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Gateside packwall design in solid backfill mining – A case study

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ABSTRACT

Based upon characteristic movement features of the overlying strata in solid backfill mining and in-situ observations, an associated model representing a roadway support system has been developed. Based on the Winkler foundation and beam model, the current study presents a static analysis of the model, thus permitting acquisition of a theoretical formula pertaining to roof convergence. Through use of working face 6304-1 (Jisan Colliery) as the research setting, the association between roof convergence magnitude and both packwall strength and width have been elucidated. Based upon observed conditions at the working face, realistic packwall parameters have been formulated, with numerical simulation results and field application results indicating that design parameters garnered from the developed formula successfully adapted to local geological movement and deformation. Accordingly, roadway deformation was shown to be within the permissible range, thus satisfying mine production requirements. The proposed method in the current study may give a design basis for pack design in the context of SBM under similar conditions.

1. Introduction

For almost half a century, gate-road retaining technology has been widely applied on longwall and retreat faces of thin and medium thickness seams in China, due to its advantages in resource extraction rate improvement and roadway excavation length reduction [1]. To date, numerous national and international studies pertaining to gate-road retaining theory and technology in the context of caving mining methods have been undertaken. These have particularly focused on the research and development of packwall materials, the design of support resistance and local geological deformation characteristics [2]. Presently, three primary packwall design theories are being utilized, namely, the Detached Block Theory, the Key Block Theory, and the Roof Beam Tilt Theory [3–11]. According to the Detached Block Theory, subsequent to the excavation of a working face, free rock exists above the roadway, with the packwall thus controlling rock movement. Conversely, the Key Block Theory is based upon the assumption that after working face completion, both the overlying strata of the roadway and the packwall exist as several smaller formations, which have been hinged together. Accordingly, the degree of movement associated with rock overlying the packwall is the primary determinant of the stability of surrounding rock. Finally, the Roof Beam Tilt Theory propounds that the overlying strata of the roadway may be characterized as a beam, tilting from the solid coal face towards the side of the goaf. All three aforementioned theories have been applied within existing coal production operations.

Due to declining national coal resources in recent years, many Chinese mining operations have initiated ‘trapped’ resource extraction from underneath buildings, water bodies and railways. This has been undertaken through the utilization of various backfill methods, of which the most widely used technique is solid backfill mining (SBM) [12]. SBM is characterized by solid materials (such as gangue, fly ash) being filled into the gob immediately after resource extraction, followed by dense compaction [13]. In order to maximize coal output, gate-roads are typically retained to service the next face, in which case, the aforementioned theories and associated methods for caving faces may not be applicable to packwall design at SBM faces, due to the gob being filled with solid materials. Accordingly, the development of an applicable design approach for the packwall in SBM is considered necessary, to ensure both cost effective design and production requirement satisfaction in the context of roadway deformation. Based upon characteristic movement features of the overlying strata in SBM, and the adoption of “beam” theory, the current study elucidated apparent associations between roadway roof convergence and several packwall component parameters, with subsequent numerical simulation results and engineering applications adjudged to have significant merit.

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2. Deformation behavior characteristic of overlying strata of gob-side entry in SBM

In caving mining, after mining of the face to a specified point, the immediate roof (potentially constituting the main roof in some cases) will collapse (cave) upon movement of the bracket; caving height is typically determined by parameters such as mining height, in addition to the thickness and the bulking property of the roof strata [14]. However, with SBM technology, the gob formed after resource extraction is densely backfilled with solid filling materials, thus significantly restricting available room for movement of the overlying strata. Consequently, caving of large areas does not typically occur [15]. Previous SBM applications indicate that the roof strata of backfilled areas within the gob remain intact, with the roof sinking as a whole, and therefore a relatively low degree of convergence [16].

Based upon the characteristics of the strata movement in SBM, in addition to the observational data from the site of the gob-side entry, relevant details pertaining to the surrounding geological rock structure at the gob-side entry in SBM were obtained as shown in Fig. 1. Advancement of the working face will cause gob filling materials to become compacted under pressure from the overlying strata; with the advance of the working face, gob filling materials, which have certain porosity, will become compact under the pressure from the overlying strata. Based upon currently employed SBM approaches, the filling material compression ratio of the filling materials (the ratio of the heights before and after compression) is generally typically less than 15%. Gob filling materials, the packwall and rib sides collectively provide support to the overlying strata, of which the gob backfill materials represent the primary source of support. The primary role of the gateside packwall is to ensure that the roof remains in contact with the overlying strata. Accordingly, it is important to allow for adequate support contractibility during packwall design, in order to avoid both top cutting and bottom bulging. Moreover, the packwall represents a significant component with respect to the control of roof subsidence (convergence and deformation) over the roadway, with roof convergence leading to compression and deformation of the packwall and the gob filling materials. Due to the compression resistance of solid coal being significantly greater than that of the filling materials, roof convergence typically occurs via ribside tilting towards the mined-out area. Thus, roadway deformation magnitude is determined by the solid coal compression resistance, the supporting parameters of the packwall and the filling ratio of the gob.

