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Numerical Simulation Study on Crosscut Roadway Floor Heave Control

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Abstract: *In response to the severe floor heave problem of the+1100m track crosscut in Liuyuanzi Coal Mine, it was found that the crosscut exists in a hard top and soft bottom surrounding rock environment. FLAC3D simulation was used to study the stress, plastic zone, and displacement of the surrounding rock when the crosscut is supported by bolt-mesh+Shotcrete+36U-type steel combined support and bolt-mesh+Shotcrete+36U-type circular shed combined support. The simulation results show that the latter reduces the floor heave by 57%.*

Keywords: *roadway, floor heave control, numerical analysis, bolt supporting, plastic failure*

1. Introduction

Floor heave is a common dynamic phenomenon in the wall rock of coal mine roadway. Dramatic floor heave dramatically affects the ventilation, transportation and miners of mines. For this reason, scholars at home and abroad have carried out a lot of research work[1-6]. Kang Hongpu et al. [7] introduce in detail the application of complete rock bolting technology to roadway supporting; Yang Shengbin, He Manchao et al. [8] study the mechanism of floor heave control by anchor bolts supporting and apply the technology to practice; Liu Quansheng et al. [9] use concrete inverted arch together with grouting and anchor cable technology to control the floor heave of soft rock roadway; Xie Guangxiang et al.[10] study on overbreak bolting & grouting-backfilling concrete to control the floor heave of deep mine roadway. Sun Jin et al.[11] put forward the pressure relief technology of cutting groove at the bottom of soft rock roadway.

The roof of the crosscut in Liuyuanzi Coal Mine is hard while the floor is relatively weak. The problems still remain to the floor heave despite of a couple of times of rebuilding. In this paper, FLAC^{3D} numerical simulation software is used to analyze the two different combined supporting methods for the hard roof and soft bottom crosscut of Liuyuanzi Coal Mine, and the combined supporting of bolting with wire mesh + shotcrete + 36 U-type steel circular shed is finalized, bringing good application results to the site.

2. Engineering Summary

Liuyuanzi Coal Mine is equipped with a rail track crosscut at the +1,100 m level with a buried depth of about 455 m, and the mine roadway occurs in mudstone, fine sandstone, medium sandstone and sandy mudstone. After the +1,100 m rail track crosscutting, the bolting with wire mesh was adopted. Two months later, the roadway floor heaved serious. So, it was rebuilt with the secondary supporting of 36 U-type steel + shotcrete. The floor heave still existed, affecting the normal operation of the coal mine. Therefore, it is extremely urgent to study the control technology of the floor heave of the crosscut. The test shows that the average natural compressive strength is 3.94~22.2 MPa of the roof and floor rocks of coal bed in Liuyuanzi Coal Mine. The initial supporting of +1,100 m rail track crosscut is designed as follows: the primary supporting is bolting with wire mesh, the secondary supporting, 36 U-type steel + shotcrete. The net section is 15.1 m^2, and the excavation sizes: 4900 mm wide and 4500 mm high. The shotcrete thickness is 200 mm.

The field survey and research indicate that serious floor heave occurs the +1,100 m rail track crosscut in Liuyuanzi Coal Mine, the maximum floor heave up to 1.5m, and the roadway floor heave speed up to 10-20 mm/d, resulting sunny-shady rail tracks and seriously impacting on the safety of passage of train and miners, and ventilation, as shown in Figure 1.

Figure 1: Deformation and Failure of Rail Track Crosscut

3. Numerical Simulation Analysis on Crosscut Floor Heave Control

3.1. Failure Analysis of Semicircular Arch Crosscut Roadway

3.1.1. Numerical Modeling of Semicircular Arch Crosscut

In order to find out the causes of deformation and failure of the wall rock of the +1,100 m rail track crosscut, a three-dimensional physical model of the semicircle arch section (the initial supporting scheme) was established using FLAC^{3D}, as shown in Figure 2. Model L×W×H=50m×20m×40m, totally 32,360 elements, 35,448 nodes. The lateral displacement of the model is limited, the bottom, fixed, the upper surface as the stress boundary, and 11.375MPa is applied to simulate the dead weight of the overlying rock mass. Mohr-Coulomb strength criterion is applied to rock mass failure. Due to much water inflow to the roadway, the Isotropic-Fluid-Flow Constitutive Model and the Fluid-Mechanical Interaction Calculation Model are adopted. See Table 1 for the physical and mechanical parameters used in the calculation.

