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Generation of a Discrete Fracture Network from digital discontinuity data captured using the 3D Axis Mapping method

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ABSTRACT: Accurate mapping of geological structures and their orientations is a crucial step for analysis of underground excavation stability. A case is presented of a novel digital mapping workflow for generating a discrete fracture network (DFN) model. The RockMass Eon applies the 3-Dimensial Axis Mapping (3DAM) method to capture orientations and locations of discontinuities, producing a statistical distribution of their natural variability. The Eon uses infrared LiDAR and an altitude heading reference system to capture a point cloud, and a clustering algorithm is applied to extract statistically significant orientations representing the discontinuities. In this case study, 83 measurements are generated for 12 structures to provide a statistical dataset of the discontinuities. The mapped data from Glencore Kidd Operations in Canada are imported into ITASCA software to generate a DFN. This paper demonstrates that the use of digital data collection can streamline analyses and increase model confidence in underground rock engineering.

Keywords: digital mapping, Discrete Fracture Network, numerical modelling, digitalization.

1 INTRODUCTION

Complex numerical models are becoming widespread in industry as computational power increases, while simultaneously digital mapping tools to capture discontinuity data are improving. The confluence of increasing data fidelity and improved computational power is making the development of discrete models more accessible to practicing rock engineers. Numerical modelling of rock masses as discrete systems allows for the simulation of rock mass behaviour as a combination of failure through intact rock and displacement along discontinuities. In the discrete approach, a pre-fractured rock mass is represented as an assemblage of discrete blocks, and discontinuities are represented as the interfaces between these blocks. In the current state of practice, an identified limitation of developing discrete models is that insufficient mapping data is available to develop statistically significant distributions from which the discrete models can be generated.

Previous research has demonstrated the appropriate field characterization of the discontinuities, since the success of these complex models largely depends on the geological assumptions used to build the underlying Discrete Fracture Network (DFN) (Elmo et al., 2013). A significant limitation to the specific field data collected is the limited availability of geotechnical measurements and the inherent error associated with manually collected compass measurements. It is important to efficiently capture sufficient data for a meaningful DFN model and to improve the data collection procedure (quantity and quality of data being collected). Increasing the population of sampled fractures would increase the degree of knowledge and improve our understanding of variability. As discussed by Elmo et al. (2016), the underlying degree of uncertainty with respect to rock mass blockiness can be reduced by updating the estimated fracture size distribution and mapping fracture terminations to better characterize the structural character of the rock mass. This requires implementing a systematic mapping of 2D rock exposures as development drifts are excavated.

This paper presents a workflow for the digital collection of discontinuity measurements using the 3D Axis Mapping (3DAM) method (Gallant, 2016) from the RockMass Eon, and then generating a DFN for use in discrete geomechanical modelling using ITASCA software (ITASCA Consulting Group, 2023). A case study from the Glencore Kidd Creek Operations near Timmins, Canada is used to illustrate the workflow.

2 BACKGROUND

2.1 Glencore Kidd Operations

Glencore Kidd Operations is an ultra-deep underground base metal mine located in Timmins, Ontario, Canada. The site primarily produces copper, zinc and silver using a simple long-hole open-stoping mining method. Opened in the mid-1960s, the site began as an open pit operation before transitioning to a fully underground operation a decade later. With a current development depth of over 3 km, the site faces various geotechnical challenges such as deep high-stress ground conditions, a complex major fault network, and active underground seismicity. The data presented in this paper was collected along the 6000 ft Level, shown in Figure 1.

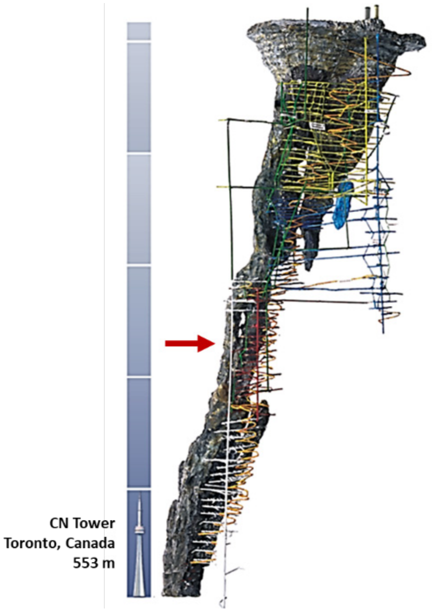

Figure 1. Schematic of the Glencore Kidd Creek Operations, with a red arrow indicating where the case study data was collected on the 6000 ft Level.

