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Structural effect of a soft–hard backfill wall in a gob-side roadway

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ABSTRACT

The stability of a backfill wall is critical to implement gob-side entry driving technology in which a small coal pillar is substituted by a waste backfill wall. Based on features of surrounding rock structures in the backfill wall, we propose a mechanical model on the structural effect of a soft–hard backfill wall using theory analysis, physical experiments and a numerical simulation. The results show that the deformation of the structure of the soft–hard backfill wall is coordinated with the roof and floor. The soft structure on the top of the backfill wall can absorb the energy in the roof by its large deformation and adapt to the given deformation caused by the rotation and subsidence of a key rock block. The hard structure at the bottom of the backfill wall can absorb the strong supporting resistance from the top surrounding rock. The soft structure on the top protecting the hard bottom structure by its large deformation contributes to the stability of the entire backfill wall. An application indicated that the stress in the backfill wall effectively decreased and its deformation was significantly reduced after the top coal remained. This ensured the stability of the backfill wall.

1. Introduction

As long wall faces advance continuously, main roofs cave periodically, forming voussoir beam structures along strikes [1–4]. Fig. 1a shows an articulated structure shaped by a triangular arc block, formed along the dip after the rotation and subsidence of a key rock B at the top of the face end [5]. Previous research indicates that the caving mode of main roofs contains active and passive caving, both of which have some obvious dynamic effects on the boundary of goafs [6]. In our previous studies we proposed substituting a non-pillar mining technology of a preset waste backfill wall for a small coal pillar, given that we know that the stability of backfill walls is critical [7,8]. The fracture and rotation of key rock B produced a dynamic load acting on the backfill wall through the immediate roof, which significantly affects the stability of the backfill wall. An unsuitable supporting resistance can easily cause deformation and instability of the backfill wall, which may result in failure of the technology. Therefore, it is necessary to study a dynamic load acting on the backfill wall and how to retain its stability.

In the present case, we propose a mechanical model to investigate the structural effect of a soft–hard backfill wall and carried out a physical experiment to study the structural effect of this backfill wall. We used a well-known universal dynamic analytical software, LS-DYNA, to simulate the dynamic effect on the backfill wall caused by the fracture and rotation of a main roof. An on-site construction method for a backfill wall was established and an industrial experiment was carried out.

2. Mechanical model for structural effect for soft–hard backfill wall

According to Fig. 1a, the top boundary of the backfill wall is a given deformation boundary because the rigidities of the main roof and the immediate roof are greater than those of the backfill wall. Before driving the next district roadway, the left boundary of the backfill wall bears the supporting force P_1 from the coal wall, because of the fracture and rotation of the key rock B. The bottom boundary of the backfill wall bears the support from the floor, the vertical displacement of the backfill wall is relatively small and the displacement of the bottom boundary is given, say 0. A mechanical model is shown in Fig. 2, where a is the width of backfill wall, b the height of backfill wall, θ the rotation angle of main roof, P the loading, and P_1 the supporting force from coal wall.

From Fig. 1a, we conclude that the immediate roof and the backfill wall are responsible for any given deformation of the key rock B [9]. To enable the stability of the backfill wall requires adequate strength, which should also meet the requirements of anti-deformability. Meanwhile, the strength and non-deformability of the backfill wall should match those of the immediate roof. Given the deformation of key rock B in Fig. 1a and the interactional relation between the immediate roof and the backfill wall, we

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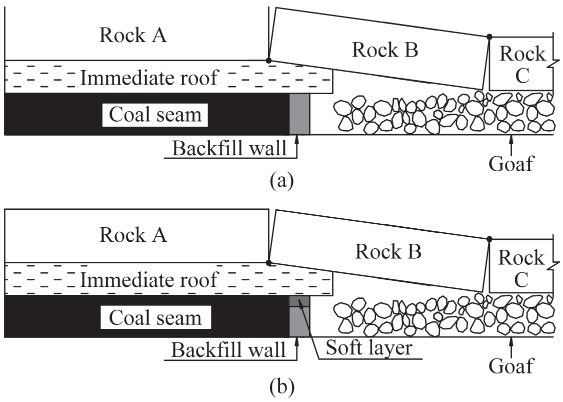

Fig. 1. Structure of rock surrounding backfill wall. (a) Ordinary backfill wall. (b) Backfill wall with soft layer structure.

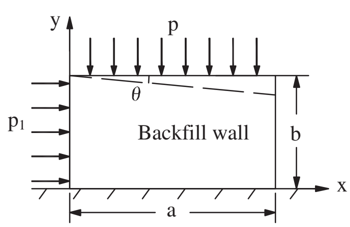

Fig. 2. Mechanical model.

simplified the structural model for the surrounding rock of the backfill wall by a serial coil model of two springs (see Fig. 3b). In this model $\varDelta$ is the given deformation of the key rock B, k_1 and k_2 are the equivalent spring stiffness coefficients for the immediate roof per unit length and the backfill wall per unit width, respectively.