The anchor rods are generated by cable elements, and the specific mechanical parameters are shown in Table 2. The U-type steel supports are simulated by shell elements, with elastic modulus, Poisson's ratio and thickness of 206000MPa, 0.26 and 200 mm respectively.

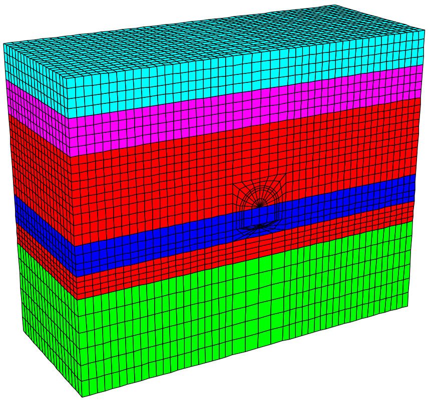


Figure 2: Mechanical Model of Arch Section Rail Track Crosscut

Table 1: Mechanical Parameters of Wall Rock and Coal Bed

No.	Names	D /m	γ /(MN/m^3)	E /MPa	v	T /MPa	C /MPa	Φ /(°)
1	sandy mudstone	4.9	0.0283	14410	0.27	1.05	1.28	36
2	fine sandstone	4.09	0.0291	28840	0.18	4.75	3.38	42
3	medium sandstone	16.27	0.026	6800	0.26	2.3	3.7	34
4	sandy mudstone	3.77	0.0257	14410	0.27	1.15	1.28	36
5	7- 1 Coal	6.25	0.0142	2410	0.29	0.36	0.41	21
6	sandy mudstone	3.77	0.0257	14410	0.27	1.15	1.28	36
7	concrete:	0.2	0.023	25500	0.2	1.6	3.18	50

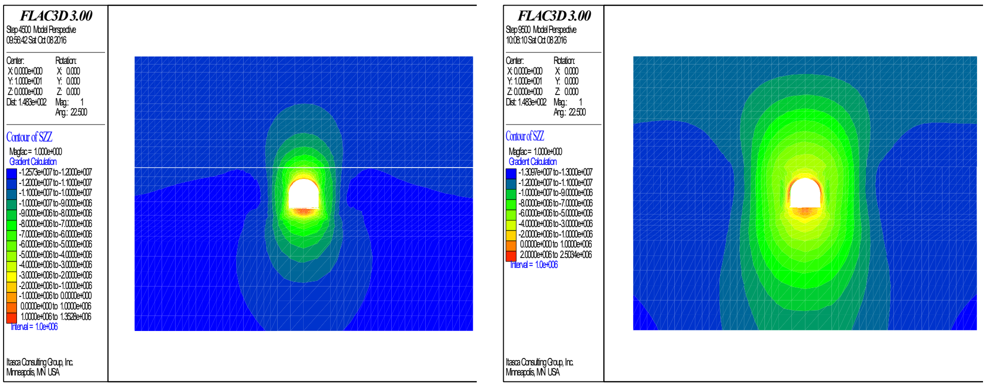
Table 2: Numeric Calculation Parameters of Anchor Rods

elastic modulus /GPa	cement grout cohesion per unit length /(kN·m^{-1})	cement grout shear stiffness per unit length /(MN·m^{-2})	outer circumference of cement grout / mm	sectional area /mm^2	prestress /kN	tensile strength /MPa
205	266	95000	61.8	314	60	490

3.1.2. Outcome Analysis of Floor Heave Control of Semicircular Arch Crosscut

3.1.2.1. Stress analysis

Please refer to Figure 3 for the stress simulation outcome of wall rock after excavating and supporting semicircular arch crosscut. In case of excavating 1 m and 6 m, the peak vertical stresses are 12.573 MPa and 13.079 MPa respectively, and the distances to the roadway sides are 4 m and 8 m respectively. Around the roadway there are tensile stresses, the maximum which are located at the center of the roadway floor, and the values, 1.3528 MPa and 2.5034 MPa respectively.