2.2 Discrete Fracture Networks

In rock engineering, DFN models are developed for both mining and civil engineering applications. In mining, DFN models are used to estimate rock mass strength and deformation characteristics, mine-scale analyses of mass mining, and to estimate fragmentation distributions (Lorig et al., 2015). DFN research has also been conducted in the context of modelling hydraulic properties of fractured rock for civil infrastructure applications, such as nuclear waste repositories.

The stochastic DFN approach provides a method of creating realistic fractured models that can represent the heterogeneous nature of a fractured rock mass by assigning random probability distributions to data obtained from geotechnical mapping (Elmo, 2006; Elmo et al., 2013). DFNs are generated based on the statistical distributions of orientations, persistence, and spatial location of discontinuities. It is good practice to generate multiple DFNs for subsequent analysis in geomechanical models, a process which is made more reliable when a larger population of measurements exists to sample from (Figure 2).

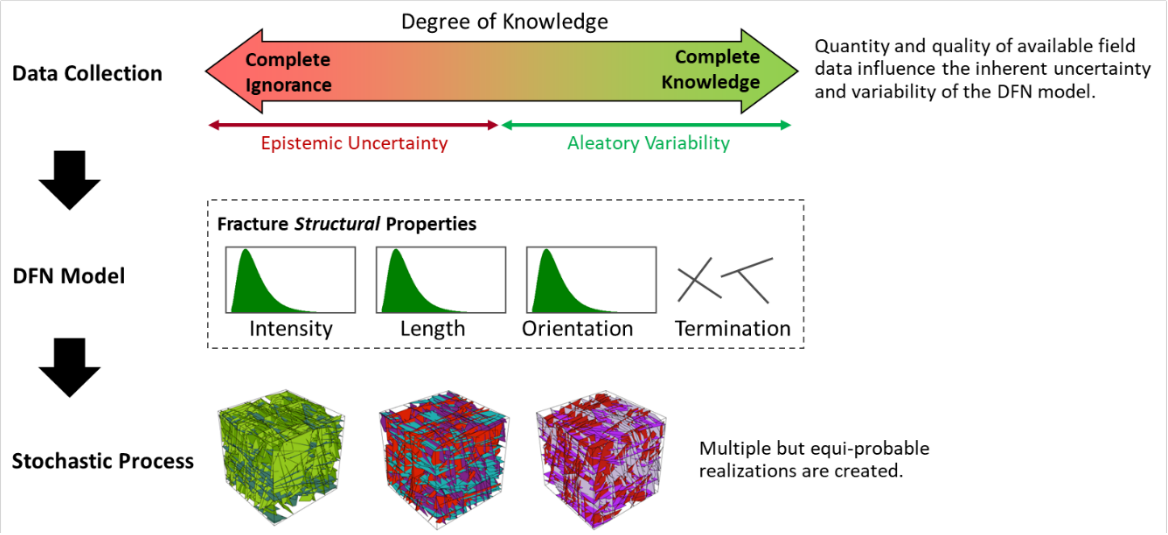

Figure 2. Illustration of how quality and quantity of field data influences the DFN model and subsequent geomechanical modelling process (adapted from Elmo, Moffitt, et al., (2016)).

3 DIGITAL MAPPING AND DATA COLLECTION

The data for this study was collected using the RockMass Eon during a geotechnical mapping campaign at Glencore Kidd Operations. The mapping was completed along approximately 10 m of drift on the 6000 ft Level, comprised of three subsequent windows mapped along a scanline. Five major features were identified as characterizing the structural domain in the area of interest. An example of one window of mapping is shown in Figure 3a. Multiple measurements of the five features were captured to obtain a distribution of 83 structural measurements. An example of The raw data (axes) clustered in the 3DAM method to produce the measurements is shown in Figure 3b.

