The Predictive Capability of Conditioned Simulation of Discrete Fracture Networks using Structural and Hydraulic Data from the ONKALO Underground Research Facility, Finland

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Abstract

Discrete fracture network (DFN) models provide a natural analysis framework for rock conditions where flow is predominately through a series of connected discrete features. Mechanistic models to predict the structural patterns of networks are generally intractable due to inherent uncertainties (e.g. deformation history) and as such fracture characterisation typically involves empirical descriptions of fracture statistics for location, intensity, orientation, size, aperture etc. from analyses of field data. These DFN models are used to make probabilistic predictions of likely flow or solute transport conditions for a range of applications in underground resource and construction projects. However, there are many instances when the volumes in which predictions are most valuable are close to data sources. For example, in the disposal of hazardous materials such as radioactive waste, accurate predictions of flow-rates and network connectivity around disposal areas are required for long-term safety evaluation. The problem at hand is thus: how can probabilistic predictions be conditioned on local-scale measurements? This presentation demonstrates conditioning of a DFN model based on the current structural and hydraulic characterisation of the Demonstration Area at the ONKALO underground research facility. The conditioned realisations honour (to a required level of similarity) the locations, orientations and trace lengths of fractures mapped on the surfaces of the nearby ONKALO tunnels and pilot drillholes. Other data used as constraints include measurements from hydraulic injection tests performed in pilot drillholes and inflows to the subsequently reamed experimental deposition holes. Numerical simulations using this suite of conditioned DFN models provides a series of prediction-outcome exercises detailing the reliability of the DFN model to make local-scale predictions of measured geometric and hydraulic properties of the fracture system; and provides an understanding of the reduction in uncertainty in model predictions for conditioned DFN models honouring different aspects of this data.

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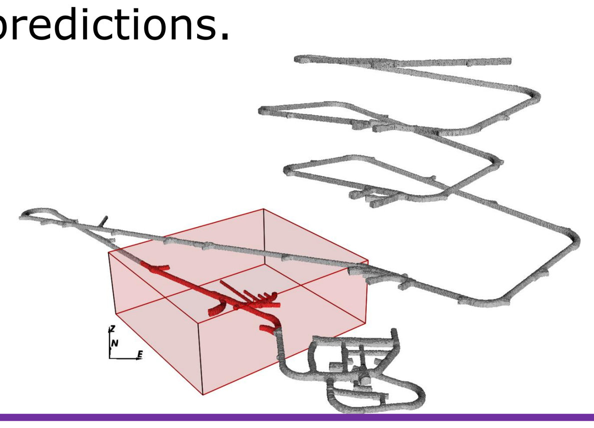
Introduction

Discrete Fracture Network (DFN) models provide an analysis framework for rock conditions where flow is predominantly through a series of connected discrete features. Fracture characterisation typically involves empirical descriptions of fracture statistics for location, intensity, orientation, size, aperture etc. from analyses of field data.

Models are calibrated to an ensemble of fracture data to reproduce observed spatial patterns, correlations and property statistics. Many realisations of the model can be generated to quantify stochastic uncertainty. However, these models are unconditioned and so do not honour specific drillhole or tunnel observations of fracture locations and properties.

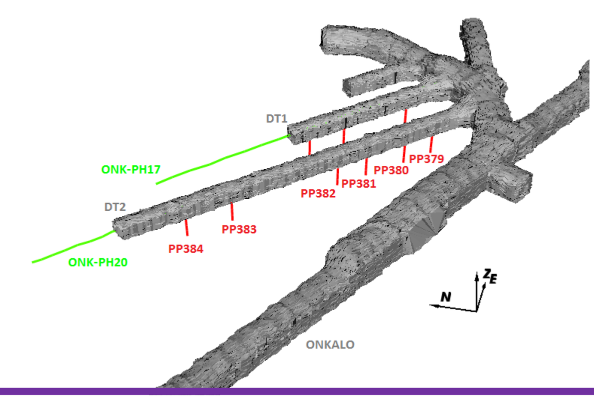
DFN models are used to make probabilistic predictions of likely flow or solute transport conditions in underground resource and construction projects. Often the volumes in which predictions are most valuable are close to data sources; in the disposal of radioactive waste, accurate predictions of flow rates and network connectivity around disposal areas are required for long-term safety evaluation. The problem at hand is thus: how can probabilistic predictions be conditioned on local-scale measurements?

