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A method for computing unsupported roof distance in roadway advancement and its in-situ application

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A B S T R A C T

A reasonable unsupported roof distance (URD) when advancing underground coal mine roadways can contribute greatly to safe and rapid roadway development. A mechanical model of the roof, using the relationship between the roof stress distribution and URD, obtained by the difference method, and roof stability according to the in-situ roof stress and rock mass strength was developed. We subsequently designed a proper range of URD, developed a testing method of URD with the function of mining protection, evaluated roof stability through analyzing the test data and then determined a reasonable URD. Considering the factors of the geological conditions, the immediate roof stability and the efficiency of the labor arrangement system, the URD of the advancing roadway of 9802 working face in Zhangshuanglou coal mine was determined to be 6 m using the proposed method. The results show that, when a 2 m length of roadway was reinforced by temporary support and high pre-stressed bolt support after the roadway advancement of 6 m per cycle, the speed and the security of the roadway development can be achieved and the advance rate can reach more than 400 m per month.

1. Introduction

Roadway development is a comprehensive operating technology, which is affected by the characteristics of excavating equipment as well as the support method utilized [1–4]. Four efficient methods are currently employed to develop coal roadways [5,6]. The first method is the operating line combining a cantilever excavator and monomer jumbolter. This technology is relatively mature and has a wide application range. It has been applied widely in the key mines of China and Europe. The limitation of this method is that the roadway drivage and support work cannot achieve parallel operation [7–10]. The second method is the operating line combining continuous miner and bolt drill carriage, which is used in the Shendong mining area, Wanli mining area and Ordos region. The main tunneling machine is a continuous miner, which needs multiple roadway development and interchange operation. The third method is the integrated method of cutting and bolting with a continuous miner and bolt drilling machine. The fourth method is the integrated method of cutting and bolting with cantilever excavator and bolt drilling machine. The integrated method of cutting and bolting is widely adopted in the USA and Australia. The speed of roadway excavation affects the coal mining speed and economic benefits. The continuous miner and monomer jumbolter are popular application in China due to the complex geological conditions of coal resources. Roof support often lags behind the headings, leaving the roof near the heading face unsupported.

The length of the exposed roof in the roadway strike is determined as the URD (as shown in Fig. 1, L_1) [11]. The correct calculation of the length of URD plays an important role in the efficiency and security of roadway drivage.

There is no acknowledged method to determine a reasonable URD. A smaller URD can guarantee security, but the excavation and support work alternate frequently, which will influence the production efficiency. By contrast, a bigger URD can reduce the number of working shifts and is beneficial to the work efficiency. However, it could lead to roof collapse and influence the development progress and threaten the safety of miners. Hence, a reasonable URD is particularly important considering safety and production [12,13].

This study proposes a mechanical model for analyzing the stability of the roadway roof. The difference method is adopted to calculate the relationship between the immediate roof stress

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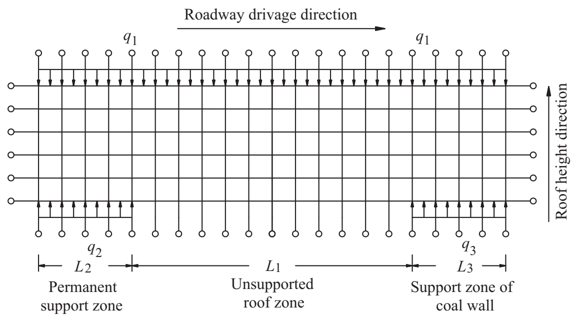

Fig. 1. Mechanical model of immediate roof in unsupported roof zone.

distribution law and the URD. A method of testing the URD for mining safety was developed. By analyzing the test data, the evaluation of the roof stability is conducted so that a reasonable URD can be reached. This method was applied in the mining roadway of 9802 working face, Zhangshuanglou coal mine, Xuzhou, Jiangsu, to determine the URD.

2. Difference method for determining URD

2.1. Roof mechanical model in the unsupported zone

Roadway advancement disturbs the stress state of the surrounding rock mass. In the shallow surrounding rock, from the original three-dimensions to two-dimensions, the bearing capability of surrounding rock is decreased [14,15]. Rock mass damage would be found to increase from the surface to the interior and the stress will also transfer to depth when the stress exceeds the ultimate strength of the rock mass [16,17]. In a short period after excavation, damage mainly occurs in the immediate roof. Hence, immediate roof reinforcement is important to maintain stability of the unsupported roof zone during roadway excavation.

