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Discrete element modelling of deformation and damage of a roadway driven along an unstable goaf — A case study

Fuqiang Gao [a,*], Doug Stead [a], Hongpu Kang [b], Yongzheng Wu [b]

[a] Engineering Geology and Resource Geotechnics Group, Simon Fraser University, Burnaby, BC, Canada
[b] Mining & Designing Branch, China Coal Research Institute, Beijing, China

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ABSTRACT

Roadways driven alongside a previously extracted longwall panel (goaf) are a common situation in underground coal mining. The unstable goaf can have a significant detrimental impact on the stability of the roadway. This paper presents a combined SRM–UDEC Trigon numerical approach to investigate the failure mechanism of a roadway driven alongside an unstable goaf. The synthetic rock mass (SRM) method is used to derive the rock mass properties and the newly developed UDEC Trigon approach is used for simulating brittle fracture and consequent roadway damage. The results indicate that the roadway suffers asymmetric damage characterized by a major rib convexity, a severe floor heave and a relatively stable roof with limited fracturing. This failure mechanism is consistent with field observations. A quantitative evaluation of the damage around the roadway indicates that shear failure plays a major role in the roadway damage. Our study suggests that the proposed combination of SRM and the UDEC Trigon is well suited to the evaluation of failure mechanisms around underground coal mine excavations.

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1. Introduction

An improved understanding of the deformation and failure mechanisms around coal mine roadways located close to previously extracted longwall panels is essential to ensure their safe drivage, support and maintenance. In underground longwall coal mining practice, the extraction of a longwall panel disturbs the rock mass in various ways depending on the location with respect to the mining stope. Mining causes the immediate roof to cave, with separation and shearing of bedding planes in the strata above the cave-in zone, and fracturing and deformation in the far field host rocks. This process can last a period of years, resulting in a dynamic loading on roadways driven along the goaf.

Numerical techniques have proven to be a powerful tool in the study of the rock mechanics problems in underground openings. Advances in computational science over the last fifty years have seen many numerical methods developed for solving rock engineering problems. These methods can be classified into continuum, discontinuum and hybrid methods. Continuum methods are well suited to solving problems involving heterogeneous or non-linear material properties. Rock failure is identified when the stresses applied on an element exceed the predefined failure strength. Continuum methods have been widely used to simulate underground coal mine excavations (Maleki et al., 2009; Meyer, 2002; Sharpe, 1999; tora Toraño et al., 2002; Zipf Jr, 2006). The major limitation in roadway simulation associated with continuum methods is that the displacement field must be continuous. Although new developments such as the ubiquitous joint strain softening model in FLAC3D (Esterhuizen et al., 2013; Sainsbury et al., 2008) allow improved continuum modelling of a rock mass extension and sliding of pre-existing fractures, generation and propagation of new fractures and their interaction with pre-existing fractures cannot be explicitly simulated in continuum models. In addition, the rock bolts in fractured rock masses are believed to provide resistance to sliding and opening along pre-existing fractures (i.e. bedding planes, cross joints) (Kang et al., 2009) and to restrain the generation and propagation of new fractures (Yang et al., 2010). This functionality of rock bolting is difficult to incorporate realistically in continuum models due to their intrinsic limitations in simulating fracture development and propagation. These limitations can be overcome using discrete element methods (DEM). In the DEM, a rock mass is treated as a series of blocks delineated by joint sets. The joints between the intact rock blocks represent pre-existing discontinuities. The constitutive criteria for the joints and intact rock are specified separately. In contrast to continuum models, one of the major advantages of the DEM is that the failure of an underground excavation (i.e. roof collapse) can be explicitly simulated. The Universal Distinct Element Code (UDEC) (Itasca, 2011) is one of the most commonly used DEM codes. Agapito and Gilbride (2002) described the application of UDEC to study the influence of high horizontal

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[*] Corresponding author.
E-mail address: gaofq0215@gmail.com (F. Gao).

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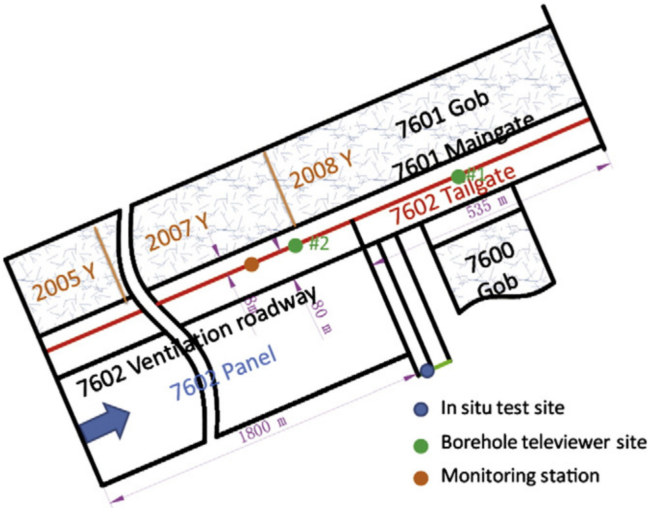

Fig. 1. Layout of panels and roadways at the study site (Wuyang coal mine). The study site was the 7602 tailgate which was driven alongside the unstable 7601 gob. The mining depth is 400 to 460 m.

stresses upon roadway roof stability. The roof was represented as an assembly of rectangular blocks bonded by horizontal and vertical joints representing bedding planes and cross joints. Alejano et al. (2008) used UDEC to study roof bed deformation in an underground excavation in stratified rock masses.

