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Technical Note

Numerical simulation of pre-mining stress field in a heterogeneous rockmass

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1. Introduction

Numerical modeling tools are increasingly being used in rock mechanics as an important supplement to methods that have traditionally relied upon experience and empirically-derived charts. An important advantage they provide lies in their prediction of rockmass behavior, based on the stress redistribution that takes place due to activities over the lifetime of a mine. The traditional approach in numerical modeling for underground openings is to initialize the pre-mining stresses in the model based on the vertical and horizontal stress components and their gradients. While this technique works for a fairly homogeneous rockmass, it does not function well for mines that comprise complicated structures and geological formations with different rockmass properties. Whereas field reports indicate that stiffer geological units attract higher stresses and shear zones dissipate them, it is shown in this paper that the initial stress tensor approach in modeling results in a uniform stress distribution across the different geological units for a given mining depth. Hence, there is a need for a different approach that is capable of replicating field observations in the numerical model.

In addition to representative input geomechanical properties, a numerical model must be calibrated based on past events and/or in-situ tests. These can include observed ground behavior, microseismic events, and in-situ measurements of the stress tensor. Authors working in this area have used different methods for calibration such as the systematic application of varying boundary tractions, comparison of the results with in-situ measurement points, and the development of stress tensor formulae from them [1,2]. Others [3] have suggested using displacement boundary conditions to simulate the pre-mining stresses. Perman et al. [4] made comparisons with the measured in-situ stress values in their case study of the Malmberget Mine in Sweden. Indirect methods include conducting laboratory tests on rock samples to obtain rockmass properties for use in the model [5], comparisons with observed and measured ground behavior [6], conducting back-analysis of events that have already been reported [7,8], and comparison of model results with the microseismic records at the mine.

McKinnon [1] established a calculation-based method to deduce the boundary tractions on a model given measurement points within it. However, he concluded that the method would work for a homogenous rockmass and that it could not be applied to heterogeneous systems, although a back analysis of a heterogeneous system was performed by the same author to study shear zones in a South American mine [2]. In this paper, the authors examine these issues based on a case study of a deep Canadian hardrock mine with a heterogeneous rockmass, and compare the traditional method of initializing pre-mining stresses to an alternative technique that is based on boundary tractions.

2. Case study model

The case study adopted for this paper is the Vale Garson Mine in Sudbury, Ontario. Located in the southeast section of the Sudbury Basin, the Garson Mine has been in operation for more than 100 years. Deposits comprise Sudbury Igneous Complex (SIC) copper–nickel sulfides with two primary orebodies designated as #1 Shear and #4 Shear located between 1220 and 1705 m (4000 and 5600 ft) below ground surface and dipping 60–75° to the south. The sheared host rocks are made up of greenstones, with a norite formation to the north and metasediments to the south. These formations are offset by a swarm of olivine diabase dykes, one of which runs through the mine in a NW–SE direction with an

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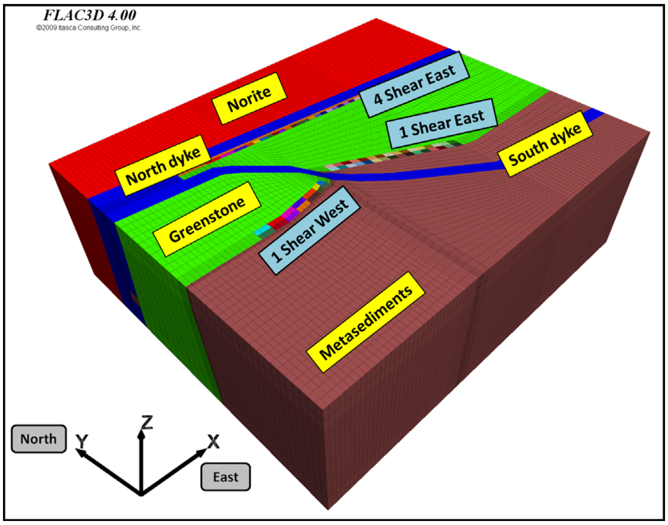

Fig. 1. Isometric 3-dimensional view of the conceptual model in FLAC^{3D}.

Table 1
Rockmass properties.

Geological unit	*E* (GPa)	ν	γ (N/m^3)
Greenstone	65.0	0.23	31,088
Dyke	86.3	0.26	29,567
Metasediments	45.5	0.24	27,291
Norite	56.4	0.25	28,380
Sulfide ore	43.8	0.30	44,449
Sublayer norite	39.4	0.25	28,383

average thickness of 30 m (100 ft). It branches into a northern section running parallel to and above the #4 Shear orebody in a W–E trend, and a southern one that runs NW–SE to cut the #1 Shear orebody into western and eastern segments.

