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Support design and practice for floor heave of deeply buried roadway

Chaoke Liu*, Jianxi Ren, Bingli Gao, Yongjun Song

School of Civil Engineering and Architecture, Xi'an University of Science and Technology, Xi'an 71005, China

*Corresponding author e-mail: liuchaoke8@163.com

Abstract. Aiming at the severe floor heave of auxiliary haulage roadway in Jianzhuang Coal Mine, the paper analysed mechanical environment and failure characteristics of auxiliary haulage roadway surrounding rock with the combination of mechanical test, theoretical analysis, industrial test, etc. The mechanical mechanism for deformation and failure of weak rock roadway in Jianzhuang Coal Mine was disclosed by establishing a roadway mechanical model under the effect of even-distributed load, which provided a basis for the design of inverted concrete arch. Based on complex failure mechanism of the roadway, a support method with combined inverted concrete arch and anchor in floor was proposed. The result shows that the ground stress environment has extremely adverse influence on the roadway, and the practice indicates that the floor heave countermeasures can effectively control the floor heave. The obtained conclusion provides a reference for the research and design on control technology of roadway floor heave in the future.

1. Introduction

The mushroom growth of the economy causes an increasing energy demand, which leads to deep mining of coal mine successively and increases the buried depth of roadway year by year [1-3]. Generally, deep mining pertains to the coal mine with a depth of 600 m. The mining depth increasing not only increases the mining cost, but also faces many challenges such as high gas, high ground stress, deformed surrounding rock and difficult roadway support, which has a direct effect on coal mine safety production [4-5], wherein roadway floor heave is the most common challenge faced by deep coal mining.

For the deformation mechanism and support technology of roadway floor heave, experts and scholars have carried out numerous beneficial researches and practices, and the research on support theory is gradually deepened. Starting from the initial pressure arch hypothesis only considering the rock weight in caving arch and the Terzaghi K. formula considering limit equilibrium arch, the theory research now has developed into the Kastner formula considering plastic zone support outside the surrounding rock of fracture zone at ultimate equilibrium [6]. Multiple control methods including anchoring and grouting, floor beam with inverted arch, concrete pouring, etc. have been formed, and a certain effect has been achieved under the specific engineering conditions [7-9]. These theories and practices have accelerated the roadway support technology but requiring further researches on how to determine the reasonable support parameters.

2. Engineering Overview

The auxiliary haulage roadway, as a horizontal development roadway in this mine, will be continuously used for ventilation and haulage in more than ten years with such a noticeable importance. The roadway surrounding rock is featured with low strength, poor integrity and high degree of polarization, and easy to weathering and deliquescence, which are all the features of weak rocks.

The average buried depth of auxiliary haulage roadway is about 700 m, the cross section shape is semicircular arch with a vertical wall height of 1.8 m, an arch height of 2.4 m and the net width of 4.8 m. At the beginning, rock bolt, anchor cable and metal mesh were used to construct a permanent support. After three months from the roadway construction, severe floor heave occurred, and even in some sections, the floor heave reached more than 1000 m. The floor was then renovated and reinforced by adding anchors in floor with a size of Φ20 mm×L2500 mm and an inter-row distance of 2400 mm×2400 mm based on the original support. Meanwhile, a 500 mm thickness of concrete was poured on the floor to increase the stiffness. Nevertheless, the floor heave in roadway was not mitigated, and the repeated renovation and reinforcement made the roadway trapped in a viscous cycle of endless digging and repairing. Thus, it is urgent to make deep research and realize optimization on its failure mechanism and support design.

The exposed rocks during tunneling of auxiliary haulage roadway were mainly composed of mudstone, sandy mudstone, muddy siltstone and fine sandstone. Rock samples on site were classified into siltstone, fine sandstone, medium sandstone and mudstone by the stone natured, and the regular physical mechanics test was carried out on rock samples by rock servo pressure tester. The test result is shown in Table 1.

