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Using DFN models to improve ground control through wedge identification and hazard mapping

William Junkin[1,2], Lorrie Fava[1], Ming Cai[1,2], Eugene Ben-Awuah[2]
1. MIRARCO – Mining Innovation, Laurentian University
2. Bharti School of Engineering, Laurentian University

Summary

Wedge identification is critical for ground control design of underground rock excavations. Wedge characterization relies on rock mass- and fracture network characterization. Rock mass quality depends on both the rock matrix and fractures (Jing, 2003). Rock matrix properties can be qualitatively assessed on-site, or quantitatively assessed in a rock mechanics laboratory. The quantitative characterization of fracture networks is difficult due to complexity and scale. An assessment of the fracture network within a rock mass is dependent on geological mapping, and estimations of the nature of fractures where they cannot be observed. The use of conditioned discrete fracture network (DFN) models comprised of semi-deterministic and stochastic fractures provide a means to assess a fracture network and its influence on rock mass quality.

Current rock mass characterization methods (RMR, GSI, Q etc.) depend on categorical estimates of rock mass quality based on field observations and laboratory results (Jing, 2003). Because these estimations are categorical, it is difficult to accurately assess specific areas of concern in respect to potential wedges and ground support requirements. Ground control protocols are determined by considering the largest possible wedges that can form based on geological observations of fracture density and orientations. This results in the consideration of the worst possible case when developing protocols, and an excess in ground support installations. It is also difficult to provide evidence that ground control installations are adequate when there is no information regarding actual wedge location or geometry. These problems apply to a wide range of engineering projects including cavern excavations, mine development and planning, deep geological repositories, and slope remediation.

Fracture network models are created using statistical distributions that represent field observations of *in situ* fractures. These distributions act as constraints on the modelling process. DFN models can also be conditioned with field mapping of fractures on observed rock faces and outcrops. A conditioned DFN model is considered to be semi-deterministic, as the locations of fractures are constrained by mapped fracture traces and orientations whereas other aspects such as size, transmissivity, and connectivity are stochastically assigned. As field observation methods are improved through technology such as Lidar, it is possible to obtain highly detailed and accurate fracture trace data in a reasonable amount of time (Vazaios, *et al.*, 2015). Using Lidar data to condition DFN models is an efficient means of incorporating mapped geological data in fracture network simulation. The high-quality data result in DFN models that are accurate proximal to mapped surfaces.

This paper presents a novel algorithm that helps to process DFN models. Rock mass classification is integrated with quantitative assessment of DFN models for *in situ* blocks and discrete wedges near exposed or excavated surfaces that pose a hazard. A simulated fracture

network is validated and used to verify the proposed workflow. This demonstrates the accuracy with which the algorithm can identify and classify wedges near excavation boundaries.

Workflow

HypoSite, shown in Figure 1, is a simulated DFN model created for use in deep geological repository siting studies (SKB, 2018). The HypoSite DFN model is conditioned to hydraulic data and multiple geometric observations. It has been used to test and validate workflows that rely on the attributes of fracture networks. A simulated DFN model generated using MoFrac (MIRARCO, 2020) conditioned to the HypoSite data is used to demonstrate the proposed workflow to improve ground control through the identification of discrete *in situ* wedges. Fracture locations from the simulated trace maps and the statistical distributions that constrain the HypoSite model are used to create a single DFN realization with MoFrac. The simulated lithological data are added as attributes to fracture mesh points. These attributes are included in order to allow for wedge characterization from DFN models integrated with rock mass data. A simulated mine-through study is carried out to validate this DFN model against known trace maps from HypoSite and the input parameters used for modelling.

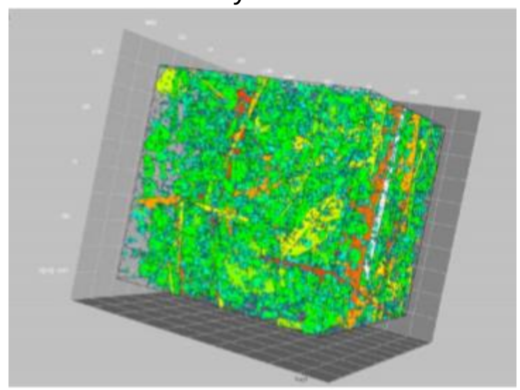

Figure 1. "Reality realization" of HypoSite DFN model (SKB, 2018)

The validated DFN model is used for the identification of potential wedges at or near excavation boundaries and rock slopes. The wedge assessment workflow is shown in Figure 2. The DFN model is evaluated using a block splitting algorithm that is conditioned to rock type using a block density threshold which controls the tolerance for concavity (Junkin *et al*., 2019). The block splitting algorithm identifies the location, shape, and size of *in situ* blocks in the simulated fracture network. With the addition of data delineating excavation boundaries, the identified blocks that form wedges at or near excavation boundaries can be isolated for further assessment of rock fall hazard and ground control requirements.