This poster presents conditioning of a DFN model based on the structural and hydraulic characterisation of the Demonstration Area at the ONKALO underground research facility at Olkiluoto in Finland. Numerical simulations using a suite of conditioned DFN models provide a series of prediction-outcome exercises, detailing the reliability of the DFN model to predict measured local-scale geometric and hydraulic properties of the fracture system and demonstrating the effect of conditioning in reducing uncertainty of predictions.



Left: the ONKALO underground research facility at Olkiluoto, Finland, with the Demonstration Area modelling volume highlighted

Right: the Demonstration Area deposition tunnels (DT), deposition holes (PP) and pilot holes (PH) as used for simulated prediction-outcome exercises in this study

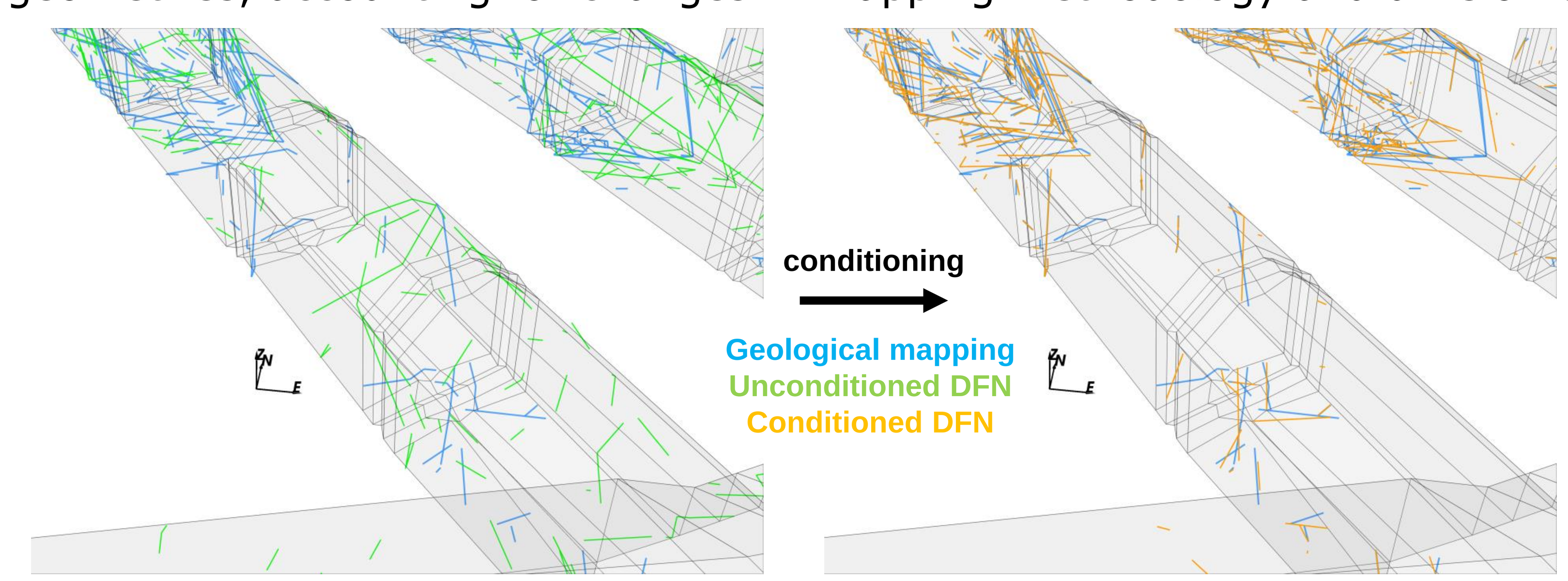


Conditioning

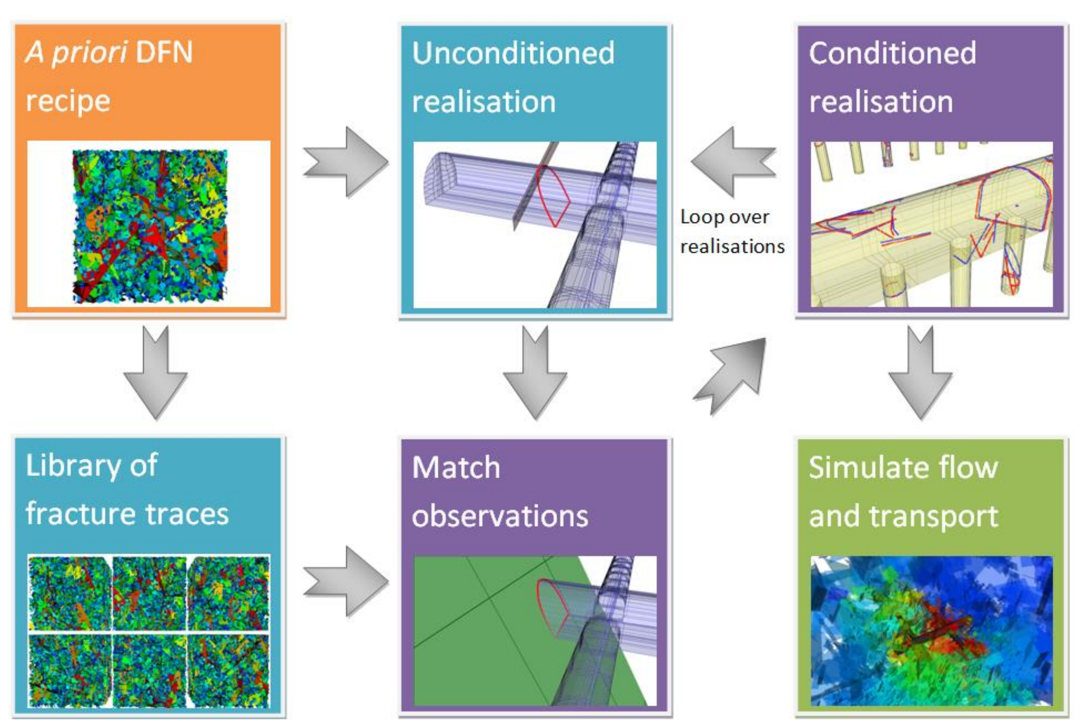
The conditioning process uses a set of closeness-of-fit measures to match observed fracture traces to candidate traces from a large library based on the unconditioned DFN model (> 26,000 realisations and > 65 million unique fracture traces).

Conditioned realisations thus honour (to a required level of similarity) the locations, orientations and trace lengths of fractures mapped on the surfaces of the nearby ONKALO tunnels and pilot drillholes. They are also constrained by measurements from hydraulic injection tests in pilot drillholes and inflows to the subsequently reamed experimental deposition holes.

Applying this conditioning process to real data presented some challenges not encountered in previous studies based on synthetic data (Appleyard et al. 2017). These required a number of new solutions, including idealisation of tunnel and trace geometries, accounting for changes in mapping methodology and division of tunnels into multiple domains (Baxter et al. 2017).