In general, mapping with the RockMass Eon is approximately four times faster than mapping with a compass, and in this case generated 83 measurements of 12 distinct discontinuities that were mapped (Figure 4).

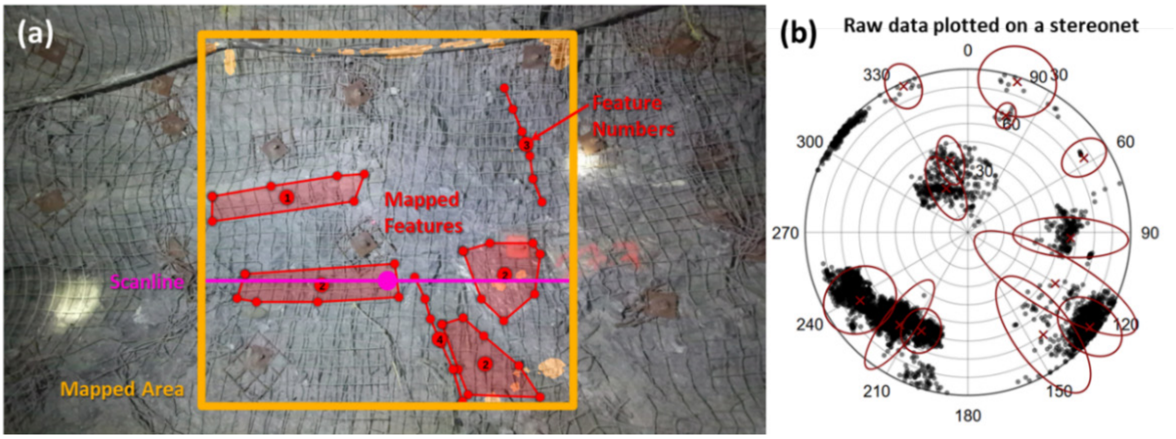

Figure 3. (a) Example of a window captured on 6000 ft Level at Glencore Kidd Operations, showing features mapped using the RockMass Eon. (b) Raw data obtained from the mapped features plotted on a stereonet, where the black poles indicate the axes captured using the 3DAM method and the red ellipses indicate the statistical variance of each cluster of poles.

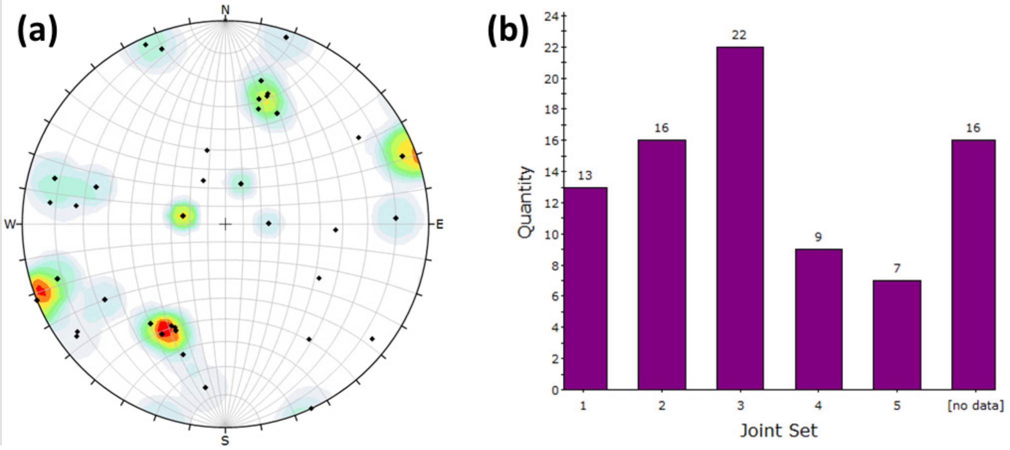

Figure 4. (a) Stereonet plot showing all 83 measurements. (b) Histogram of 83 measurements, indicating representation of each of the five dominant features and random fractures [no data].

