Analysis and Application on Inverted Arch Support of Cross-cut Floor Heave

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Abstract. The cross-cut is an important gateway to connect the main roadway and the coal seam. The transportation, the pedestrian and the ventilation of mine could be seriously influenced by floor heave of cross-cut. Aiming at the severe floor heave of +1100 m track cross-cut in Liu Yuan Zi Coal Mine, the cross-cut surrounded with hard roof and soft floor was found. To solve this problem, the bolt-net-shotcrete and 36U-shape steel combined supporting (the original supporting scheme) and the bolt-net-shotcrete and 36U-shape steel round shed combined supporting (the new supporting scheme) respectively were applied to the cross-cut by numerical analysis. The simulation results indicate that the floor heaves is reduced by 57%, and the surrounding rock stress was changed from tension to compression at the bottom and the plastic range decreased and trended to homogenization. Field application results indicate that the cross-cut floor heave can be controlled effectively by bolt-net-shotcrete and 36U-shape steel round shed combined supporting. The conclusions provide a reliable technical scheme for hard roof and soft floor roadway.

Keywords: Cross-cut; inverted arch; numerical simulation support; strength of surrounding rock; yield zone

1. Introduction
Floor heave is a kind of common dynamic phenomenon of coal mine tunnel and underground engineering. It not only seriously affects ventilation, transportation and pedestrian, but also may lead to roadway instability, water inrush and other engineering disasters, which increase complex maintenance workloads and the control costs and influences the security application of underground engineering [1-6]. Therefore, domestic and foreign scholars made extensive research [7-11] such as Royanfar A. and Shahriar K. [12] found that abutment pressures are major factors for increasing the length of packs and the method of rib pillar and pack can be used for control the deformation of height and width. Perry Kyle et al. [13] studied the repetition of floor heave and related problems outby the seals with the methods of ground control measures and 3D numerical modeling. Kang Hongpu et al. [14] introduced a complete sets of bolt support technology in roadway support. Yang Shengbin and He Manchao et al. [15] studied and used foot bolt to control floor heave in practice. Liu Quansheng et al. [16] used concrete arch grouting and anchor technology to control soft rock roadway floor heave. Xie Guangxiang et al. [17] studied the control technology of overbreak grouting backfill in deep tunnel floor heave. Sun Jin et al. [18] presented the pressure relief technology grooving at the corner of soft
rock roadway etc.

The reinforcement method is a common control method of floor heave, including bolting and grouting reinforcement, inverted arch reinforcement and closed support etc. The bolt reinforcement can increase the cohesion of surrounding rock, and enhance the flexural strength and shear resistance of rock, which is applicable in rock mass with better geological conditions generally. The grouting reinforcement can improve the stress condition of the supporting structure with grout filled in rock fracture, and generally is used in combination with other supporting forms. The inverted arch is usually poured by concrete, which can apply the uniform resistance to the floor, but it is difficult to deal with after the damage. The closed support can provide larger support resistance to prevent the development of the rock failure zone in the bottom of the floor, but it lead to high cost and complex construction procedure.

The main cross-cut is an important channel connecting the main roadway and the coal seam, which have important roles of coal transportation, auxiliary transportation, ventilation and personnel transportation. Because of the complex coal-bearing rock series, the surrounding rock of cross-cut is variable, which lead to cross-cut to be located in two or more hard and soft rock generally. Although rebuilt many times, it was still heaving in floor seriously that the cross-cut located in rock stratum with hard roof and soft floor in Liu Yuan Zi Coal Mine. FLAC³D is used to analyze the inverted arch supporting scheme of cross-cut floor heave in Liu Yuan Zi Coal Mine in this paper. By analysis of the stress, the plasticity and the displacement, it is accepted to be the implementation plan that the combined supporting of bolt-net-shotcrete and 36U type round shed.

