



A Comparative Study of Deterministic and Stochastic DFN Models for Rock Mass Hydraulic Property Estimation

Marina Facci¹, **Silvia Favaro**¹, Stefano Casiraghi¹, Federico Agliardi¹, Silvia Mittempergher¹, Waqas Hussain¹, Jeffrey Hyman², Ramil Gainov³, Oleksandr Slipeniuk³, Massimo Fogazzi⁴, and Andrea Bistacchi¹

¹Department of Environmental and Earth Sciences, University of Milano-Bicocca, Milan 20126, Italy

²Computational Earth Science Group, Earth and Environmental Sciences Division, Los Alamos National Laboratory, US

³Rigaku Europe SE, Neu-Isenburg, 63263, Germany

⁴Assing S.p.A., Monterotondo, Roma, 00015, Italy

Discrete Fracture Network (DFN) models are widely used for predicting the hydraulic properties of heterogeneous fractured rock masses through the implementation of diverse numerical and semi-analytical methods. However, recent advancements in the parametrization of fracture networks by statistical analyses of field and geophysical data are not yet fully integrated into the capabilities of standard DFN simulators. Available 3D stochastic DFN generators (i) lack the ability to produce realistic topological relationships, and (ii) are limited to random spatial distributions of fracture seeds based on Poisson processes, thereby excluding clustered or regular patterns common in real fracture systems. In the case of heterogeneous rock masses with multiple clustered fracture sets, this leads to an inaccurate representation of connectivity, which significantly impacts the accuracy of hydraulic property estimates and flow modeling results. In addition, the simplified shape of fractures in DFN codes – either rectangular or elliptical, is very different from what observed in our natural sample, where due to mutual abutting relationships the fractures tend to have a triangular or trapezoidal shape, with a strong impact on the evaluation of P32 (i.e. the volumetric fracture intensity), that is a critical parameter in DFN generation. We present a comparative experiment in which a 3D deterministic fracture network was reconstructed from high resolution micro-CT scans of Miocene diatomitic marls (equivalent to the Tripoli Fm., Palena, Central Italy) using a combination of open-source and commercial software, including Move, Petrel, and PZero. This deterministic model was then compared with multiple stochastic DFN realizations sharing the same statistical parameters, generated with DFNWorks, Move and Petrel. Finally, the hydraulic properties of resulting fracture networks and their impacts on flow simulations were assessed using the flow-based model (Petrel), the semi-analytical Oda approach (Petrel and Move) and fully numerical simulations (finite volume in DFNWorks).

Our results indicate that advanced numerical methods, where flow is really simulated along interconnecting fractures, exhibit a greater sensitivity to input data quality than semi-analytical approaches. This discrepancy arises because methods such as the Oda approach rely on idealized assumptions and spatially averaged parameters, disregarding critical parameters such as network

topology, connectivity, and fracture aspect ratios. In absence of experiments conducted under controlled lab conditions, we tend to trust the more advanced numerical results (e.g. DFNWorks finite volume) with respect to simplified semi analytical approaches (e.g. Oda).