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Technical Note

Quantifying rock mass bulking at a deep underground nickel mine

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1. Introduction

In deep underground mining and construction, high stress-induced rock fracturing is inevitable.[1] Rock near the boundary of an excavation is confined in the tangential direction, and the volume increase due to rock failure is often translated into a significant convergence of the excavation boundary, and this phenomenon is known as rock mass bulking.[2] Fig. 1 shows how the periphery of an excavation can deform from the original shape (shown as a dashed line) to a new shape (shown as the solid interior line), as a result of an increase in volume of the shaded failed zone. Rock mass bulking can cause problems when the wall displacement exceeds the displacement capacity of the support elements.[3,4] In extreme cases the wall deformation can be very large, reducing the effective span of the drift and making the drift unsuitable for mining access. Thus, it is important to predict and manage rock mass bulking when mining in highly stressed grounds.

The amount of convergence that can be expected due to rock mass bulking can be predicted by multiplying a Bulking Factor (BF) by the expected depth of failure. The relationship between the bulking factor and the total wall convergence (U_w), the convergence due to elastic deformation at the boundary of the non-failed and failed zones (U_{df}), and the depth of failure (d_f) is:

$$BF = \frac{U_w - U_{df}}{d_f} \tag{1}$$

Compared with U_w, the amount of deformation of U_{df} is small; therefore, the wall convergence can be approximated by

$$U_w \approx BF \times d_f \tag{2}$$

Current empirical methods for predicting bulking factors are based on limited, often qualitative data because there are few case studies where the necessary parameters have been collected or documented. In order to back calculate a bulking factor, the depth of failure and the convergence of the surface of the excavation must be measured. Measuring U_{df} is not crucial because it can be predicted using conventional continuum numerical modeling techniques. This amount of deformation is small relative to wall convergence due to rock mass bulking and as such will have a negligible effect on the back calculation of the bulking factor.

The data included in previous case studies used to back calculate bulking factors[5] were usually not collected with similar objectives. For the purpose of this study, there was an obvious lack of information on the depth of failure in these datasets. Case studies with extensometer data from Kloof Gold Mine[6] and the Donkin-Morien Tunnel[7] are more useful because the convergence was directly measured and the depth of failure can be inferred from the measurement from the point where the convergence transitions from linear (elastic deformation) to nonlinear (plastic deformation/bulking). Limitations associated with the use of extensometers are their limited deformation coverage range, limited resolution that is dependent on the spacing of the measurement points, and high cost when installation at multiple locations

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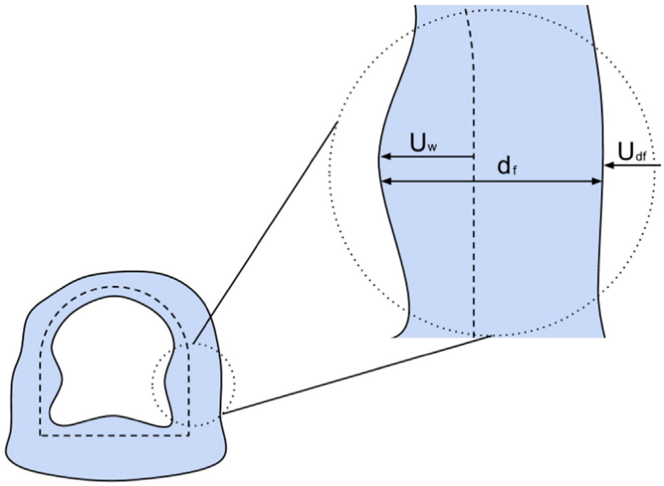

Fig. 1. Concept of rock mass bulking (based on Ref. 2).

around the periphery of an excavation is required.

The need for case studies focusing on rock mass bulking is apparent to researchers and engineers working to advance methods of modeling or predicting rock mass bulking. The objectives of this study were to collect quantitative bulking measurements and to study factors that influence rock mass bulking at Creighton Mine in Sudbury, Ontario, Canada. Various data collection techniques have been used to ensure that the site monitoring is as complete as possible, and the merits of the techniques can be judged for future rock mass bulking observations.