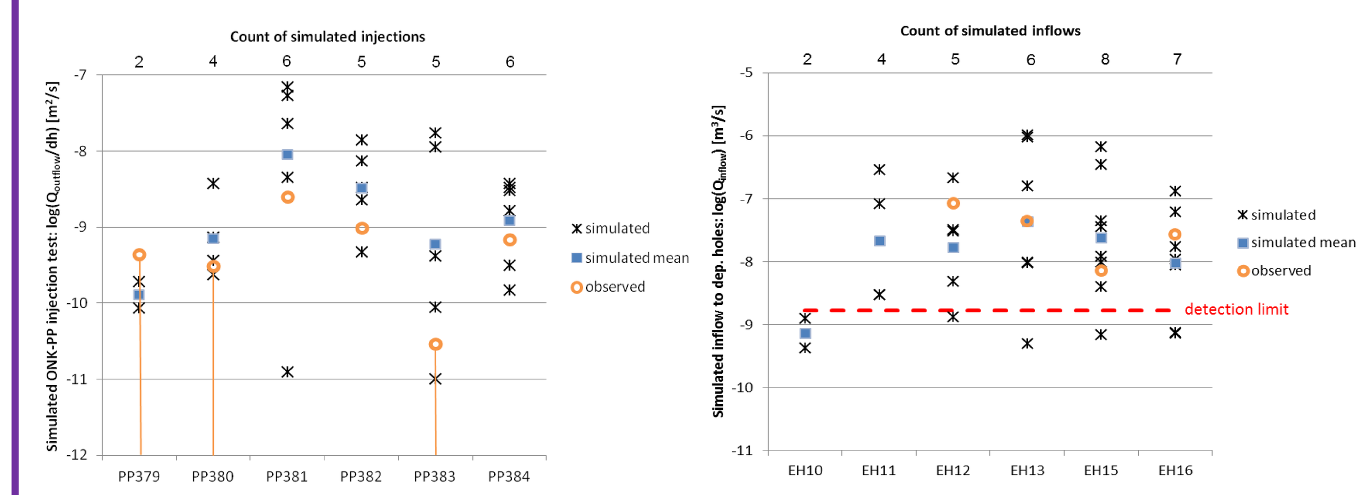


Conditioning methodology as previously demonstrated on a synthetic dataset (Appleyard et al. 2017)

