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Study on the Deformation and Failure Mechanism of Soft Rock Roadways under the Impact of Fracture Zones

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Abstract: *The common failure characteristics are summarized to roadways under the impact of fracture zones based on the field investigation of the east area of a newly developed mine. And the subject lies on a -120 main return airway at the east area of the mine. First the failure processes of roadways without supporting and roadways with bolt-and-mesh supporting are presented with the aid of a numerical simulation software, then the study goes to the deformation and failure mechanism of soft rock roadways under the impact of fracture zones, and last why soft rock roadways fail under fracture zones attributes to: high existing stress, low rock mass strength, and large deformation of original supporting that is not suitable for plastic rheology. It lays a solid foundation for the tailored stability control of soft rock roadways under the impact of fracture zones.*

Keywords: *fracture zone, soft rock roadway, failure characteristics, mechanism of deformation and failure*

1. Introduction

As coal is the main part in China's energy structure, continuously rising demand impels to mine coal in deeper strata, where adverse geological conditions are common and changing geological stress environment in which rock mass involves are frequent. Such factors attribute to variation of characteristics of rock mass fracture [1,2], resulting widespread rock mass fragmentation, difficult maintenance and construction of roadways, and unsafe mining[3,4]. As the coal mine campaign extends and the mining depth increases, especially when the fracture zones are under the impact of geological structure, the situation becomes worse when roadways deform or even fail, harder for supporting, and unstable conditions last longer after drivage due to larger deformation; a number of renovations are necessary, making it difficult for maintenance. Therefore, a numerical simulation software is used to study the stability and deformation of roadways under the impact of fracture zones, in order to provide reference for the stability control of soft rock roadways under the influence of fracture zone.

2. Engineering Summary

In the subject mine field there is fracture development, and complex faulted structure in the east and west areas of the field in particular. Both the prospection and roadway investigation confirm that there are over 140 faults, among which there are 20 major faults with a drop over 20 m, 85 medium ones with a drop over 5 m, and many minor spindle-shaped parallel ones of xi type and λ type, resulting well development in the mine field. Major faults in the east area of the field are S-1 and S-18, such two major faults associate many secondary ones. These intricate faults cut each, causing serious damage to normal occurrence of coal beds, and to make it worse, a number of fracture zones occur under the impact of structure.

In light of the underground geological conditions in the east area, the floor of the S-120 main return airway is gray medium sandstone. Based on the results of water absorption and softening experiment, the detail physico-mechanical properties of the gray medium sandstone in the east area are as follows: the compressive strength of the intact rock samples are from 41.86 Mpa to 90.89 Mpa; the water absorption test shows that the absorption can be up to 12.15 ml within 740 h, the coefficient of softening from 0.37 to 0.84, the average coefficient of softening, 0.54; the lithology of roadway wall rock is poor in case of serious flood.

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3. Numerical Simulation Analysis of Roadway Deformation and Failure

3.1. Engineering Geological Model

Based on the site real geological conditions, an engineering geological mode (Figure 1) is created, in the middle of such model there is set a 12 m wide parallelogram fault fracture zone, and the size of such zone is L×W×H = 100m×45m×45m. The modeling is based on the real angle of coal bed in the stratum, namely the dip angle of 25°. The horizontal movement is limited to the sides of the model, while the bottom is fixed, and the top surface is the stress boundary. To simulate the dead weight boundary of rock mass, the load of 13 MPa (about 500 m under the ground) is applied.