The given deformation $\varDelta$ is related to the thickness of the coal seam, the mining height, the thickness and the bulking coefficient of the immediate roof, as well as the thickness and breaking interval of the main roof. For a specific immediate roof, the equivalent spring stiffness coefficient k_1 is defined and, in general, cannot be modified by human intervention. This coefficient is related to a stress environment at the top of the backfill wall and to the degree of development of the fracture of the immediate roof. In relation to the material properties of backfill, the equivalent spring stiffness coefficient k_2 of the backfill wall can be modified by a water cement ratio and a mixture ratio of backfill material. The $\varDelta_1$ and $\varDelta_2$ are deformations of the k_1 and k_2 spring coefficients (see Fig. 3b). Based on the interactional relation between the roof and the backfill wall, the following formula can be posed:

$$\varDelta = \varDelta_1 + \varDelta_2 \quad (1)$$

where $\varDelta$ is the given deformation of the main roof and is about 10–15% of the thickness of the coal seams. Given the deformation condition of the main roof, $\varDelta$, i.e. the sum of $\varDelta_1$ and $\varDelta_2$, defines the deformations of the immediate roof and backfill wall. $\varDelta_1$ and $\varDelta_2$ vary with a change in the modulus of elasticity, which indicates the degree of anti-deformability of the material. Given the fixed physical dimensions of the immediate roof and the backfill wall, their rigidity depends on the modulus of elasticity. The rigidity of immediate roof is generally larger when the modulus of elasticity $E_1 > 15$ GPa, hence $\varDelta_1$ is rather small and we may assume $\varDelta \approx \varDelta_2$. Control of the deformation of the immediate roof and the backfill wall is mainly a function of controlling the modulus of elasticity E_2 and the width of the backfill wall. However, the backfill wall is

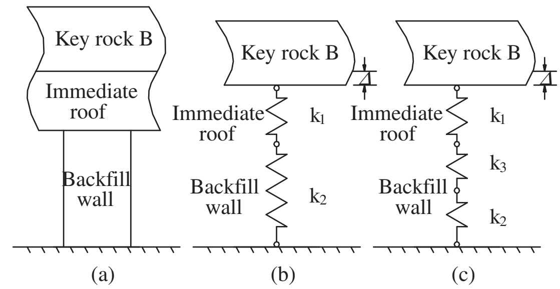

Fig. 3. Structural model for rock surrounding the backfill wall.

made of gangue concrete material of with a modulus of elasticity $E_2 > 20$ GPa, so that $\varDelta_2$ is also rather small, which hardly meets the requirement of a large deformation.

In order to meet the requirement for a given deformation of key rock B, we propose a structural mechanical model for a soft–hard backfill wall (shown in Figs. 1b and 3c). This required that Eq. (1) be changed into Eq. (2).

$$\varDelta = \varDelta_1 + \varDelta_2 + \varDelta_3 \quad (2)$$

where $\varDelta_3$ is the deformation of the soft structure.

The primary function of the soft–hard backfill wall is for the soft structure on the top of backfill wall to absorb the energy in the roof in order to meet the rotation and subsidence of key rock B and to seal the goaf, preventing air leakage. Moreover, the hard structure of the backfill wall can support the roof and provides the given support resistance.

3. Physical experiment on the structural effect of a soft–hard backfill wall

3.1. Experimental system

Our experimental system is a multifunctional installation for special experiments, which can serve for testing large sized coal or rock samples from many fields. The maximum size for any specimen is 1500 × 600 × 900 mm (length × width × height). This stable system allows a maximum pressure of about 20 MPa, the maximum pressure loading on test specimens is 15 MPa and the nominal force of axial load can reach 15,000 kN. The deformation is measured in parts of $\mu\varepsilon$. The experimental system is shown in Fig. 4.

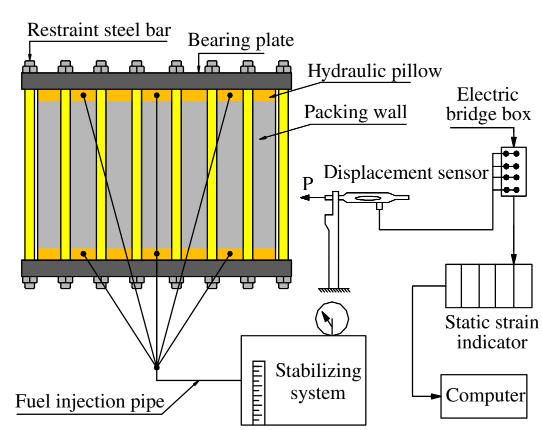

Fig. 4. Experimental system.