforcement section on the track rise. Four monitoring points were set up at the roof-to-floor plates and side-to-side of the section for observing the change of surface displacement of the track rise during the mining of the working face. The variation curves of the deformation of the track rise were obtained as shown in Figure 11.

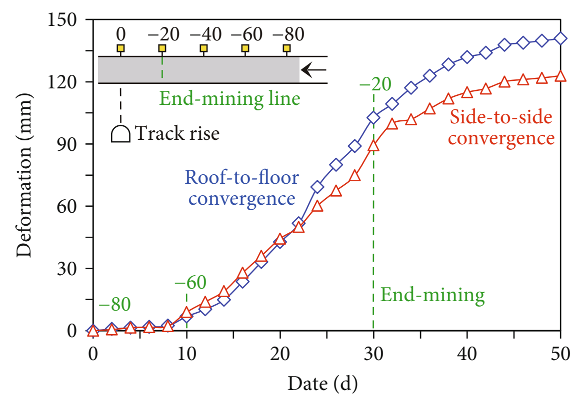

Figure 11: The variation in the convergence of roadway surface.

On the first day, the horizontal distance of II8222 working face from the track rise is 80 m, the track rise is less affected by the mining of the working face, and the amplitude and rate of roadway deformation are low. On the 10th day of the observation time (-60 m horizontal distance between II8222 working face and track rise), the impact of mining on the track rise became apparent, and the amplitude and rate of deformation of the roadway gradually increased. As the working face continued to advance, the track rise was gradually affected by the mining, and the deformation rate of the surrounding rock was accelerated. On the 30th day of the observation time (-20 m horizontal distance between II8222 working face and track rise), the working face stopped mining. The deformation of the roadway still increased, while the rate of deformation slowed down. It means that the influence of the track rise by the mining of II8222 working face gradually decreases. On the 50th day of the observation time, II8222 working face has stopped mining for 20 days, and the deformation of the roadway has stabilized. The amount of roof-to-floor convergence is stabilized at about 135 mm, and the side-to-side convergence is 120 mm. Through the analysis of the observation results, it can be seen that after strengthening the support of the roadway, the deformation of the surrounding rock is low, and the surrounding rock is effectively controlled, indicating that the support effect is good.

6. Conclusions

(1) Based on the random damage and Mogi-Coulomb strength theory, the variation rules of the stress field on the track rise induced by the workface advancement disturbance

and the resulting rupture damage impact were studied. It was found that the surrounding rocks near the track rise were gradually affected by the disturbance of the workface as the stope kept approaching in the process. In particular, when the working face crosses the track rise, the range of the surrounding rock fracture zone will be greatly increased, indicating that the track rise is strongly affected by the advancement of the working face. So the key considerations need to be given to the advancement of the working face and the design of the track rise support

(2) The fracture evolution law of the surrounding rock on the track under the continuous influence of the oversupport pressure (dynamic loading) during the advance of the working face was analyzed. As the working face continued to approach, large-scale cracks appeared in the surrounding rock on the track rise. The equivalent stress τ_{oct} concentration area expanded, gradually intersecting with the surrounding rock concentration area of the roadway. It indicates that the working face advancement caused a dramatic change in the stress field of the roadway envelope, which will have an immediate adverse effect on the track rise. Considering factors such as support costs and economic benefits, the working face will no longer cross the track rise, and the mining stop line will be roughly controlled at about -20 m so that the track rise will serve other stopes for a long time

(3) According to the influence of mining on the II8222 working face on the track rise, the surrounding rock rupture and evolution of the roadway is triggered. Therefore, the reinforcement support scheme of "anchor mesh spray + - grouting anchor" is proposed for the key areas such as arch shoulder. Based on on-site monitoring and analysis of the roadway surface displacement, the deformation of the surrounding rock of the roadway shows a trend of first increasing and then becoming stable over time. The deformation rate and deformation volume of the roadway enclosure are effectively controlled, which indicates that the support effect was good and greatly improved the stability and safety of the roadway

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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