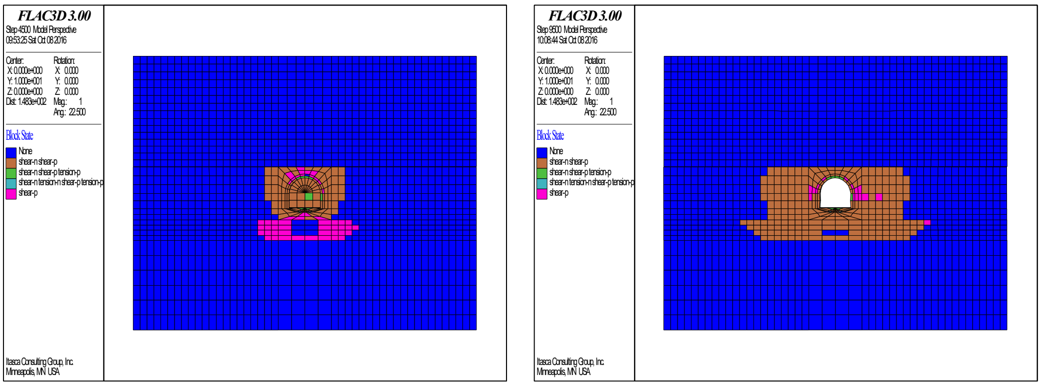


(a) vertical stress isoline of in case of excavating 1 m *(b) vertical stress isoline of in case of excavating 6 m*

Figure 3: vertical stress isoline of in case of excavating 1 m (a) and 6 m (b) of semicircular arch roadway

3.1.2.2. Analysis of plastic zone

Please refer to Figure 4 for plastic zone simulation outcome of wall rock after excavating and supporting semicircular arch crosscut. With the excavating progress, the plastic range of the roadway wall rock gradually expands, while the width of the plastic zone of the floor is larger than that of the two sides; when excavating 6 m, the plastic range of the floor has expanded to about 10 m from the roadway sides and about 6 m to the roadway floor; the failure type of wall rock is shear failure.

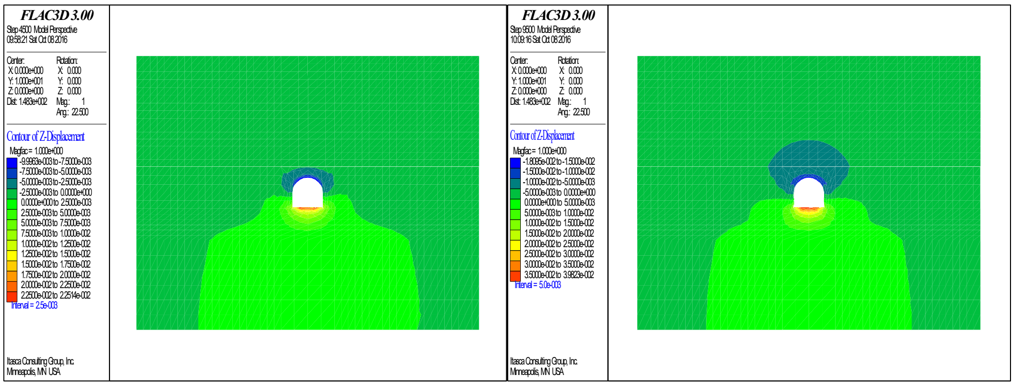


(a) Plastic Zone in Case of Excavating 1 m *(b) Plastic Zone in Case of Excavating 6m*

Figure 4: Plastic Zone in Case of Excavating 1 m and 6 m of Semicircular Arch Roadway

3.1.2.3. Displacement analysis

Please refer to Figure 5 for the displacement simulation outcome of wall rock after excavating and supporting semicircular arch crosscut. The displacements of roadway floor are 22.5 mm and 39.8 mm respectively in case of excavating and supporting 1 m and 6 m.