2. Geological setting and description of the observation site

2.1. Geological setting

Creighton Mine, which is owned and operated by Vale, is a deep underground nickel mine located in the Sudbury Basin. The mine has been in continuous production for more than a century with current active mining levels at depths of 2.3–2.5 km. The mine is seismically active[8] and managing seismic risk and controlling rockburst damage are challenging tasks facing the mine as mining progresses to deeper levels.

Creighton Mine is located in the southeast corner of an embayment of a nickel irruptive into the footwall rocks. In general, the lower norite member of the main irruptive is the hangingwall of the orebody. The footwall rocks are metavolcanics of the Elsie Mountain Formation, Lower Huronian in age and intruded by granite/gabbros. The orebody (OB) at depth is generally steeply dipping within high grade massive and inclusion massive sulfides adjacent to the barren granites and gabbros and a gradational lower grade hangingwall zone. Structurally controlled, the orebody has gradually shifted into two distinct production areas below the 2340 m production level. Massive and inclusion massive sulphides are high grade and copper rich, considerable shearing and quartz veining exists throughout the third production front at depth. Quartz veining and shearing, often infilled with quartz carbonate, is typically inter-connected through the footwall rocks by a family of distinct splays, influencing how mining-induced stresses are redistributed and contribute to mine seismicity.

2.2. Observation site

An observation site for the project (Fig. 2) was set up in a newly developed drift in the mine at a depth of approximately 2.4 km from the surface. This site was selected because it was situated at a location that was already under high stress due to the overburden depth and proximity to the orebody. This location was expected to undergo an increase in mining-induced stress with the excavation of nearby stopes as the stresses are further redistributed. The purpose of establishing the observation site was to quantitatively monitor the development of stress-induced damage around the drift and the associated rock mass bulking as a result of the damage.

Eleven BQ size diamond drill holes (DDH) were drilled in an array around the excavation (Fig. 3). Diamond drilling provided key advantages because it allowed for core logging and testing in the lab and resulted in a smooth inner surface for quality observation of the holes. A smooth inner surface of the observation holes greatly improves the quality of data that can be retrieved using various down-the-hole probes. Six pairs of reference points marking vertical cross-sections were used for subsequent convergence monitoring (Fig. 2). Following drilling of the holes, a safety bay was excavated at a later stage, changing the profile of the drift where the observation holes were located. The safety bay was used to observe the rock mass condition of the drift wall itself by providing a cross-sectional view of stress-induced surface parallel fracturing. The DDH holes were used to monitor the depth of stress-induced fracturing using a variety of tools and the reference points were used to align recurring vertical cross-sections

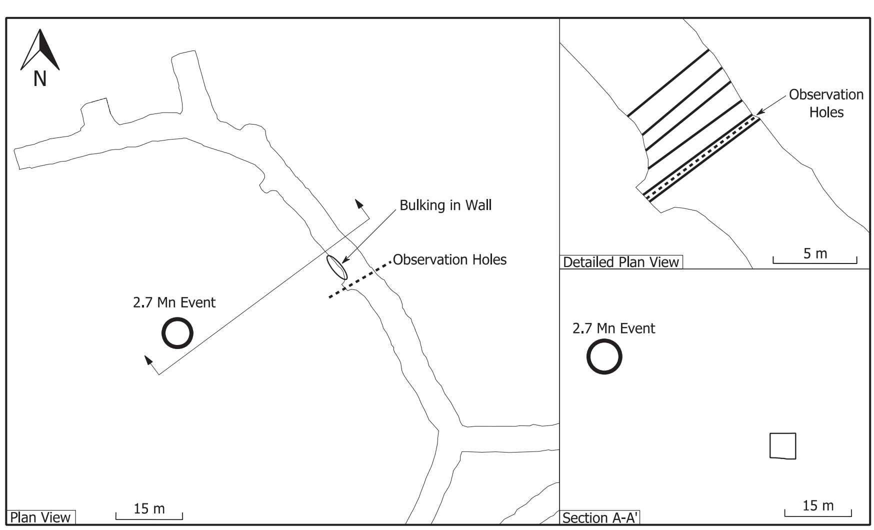

Fig. 2. Locations of observational cross-sections at the observation site and the position of the 2.7 M_n seismic event.

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