A limitation of most DEM is that sliding and separation can only occur along continuous joints and that the direction of the sliding and the rupture surface is both pre-defined and confined to joints. In the conventional use of UDEC these pre-defined joints must be persistent between two blocks and fracturing of intact rock material is not allowed. This limitation is overcome however by the use of a Voronoi tessellation generator. This methodology facilitates the formation of randomly sized polygonal blocks bonded together through contacts and thereby allowing simulation of fracturing through intact rock. Pre-existing discontinuities including joints, bedding planes, faults and shears can also be incorporated. Previous studies have been performed using the UDEC Voronoi approach to simulate underground excavation. For example, Shin (2010) adopted the UDEC Voronoi method to predict the excavation disturbed zone developed around underground openings excavated in massive Lac du Bonnet granite and found that the UDEC Voronoi model was capable of capturing the extent and depth of the damaged zone around a tunnel.

In this paper, we present a modified DEM numerical approach to investigate the failure mechanism of a roadway driven alongside an unstable goaf. The study is based on a real case study at an operating mine. Discrete Fracture Network (DFN) models were first created based on the data obtained from borehole televiewer imaging and face mapping. The DFNs were then incorporated into PFC3D (Itasca Consulting Group Inc., 2008) to create a synthetic rock mass (SRM) model. Compression and direct tension tests were performed on the SRM model to obtain the rock mass properties of the coal and the immediate roof. The damage of the roadway was then simulated through a new proposed UDEC Trigon method. In this approach, a rock mass is represented as an assembly of triangular blocks bonded through contacts. The triangular blocks are formed using a used defined FISH function to subdivide the original polygons into triangles. The properties of the triangular block contacts were calibrated to the rock mass properties obtained from the SRM. The extraction of the longwall panel was incorporated within the UDEC Trigon model in order to simulate realistic mining-induced stresses. The numerical results were calibrated against field observations at an underground Chinese coal mine.

2. Description of study site

2.1. Introduction

The Wuyang coal mine is located in the Lu'an Coal District, Shanxi Province, China. It was opened in 1956 and is operated by the Lu'an Group, producing around 3.0 million tonnes of coal per year. Mining activity is carried out in the #3 coal seam. The thickness of the coal seam varies between 1.5 and 7.9 m with an average thickness of 6.2 m. The extraction method is longwall mining.

The study site is located in the tailgate of the 7602 panel. The layout of the panels and roadways around the study site is illustrated in Fig. 1.

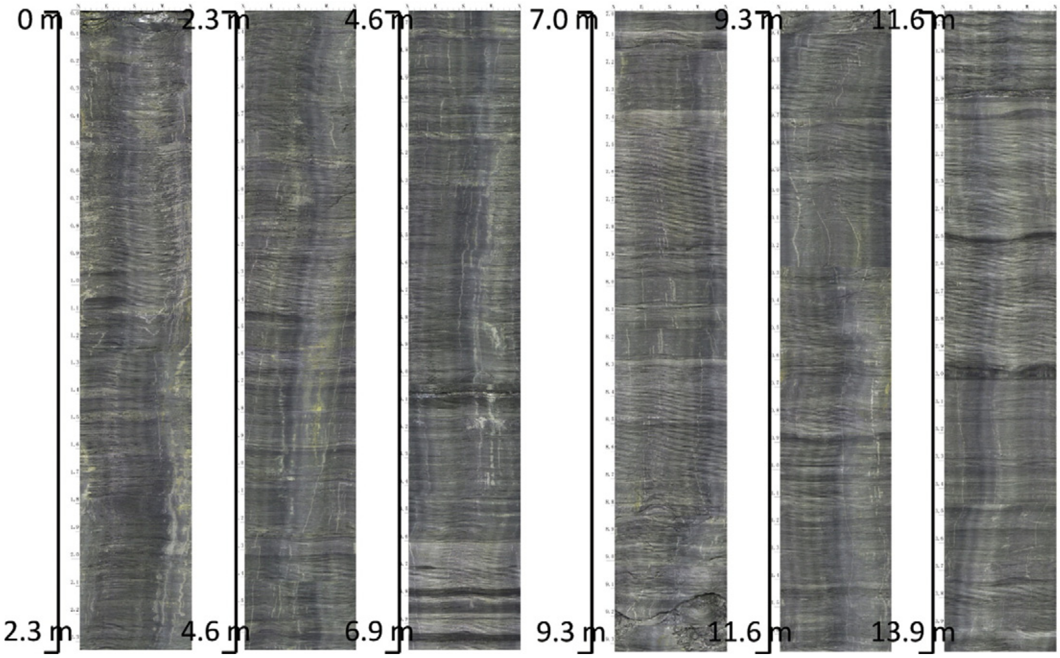

Fig. 2. Optical-televiewer image of the 56-mm diameter borehole drilled vertically in the roof at the Wuyang coal mine.

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