Table 1.physical and mechanical properties of stratum

Rock type	Shear modulus (GPa)	Cohesion (MPa)	Uniaxial compressive strength (MPa)	Internal friction angle (degree)	Density (kg/m^3)
Fine grain Sandstone	5.08	10.1	38.2	40.7	2700
Siltstone	5.82	7.9	31.5	39.7	2500
Mudstone	1.3	3.5	18.6	32.1	1900
# 4coal	0.76	3.64	12.0	31.55	1500
Mudstone	5.91	8.2	22.4	34.6	2480

3. Roadway Floor Support Design

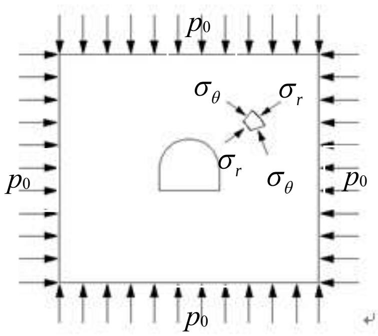

Figure 1. Mechanics model

Figure 2. Loose circle

3.1. Mechanical model establishment

According to the theories of rock mechanics and elastic mechanics, a roadway mechanical model under the even-distributed loads from two directions was built as shown in Figure 1. The buried depth of roadway was so great that the self-weight of rock stratum on the roadway roof and floor was much less than q which could be neglected. For convenience of obtaining the analytical solution, the following assumption was made:

1. The cross section of auxiliary haulage roadway was calculated by the shape of equivalent circumcircle;
2. It was assumed that lateral pressure coefficientλ=1 because the measured horizontal stress is closed to the vertical stress;
3. The roadway wall had the support action, so the support resistance to surrounding rock was assumed as p_i.

According to the equilibrium equation, geometric equation and physical equation, the elastic stress equation is obtained [10]:

$$\sigma_r = p_0\left(1-\frac{r_a^2}{r^2}\right) \tag{1}$$

$$\sigma_\theta = p_0\left(1+\frac{r_a^2}{r^2}\right) \tag{2}$$

The elastic stress equation is obtained:

$$\sigma_{rp} = \left(p_i+\frac{\sigma_c}{\xi-1}\right)\left(\frac{r}{r_a}\right)^{\xi-1}-\frac{\sigma_c}{\xi-1} \tag{3}$$

$$\sigma_{\theta p} = \xi\left(p_i+\frac{\sigma_c}{\xi-1}\right)\left(\frac{r}{r_a}\right)^{\xi-1}-\frac{\sigma_c}{\xi-1} \tag{4}$$

$$\xi = \frac{1+\sin\theta}{1-\sin\theta} \tag{5}$$

$$\sigma_{\theta p}+\sigma_{rp} = 2P_0 \tag{6}$$

From the formula (3), (4) and (6), the supporting force of plastic region are expressed in the following form when the supporting force exists.

$$P_i = \frac{1}{\xi^2-1}[2p_0(\xi-1)+2\sigma_c]\left(\frac{r_a}{R_p}\right)^{\xi-1}-\frac{\sigma_c}{\xi-1} \tag{7}$$

Where r_a is roadway radius, σ_r is radial elastic stress, σ_θ is tangential elastic stress, σ_{rp} is radial plastic stress, $\sigma_{\theta p}$ is tangential plastic stress, p_0 is surrounding rock pressure, r is radius, P_i is supporting resistance, c is cohesion, R_p is radius of plastic zone. θ is internal friction angle.

3.2. Mechanism analysis of roadway floor heave

The average buried depth of auxiliary haulage roadway was 700 m, then the average unit weight of upper overlaying stratum was considered as 25 kN/m^3, and the self-weight stress should be 17.5MPa. Based on the mechanical model, the cross section of roadway chambers was equivalent to its circumcircle with a radius of 2.83 m. It could be calculated based on the elastic theory that the shear stress of floor was 25.74 MPa when the floor was not supported, which was greater than the shear strength of floor mudstone. Shear slip occurred to the floor, and the floor mudstone crushed, resulting in the volume expansion of crashed mudstone on the floor; and the squeezing action of two sides aggravated the floor heave. It can deferred from the above theory that if the floor is not supported when the deeply buried roadway surrounding rock is subject to the high stress, and the floor shear stress is bound to be larger than its shear strength, so that floor heave occurs. Therefore, the floor must be supported to control roadway floor heave.

3.3. Inverted arch design

Currently, method for dealing with floor heave mainly includes reinforcement method, relieving method and combination method [11-15]. The reinforcement method is mainly suitable for the floor heave roadway with poor floor rock nature, this method is further divided into floor grouting, floor anchoring and inverted concrete arch. Floor anchoring and inverted concrete arch are widely used in the rock roadway, while floor grouting is difficult to achieve the desired results. Considering the importance and service life of auxiliary haulage roadway, the support scheme with combined concrete inverted arch and anchor in floor is adopted.