3. Mechanical model representing the overlying strata structure of gob-side entry in SBM

3.1. Mechanical model development

According to the Winkler Foundation Hypothesis [17,18], displacement at any point on the surface of a foundation is proportional to the pressure per unit area at that point, represented by:

$$p(x) = kw(x)$$

The roof (immediate and main roof) overlying the working face was selected as the primary object model analyses. Based upon characteristic behaviors of overlying strata in SBM and the Winkler foundation assumption, the model may be simplified as a beam on a Winkler foundation under the action of a distributed load mechanical model of infinite length (Fig. 1). The coordinate origin was positioned at the junction between roadway and packwall, with displacement function $w(x)$ as the basic unknown value.

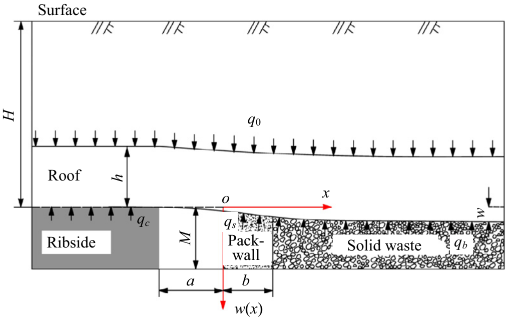

Fig. 1. Mechanical model of the surrounding strata structure and roof.

As shown (Fig. 1), the coal seam depth of the working surface is H, the roof above the coal seam of thickness h is a beam of infinite width and the weight of the overlying strata with thickness $(H–h)$ was simplified as a uniformly distributed load [19]. Further, the force of the ribside on the roadway side generated on the roof is $q_c(x)$, the force of the packwall generated on the roof is $q_s(x)$ and the force of the gob filling materials generated on the roof is $q_b(x)$. Accordingly, the effects of ribside, packwall and backfill materials on the beam were considered based on Winkler foundation theory [20,21];

$$\begin{cases} q_c(x) = k_c w(x) \\ q_s(x) = k_s w(x) \\ q_b(x) = k_b w(x) \end{cases}$$

where k_c, k_s and k_b are the Winkler Foundation coefficients corresponding to ribside, packwall and the backfill materials, respectively, and are related to their respective mechanical natures.

The Winkler Foundation coefficient k_s of the packwall may be determined by the properties of the backfill materials and their relevant engineering parameters [22]; thus,

$$k_s = \frac{E_s b}{h_s}$$

where E_s is the elastic modulus of the packwall, h_s is packwall height (analogous to the height of the roadway and mining height M), and b is packwall width.

3.2. Mechanical model solution

Based upon Winkler foundation and Beam theory [23], the equations for roof convergence above the gob-side, roadway, packwall and backfill bodies were obtained as follows:

$$\begin{cases} EI\frac{d^4w(x)}{dx^4} + k_c w(x) = q_0, & -\infty \leqslant x < -a \\ EI\frac{d^4w(x)}{dx^4} = q_0, & -a \leqslant x < 0 \\ EI\frac{d^4w(x)}{dx^4} + k_s w(x) = q_0, & 0 \leqslant x < b \\ EI\frac{d^4w(x)}{dx^4} + k_b w(x) = q_0, & b \leqslant x < +\infty \end{cases} \tag{1}$$

where EI represents the flexural rigidity of the beam and a is roadway width.

Let $\alpha = \sqrt[4]{\frac{k_c}{4EI}}, \beta = \sqrt[4]{\frac{k_s}{4EI}}$ and $\gamma = \sqrt[4]{\frac{k_b}{4EI}}$. Accordingly, Eq. (1) becomes:

$$\begin{cases} \frac{d^4w(x)}{dx^4} + 4\alpha^4 w(x) = \frac{q_0}{EI}, & -\infty \leqslant x < -a \\ \frac{d^4w(x)}{dx^4} = \frac{q_0}{EI}, & -a \leqslant x < 0 \\ \frac{d^4w(x)}{dx^4} + 4\beta^4 w(x) = \frac{q_0}{EI}, & 0 \leqslant x < b \\ \frac{d^4w(x)}{dx^4} + 4\gamma^4 w(x) = \frac{q_0}{EI}, & b \leqslant x < +\infty \end{cases} \tag{2}$$