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Current Status of The Mechanism of Floor Heave in Deep Tunnels

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Abstract

Floor heave is an important problem in coal mining. And there has been no consensus on the mechanism of floor heave in deep roadways. Severe floor heave can affect the ventilation, bottom slope and normal use of machinery in the roadway. In this case, analyzing the current situation of the research on the mechanism of floor heave in deep roadway, and we can divide the floor heave into three types. According to the form of floor heave by using similar material simulation and numerical simulation: flexure and folded type, water swelling floor heave type and extrusion liquidity floor heave type. Among them, the soft rock roadway is mainly extruded fluidity floor heave, and when the bottom rock is hard, the flexure and folded type floor heave is mainly form, and there are rocks with strong water absorption in the surrounding rock, such as montmorillonite, which will produce large water swelling deformation. Commonly the prevention and control of floor heave can be divided into two categories: reinforcement and pressure relief.

Keywords

Floor heave; numerical simulation; deep mining; disaster prevention and control.

1. Introduction

China is a country abundant in coal resources but relatively poor in oil and natural gas reserves, with coal constituting 95% of its domestic fossil energy reserves. The distribution of coal resources across the nation is highly uneven, particularly regarding deep-seated coal reserves. These deep coal resources are primarily concentrated in the Northeast China region, North China region, and East China region.

With the development of China's economy, the large-scale consumption of energy, especially coal resources, has led to the near depletion of shallow coal mining in China, and the mining has gradually shifted to deeper levels. It is predicted that coal reserves buried deeper than 1,000 meters account for about 53% of the total predicted reserves in the country[1]. There are 47 coal mines in China with a mining depth greater than 1,000 meters, among which Sun Village Coal Mine has reached a mining depth of over 1,500 meters, with an annual production capacity of 1.2 million tons. It is believed that within the next few years, our country will enter a stage of comprehensive and in-depth exploitation.

Compared with shallow coal mining, deep mining is more difficult and the construction process is more complex. This is because the mechanical properties of deep rock change compared with those of shallow rock. Shallow rock mostly shows brittle characteristics, with only a small amount of permanent deformation during rock deformation. However, deep rock under the influence of high ground stress, high ground temperature and high karst water pressure will show ductile properties, and at this time, time-related deformations such as creep and rheology often occur. In such cases, the resulting damage is often difficult to predict. While shallow rock can still be analyzed and solved using elastic-plastic theory, this is not applicable to deep rock. When solving deep rock problems, nonlinear large deformation theory should be adopted. The

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failure forms of deep rock and shallow rock are also quite different. During excavation, the horizontal and vertical stresses of shallow rock are relatively small, and the amount of rock movement is also small. The support method for the tunnel is relatively simple and the cost is low. However, deep rock, due to the influence of geological movements and other factors, has relatively large in-situ stress. When disturbed by excavation, the in-situ stress will redistribute, and the rock mass within a certain range will be affected by the stress redistribution. At this time, the surrounding rock may move into the tunnel under the action of stress, and in severe cases, the tunnel may not be able to be used normally. Even high-strength rock may experience rock-burst phenomena.

Deep underground roadway damage includes roof subsidence, inward movement of both sides and floor heave. Different forms of damage require different support forms. Statistical data show that the floor heave accounts for more than half of the displacement of the roof and floor [4]. Severe floor heave not only increases the cost of roadway maintenance but also poses a threat to production work. Therefore, controlling the amount of floor heave is an important factor for the safe production of roadways.

For a long time, people's understanding of the mechanism of roadway floor heave has been incomplete, which has led to many problems being unsolvable during deep mining, causing many safety accidents. Studying the mechanism of floor heave generation and prevention measures is an important topic in the field of roadway support.

2. Current Research Status on Floor Heave in Roadways

The methods for studying the floor heave of soft rock roadways directly affect the reliability of the research results. Currently, three methods, namely theoretical analysis, simulation research, and engineering measurement, are widely adopted.

In China, Jiang Yaodong et al.[4,5] believe that the four forms of floor heave failure in roadways are extrusion flow floor heave, flexural wrinkling floor heave, water absorption swelling floor heave, and shear dislocation floor heave. They designed a true triaxial plane simulation test rig for simulation research, and analyzed the generation mechanisms and prevention measures of these four forms of floor heave. Gao Mingzhong[6] derived and calculated the formula for the critical load of buckling floor heave according to the elastic thin plate theory, and explored the relationship between the critical buckling stress and the thickness-span ratio. When the critical stress is not greater than the uniaxial compressive strength of the rock, the larger the thickness-span ratio, the greater the critical stress.

Wang Nan[7] believes that the floor heave of the roadway is caused by the disturbance resulting from the roadway excavation. The stress of the roof is transmitted to the roadway floor through the rock masses on both sides of the roadway, increasing the stress on the roadway floor. At this time, the surrounding rock of the floor moves into the roadway under the action of stress, resulting in floor heave. Xu Feng[8] believes that when the surrounding rock is mudstone, the cause of the roadway floor heave is that the weak rock layer in the circumferential stress circle generates radial displacement after being subjected to the circumferential stress, and holds that the degree of roadway floor heave is larger in the middle and smaller on both sides.