4 NUMERICAL MODELLING

As previously discussed, mapped geological features can be used to inform numerical models used to assess stability of rock excavations. ITASCA software Version 9 (3DEC, PFC and FLAC3D, ITASCA 2023) includes the ability to import structural data that is output from the RockMass Eon. There are two methods for doing this:

1. *Deterministic*. Individual features are imported (location, orientation and other properties). These can be plotted and then used to generate actual fractures in the model.
2. *Stochastic*. Fracture data is imported as in 1, however individual fractures are not created in the model. Instead, the orientation data is used to inform the generation of a Discrete Fracture Network (DFN), where the fracture sizes and locations are chosen from a user-defined random distribution, and the orientations are "bootstrapped" (randomly sampled) from the field measurements.

An example using the digital mapping completed at the Glencore Kidd Operations is described here. Figure 5a shows one of the three windows mapped along the scanline, represented by a mesh generated from the point cloud, and the measured fractures, represented by structural discs, plotted on top of a simple tunnel model. Note that it is not possible to obtain an accurate fracture size (persistence) when measuring in the field. In Figure 5b, a diameter of 1 m is assumed for plotting purposes. The field data can then be used to generate deterministic fractures. Five (5) distinct features were measured with multiple measurements for each feature. The location and orientation of each feature were averaged and a model containing 5 fractures was created, assuming a fracture diameter of 10 m (Figure 5b).

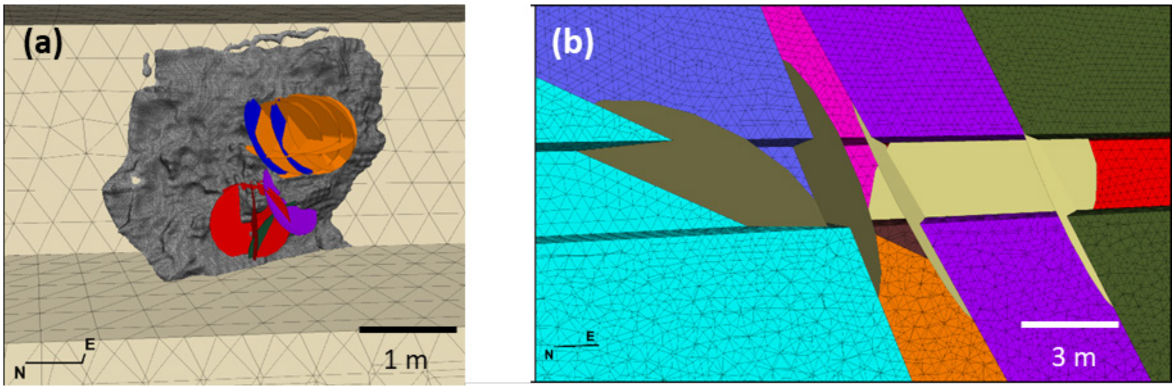

Figure 5. (a) Simple tunnel model with a height of 3 m showing the point cloud captured with the RockMass Eon (grey) and the measured fractures plotted as structural discs. The fractures have a diameter of 0.5 m and are colored by feature number. Half of the tunnel model is cut away to enable viewing of the inside. (b) The tunnel model with 5 fractures corresponding to 5 measured features (yellow disks). Fracture diameter is assumed to be 10 m.

As mentioned above, measured fracture orientations can be used to inform the creation of a DFN. The 83 fracture measurements from Glencore Kidd Operations (unaveraged) were used to set the fracture orientations in a DFN which was then used to create a jointed numerical model. A fracture volume of 60 x 60 x 60 m was filled with disks with a power-law size distribution with an exponent of 3, with diameters ranging from 5 to 50 m. 5000 disks were generated as shown in Figure 6a. The disks were then used to "cut" fractures into a numerical model of the tunnel as shown in Figure 6b and c. The model can now be used to evaluate stability of the tunnel or effectiveness of support if in situ stresses and material properties are known. A stereoplot of the 5000 fractures in the generated DFN are shown in Figure 6d, with the corresponding block sizes shown in Figure 6e.

