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Influence of fracture-induced weakening on coal mine gateroad stability

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ABSTRACT

The ground stability of gateroads is a major concern in underground coal mines, especially when the surrounding strata are weak and fractured. This paper presents a novel numerical modelling technique for gateroad stability analysis based on a case study conducted at Zhaogu No. 2 mine, China. Considering the occurrence of fracturing and its weakening effect on the stiffness of the rock mass, a tension-weakening model is implemented into FLAC3D, whereby the stiffness of the rock mass is progressively decreased with the failure state. A relationship between the intensity of fractures and the residual strength of the rockmass is built in the numerical model. A parametric study of the tension-weakening model is carried out, and the results are compared to elastic-perfectly plastic and strain-softening models. It is shown that the tension-weakening model exhibits noticeable effects on ground deformation and rock support loading, which are observed from field measurements. Thus, the tension weakening model offers a more realistic simulation of the gateroad behavior than elastic-plastic and strain softening models. The proposed model can be utilized for other applications involving rock reinforcement of mine openings under similar geotechnical conditions.

1. Introduction

The stability of roadways is a long-standing issue in underground coal mines, especially for gateroads that serve and ensure the safe production of longwall panels. Ground stability and failure mechanisms of roadways vary depending on stress, geological and geotechnical conditions. However, the difficulty of maintaining gateroad stability stems from the weak surrounding rock mass and continuous geotechnical disturbance. Serving the longwall panels, gateroads are always located in the coal seam, which generally has relatively weak properties compared to roof and floor rock formations. A database of coal mine rock mechanical properties, which consists of over 4,000 samples from fifty coal seams in ninety mines, was developed by Sun and Peng [1]. According to their work, most coal seams have uniaxial compressive strength less than 34 MPa and tensile strength less than 2.7 MPa. Thus it can be expected that the weak properties of coal contribute significantly to the deformation of a gateroad once it is driven. Secondly, after coal in a longwall panel is extracted, and a void (goaf) behind the face is created, rock fracturing and yielding as well as stress concentration in the surrounding rock take place. Because of coal extraction, the gateroad is subjected to a complex loading pattern. In some cases such as gateroad entry layouts driven along goaf-edge, [2] the gateroad will furthermore undergo multiple mining influences.

Numerous studies have been done in different methods to estimate the stability of gateroads and design support schemes. Empirical methods [3–5] are often utilized based on the statistical analyses of adequate data collected in field practices. Many studies employ analytical methods [6–8] for better understanding of the failure mechanism and rock support performance. In recent years, an increasing number of studies have been done with different numerical methods. [9] Although numerical modelling is a state-of-the-art technique for rock mechanics study and different numerical methods are utilized, the constitutive models and parameters used to simulate the behavior of the rock mass ought to be rigorously considered and calibrated.

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Many researchers analyzed gateroad stability with numerical modelling methods for the past few years. The most commonly used constitutive models are the elastic-perfectly plastic and strain-softening models, which use Mohr-Coulomb failure criterion. Shen [10] assessed the stability of a soft rock roadway with discrete element software UDEC whilst assuming strain-softening of the soft rock. In the study, the strain-softening parameters are determined based on previous simulation experiences for coal and surrounding strata. Zhang [11] evaluated rock bolt design under the effect of a longwall mining face with a strain-softening model for all rock strata. In this model, a plastic shear strain threshold of 0.3% and the residual cohesions are determined. In previous studies, [2, 12, 13] strain-softening model is applied for coal, and elastic-perfectly plastic model is chosen for other rock materials.

Due to the sedimentary effect of coal-forming process, the surrounding rock mass of underground coal mines exhibit a geologically stratified structure. Under this geological feature, tensile failure plays a dominant role especially when the surrounding rock is not subjected to high horizontal stress (ratio of horizontal-to-vertical stress > 3). [14, 15] Rock failure due to underground coal mining activities is also demonstrated with field investigation [16] and numerical analysis. [10, 17] Since joints and other fractures in the rock can offer little or no resistance to tensile stresses, fractures will take place and develop in a brittle manner when the rock mass is subjected to tensile stress. [18] Other studies [19–22] elaborate on the relation between the modulus of elasticity of rock mass and the occurrence of cracks and fractures, and corresponding formulas are proposed. In light of previous studies examining the post-peak behavior of surrounding rock, it is reasonable to take the variation of elastic modulus during tensile failure into consideration for stability analysis of openings in underground coal mines.

In the present study, tension-weakening model, which allows for the reduction in the rock mass stiffness due to fracture generation is developed and implemented with FISH, which is a programming language embedded within 3-dimensional explicit finite-difference software FLAC3D. The study examines gateroad stability at the Zhaogu No.2 mine. In the numerical model, the failure state of the rock mass is continuously monitored during the analysis, and the properties are weakened according to failure state to simulate the post-failure behavior. Numerical simulations with elastic-perfectly plastic model, strain-softening model and tension-weakening model are conducted for comparison with field measurements. In addition, a model parametrical study with respect to the tension-weakening model is carried out to examine the effect of tension-weakening and provide a basis for gateroad stability investigation and rock support design.