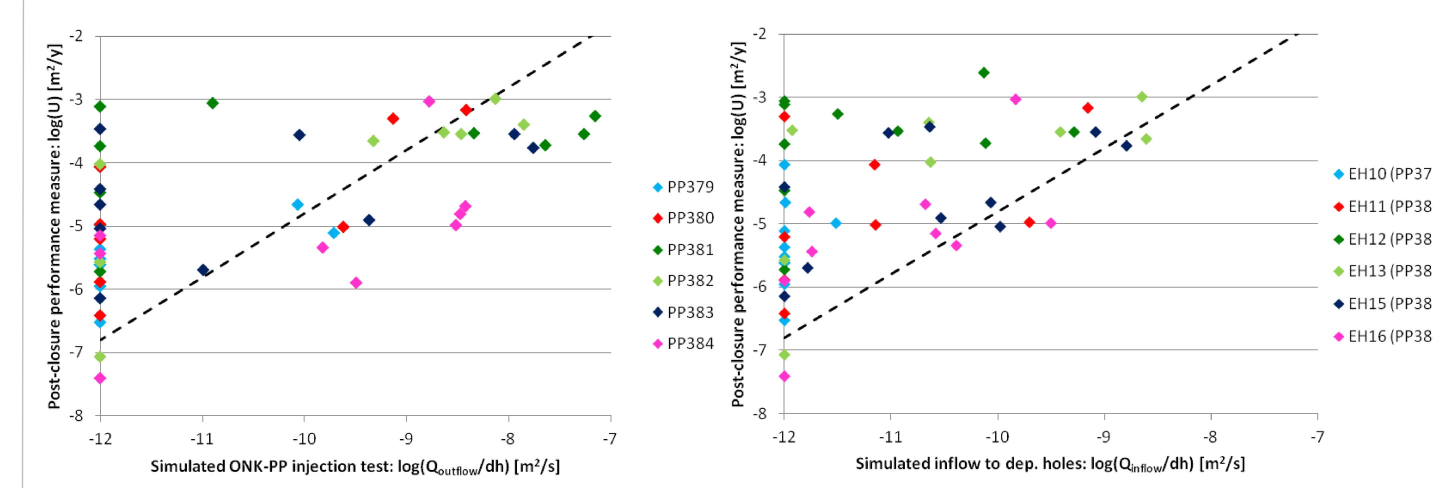


Appleyard, P., Jackson, P., Joyce, S., and Hartley, L., 2017. *Conditioning discrete fracture network models on intersection, connectivity and flow data. SKB R-17-11, Svensk Kärnbränslehantering AB.*

Unconditioned Results

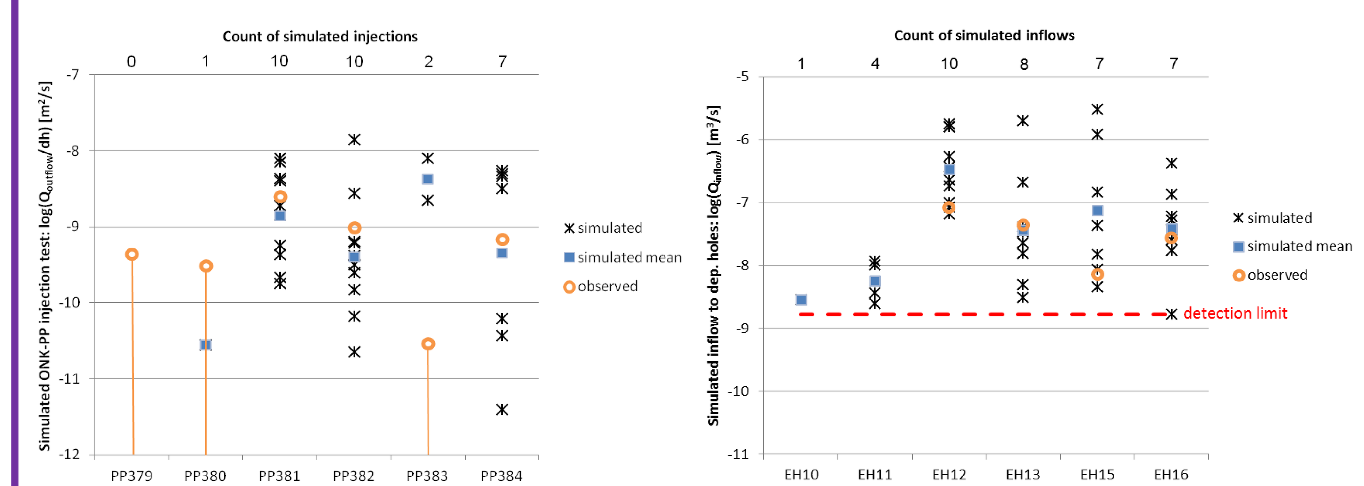


Simulations of injection to pilot holes (left) and inflows to corresponding deposition holes (right). When compared to measured flows (orange), multiple realisations (black) span a range of flow magnitudes, producing uncertain predictions of flow. Measured flows at/near the detection limit are indicated with an orange line representing the uncertainty in flow magnitude. The number of simulations in which at least one flowing intersection exists is counted (top).