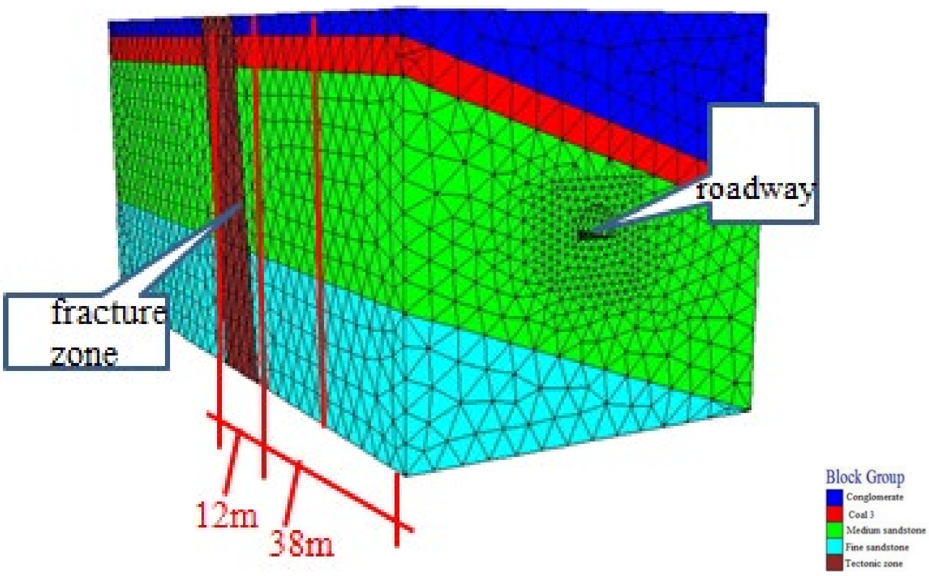

Figure 1: Engineering Geological Model

In light of the site conditions, the parameters of the bolt-and-mesh supporting are as follows: the roadway section is 3800 mm×3200 mm, using left hand thread bolts without longitudinal ribs, while the size of such bolts is Φ20 mm×L3000 mm, and the interval, 800 mm×800 mm; using stranded steel wires of Φ17.8 mm×L8000 mm with intervals of 1500 mm×1500 mm as the mesh; using Φ10 welded steel fabric with specification of L×W=1500 mm×2000 mm, and the mesh size of 100 mm×100mm. See Figure 2 for more details.

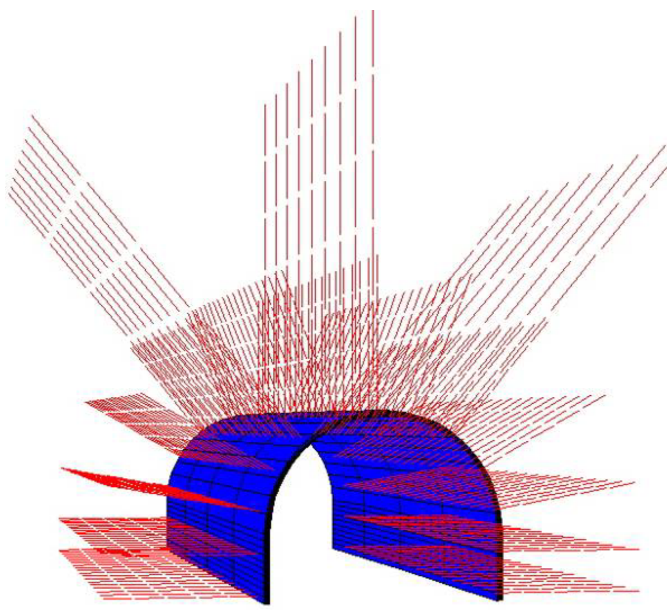

Figure 2: Mechanical Model of Working Conditions of Bolt-and-Mesh Supporting (15 m)

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3.2. Simulation Analysis for Roadways without Supporting

First the simulation and step-by-step calculation apply to the deformation and force bearing of roadways without supporting, while the calculation results are stored at interval of 1,000 steps, and then the corresponding displacement distribution diagrams are obtained. And last, through various displacement zones under the impact of tectonic stress on the basis of the analysis of 4,000 steps of simulation results, the process study of deformation and failure of roadway without supporting is carried out. Limited by space, only the final results are given for the simulation. Please see Figure 3 for more details.

Such typical sections are chosen as regions far away from the fracture zone (20 m), the boundary areas of the fracture zone (38 m), and the fracture zone (55 m). The radial displacements of each section are used to judge the how much they are impacted on. The above classification also applies to corresponding analysis of roadways with bolt-and-mesh supporting.

