



Fissure evolution and evaluation of pressure-relief gas drainage in the exploitation of super-remote protected seams

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Abstract: Based on nonlinearity contact theory and the geological structure of the Xieqiao Coal Mine in the newly developed Huainan coal field, rock movements, mining fissures and deformation of overlying strata were simulated by using the interface unit of FLAC3D to evaluate the pressure-relief gas drainage in the exploitation of super-remote protected seams. The simulation indicates that the height of the water flowing fractured zone is 54 m in the overlying strata above the protective layer. The maximum relative swelling deformation of the C13 coal seam is 0.232%, while the mining height is 3.0 m and the distance from the B8 roof to the C13 floor is 129 m, which provides good agreement with a similar experiment and in situ results. The feasibility of exploitation of a super-remote protective coal seam and the performance of the pressure-relief gas drainage in a super-remote protected layer are evaluated by comparisons with practice projects. It demonstrates that the relieved gas in the super-remote protected layers could be better drained and it is feasible to exploit the B8 coal seam before the C13 super-remote protected coal seam. The method is applicable for the study of rock movements, mining fissures and deformation of the overburden, using the interface unit to analyze the contact problems in coal mines.

Keywords: protected layers; super remote; contact analysis; gas drainage; numerical simulation

1 Introduction

Clauses 192~193 of the Safety Regulations in Coal Mine (2006 edition) provide as follows: before coal seams with coal and gas outbursts are excavated, protective layers must be excavated first^[1]. Excavation technology of protective layers has been proven by many practices, is considered to be an effective way of eliminating coal and gas outbursts and is widely used in a number of mineral fields^[2-6]. The excavation of protective layers uses overburden dribbling to release the elastic deformation energy and the gas stored in coal seams and increases permeability of coal seams in certain areas, which could reduce the gas content to eliminate coal and gas outbursts through proper gas drainage.

Clause 48 of the Detailed Rules for Coal and Gas Outburst Prevention provides that the maximum vertical effective distance is no more than 100 m between the protective layer and the protected layer^[7]. This is referred to as the super-remote protective layer when the distance to the protected layer is more than 100 m.

Research on the exploitation of super-remote pro-

TECTIVE layers did not start until the publication of the fifty articles of the gas control experience in coal mines, which provides that gas control should, in first instance, select district measurements, including the exploitation of protective layers and gas drainage^[8].

At present, the feasibility of the exploitation of protective seams is largely predicated on the deformation of coal seams, which is a macro reflection of mining fissures. Similar material experiments and numerical simulations are used to study overburden movements and deformations in coal mines. Experiments with similar material can be quite exhausting and the number of measuring points is usually limited and discrete, while the results of most numerical simulations are not suitable in practice since the surface between two layers is taken as agglutination, which cannot simulate separation. Therefore, research and further discussion should be extended to separation and deformation in numerical simulations of protective layers.

For our study, we selected the interface between two layers as contact surfaces, according to a nonlinear contact theory. The deformation and mining fissures of the overburden were computed by using FLAC3D, based on the geological structure of the Xieqiao Coal Mine in a newly developed coal field of Huainan. Finally, the performance of pressure-relief gas drainage under super-remote protected seam ex-

exploitation was evaluated in a comparison with the practice of protective layers.

The Xieqiao Coal Mine of Huainan is located in a newly developed coal field, covering a thick quaternary sediments layer with complex geological structure, deeply embedded (600~800 m), with significant crustal stress during excavation and high gas pressure and content^[3].

Coal seams C13, B11 and B8 are major seams for exploitation in the Xieqiao Coal Mine. The C13 coal seam is a stable and minable coal seams in all areas with a high risk of coal and gas outbursts, an average thickness of 4.72 m, a maximum measured gas pressure of 5.8 MPa, a gas content of 12~22 m³/t and an original permeability coefficient of 3.92×10⁻² m²/(MPa²·d). The B11 coal seam is also a near stable, minable and very hard coal seam, 66.95 m below C13, with a low risk of coal and gas outbursts, given its low gas content (4~7.5 m³/t), but not all its areas in this mine field are minable. The B8 coal seam, 86.70 m below B11, is a stable and minable coal seam with low gas content (4~7 m³/t) and no risk of coal and gas outbursts.

