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Research and application of schemes for constructing concrete pillars in large section finishing cut in backfill coal mining

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ABSTRACT

Based on the technology of controlling surrounding rock deformation by constructing concrete pillars in large section finishing cut in backfill coal mining, the characteristics of vertical stress on concrete pillars and main factors influencing pillar stability are analyzed. By building a Winkler elastic foundation mechanical model for the support system constituted of coal pillar, backfill body and concrete pillars, mechanical calculation on stability of concrete pillar is carried out to evaluate the pillar stability and safety. Seven numeral models in three schemes with different pillar sizes, inter-row distances and compression ratios at the stopes were analyzed through numerical simulation according to width reduction principle. The practice of finishing cut at III644 workface at Yangzhuang coal mine shows that: when the actual compression ratio is 86.5%, construction size inside the finishing cut is 2000 mm × 2000 mm and the interval between concrete pillars is 2000 mm × 2000 mm, the pillars can be stable with the maximum movement of two sides of each pillar being only 83 mm and 54 mm, which achieves the expected effect.

1. Introduction

In recent years, fully mechanized solid backfill mining technology has become one of the commonly adopted environmentally-friendly technologies for mining under railways, buildings, and water bodies [1,2]. Due to the unique operating mode using hydraulic support, the backfill coal mining workface is generally designed with a long top beam, which can cause large section in workface. When the workface advances to the boundary stop line, the section distance of finishing cuts is often greater than 10 m. Without any effective control measures, the workface may encounter roof caving when the hydraulic support is removed, which may cause safety issues and impact the backfilling effect, hence influencing surrounding rock movement, surface deformation control and building protection on the ground surface.

Based on practical experience in finishing cuts at solid backfill mining, and taking into account the characteristics of surrounding rock support technology adapted for large section combined with solid backfill technology, the III644 workface at Yangzhuang coal mine uses concrete pillars to control surrounding rock deformation in the finishing cut [3–8]. The corresponding technical process is as follows: roof alignment, bolt insertion in the wall, constructing concrete pillars in the finishing cut at an early stage, and gangue and mud backfilling into the finishing cut at a later stage. The key to the technology is to determine a reasonable scheme for constructing concrete pillars so as to ensure stability.

Based on engineering practice in controlling surrounding rock deformation by constructing concrete pillars in the finishing cut at III644 workface at Yangzhuang coal mine, the factors influencing the stress characteristics and stability of concrete pillars in the finishing cut are analyzed in this paper. On this basis, through building a Winkler elastic foundation mechanical model for a support system consisting of the coal pillar, backfill body and concrete pillars as well as numerical simulation analysis on realistic concrete pillar construction schemes, research results have been validated by engineering application at Yangzhuang coal mine.

2. Analysis of stress characteristics of concrete pillars and the influencing factors

Fig. 1 shows the process of removing support and constructing concrete pillars in the finishing cut at the III644 workface at Yangzhuang coal mine. Before being removed, the supports form the

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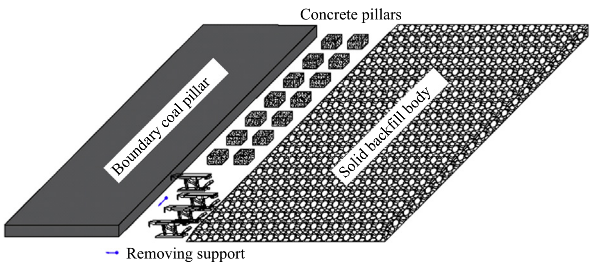

Fig. 1. Process design of concrete pillars in the finishing cut.

supporting system, together with the backfill body and boundary protecting coal pillars at the mining boundary to control overlying strata movement and deformation. When the supports are removed, woodpiles are built in "#" form with concrete grout and gangue cementitious materials being used as a filler. Moreover, concrete pillars are built to replace the supporting system consisting of support, backfill body and coal pillars at the mining boundary to control movement of the overlying strata.

By summarizing related research results [9–13], it is shown that the failure characteristics of concrete pillars are mainly characterized by crack generation, crack spreading and branching as well as peeling from the sides and instability. Integrating the practical engineering application of concrete pillars in the finishing cut, the factors influencing the stability of concrete pillars have been analyzed and mainly include: aspect ratio, inter-row distance, stress load, strength of concrete pillars and compression ratio at the stope. Reference to the following provides more details:

(1) Aspect ratio of concrete pillars.