(a) Displacement Isoline of in Case of Excavating 1 m *(b) Displacement Isoline of in Case of Excavating 6 m*

Figure 5: Displacement Isoline of in Case of Excavating 1 m and 6 m of Circular Arch Roadway

3.2. Supporting Schematic Design and Numerical Simulation Analysis of Circular Crosscut

3.2.1. Numerical Modeling of Circular Crosscut

In view of the causes of failure of the +1,100 m rail track crosscut in Liuyuanzi Coal Mine, the combined supporting scheme of bolting with wire mesh + shotcrete +36 U-type steel circular shed is proposed. The three-dimensional physical model is shown in Figure 6, and the model length is L×W×H=50m×20m×40m, totally 39,600 elements, 43,134 nodes, and the strength criteria, constitutive model, calculation mode and parameters are the same as the initial supporting scheme. The anchor rod is generated by cable element, and the specific mechanical parameters are shown in Table 2. The U-type steel supports are simulated by shell elements, with elastic modulus, Poisson's ratio and thickness of 206000MPa, 0.26 and 200 mm respectively.

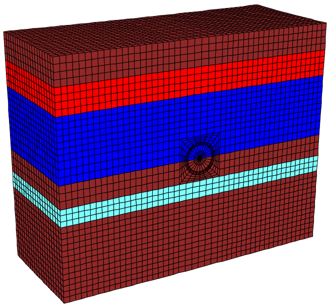
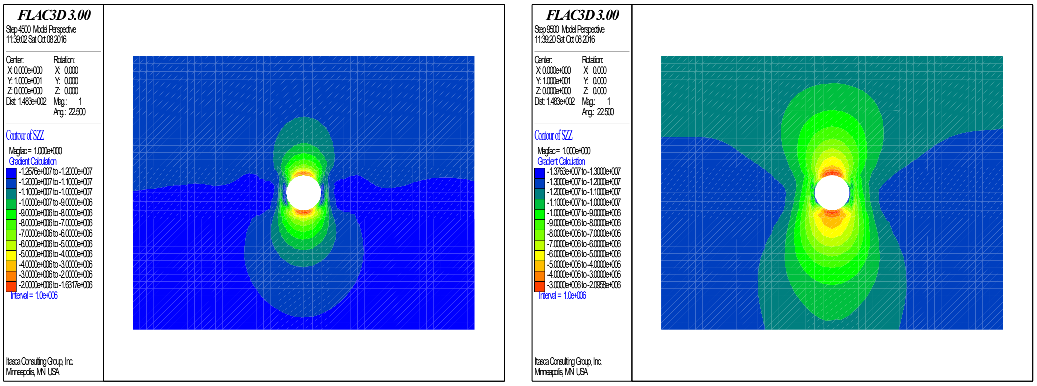


Figure 6: Mechanical Model of Circular Section Rail Track Crosscut

3.2.2. Outcome Analysis of Floor Heave Control of Circular Crosscut

3.2.2.1. Stress analysis



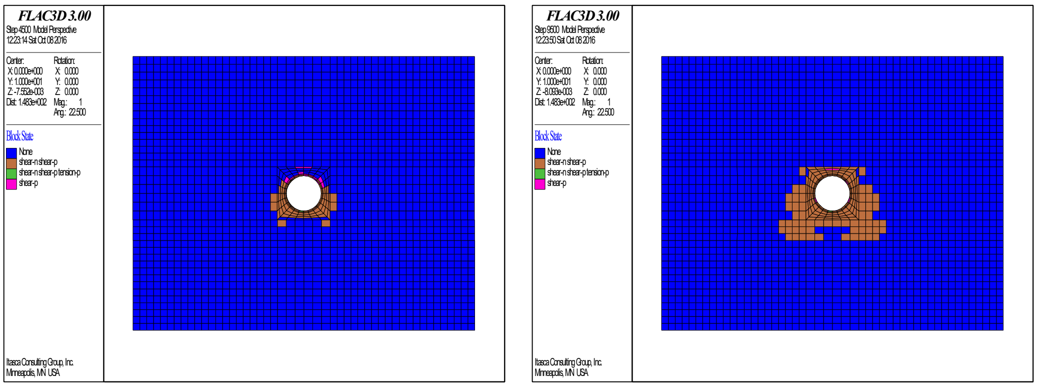
(a) Stress Isoline of in Case of Excavating 1 m *(b) Stress Isoline of in Case of Excavating 6 m*

Figure 7: Stress Isoline of in Case of Excavating 1 m and 6 m of Circular Roadway

Please refer to Figure 7 for the stress simulation outcome of wall rock after excavating and supporting circular crosscut. In case of excavating 1 m and 6 m, the peak vertical stresses are 12.676 MPa and 13.763 MPa respectively, and the distances to the roadway sides are 2 m and 5 m respectively. In the central area around the roadway sides of the circular shed there are higher tensile stress with the same value of peak vertical stress, and the compressive stresses at the floor, 2 MPa and 2.5034 MPa respectively.