2. Engineering Characteristics

2.1. Occurrence Environment of Cross-cut
The coal seams of Liu Yuan Zi Coal Mine is deposited in Jurassic Yan-an group, which are divide to two groups named upper group and lower one. Coal seams of 4-1 and 5-1 belong to the upper group and 7-1 and 8-3 belong to the lower one. The track cross-cut and the belt conveyor cross-cut and the returning air cross-cut are all located in the +1100 m level (the lowest level of 5-1 coal seam), which are buries in depth about 455 m. The track cross-cut is surrounded by mudstone, fine sandstone, sandstone and sandy mudstone etc. The bolt-net supporting is used to the track cross-cut after the excavation, while serious floor heave occurred later in two months. The shotcreting and 36U-shape steel are used for the second supporting scheme, but the floor heave still exists and influences the normal production operation. Therefore, it is imminent to research the control technology of the cross-cut floor heave in Liu Yuan Zi Coal Mine.

2.2. Deformation and Failure in Cross-cut
The average rock RQD is 39-87% in Liu Yuan Zi Coal Mine. The experimental results indicates that the compressive strength of the floor of 5-1 and the roof of 7-1 is 3.94-22.2 MPa in natural state while is 0.16-10.5 MPa in saturated state, and the softening coefficient is 0.04-0.47. The original supporting scheme of the track cross-cut in Liu Yuan Zi Coal Mine is as follows: the bolt-net supporting is used for the first support, the shotcreting and 36U-shape steel are used for the second support, as shown in figure 1(a).

The field investigation results indicate that the cross-cut heaves anomaly, the maximum of floor heaves is to 1.5 m (beyond the waistline), the speed of floor heave is from 10 to 20 mm per day. The transportation, the pedestrian, the ventilation and the safety are still influenced through several reconstruction. Even that the inverted arch supporting to be used can’t be effectively controlled yet.
3. Design and Simulation of Inverted Arch Supporting Scheme in Cross-cut

3.1. Supporting scheme
The bolt-net-shotcrete and 36U-shape steel round shed combined supporting is designed for the track cross-cut because of the complicated failure in Liu Yuan Zi Coal Mine. The supporting scheme is shown in figure 1(b).

3.2. Numerical Model
The semi-circle arch section (the original supporting scheme) and the circular cross-section (the new supporting scheme) are built by FLAC$^3$D. The three-dimensional models are shown in figure 2 and figure 3 respectively. The model size (length and width and height) is 50 m and 20 m and 40 m respectively. The semi-circle arch tunnel model has 32360 units and 35448 nodes while the circular one has 39600 units and 43134 nodes.

The model is limited by the lateral displacement and fixed under the bottom. The stress boundary is applied to the upper surface of the model, which is equal to 11.375 MPa to simulate the weight of the overlying rock mass.

Figure 1. Supporting design of track cross-cut.

Figure 2. Mechanical model and supporting structure of semi-circle arch track cross-cut.
3.3. Calculation Mode and Parameter Setting
Mohr-Coulomb strength criterion is used to rock failure. Considering the large water inflow, the Isotropic-Fluid-Flow model and Fluid-Mechanical Interaction model are used to model calculation. The physical and mechanical parameters are shown in table 1.

The bolt is generated by CABLE unit, and the specific mechanical parameters are shown in table 2. The U-shape steel supporting is simulated by SHELL unit. The elastic modulus, Poisson's ratio and thickness are 206000MPa, 0.26 and 200mm respectively.

### Table 1. Mechanical parameters for rock and coal.

| Number | Name              | D  | γ   | E   | ν  | T  | C  | 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-grained 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. Parameters for bolting and shotcreting.

| Elastic modulus /GPa | Cohesion of cement paste /(kN·m⁻¹) | Shear stiffness of cement paste /MN·m⁻² | Outer perimeter of cement paste /mm | Cross sectional area /mm² | Prestress /kN | Tensile strength /MPa |
|----------------------|----------------------------------|----------------------------------------|----------------------------------|--------------------------|----------------|----------------------|
| 205                  | 266                              | 95000                                  | 61.8                             | 314                      | 60             | 490                  |