Research shows that a size effect exists in coal pillars and jambs [14], namely, the compressive strength, tensile strength, and shear strength may vary in coal pillars and jambs of different sizes. In most cases, when the aspect ratio of the jamb is less than 2.5, the failure mode will be shown as progressive peeling and cataclysmic failure. A large aspect ratio will contribute to better stability. Therefore, the aspect ratio is often used as the major indicator in scheme design [15–17]. The sizes of concrete pillars, being controlled within a reasonable range, will be of great importance for stability.

(2) Inter-row distance of concrete pillars.

Concrete pillars should be distributed at coordinated inter-row distances and conform to the construction sizes. A small construction size and a large supporting area may result in support failure, and the load will be transferred to adjacent pillars, hence causing roof subsidence and a large area of caving. However, a large construction size will increase labor and economic costs and cause delay. Therefore, a reasonable inter-row distance is also very important for the stability of concrete pillars [18–20].

(3) Strength of concrete pillars.

The strength of the concrete pillars has a great impact on stability [21,22]. However, the strength of concrete pillars is associated with the content of cementitious materials and aggregate, particle size, matching ratio and setting time, etc. Concrete pillars play a dominant role in bearing the load of overlaying strata and controlling roof subsidence.

(4) Compression ratio of backfill body.

When the backfill body is filled into the goaf, it can provide effective support and control of overlaying strata movement, bending and subsidence; therefore, a backfill body with high compression ratio can effectively control the overlaying strata [23–25]. If the overlaying strata can be well controlled, it can facilitate the setting up of concrete pillars and enhance stability at later stages.

3. Stability analysis of concrete pillars

3.1. Building the mechanical model

After removing the supports in the finishing cut, the concrete pillars form a roof support system together with the backfill body and boundary protecting coal pillars. In the Winkler elastic foundation, concrete pillars in the finishing cut and the backfill body are approximately distributed in an equivalent and continuous manner. Fig. 2a and b shows the plan and side views respectively of the mechanical model.

In the figures: l is the advance length of the backfilling stope, a is the construction size of concrete pillars in the finishing cut, b is the distance between concrete pillars, q is the uniformly distributed load of the overlaying strata, k_c and k_b are the elastic foundation coefficients of concrete pillar and backfill body respectively, and $w(x)$ is the deflection of the roof. The two ends of the model are clamped.

3.2. Mechanical calculation and solution

Based on the Winkler assumption of an elastic foundation, the relationships between the deflection, $w(x)$, the load, q, and the elastic foundation pressure, as well as the deflection equations for the concrete pillar and the roof between pillars and above the backfill body are shown below:

$$EI\frac{d^4w(x)}{dx^4} = q - k_c w(x) a \quad (1)$$

$$EI\frac{d^4w(x)}{dx^4} = q \quad (2)$$

$$EI\frac{d^4w(x)}{dx^4} = q - k_b w(x) d \quad (3)$$

In these formulas, k_c is the elastic foundation coefficient of the concrete pillar, k_b is the elastic foundation coefficient of the backfill body, EI is the flexural rigidity of the beam section, and the inertia moment I is as follows:

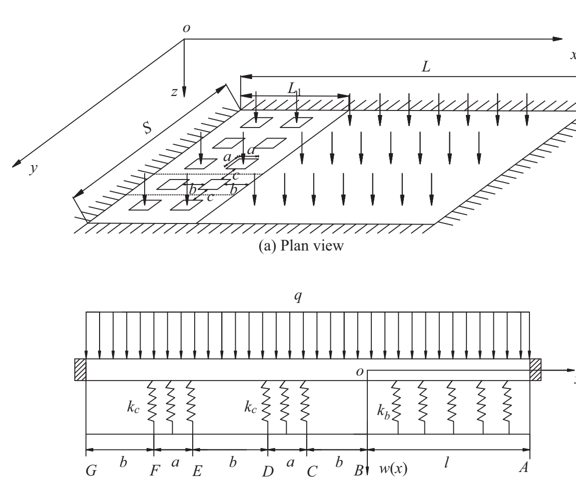

Fig. 2. Mechanical model of concrete pillars in finishing cut.