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Simulation of tabular mine face advance rates using a simplified fracture zone model

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ABSTRACT

This paper describes a method to determine the time-dependent stability of the fracture zone near the edges of tabular excavation layouts when different mining rates and face advance increment lengths are scheduled. Some analytic properties of the proposed time-dependent fracture zone evolution model are presented initially for a simplified mining geometry. The implementation of the model in a general tabular layout setting is described next including a novel scheme to allow for partially fractured elements. The reef plane stress distribution in the fracture zone is solved using a fast marching method that is coupled to a displacement discontinuity solution of the excavation and fracture zone deformations. The numerical scheme is illustrated by considering the extraction of a hypothetical deep-level mining layout. The sensitivity of the results to changes in the mining rate schedule and the face advance step size are discussed. Further extensions to the solution scheme are noted.

1. Introduction

One of the key problems in deep level tabular mine design is the scheduling of mine face positions and face advance rates. The scheduling problem is constrained by the available access to the tabular orebody and by the need to prevent unstable rock failure near mining faces. This requirement is of paramount importance when mining personnel are engaged in operations such as face cleaning, drilling and blasting. In a mechanised environment, it is equally necessary to ensure that automated mine equipment is used efficiently and is protected as far as possible from fall of ground losses.

As early as 1966, Cook et al.[1] described an increase in rockbursts in the South African gold mines if the face advance rate exceeded more than 4 m/month for small abutments and 8 m/month for large abutments. Studies of mining rate were conducted by Malan.[2] It is generally accepted that high stress peaks close to the face may increase the likelihood of violent failure. A continuum viscoplastic model was studied as an approximation of the time dependent nature of the fracture zone. This model illustrated that high mining rates may lead to higher stress peaks close to the stope face. Similar qualitative results were obtained using a viscoplastic discontinuum model.[3] The authors demonstrated that the cumulative fracture length decreases for faster mining rates, leading to an increase in the value of seismic energy released. As a drawback, these preliminary studies only considered two-dimensional models. Regarding coal mining, Linkov[4] noted that in the Kizel coal mines, doubling the rate of coal cutting on the face from 0.27 m/min to 0.54 m/min resulted in a drastic increase in incidence of rockbursting. Nawrocki[5] developed a one-dimensional semi-analytical solution for the time-dependent behaviour of a coal seam to investigate the rate of face advance. The analysis indicated that rapid ore extraction produced zones of high stress concentrations close to the longwall face.

The extraction technique that is used in tabular mining is dictated by the deposit depth and by the rock strength of the orebody. Large-scale mechanised operations are often available in comparatively shallow coal mining operations (at depths that are of the order of hundreds of metres) whereas deep level, hard rock platinum and gold mining operations (at depths that can reach four kilometres) may demand labour-intensive drill, blast and cleaning cycles. It is necessary in all cases to determine an appropriate extraction schedule that does not trigger unstable ground conditions. The planning of these operations can be assisted if proposed mining sequences can be evaluated computationally to determine the likely consequences of mining rate variations, selection of the face advance increment and the choice of the geometric configuration of the excavations.

A simple time-dependent limit equilibrium model of the fracture zone extent near the edges of tabular excavations is described in this paper to facilitate this analysis. The model is applicable specifically to planar seam or reef deposits where the excavations are generally hundreds of metres in extent in the plane of the orebody but where the

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mining height is limited typically to vary between one and ten metres. This characteristic narrow mining height geometry can be approximated as a crack-like surface where the opposing crack faces (the excavation roof and floor) interpenetrate one another in response to the imposed stress field.[6–8] The displacement discontinuity boundary element method (DDM[9,10]) is an appropriate computational tool that can be used to solve the relative roof to floor movements.

The main deficiency of this numerical technique is that the simplified crack-like geometry provides a limited depiction of the mining-induced fracture configuration at the excavation edges. The present paper addresses this deficiency by introducing a simplified representation of the time-dependent evolution of the fracture zone extent in the plane of the excavation. An extensive analysis of the properties of the model is given and it is indicated how the model can be incorporated in a general tabular layout. This enhanced facility enables a more realistic investigation of mining rates and face advance increment choices to be carried out. This is illustrated by considering an important problem of contrasting the face advance rate with the size of the face advance increment.

2. Time-dependent limit equilibrium model

Fig. 1 shows a plan view of a particular tabular layout at depth where the coloured regions depict the successive planned mining sequence of a series of panels. The echelon extraction sequence in this case was designed to leave a central dip pillar (the dip direction is from the top to the bottom of the diagram). One of the essential problems in determining the mining sequence is the geometric sizing of the panels and the detailed extraction rate schedule. The narrow excavation height of the reef deposit generally leads to a significant stress concentration ahead of the mining face which leads to ongoing fracturing of the panel edges as indicated in the adjacent photograph in Fig. 1. The fracture zone formation has been studied extensively in deep level gold mines.[11] In addition to these observations, monitoring of the movements between the roof and the floor of tabular excavations at fixed points in the mined area has been carried out.[12] These observations indicate that the relative roof to floor normal component of deformation (termed stope convergence or closure) has a characteristic time-dependent profile that evolves after each face advance increment (face blast). The closure profile shape depends on the host rock strength properties and on the local excavation configuration and mining rate. It is evident that the observed time-dependent stope convergence movements are related to ongoing deformations in the adjacent fracture zone following each mining step and can provide an indirect indication of local mining face stability.[12,13]

