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Support technology of deep roadway under high stress and its application

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ABSTRACT

Roadway instability has been a major concern in the fields of mining engineering. This paper aims to provide practical and efficient strategy to support the roadways under high in-situ stress. A case study on the stability of deep roadways was carried out in an underground mine in Gansu province, China. Currently, the surrounding rock strata is extremely fractured, which results in a series of engineering disasters, such as side wall collapse and severe floor heave in the past decades. Aiming to solve these problems, an improved support method was proposed, which includes optimal bolt parameters and arrangement, floor beam layout by grooving, and full length grouting. Based on the modeling results by FLAC3D, the new support method is much better than the current one in terms of preventing the large deformation of surrounding rock and restricting the development of plastic zones. For implementation and verification, field experiments, along with deformation monitoring, were conducted in the 958 level roadway of Mining II areas. The results show that the improved support can significantly reduce surrounding rock deformation, avoid frequent repair, and maintain the long-term stability of the roadway. Compared to the original support, the new support method can greatly save investment of mines, and has good application value and popularization value.

1. Introduction

With the rapid development of economy, global demand for mineral resources is ever-growing and shallow resources have asymptotically dried up. Thus, deep mining engineering is the inevitable trend of the future. According to statistics, a lot of countries have turned into deep mining stage, for example, the United States, Canada, South Africa and so on [1–4]. Among them, the South Africa embraces most of the deep mines. The depth of those mines in South Africa has been more than 1000 m. For instance, the Anglogold mine has reached 3700 m, and West Driefovten golden mine arrived at a depth of 6000 m. In addition, in Canada, Australia, United States and many other countries, the depth of mining has been over one thousand meters.

As mining and underground constructions migrate to deep grounds, the depth of the roadway is ever-increasing and crustal stress is also escalating, leading to serious damage in high stress area. Due to high crustal stress and complex geological environment, the supporting project of deep roadway has been a focus in the fields of mining and rock engineering [5–14]. Jinchuan Nonferrous Metals (Group) Company, the nation's largest nickel production base, occupies an important position in national economy. However, after decades of exploitation, the resources of upper part have been depleted gradually and mining is growing deeper and deeper. Currently, the No. 2 Jinchuan Mine has already reached a depth of 850 level, about 1000 m far from the surface. Because of extremely complex geological structure and poor geological mechanics condition, the stability of deep roadway of Jinchuan Mine has become extraordinarily important.

Based on the existed research achievement on specific supporting engineering of deep surrounding rock in Jinchuan Mine, the characteristics of the surrounding rock deformation and the supporting system failure are analyzed, and the original supporting method is optimized and a new support scheme combined long anchor with steel beam is presented in this study. Based on the results investigated by the finite difference technique (FLAC3D) and field tests, the proposed support technology is of great application value in stability analysis of deep roadway under complex geological environment, which sets reference for similar deep supporting project.

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2. Failure modes and key issues

2.1. Failure modes of roadway

The deformation and damage of deep roadway in Jinchuan is serious. And most of the roadways need to be repaired several times in its service period, every 3–6 months generally. Field investigation discovers significant deformation in every roadway, which usually reaches tens of centimeters. In severe cases, the failure surrounding rock can block the entire roadway. In addition to the horizontal convergence, the deformation of floor heave is also massive. The major existed support is comprised of double shotcrete lining and U-shaped steel, as shown in Fig. 1. The bolt length is 2250 mm, the bolt spacing is 800 mm, and U-shape steel row distance is 800 mm.

Under the present supporting, the damage of Jinchuan deep roadway is mainly reflected in the following two ways:

(1) Convergence and collapse of sidewall, as shown in Fig. 2a: under high ground stress, the surrounding rock near the side wall is seriously deformed and the extruding force is directly applied to the supporting system. And then shotcrete lining deforms together with the surrounding rock. In the weak area, broken rock thrusts through shotcrete layer, breaking the supporting body.

(2) Floor heave (Fig. 2b): under the high horizontal stress, the surrounding rock of the side wall changes its shape severely and a wide range of convergence is observed around the rock of foot position. Once plastic slip occurs, the bottom rock mass will be squeezed, leading to serious floor heave.