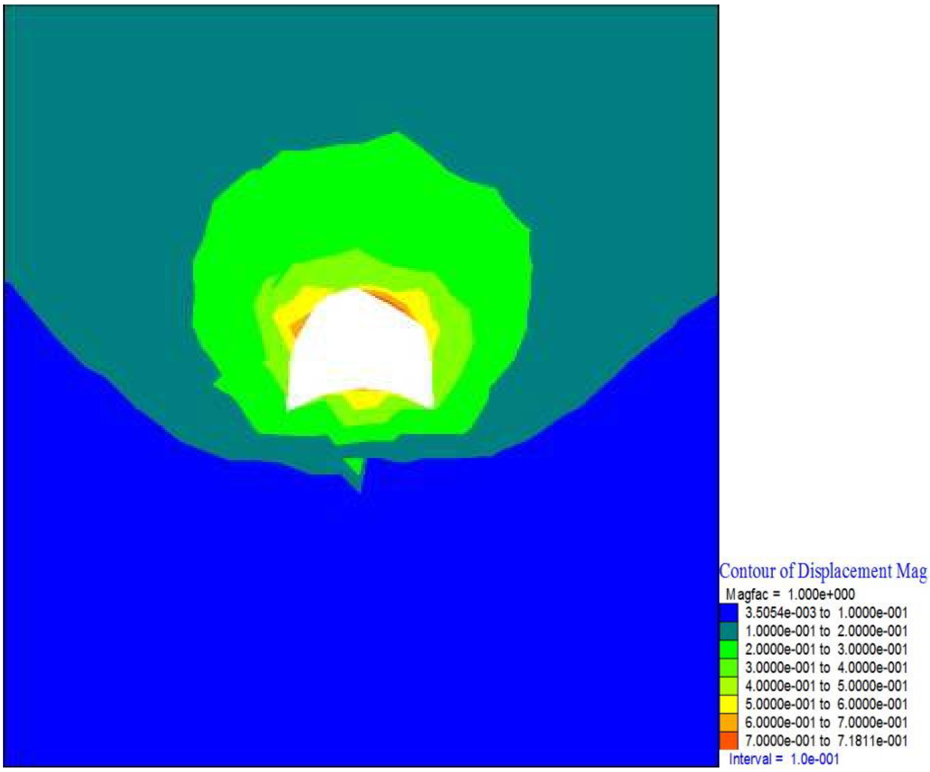

Figure 3: Total Displacement Diagrams of Roadways without Supporting

From the simulation results, it can be concluded that significant deformation and failure occur to the wall rock of roadways without supporting due to the impact of tectonic zone in each area and the distribution of plastic zone. In comparison of results from each monitoring point, the roof-to-floor convergence is up to 1.103 m for the section at 45 m, and the convergence at each side is 0.975 m; the section deformations at 20 m and 38 m ease progressively in comparison with the deformation of the section at 55 m; the roof-to-floor convergences are 0.932 m and 0.962 m respectively for the section at 20 m and 38 m, and the convergences at each side are 0.859 m and 0.923 m respectively. The minimum thickness of the plastic zone is estimated to be about 4.5 m, but the thickness increase is so significant between the sections of 38 m and 55m and the section of 20 m, that it implies the fracture zone playing an important role in the development of plastic zone. The thickness of plastic zone on both sides and some part of the left roof of roadway is relatively large, the maximum thickness of the plastic zone is up to 8 m.

3.3. Simulation Analysis for Roadways with Bolt-and-Mesh Supporting

The step-by-step calculation also applies to the roadways with bolt-and-mesh supporting. From the simulation results of each section, it can be concluded that slight deformation and failure occur to the wall rock of the subject roadways due to the impact of fracture zone in each area and the distribution of plastic zone. The generic effect is almost the same to deformation and plastic zone for roadways without

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supporting, while a certain control effect is gained for ordinary supporting in case of roadways without supporting. In comparison of results from each monitoring point, Figure 4 can be obtained. The roof-to-floor convergence is up to 0.774 m for the section at 55 m, and the convergence at both sides is 0.732 m; the section deformations at 20 m and 38 m eases progressively in comparison with the deformation of the section at 55 m; the roof-to-floor convergences are 0.681 m and 0.723 m respectively for sections at 20 m and 38 m, and the convergence at both sides are 0.589 m and 0.640 m respectively. The minimum thickness of plastic zones is estimated to be about 4 m; The thickness of some part of the plastic zones at the left roof is relatively large, the maximum thickness up to 7 m. It indicates that the larger plastic zones are, the more severe the stress releases, and the greater the probability of wall rock fails. Please see table 1 for radial displacement for roadways without supporting.