A model of the time-dependent behaviour has been proposed previously by Napier and Malan.[14] The model is based on a simple limit equilibrium representation of the fractured rock and is embedded in a displacement discontinuity representation of the excavation region. It is assumed that a zone of crushed rock exists adjacent to the excavation edge, within the plane of the excavation, and that the reef-normal stress distribution in the fracture zone is determined by the reef-parallel confining stress ahead of the excavation edge. Fig. 2 shows a schematic differential force balance within a plane section normal to the reef

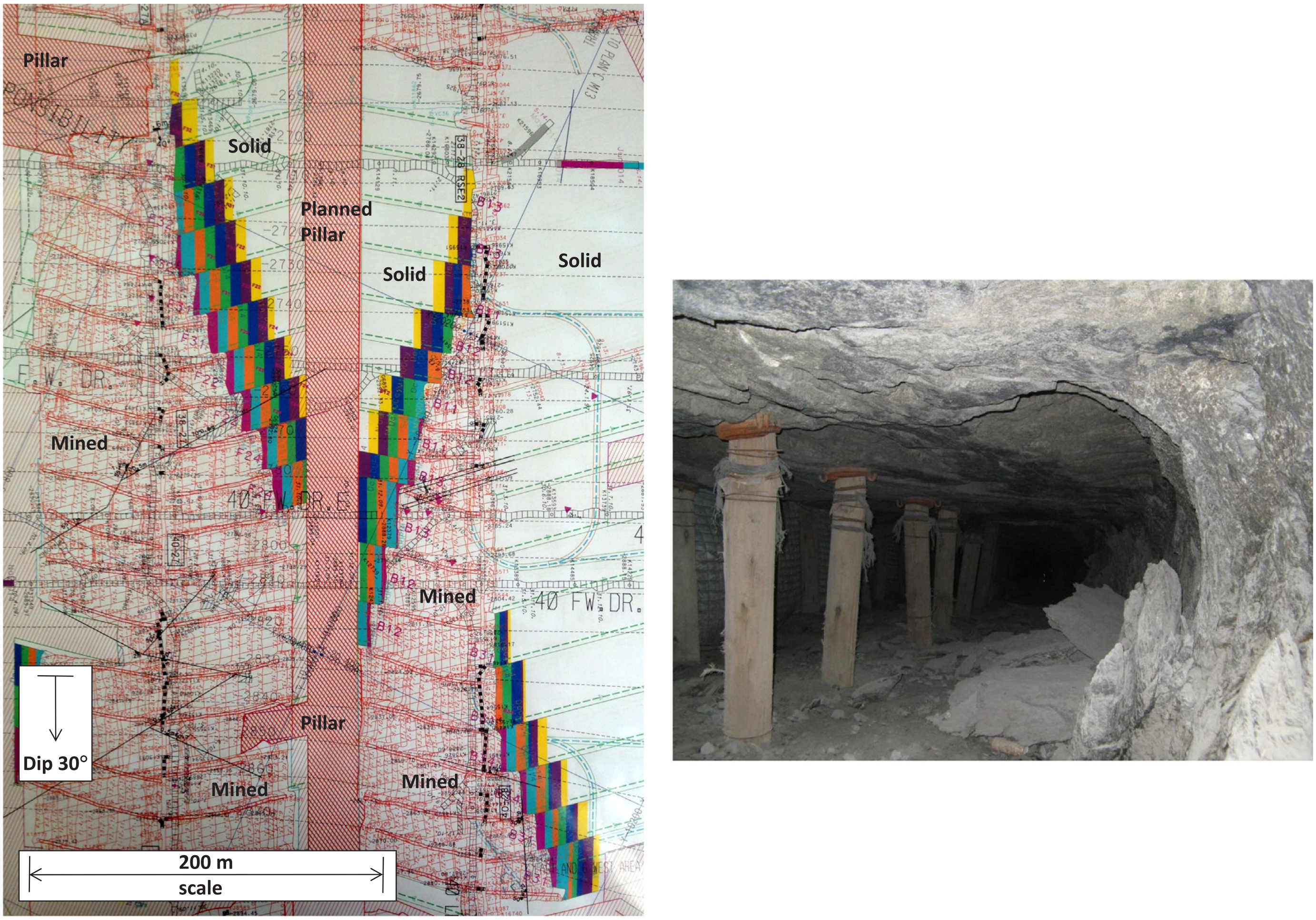

Fig. 1. Plan view of a dip pillar mine layout indicating planned panel extraction sequences. The different colours indicated the planned mining for successive months. The adjacent diagram shows typical conditions in the stope face area of one of the layout panels. The mining face is on the right and the fracturing caused by the stress concentration in this area is evident. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)