2. Case study

2.1. Geology and geotechnical overview of Zhaogu No.2 mine

Zhaogu No.2 mine is located in Xinxiang City, Henan Province, China. All panels in this mine are using retreating longwall method to extract coal seams. The coal seam is nearly horizontal with a mean thickness of 6.12 m.

The target gateroad for this case study is the tailgate of panel 11050 at a depth of 600 m. The panel is approximately 180 m wide along the dip and 2000 m long along the strike as illustrated in Fig. 1. A typical geological column based on core logging is shown in Fig. 2. The roof strata of this panel are mainly composed of mudstone, sandy mudstone and sandstone. The immediate roof is a layer of less than 2 m thick mudstone, which would cave and fall into the goaf, following the advance of coal extraction and shield support.

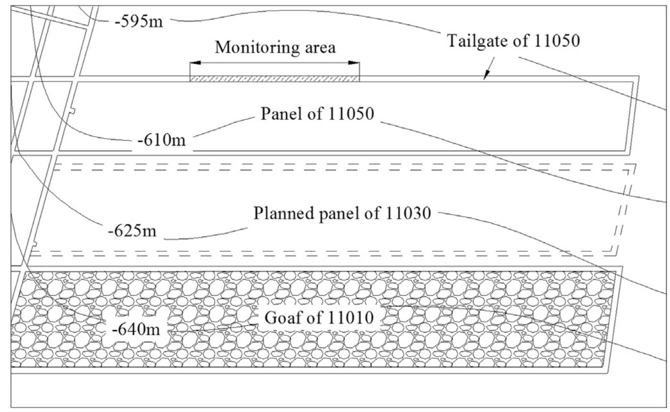
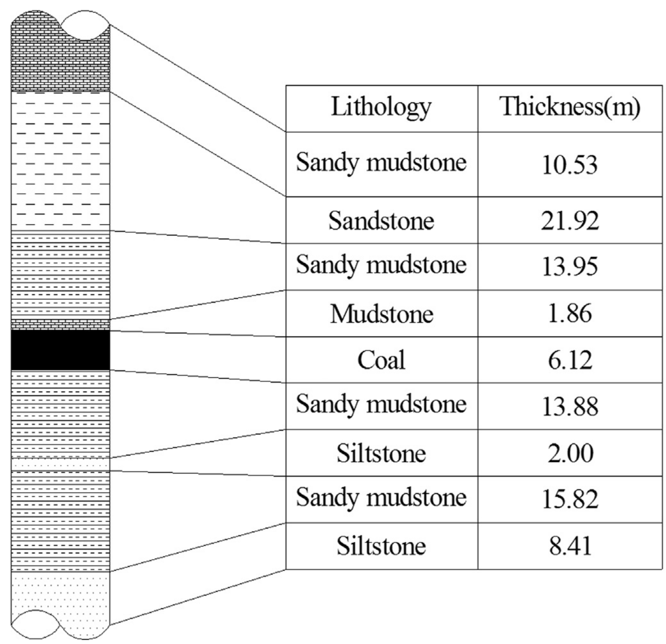


Fig. 1. Plan view of local panel layout.



Lithology	Thickness(m)
Sandy mudstone	10.53
Sandstone	21.92
Sandy mudstone	13.95
Mudstone	1.86
Coal	6.12
Sandy mudstone	13.88
Siltstone	2.00
Sandy mudstone	15.82
Siltstone	8.41

Fig. 2. Typical geological column.

The tailgate of panel 11050 is 3.3 m high and 4.8 m wide. The gateroad is driven along the roof line of the thick coal seam, which leaves the ribs and immediate floor consisting of coal. Cable bolt support is employed as primary support, and wire mesh is utilized to prevent rock falling, as shown in Fig. 3. Rebar bolts that are 2.4 m long, and 20-mm in diameter, are installed both in the roof and ribs on a square pattern of 800 mm $\times$ 800 mm. Cable bolts, which are 8.25 m long and 21.6 mm in diameter are installed in the roof with 800 mm spacing and 1300 mm between rows. Both rebar bolts and cable bolts are partially grouted with resin cartridge, and the grouted lengths are 1200 mm and 2400 mm, respectively.

2.2. Rock mechanical properties experiment

Laboratory experiments were conducted on the rock core samples collected from roof and floor of the gateroad. The experiments were carried out with a servo-controlled testing system (RMT-150B) manufactured by the Institute of Rock and Soil Mechanics, the Chinese Academy of Sciences. RMT-150B is a special apparatus used to test the mechanical properties of rocks with maximum axial load of 1000kN, maximum shear load of 500kN and maximum lateral pressure of 500kN. [23] The failure duration

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