After excavation, the immediate roof in the unsupported roof zone is supported by the rib coal mass, the front coal mass and the permanent bolting and mesh support behind the zone. For simplicity, the bolting and mesh support and the coal mass support are assumed to be a symmetrical structure. The contribution of the rib to the reinforcement of the immediate roof is not taken into account in the proposed model, which can yield safe and simple results. The heading end was extended in the roadway drivage direction by 2 m and the bolting end in the opposite direction by 2 m. The entire length of the model consisted of the drivage per cycle (the length of unsupported roof zone along the roadway axial direction), the support length of the coal wall and the bolting support length. The thickness of the immediate roof was set as the model height. The load is distributed uniformly on the immediate roof (the upper boundary of the model). As the unsupported time was relatively short, the immediate roof could be regarded as a continuous homogeneous medium when it was intact. Based on the above assumptions, taking the example of the URD of 6 m and immediate roof thickness of 2.5 m, a mechanical model of the immediate roof in the unsupported roof zone along the roadway axial direction was established, as shown in Fig. 1.

According to the principle of numerical solutions of differential equations and integral–differential equations [18,19], the immediate roof of the model was divided into latitude–longitude grids of 0.5 m × 0.5 m and the boundary load was applied on the model. The calculation model of the stress difference method [20,21] is shown as Fig. 1. The model size is 10 m × 2.5 m and grid intersection points are nodes whereas nodes out of boundary are virtual nodes. The load caused by the above strata is q_1, and the support provided by the coal wall and the bolting and meshing support are q_2 and q_3 respectively. The length of URD, coal wall support section and permanent support section in the model are L_1, L_2 and L_3 respectively.

2.2. Roof mechanical model in the unsupported zone

A part of the model is chosen to illustrate the solving process as shown in Fig. 2. The mesh width is equal in the x and y directions, and A and B are node numbers, φ is a stress function, φ_i (i = 1, 2, 3, 4, ...) is the stress value.

The steps in calculating the immediate roof stress components by the difference method are as follows:

(1) Select a random node on the boundary as base point A, setting:

$$\varphi_A = \left(\frac{\partial \varphi}{\partial x}\right)_A = \left(\frac{\partial \varphi}{\partial y}\right)_A = 0 \tag{1}$$

All node values (φ) on the boundary and the values of $\partial\varphi/\partial x$ and $\partial\varphi/\partial y$ can be calculated by the moment of the surface force and the sum of surface forces. For Eq. (2):

$$\left.\begin{aligned} \varphi_{13} &= \varphi_9 + 2h\left(\tfrac{\partial \varphi}{\partial x}\right)_A \\ \varphi_{14} &= \varphi_{10} + 2h\left(\tfrac{\partial \varphi}{\partial y}\right)_B \end{aligned}\right\} \tag{2}$$

The left sides of Eq. (2) are virtual nodes out of the boundary, whereas the right sides are real nodes.

(2) The value of virtual nodes on the boundary were expressed by the corresponding node value φ inside the boundary using Eq. (2).

(3) At the node of "0", the difference equation is:

$$20\varphi_0 - 8(\varphi_1 + \varphi_2 + \varphi_3 + \varphi_4) + 2(\varphi_5 + \varphi_6 + \varphi_7 + \varphi_8) + (\varphi_9 + \varphi_{10} + \varphi_{11} + \varphi_{12}) = 0 \tag{3}$$

The difference equation in the form of Eq. (3) for each node inside the boundary can be established. Hence, each node value (φ) can be solved.

(4) Each value (φ) of virtual nodes on a line outside the boundary can therefore be calculated by Eq. (2).

(5) Stress components of node "0" can be reached using Eqs. (4)–(6).

$$(\sigma_x)_0 = \left(\frac{\partial^2 \varphi}{\partial y^2}\right)_0 = \frac{1}{h^2}[(\varphi_2 + \varphi_4) - 2\varphi_0] \tag{4}$$

$$(\sigma_y)_0 = \left(\frac{\partial^2 \varphi}{\partial x^2}\right)_0 = \frac{1}{h^2}[(\varphi_1 + \varphi_3) - 2\varphi_0] \tag{5}$$

$$(\tau_{xy})_0 = \left(-\frac{\partial^2 \varphi}{\partial x \partial y}\right)_0 = \frac{1}{4h^2}[(\varphi_5 + \varphi_7) - (\varphi_6 + \varphi_8)] \tag{6}$$

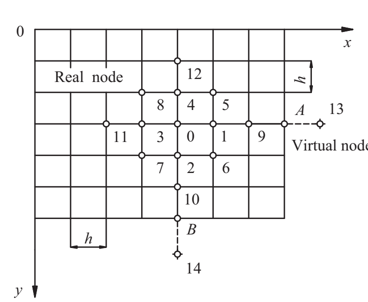

Fig. 2. Calculation of the immediate roof stress using difference method.