3.2.2.2. Analysis of plastic zone

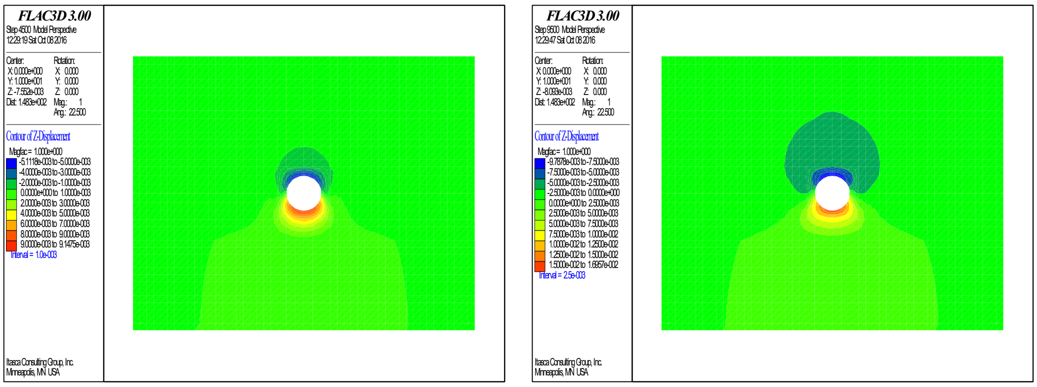
Please refer to Figure 8 for plastic zone simulation outcome of wall rock after excavating and supporting circular crosscut. With the excavating progress, the plastic range of the roadway wall rock gradually expands, while the width of the plastic zone of the floor is larger than that of the two sides; when excavating 6 m, the plastic range of the floor has expanded to about 5 m from the roadway sides and about 4 m to the roadway floor; the failure type of wall rock is shear failure.



(a) Plastic Zone in Case of Excavating 1 m *(b) Plastic Zone in Case of Excavating 6 m*

Figure 8: Plastic Zone in Case of Excavating 1 m (a) and 6 (b) of Circular Roadway

3.2.2.3. Displacement analysis



(a) Displacement Isoline of in Case of Excavating 1 m *(b) Displacement Isoline of in Case of Excavating 1 m*

Figure 9: Displacement Isoline of in Case of Excavating 1 m and 6 m of Circular Roadway

Please refer to Figure 9 for the displacement simulation outcome of wall rock after excavating and supporting circular crosscut. The displacements of roadway floor are 9.2 mm and 16.9 mm respectively in case of excavating and supporting 1 m and 6 m.

3.3. Comparison of supporting Schemes

Under the same supporting parameters, the surrounding of circular crosscuts is under compressive stress, and the floor of the semicircle arch crosscut is under tensile stress. The stress peak of the semicircle arch crosscut is deeper than that of the circular crosscut; the wall rock of circular crosscut and semicircular arch crosscut are all shear slopes, but the failure range of the former is much smaller than that of the latter; the floor displacement of the circular crosscut roadway is far less than that of the semicircular arch crosscut. To sum up, the supporting method of circular crosscut roadway is selected as the final implementation scheme.

4. Conclusion

In the event that the crosscut applies to bolting with wire mesh + shotcrete + 36 U-type steel supporting, the foot slope hornstone mass tends to jerks and slips, resulting floor heave. To make it worse, the rock mass at the floor center breaks under tension, resulting further failure of the bottom rock mass, and continuously increased floor heave.

In case of applying the combined supporting of bolting with wire mesh + shotcrete + 36 U-type steel circular shed, the floor displacement reduces by 57% due to shear failure of wall rock, and free of tensile failure zone around.

Acknowledgement

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