With support force obtained by the formula 7 as the load on inverted arch, radius of plastic zone was gotten by actual measurement as shown in Figure2. The maximum axial force $N_{\max}$ on inverted arch can be obtained by the structural mechanics.

$$N_{\max} = \alpha_1 f_c b h_0 + f_y A_s \tag{8}$$

Rebar arrangement can be adopted for the concrete inverted arch. The inverted arch span was the roadway width 4.8 m and the arch height to ground was 1.5 m; the concrete grade of inverted arch was C30, rebar grade was RRB400, inverted arch thickness was 400 mm, inverted arch length of each truss was 4 m; and the span of temperature joint was 150 mm. The area of main rebar in the inverted arch could be figured out by formula 8; the diameter of Φ20 mm was adopted by referencing to the table, and the vertical layout space was 250 mm. Fill the inverted arch with coal slag and then compacted it, and finally pave concrete with a thickness of 200 mm on the coal slag to harden the surface.

Two left-hand thread steel bolts with a diameter of Φ20 mm and a length of 2500 mm were used as the anchor in floor on each side with an inter-row space of 800×800 mm and cement paste was grouted. The anchor in arch forms an angle of 45° with the floor, imposing a priestess of 50 kN. The Φ18 mm vertical rebar was laid out longitudinally along the roadway with an interval space of 200 mm. The concrete strength was graded as C30, and 425# ordinary Portland cement mixed with waterproof agent blended.

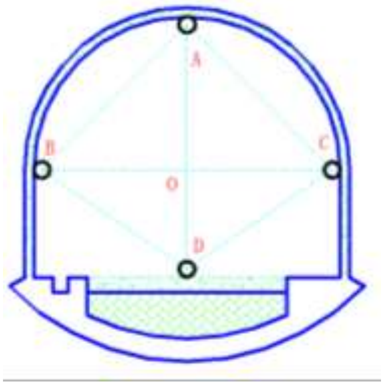

Figure 3. Monitoring profile

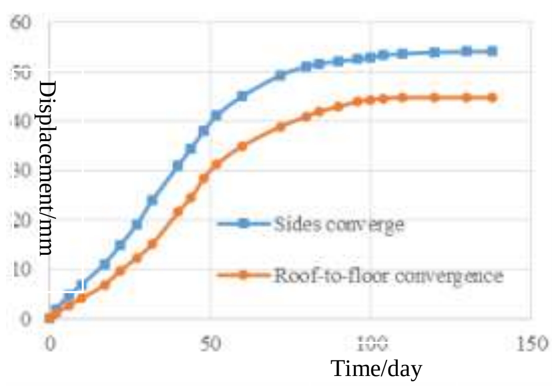

Figure 4. Roadway displacement monitoring curve

4. Engineering application effect

The above research results were applied to the incomplete surrounding rock support for haulage roadway to check the effectiveness and reasonability of the support. To accurately know the convergence and deformation of roadway surrounding rock, 3 observation stations were set up with an interval of 30 m with each other, monitoring profile is shown in Figure 3. The deformation observation on the roadway was carried out for 5 months, and the obtained typical curves of displacement and time are shown in Figure 4. It can be observed from Figure 4 that the overall roadway support is good, and the deformation of surrounding rock is effectively controlled, according to the two-side contraction of 56 mm and the maximum roof-floor convergence of 48 mm. The deformation of surrounding rock at the initial stage is not obvious, but during the period of 22～72d, the displacement change is relatively large and the two-side contraction is larger than the roof-floor convergence with the slow release of surrounding rock and the influence of construction disturbance. When the roadway tends to be stable, the deformation of two sides and the roof and floor are controlled within the allowable range and meet the engineering requirements, indicating that the support technology is successful in controlling the stability of deeply buried roadway floor.

5. Conclusion

Aiming at the floor heave of auxiliary haulage roadway in Jianzhuang Coal Mine, the paper proposed specific control measures by considering the theoretical analysis, value calculation, indoor test and site test data and comprehensively analyzed the deformation failure mechanism of roadway floor heave. The following conclusion is obtained by this study:

(1) Based on the stress environment of auxiliary roadway in Jianzhuang Coal Mine, a force model for the roadway under the even-distributed load from two directions is created, and the research discloses the mechanical mechanism of roadway deformation and failure, drawing a conclusion that the shear failure of floor surrounding rock is the key factor of roadway floor heave, because the floor shear stress is certain to be larger than the roadway shear strength if the floor is not supported in the roadway subject to high stress;

(2) The paper also proposes a support scheme combined inverted concrete arch and anchor in floor. The application of site construction and deformation observation results indicate that the surrounding rock deformation is mitigated and good support effect is obtained after adopting the above mentioned support scheme;

(3) The results mean that the technology is successfully applied in the engineering practice of floor heave control for the deeply buried roadway, which provides a beneficial reference for the stability control of surrounding rock in other works under the similar conditions and worthies wide promotion.

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