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A roof model and its application in solid backfilling mining

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ABSTRACT

Through changing the axial load on backfilling material compaction test to reflect different overlying strata pressure on backfilling material, the stress-strain relations in the compaction process of backfilling material under the geological condition can be obtained. Based on the characteristic of overlying strata movement in backfill mining, a model of roof thin plate is established. By introducing the stress-strain relation in compaction process into the model and using RIZT method to analyze the bending deformation of roof, the bending deflection and stress distribution can be obtained. The results show that the maximum roof subsidence and maximum tensile stress occurring at the center are 255 mm and 5 MPa, respectively. Tensile fracture of roof under the geological condition of Dongping Mine did not occur. The dynamic measurement results of roof in Dongping Mine verify the theoretical result from the aforementioned model, thereby suggesting the roof mechanical model is reliable. The roof thin plate model based on the compaction characteristic of backfilling material in this study is of importance to research on backfill mining theories and application of backfilling material characteristics.

1. Introduction

Solid backfilling mining (SBM) is a green mining technology in which the solid waste materials is placed into the gob to support the overlying strata and to control roof's subsidence and movement [1–3]. SBM has been successfully used in several mines to solve many problems, including coal extraction under buildings, water bodies and railways, surface subsidence, and environmental problems. Good results have been obtained in many mines [4]. The key in the application of SBM technology is to control strata movement. However, the critical factor influencing the controlling effect of strata movement is compaction characteristics of backfilling materials. Thus, a roof model of SBM is built based on the filling materials' compaction characteristics. A subsidence equation and the critical failure condition of roof was given and field verification was performed at panel 15061 of Dongping Mine.

To date, many studies have been conducted to investigate the roof movement in SBM and tremendous progress has been made. For example, Zhang analyzed the key layer deformation by building a beam model on an elastic foundation; Huang used a numerical model to access the effect of backfilling ratio on strata movement control and surface subsidence; Li analyzed the effect of elastic foundation coefficient of filling materials on roof's deformation and failure using a foundation plate theory. However, the aforementioned research which assumed filling materials as a constant foundation coefficient did not introduce filling materials' compaction characteristics to the mechanic model [5–9]. Therefore, the models built in their research cannot accurately reflect the characteristic behavior of filling materials. In this study, the constitutive relation of the filling materials during compaction will be first obtained in the laboratory, and then introduced in a model. Finally, a deformation equation and bending stress will be given.

2. Principle and deformation characteristics of the surrounding rock of SBM

2.1. Basic principles of SBM

In SBM, solid waste materials, such as gangue, fly ash and loess, are transported through a vertical pipe and then were delivered to the backfilling area with the belt conveyor. With the backfilling conveyor, backfilling hydraulic support and compactor, the filling materials are delivered to fill up the gob. The face layout of SBM is shown in Fig. 1. Comparing with the conventional face layout, a belt conveyor in the tailgate in a SBM face delivers the filling materials to a conveyor in the gob side of the face behind the shield supports. Therefore in SBM, the face layout allows simultaneous mining and backfilling operations.

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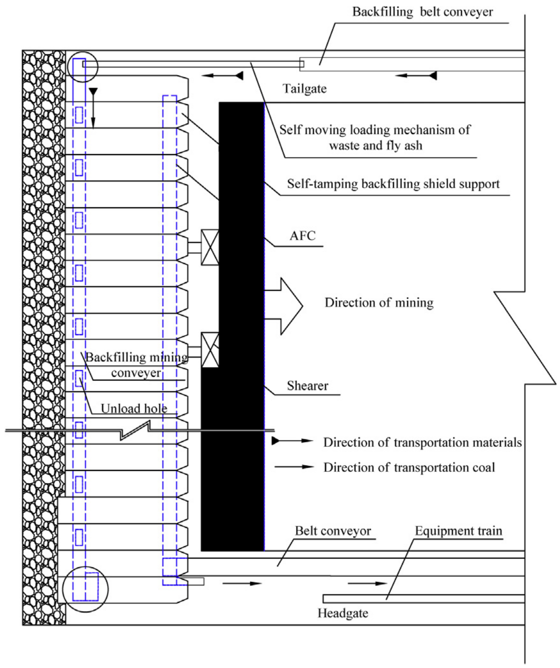

Fig. 1. A SBM face layout.