Pan Yishan[9,10] proposed three models reflecting the floor heave deformation of roadways, namely the rheological elasto-plastic model, the Newtonian visco-plastic fluid model, and the seepage swelling softening model. By using the numerical analysis method, it is concluded that reinforcing the floor and making slotting treatment on the floor can effectively reduce the amount of floor heave. Moreover, according to the images of the simulation test, both the floor reinforcement and the slotting treatment have a critical value, and only when it is greater than the critical value will the amount of floor heave be significantly reduced.

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He Manchao et al.[11,12] believe that the two sides, the roof, and the bottom corners have an important influence on the roadway floor heave. The finite difference calculation software FLAC was used to analyze these three parts respectively, and it was concluded that the stability of the roadway floor is a process jointly affected by the roof, the two sides, and the bottom corners. Establishing an integrated support structure can effectively reduce the amount of floor heave. At the same time, the large deformation theory was also proposed to calculate the amount of roadway floor heave.

Kang Hongpu[13–15] and others believe that there are many factors affecting the floor heave, mainly in two aspects, namely: the surrounding rock stress and the lithological state of the rock strata. The roadway floor heave caused by the buckling, dilation, and swelling of the rock strata was particularly studied. And the formulas for calculating the amount of floor heave in these three cases were given. The calculation shows that buckling accounts for 76.3% of the total floor heave. When analyzing the floor heave of soft rock roadways, it is believed that the characteristic of swelling upon water absorption is the main factor leading to the floor heave of soft rock roadways. The displacement was calculated respectively using the one-dimensional and three-dimensional swelling theories, and the size of the swelling range was obtained accordingly. Combined with the engineering measurement, it is concluded that the calculated value is 36% to 43% of the measured value. It can be seen that swelling is a very important part of the total floor heave. The paper points out that the main factors affecting swelling are the swelling parameters and the stress state, and these two aspects can be considered when designing the support.

When Xie Weihong[16] studied the wrinkling type of roadway floor heave, the roadway floor was simplified as a beam, and the catastrophe theory was used to analyze the conditions for the occurrence of floor heave. It was concluded that the floor heave is related to the span of the floor, the magnitude of the self-weight stress, the magnitude of the horizontal stress, and the flexural stiffness of the floor. Wang Weijun[17,18] studied the mechanism of floor heave in the mining roadway, taking into account the influence of the advanced bearing pressure on the roadway floor heave. When the roadway is excavated, the rock strata change from a three-dimensional stress state to a two-dimensional stress state, resulting in energy release. When the maximum surrounding rock stress is greater than the uniaxial compressive strength of the rock, the rock strata will be damaged. Under the action of the advanced bearing pressure, the coal bodies on both sides of the roadway will move into and sink in the roadway, causing secondary horizontal stress, and squeezing the broken rock mass to gush into the roadway.

Based on the measured data of the south wing of Gubei Coal Mine and the inverted triangular or trapezoidal form of the roadway floor heave, Liu Quansheng[19] concluded that the floor heave of the broken roadway is due to the extrusion of the broken rock layer at the floor into the roadway under the action of high stress.

3. Prevention and Control Measures for Floor Heave

Kang Hongpu and Lu Shiliang[13] calculated the magnitude of floor heave and proposed the pressure relief gallery method to reduce stress in the surrounding rock of the floor, thereby controlling floor heave, based on factors influencing its occurrence. Hou Chaojiong[20] and Wang Weijun[21], through numerical simulations, similar material testing, and engineering case studies, suggested that reinforcing the roadway's two sides (ribs), roof, and floor corners can effectively mitigate floor heave. Liu Quansheng[19], combining the practical conditions of the Gubei Coal Mine project, proposed using inverted arch flooring combined with prestressed anchor cables to control floor heave. Field measurements demonstrated that this method not only significantly reduces the rate of floor heave but also improves the mechanical properties of the surrounding rock in the roadway's sides. Xie Guangxiang and Chang Jucai [22], building on

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existing control technologies and adapting to specific engineering conditions, introduced a novel deep roadway floor heave control technique: over-excavation anchor-grouting backfill technology. This involves first over-excavating 1.6m of the floor rock layer, installing 1.5m anchor bolts, and finally backfilling with concrete. Field tests confirmed that this method achieves excellent control over floor heave.

4. Conclusion

In summary, current mechanistic analyses of roadway floor heave can be broadly categorized into three types: deep soft rock roadway floor heave, buckling-fold-type floor heave, and swelling-type floor heave. During roadway excavation, the stress state of the floor's surrounding rock transitions from triaxial to biaxial, with deformation primarily occurring toward the roadway interior. Under high stress conditions in deep soft rock roadways, this leads to squeeze-flow deformation into the roadway.

Buckling-fold-type floor heave typically occurs in roadways with well-stratified, intact rock layers and minimal fracture zones. Rock failure often propagates along bedding planes or joints. However, the specific failure modes and geometries of slip surfaces remain poorly understood.

Swelling-type floor heave is common in rock layers containing water-absorbent minerals such as montmorillonite and illite. These rocks expand upon water absorption, and the presence of moisture in roadways (due to various factors) softens or disintegrates the rock, eventually triggering squeeze-flow deformation.

While significant progress has been made in floor heave research, critical gaps persist in understanding buckling-fold-type floor heave in deep roadways, such as the inclination angles of shear slip surfaces and their formation mechanisms. Additionally, challenges remain in developing effective support technologies for deep roadways. Designing universal and cost-effective support systems that address the complex conditions of deep mining environments remains a key focus for future research.

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