4. Analysis of Simulation and Implementation Results of Inverted Arch Control in Cross-cut

4.1. Stress Analysis
The stress simulation results of surrounding rock after excavation and support in cross-cut are shown in figure 4. When excavating 6 m, the vertical stress peak value of semi-circle arch cross-cut and circular cross-cut is up to 13.079 MPa and 13.763 MPa respectively, and the peak position is located in 8 m and 5m away from roadway side respectively. The tension stress is distributed around the semi-circle arch cross-cut. The maximum tension stress located in the center of the floor is up to 2.5034 MPa. The compressive stress is distributed around the circular cross-cut and the larger one (the numerical value is equal to the crest value of the vertical stress) located in the center of the circular shed on both sides of the roadway is up to 3 MPa. Thus, the supporting scheme of circular section roadway can change the tension stress state of surrounding rock into the state of compressive stress,
which can also homogenize confining pressure and increase the strength of surrounding rock.

![Figures showing stress contours](image)

**Figure 4.** Roadway vertical stress contours in excavation 6m.

4.2. Plastic Analysis

The plastic states simulation results of surrounding rock after excavation and support in cross-cut are shown in figure 5. The plastic zone gradually expanded with excavating, and the width of floor plastic zone is larger than that of two sides in semi-circle arch roadway while the bottom is slightly larger than that of the two sides in circular roadway. When excavating 6 m, the plastic range is extended to about 10 m and 5 m away from the roadway side respectively in the floor of semi-circle roadway and the circular one while is about 6 m and 4 m depths away from the roadway floor. The surrounding rock is sheared. Thus, the plastic expansion and size of surrounding rock can be controlled effectively and reduced greatly by the supporting scheme of circular section.

![Figures showing yield zone](image)

**Figure 5.** Roadway yield zone in excavation 6m.

4.3. Displacement Analysis

The displacement simulation results of surrounding rock after excavation and support in cross-cut are shown in figure 6. The floor displacement is extended to 39.8 mm and 16.9 mm respectively in semi-circle arch roadway and circular roadway when excavating 6m. Thus, the deformation and displacement of surrounding rock can be effectively reduced by the circular roadway supporting scheme.
4.4. Determination and Implementation of Supporting Scheme

In the same supporting parameters, the compressive stress is distributed in the surrounding of circular tunnel while the tensile stress is distributed in the semi-circle arch tunnel in floor and the stress peak position of semi-circle arch cross-cut is deeper than that of circular cross-cut. The surrounding rock of circular tunnel and semi-circle arched tunnel are all sheared while the failure range of the former is much smaller than that of the latter. The floor displacement of circular cross-cut is much smaller than that of the semi-circle arch cross-cut. Comprehensive all above factors, the circular cross-cut supporting method is determined as the final implementation plan because the original circle arch cross-cut support has seriously affected the normal production. The combined supporting scheme of the bolt-net-shotcrete and 36U-shape steel round shed is used to the cross-cut. Then the deformation of surrounding rock is greatly decreased and the floor heaves is reduced by 69.1% in two months.

5. Conclusion

(1) Compared with the support of semi-circle arch section roadway, the support of circular section roadway can change the stress state of surrounding rock, and homogenize confining pressure and increase the strength of surrounding rock.  
(2) The numerical simulation results indicate that the surrounding rock is sheared but not tensioned and the floor displacement is decreased by 57% using the bolt-net-shotcrete and 36U-shape steel round shed combined supporting.  
(3) Field support monitoring indicate that the floor heaves is reduced by 69.1% using the bolt-net-shotcrete and 36U-shape steel round shed combined supporting, which ensures the safety and reliability of the operation of the locomotive effectively.

Author Brief Introduction

Wang Chao (1979– ), male, Shanxi, Weinan, M. D. associate professor, vice director of Department of mining engineering, Inner Mongolia University of Science and Technology, mainly engaged in teaching and research of mine rock control and disaster control.

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