2.2. Key issues to be addressed

Investigating the field failure characteristics of the present supporting system, it can be found that although the deep roadway of Jinchuan has been damaged seriously, most of the anchor plate astringes together with the surrounding rock along the roadway free face instead of being broken (Fig. 3). Only a small number of anchor plates are teared up into the interior rock. This indicates that the bolt did not play full effect in strengthening the surrounding rock, because the bolt is not long enough to be anchored in stable rock but can only stay in the loose zone. Therefore, anchor arrangement design should ensure that bolt is long enough to be anchored into stable rock, forming an effective reinforcement in the deeper and larger region of loose zone.

In addition, the deformation control of surrounding rock around foot and bottom needs to be addressed urgently. Under the high horizontal stress, the surrounding rock of the sidewall deforms severely and a wide range of convergence emerges around the rock of foot position of roadway, then the bottom rock mass is squeezed, and eventually shows serious floor heave phenomenon. Finally, the continuous deformation leads to an overall failure of roadway. As shown in Fig. 4, the floor rises to 1200 mm under the effect of extrusion. For this reason, deformation of the rock around foot position needs to be restricted in the initial stage to ensure enough supporting resistance and stiffness in later period.

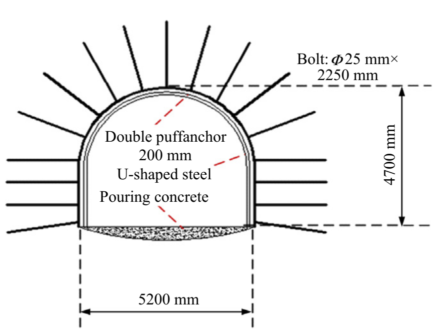

Fig. 1. Original support.

3. Roadway support design

3.1. Adjustment and placement of bolt length

The distribution of loose circle in Jinchuan deep roadway was tested. On the basis of results shown in Fig. 5, the maximum depth of loose circle was monitored to be approximately 2000 mm at the spandrel, 2450 mm at the lower rib. However, the length of bolt can only reach to 2250 mm in the existing puffanchor supporting system. So it illustrates that in the existing supporting, the anchor length in spandrel and foot position cannot deep into the stable rock and not be able to reinforce the rock in loose circle under high stress.

In the supporting design, anchor length should be determined based on the depth of loose circle as follows [16,17]:

$$L = L_1 + L_p + L_2 \tag{1}$$

where L is the length of the bolt, mm; L_1 the exposed length, and the value of L_1 is in the range of 50–100 mm; L_P the depth of loose circle, mm; and L_2 the length of bolt anchored in stable rock, generally 300–400 mm.

Maximum depth of loose circle from test is 2300 mm, the exposed length (L_1) is 100 mm and the length of bolt anchored in stable rock (L_2) should be as large as 400 mm. According to test Section 1, the length of bolt in two-side walls should reach to 2200 mm. Near the spandrel and foot, the supporting length should be 2700 and 2950 mm, respectively. According to test Section 2, the length of bolt in two-side walls should reach to 2300 mm. Near the spandrel and foot, the supporting length should be 2580 and 2350 mm, respectively. Thus, combined with the actual situation of the project construction, the bolt length of spandrel and foot should be adjusted to 3000 mm.

3.2. Roadway floor heave prevention and control technology

To prevent rock masses of foot from plastic sliding and control the bottom uplift magnitude, the floor steel beams should be used to control the deformation of surrounding rock near the floor. And steel beams are laid out by the method of floor grooving, as shown in Fig. 6. Steel beams are placed in the middle of the groove, the steel beam is made up of ordinary carbon round steel, with a size of 16 mm in thickness, and the outer diameter is 219 and 4500 mm. The stability coefficient of compression is 0.88, the yield strength reaches 238 MPa, and the axial bearing capacity is 1900 kN.

The depth of the groove in each place is different and it should be over 600 mm for the central part. Then the groove should be backfilled by pebble that is less than 25 mm in the grain size after the steel beams are put down. It should be pointed out that a space on both sides of steel beam should be left down, and finally the top should be covered by prefab.

The floor beams aimed at limiting rock mass deformation and plastic sliding near the floor should be set up. Although it is inevitable for the floor to rise in a certain degree as time goes by, the rock will squeeze pebbles when floor rises as the steel beams are laid by the method of floor grooving, and the pebbles will move to the reserved space (Fig. 7).

In this way, the rock mass cannot come into contact with the steel beam and the steel beam avoids being jacked up. At the same