Given the initial geological conditions, it is clear that B11 should be exploited first in order to protect the C13 coal seam, but not all areas in this mine field can be exploited. Therefore, the B8 coal seam has been selected as the protective layer in those sections where B11 is not minable, but the distance from the roof of B8 to the floor of C13 is 153.65 m, clearly beyond the maximum vertical effective distance between the protective and the protected layers provided by Clause 48 of the Detailed Rules for Coal and Gas Outburst Prevention. Therefore, the exploitation of super-remote protective layers and the performance of pressure-relief gas drainage must be predicted before exploiting the B8 coal seam, in order to eliminate the hazards of coal and gas outbursts in the C13 coal seam.

2 Contact analysis between rock (coal) layers

Deformation of coal and rock in mining can be quite different, given the various properties in physical mechanics which leads to the appearance of tensile and shear stresses. Most results of numerical simulation are not suitable for practical use, since the surface between two layers is taken as agglutination which cannot simulate separation. Therefore, we analyzed the mechanical situation between layers by FLAC3D, based on contact theory.

2.1 Theory of contact analysis

It is well known that the augmented Lagrangian method is the most popular numerical method to solve the problem of contact with friction, a highly nonlinear problem^[9-10].

Assume that the opening function of two contact

objects is g_N . The initial opening is g_0 and the contact conditions are as follows^[10]:

$$\begin{cases} g_N = u \cdot n + g_0 \geq 0 \\ P_N(u) = n \cdot \sigma \leq 0 \\ P_N(u) \cdot g_N = 0 \end{cases} \quad (1)$$

where u is the displacement vector of the contact boundary; n the normal direction of the contact boundary; σ the stress of contact objects and $P_N(u)$ the normal stress of the contact boundary.

After introducing the independent Lagrangian coefficients λ_N , λ_T and the penalty program based on the Coulomb friction law and the Kuhn-Tucker condition, we obtain the weak virtual function^[10],

$$\begin{cases} G(u \cdot \delta u) = \int_S (-P_N n \cdot \delta u - P_T \cdot \delta u_T) ds \\ P_N = \lambda_N + \Delta_N g_N \\ u_T = \frac{1}{\Delta_T} (P_T - \lambda_T) \end{cases} \quad (2)$$

where Δ_N and Δ_T are the penalty parameters; $P_T(u)$ the tangential stress of the contact boundary and u_T the tangential component of the displacement vector.

2.2 Nonlinear analysis of interaction between rock (coal) layers

After excavation of the protective layer, the overburden is in a state of tensile stress, affected by the overburden dead weight and appears as spalling and separation. Spalling is a type of damage of the separation among low-impedance surfaces in media, including shear spalling (dislocation between layers) and extensive spalling (separation). Spalling is generated suddenly when, to some extent, tensile stress accumulates gradually. The dislocation closes in a vertical direction near the stope and becomes the separation far away from the stope.

There are two different kinds of nonlinearity in the interaction of rock or coal layers: 1) a material nonlinearity caused by inelasticity; 2) a static nonlinearity of separation or slip generated in the surfaces of the media.

1) Simulation of material nonlinearity between contact surfaces. We selected plastic action as the elastic-perfect plasticity and adopted the Hoek-Brown failure criterion and other related stream criteria^[11].

2) Simulation of static nonlinearity in contact surfaces. We used the interface unit of the FLAC3D program to analyze contact problems. FLAC3D is a three-dimensional program which computes explicit finite-differences in engineering mechanics. It offers a wide range of abilities to solve complex problems in mechanics, especially in geomechanics. The program has many basic built-in material failure criteria, such as the Drucker-Prager, Mohr-Coulomb, strain-

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