2.2. General characteristics of overlying strata movement in SBM

In SBM, the movement of overlying strata is divided into two zones, fractured and continuous bending zones, as compared to three zones in the conventional mining [10,11]. After the backfilling materials have filled up the gob, a new support system consisting of solid coal, shield support and backfill materials body forms, which is different from the traditional support system consisting of the solid coal, shield support and caved gob [12–14]. The immediate roof and main roof will not fail and only localized fractures will occur when the backfilling operation is properly implemented. There will be no caving zone in SBM. The rock strata above the fractured zone bend, subside and deform slightly, inducing little surface subsidence.

3. Compaction test of solid backfilling materials

3.1. Test equipment

The YAS-5000 electro-hydraulic servo-controlled rock mechanic test system, manufactured Changchun Kexin Test Instrument Company, was employed for the compaction tests. The circular cylinder for test sample was a Q235 seamless steel tube with a yield strength of 170 MPa. Using a safety factor of 1.5, a compaction cylinder chamber with an outer diameter of 274 mm, an inside diameter of 250 mm, a thickness of 24 mm and a height of 304 mm was made. The test machine and compaction cylinder are shown in Fig. 2.

3.2. Test materials and scheme

The test materials were waste rocks from Dongpin Mine. Given the mining depth was 120 m, a maximum uniaxial pressure of 3 MPa was chosen in the compacting test. The loading rate was 0.1 kN/s, resulting in a testing period for each group of 1500 s. The data were recorded every 3.0 s. The maximum radial pressure was 2.01 MPa when the confining pressure coefficient was 0.67.

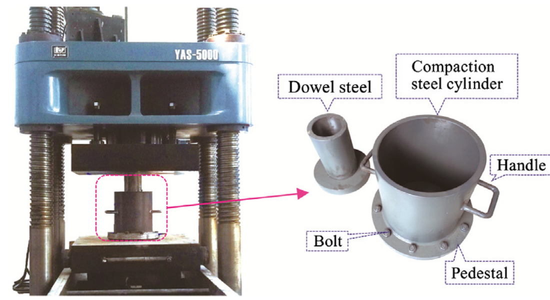

Fig. 2. Test equipment and compaction cylinder chamber.

3.3. Test results

Fig. 3 shows the stress and strain curve for axial stress from 0 to 3 MPa. The curve was regressed in the polynomial equation form (Eq. (1)) to obtain Eq. (2) as the regression equation. The maximum strain was 0.084 in the compaction test.

$$\sigma(\varepsilon) = d_1\varepsilon^3 + d_2\varepsilon^2 + d_3\varepsilon + d_4 \quad (1)$$

$$\begin{aligned} &\sigma(\varepsilon) = 6778.19\varepsilon^3 - 306.43\varepsilon^2 + 12.01\varepsilon - 0.0045 \\ &R^2 = 0.99 \end{aligned} \quad (2)$$

4. Elastic foundation plate model and solution for SBM

4.1. Model assumptions

In theory of elasticity, a thin plate must satisfy the following conditions [9,15,16]:

$$\left(\frac{1}{100} \sim \frac{1}{80}\right) \leqslant \frac{h}{l} \leqslant \left(\frac{1}{8} \sim \frac{1}{5}\right) \quad (3)$$

where h is the height of plate, m; and l the short length of plate, m. The panel width is usually from 80 to 150 m and the roof is from 3 to 20 m in SBM. So the ratio of the thickness and width meet the condition of an elastic plate.

4.2. Roof model

The roof which carries the overburden load $q(x, y)$ and supports by elastic foundation $p(x, y)$ at the bottom in SBM can be treated as a quadrilateral rectangular plate. A backfilling roof model is established as shown in Fig. 4, in which the positive of x coordinate in the model is the face advancing direction, while y is the seam dip direction, being b wide. Z is the vertical direction.

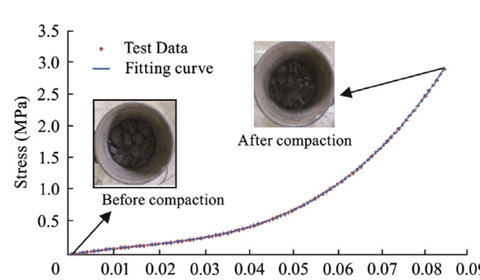

Fig. 3. Stress-strain curve for waste rock compaction test.