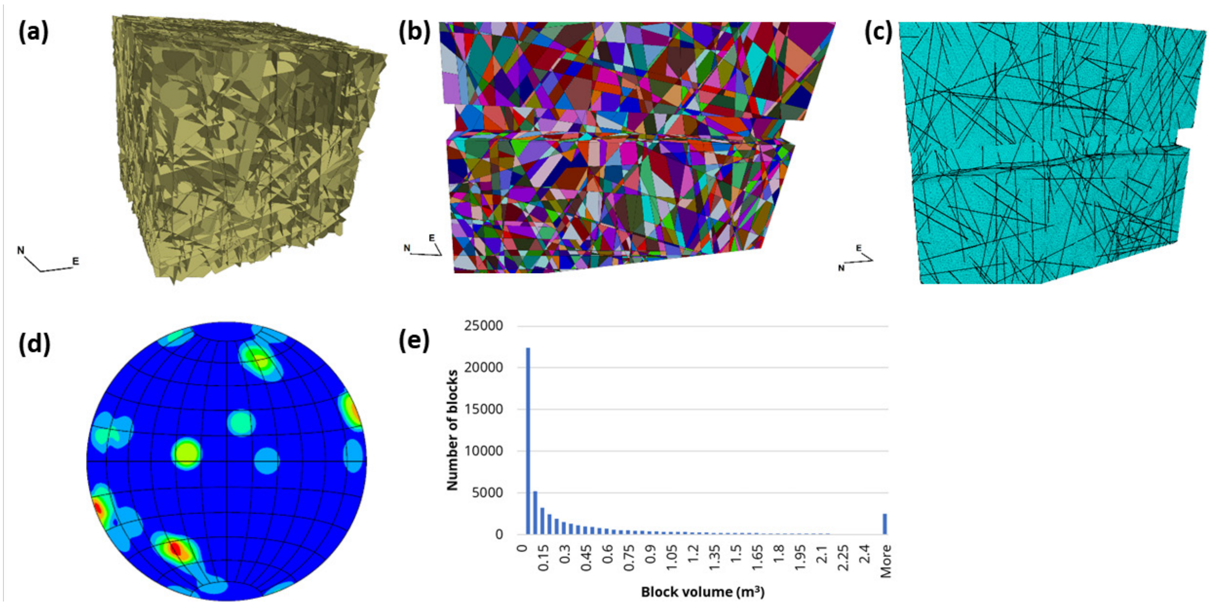

Figure 6. (a) DFN in a 60 x 60 x 60 m volume created by bootstrapping the fracture orientations measured by the RockMass Eon. (b) The resulting numerical model showing the simplified tunnel profile. (c) Discrete fractures along the tunnel profile. (d) Stereoplot of 5000 fractures in the generated DFN. (e) Block size histogram based on generated DFN.

5 DISCUSSION AND CONCLUSIONS

This paper presents a workflow that comprises digital geotechnical mapping of discontinuity data, and subsequent generation of a DFN model that can be used in discrete geomechanical modelling. The data presented was captured at Glencore Kidd Operations in Timmins, Canada, representing 83 measurements of 5 main discontinuities along a 10 m long drill and blast tunnel. Three windows were mapped along a scanline using the 3DAM method via the RockMass Eon device. Subsequently, the discontinuity data was imported into ITASCA software using a custom developed import function to generate a DFN of the mapped rock mass. Deterministic and stochastic approaches to importing the data into FLAC3D and 3DEC were demonstrated.

Despite the availability of computational power and access to sophisticated codes such as those provided by ITASCA, the generation of appropriate DFN models in engineering practice is hindered by a lack of adequate discontinuity data. Simplifying assumptions are often made to bridge the data gaps, and brute force upper and lower bound statistical methods are often applied in the absence of a comprehensive dataset. The digital mapping workflow described herein aims to address this gap by presenting a digitalized geotechnical mapping platform that uses the 3DAM method to extract discontinuity data, thereby increasing the speed and amount of mapping that can be completed in the field. Improved data fidelity offers the opportunity to increase the confidence practicing engineers have in DFNs and discrete geomechanical models of rock masses, making these tools more accessible in engineering practice.

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