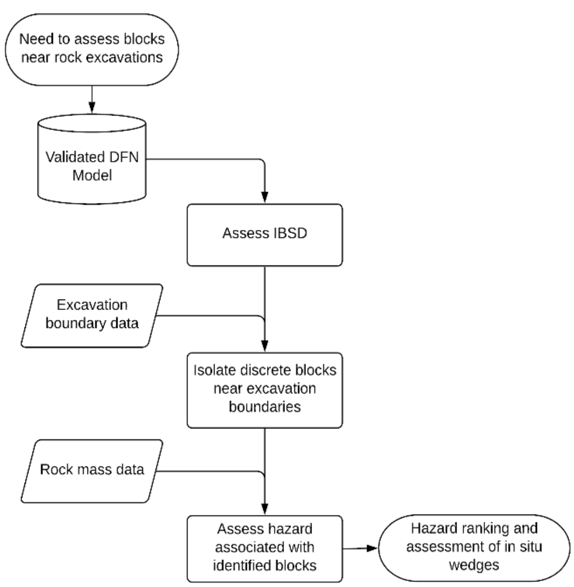

Figure 2. *In situ* wedge identification and assessment workflow.

The hazard assessment is integrated with rock mass classification data. With the incorporation of information regarding rock quality and the *in situ* stress field, estimates regarding joint strength can be made to assist with wedge hazard ranking.

Results

Figure 3 demonstrates the output from the proposed workflow; *In situ* blocks near the back of an excavated tunnel are isolated. Fracture trace maps are coloured according to hazard assessment. The workflow proposed in this study allows for the integration of data regarding rock mass properties with the geometrical assessment of *in situ* wedges identified in fracture network simulations.

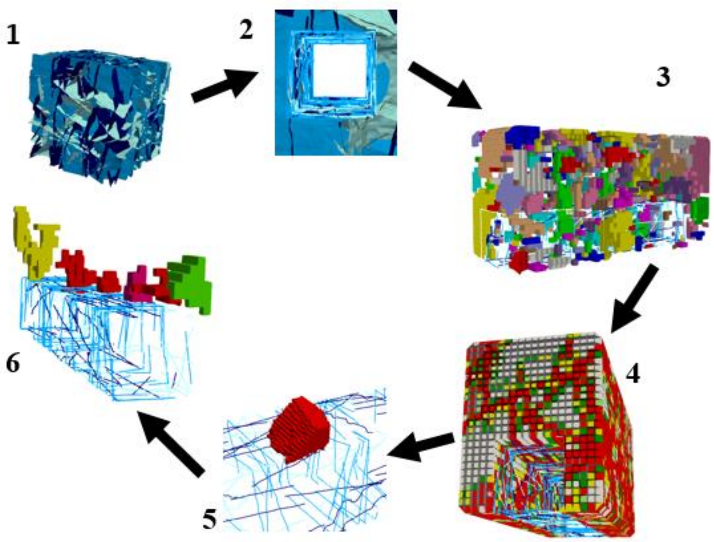

Figure 3. Wedge identification and assessment process. DFN model (1) has excavation boundaries extracted (2), unfractured blocks are identified (3), rock mass parameters are considered (4), isolated wedges are characterized (5), and ground control hazard is assessed (6).

Conclusions and Scientific Contribution

The development of an algorithm to identify and assess the hazard associated with *in situ* wedges near excavation boundaries provides a useful tool for civil and mining engineers. The ability to demonstrate that ground control installations are adequate is necessary in order to optimize ground control design.
A workflow representing wedge detection and a hazard assessment algorithm is presented in this paper. This algorithm expands on post-processing capabilities of MoFrac and the block splitting algorithm developed to determine block size distributions conditioned to rock type.

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References

Jing, L., (2003). A review of techniques, advances and outstanding issues in numerical modelling for rock mechanics and rock engineering. *International Journal of Rock Mechanics and Mining Sciences*. 40. 283-353.

Junkin, W, E. Ben Awuah, L. Fava, (2019) DFN Variability Analysis through Voxelization. *ARMA 2019, New York, NY.* 19–345. (Available at https://www.mirarco.org/wp-content/uploads/mirarco_Mofrac/ARMA-19-345.pdf)

MIRARCO Mining Innovation, (2020). *MoFrac Discrete Fracture Network Modelling Software*, www.mofrac.com

Swedish Nuclear Fuel and Waste Management Company [SKB], (2018). *Methods and workflow for geometric and hydraulic conditioning – DFN-R status report 2013-2015,* SKB report R-17-12, Tomas Bym and Jan Hermanson, (Available at https://www.skb.com/publication/2489619/R-17-12.pdf)

Vazaios, I, N. Vlachopoulos, M. Diederich, (2015). DFN generation for mechanical stability analysis of underground works*. ITA World Tunneling Congress 2015, Dubrovnik, Croatia.* 11p. (Available at https://www.researchgate.net/publication/282913908_DFN_generation_for_Mechanical_Stability_Analysis_of_Underground_Works)