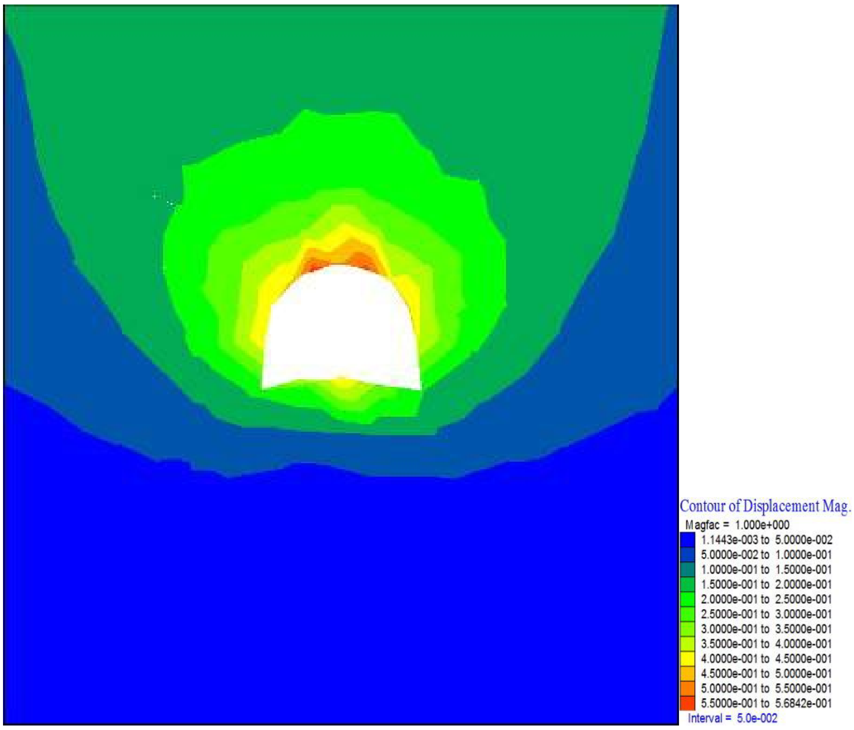

Figure 4: Total Displacement Diagrams of Roadway with Bolt and Mesh Supporting

To sum up, from the monitoring points set up in accordance with the numerical simulation and the above detailed analysis, a law can be drawn that the deformation increases under the impact of fracture zone and its progressive influence. Such law is reflected in the convergence of the roof-to-floor and the sides. So, it can be concluded that fractured rock mass is a key factor to the deformation of soft rock roadways.

Table 1: Deformation of Roadways without Supporting and Roadways with Bolt-and-Mesh Supporting under the Impact of Fracture Zones

Supporting conditions	Region far away from fracture zone (20 m)		Boundary region of fracture zone (38 m)		Fracture zone (55 m)	
	Roof-to-floor /m	Two sides /m	Roof-to-floor /m	Two sides /m	Roof-to-floor /m	Two sides /m
Without supporting	0.932	0.859	0.962	0.923	1.103	0.975
With bolt-and-mesh supporting	0.681	0.589	0.723	0.640	0.774	0.732

4. Failure Mechanism of Soft Rock Roadways in Fracture Zones

Based on the summary and analysis of the failure phenomena of soft rock engineering under the impact of coal fracture zone, as well as the geological conditions, it can be concluded that there are two main manifestations of the deformation mechanism of soft rock engineering under the impact of coal fracture zone. One is the unconformity of different rock strata caused by complex wall rock fractured structure under normal symmetric supporting conditions, and the other one is dislocation deformation caused by the shear slip deformation of fracture zones and fracture rock strata extrusion. The specific causes of deformation and failure are as the following aspects:

1) High Stress in Roadways. The stress by the wall rock is the critical factor affecting the roadway stability. The fault tectonic development at the east area of the mine: At the east part of the mine, S-18 is a major fault, two rocks of which are seriously fractured. Serious deformation and failure of wall rock attribute to the vertical and horizontal forces resulting from tectonic stress.

2) Low Rock Mass Strength. In the east area of the mine features fractured rock mass, low strength, and large ratio between stress and strength of rock mass; the east mine suffered serious flood in the roadway construction, and to make it worse, serious degradation in water occurred to the wall rock. All these factors attribute to depletion of self-bearing capacity of wall rock.

3) Large Deformation of Original Supporting That Is Not Suitable for Plastic rheology. Supporting technology and chosen parameters are critical to the stability of roadways. Based on the analysis of simulation of roadways without supporting and roadways with bolt-and-mesh supporting, serious deformation occurs to roadways in both cases, while the deformation lightens for roadways with bolt-and-mesh supporting, but such deformation still brings bad influence to construction and production. So, in complicated soft rock engineering, it is a must to pay attention to the characteristics of different supporting materials in order to realize coupled effect among varied supporting materials. Furthermore, unreasonable configuration of intervals of supporting is prone to stress concentration, causing crack and failure to wall rock and supporting, such as the spray layer, and finally egrading the integral supporting effect.

5. Conclusion

1) Based on the investigation and study of the site engineering geological conditions, and the characteristics of deformation and failure of roadways, the main characteristics of deformation and failure mechanism of soft rock roadways under the impact of coal mine fracture zones is analyzed. Main manifestations of deformation and failure: Under the action of traditional U-type arch supporting and common bolt-and-mesh supporting, the convergences of roof-to-floor and the two sides are large in area; much supporting under the impact of fracture zone fails, and the failed supporting is significantly asymmetric.

2) Based on the analysis and research of the characteristics of the displacement field of wall rock of roadways without supporting and roadways with common bolt-and-mesh supporting during excavation, the conclusion is that the mechanism of deformation and failure indicates the unconformity of different rock strata, the shear slip deformation of the fracture zone and the dislocation deformation caused by the extrusion of fractured rock strata under the condition of conventional supporting and the influence of the complexity of the fragmented structure of the wall rock. The causes of deformed and failed roadways can attribute to as below: high stress, low rock mass strength, and large deformation of original supporting that is not suitable for plastic rheology.

3) A solid foundation is laid for further study, the stability control of soft rock roadways under fracture zone with the aid of the study of deformation and failure mechanism of soft rock roadways under the impact of fracture zones.

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