Fig. 1 shows an isometric view of the geological units in a conceptual 3D mine-wide numerical model, which is constructed in the finite difference code FLAC^{3D} to examine methods of generating the pre-mining stresses. It comprises the overall geometry and geological units described above and includes Levels 4470 (1365 m) to 5100 (1555 m), extending to Level 3500 (1170 m) at the top and to Level 5500 (1675 m) at the bottom of the model. The overall dimensions are 915 m (3000 ft) in the W–E direction, 760 m (2500 ft) in the N–S direction, and 610 m (2000 ft) in depth, comprising a total of nearly 600,000 zones. The model is run in linear elastic mode.

The rockmass properties of the different geological units are derived from laboratory tests on intact rock samples as well as a thorough analysis of borehole geomechanical data. These are presented in Table 1 and are used as input parameters for the numerical model. As can be seen, the rockmass modulus for the dyke (86.3 GPa) is 1.3 times that of the greenstone, and as much as 1.9 times that of the metasediments formation.

3. Methodology

The vertical component of the in-situ stresses σ_v is assumed to be due to overburden weight and, based on the average unit weight of rocks, gives a stress gradient of 0.027 MPa/m [9]. The maximum and minimum horizontal stress components, σ_{Hmax} and σ_{hmin}, are calculated based on the equations put forward in [10] for the Canadian Shield as 1.9σ_v and 1.2σ_v, respectively, for Level 3500 (1065 m) at the top of the model domain. These change to 1.7σ_v and 1.1σ_v towards the bottom at Level 5500 (1675 m). Based on the values for the main levels of interest, σ_{Hmax} and σ_{hmin} for the entire model were taken as 1.8σ_v and 1.1σ_v, respectively.

The initial stress model uses a kinematic boundary condition of zero displacement perpendicular to the model boundary all around as shown in Fig. 2a, which represents a vertical W–E cross section of the conceptual model. Hence, and based on the derivation of the vertical and horizontal stress components explained above, the initial stress tensor σ_{ij}^0 representing the pre-mining stress field in the modeled domain is defined as follows:

$$\sigma_1^0 = 1.8\gamma H \quad (1)$$

$$\sigma_2^0 = 1.1\gamma H \quad (2)$$

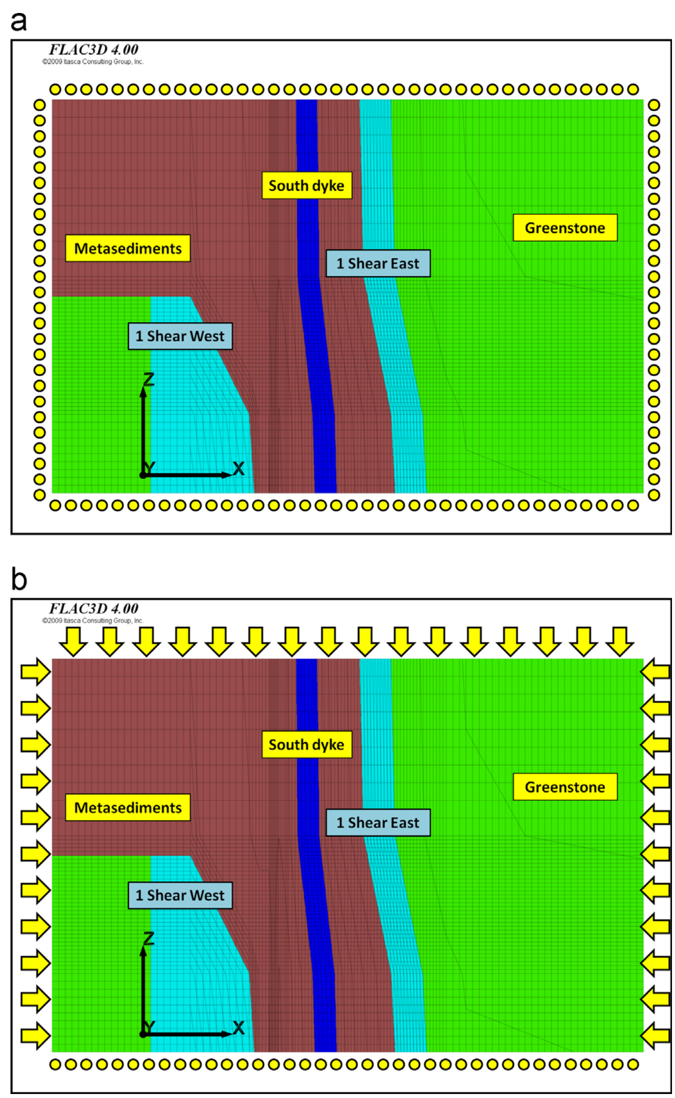

Fig. 2. Initial stress model and boundary traction model methodologies of stress generation. (a) Initial stress model stress generation. (b) Boundary traction model stress generation.

Table 2
In-situ stress components on different levels.

Principal stress	Level 3500	Level 4500	Level 5500
σ1	51.85	66.66	81.47
σ2	31.68	40.74	49.79
σ3	28.80	37.03	45.26