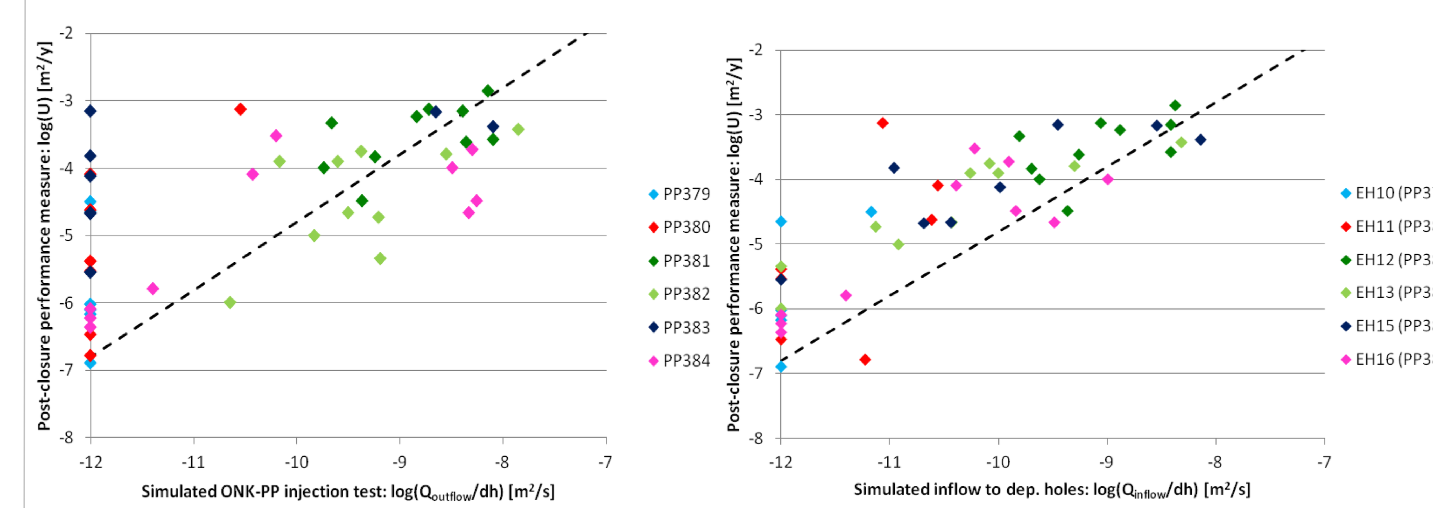


Predictions of post-closure flows from simulated injection to pilot holes (left) and inflows to corresponding deposition holes (right) show a weak correlation. A large number of realisations exist in which post-closure flows are high but there are no injection test flows (due to fractures intersecting with deposition holes but not pilot holes) or inflows (due to fractures connecting deposition holes to the tunnel and thus removing the pressure gradient needed for inflows).

Conditioned Results



Simulations of injection to pilot holes (left) & inflows to deposition holes (right) show improved consistency and reduced uncertainty after conditioning, with decreased spread over realisations and fewer flows simulated where they are small or zero in reality.



Predictability of post-closure flows from injection to pilot holes (left) and inflows to deposition holes (right) is improved, with a reduction in high post-closure flows for small specific capacities in both cases.

Conclusions

- Predicted inflows to deposition holes:
  - Conditioned models reduce uncertainty of predicted inflows to deposition holes by up to ~ 1 order of magnitude.
  - Conditioned models indicate improved correlations between pilot hole injections and deposition hole inflows.
- Predicted post-closure flows:
  - Conditioned models provide better correlations between post-closure flow and specific capacities from injection to pilot holes / inflows to deposition holes.
- These results (Baxter et al. 2017) support efforts to define effective hydraulic acceptance criteria for the Olkiluoto site.
  - The extent/reliability of simulated predictions of the hydraulic measurements for the open facility by local conditioning of the DFN has been assessed; predicting the inflows to deposition holes is critical for predicting the buffer performance.
  - Understanding has been gained of how post-closure flow and transport predictions are constrained by local conditioning.

Baxter, S., Appleyard, P., Hartley, L., Hoek, J., and Williams, T., 2017. *Exploring Conditioned Simulations of Discrete Fracture Networks in Support of Hydraulic Acceptance of Deposition Holes – Application to the ONKALO. Posiva SKB Report 07, Posiva Oy, Eurajoki, Finland.*