Upscaling of brittle deformation zone flow and transport properties

S. Baxter, Amec Foster Wheeler
L. Hartley, Amec Foster Wheeler
J. Hoek, Amec Foster Wheeler
S. Myers, Amec Foster Wheeler
V. Tsitsopoulos, Amec Foster Wheeler
J.-O. Selroos, Swedish Nuclear Fuel and Waste Management Company (SKB)
O. Vanhanarkaus, Posiva Oy
L. Koskinen, Posiva Oy

Key words: Discrete Fracture Networks (DFN), Faults, Upscaling

Introduction

An understanding of the properties of natural fractures is a fundamental requirement for the performance assessment of the long-term safety of a spent nuclear fuel repository located in low permeability crystalline rocks such as those planned at Forsmark, Sweden or Olkiluoto, Finland. Groundwater flow through the void space of the interconnected fractures in the bedrock is the dominant pathway for the migration of any arising radionuclides. Geometric, hydraulic and mechanical properties of fractures are also relevant to planning construction and operation of a disposal facility through their implications to managing water inflows and bedrock stability. Related fracture characteristics are also important to operational procedures for determining disposal volumes and to the closure design. For these reasons, quantitative description and analyses of fracturing is an important component of both SKB’s and Posiva’s programmes.

DFN approaches for representing brittle deformation fault zones

In consultation with SKB, Posiva has been developing their methodology for discrete fracture network (DFN) modelling toward the Olkiluoto site descriptive model (SDM) 2018. The DFN methodology has been elaborated in several ways in order to achieve greater integration between geological sub-models (ductile domains, lithology, and brittle deformation zones) and also hydrogeological models toward reducing uncertainty in location specific predictions. One key element of these methodology changes is around the representation of brittle deformation fault zones within the DFN which have historically been modelled as single triangulated planes (or surfaces) with effective hydraulic and transport properties. However, these effective properties are often difficult to constrain with only a handful of well-characterised fault zones at Olkiluoto providing sufficient measurements (typically from drillhole intercepts). In addition, the majority of fault zones have no or such limited characterisation data that it is necessary to infer their effective properties from analogy. In the latest round of DFN modelling in support of the Olkiluoto SDM 2018, the methodology for integrating fault zones with background fracturing of the rock mass has been updated to represent the faults as swarms of individual fractures each having their properties sampled from statistical distributions. In this case, stochastically generated fault related fractures are located around the fault mid-planes according to an exponential distribution of fracture centres, corresponding to a defined intensity at the mid-plane and a decay of intensity according to distance from the mid-plane. The resulting DFN models associated with each fault zone better reflect the structural geology observed around faults, and capture much of the site data including spatial distribution, intensity, orientation, traces in tunnel, as well as magnitudes of flow. Representing the faults in this way provides a mechanistic approach to the description of connectivity, hydraulic properties, anisotropy and heterogeneity, as well as transport properties across the extent of the faults. Figure 1 shows the resulting swarms of fractures around these mid-planes local to the base of the ONKALO at Olkiluoto, generated according to fault specific intensity and thickness. It can be seen that where a zone is either thick (e.g. BFZ020b and BFZ160) or has a high intensity (e.g. BFZ045), then the swarms are well connected, whilst for thinner (e.g. BFZ046 and BFZ346a) or less intense zones (BFZ230 and BFZ265) fractures only connect over parts of the fault area.

Upscaling fault related fractures

Although this methodology to represent the faults as swarms of individual fractures provides a well-founded approach to fault zone property description, it is difficult to communicate the properties it implies and the sensitivity of those properties to uncertain DFN parameters such as size distribution and intensity. Related to this is the issue of how to parameterise models of faults where the end–user requires a simplification of the zone to a plane with effective properties (e.g. transmissivity, porosity, and flow wetted surface). This presentation includes a methodology for producing such equivalent mid-plane representations based on the following approach:

1. The DFN model is first upscaled to an equivalent continuous porous medium (ECPM) model using a flux based approach for determining flow and transport properties at a cellular resolution (e.g. permeability, porosities and flow wetted surface).
2. These cellular ECPM properties are aggregated within the framework of the fault zone geometries to provide effective transmissivity, transport aperture, and flow wetted surface properties on the mid-plane of the fault.

Figure 2 illustrates the effective transmissivity calculated by the above approach for two faults zones at Olkiluoto, BFZ020a (left) and BFZ099 (right).

One limitation of the above process for upscaling fracture swarms to equivalent planar fault properties is the necessary computational requirements for performing such a task (requiring generation of first the DFN fault model, subsequent upscaling to ECPM properties, and finally processing to equivalent planar values). As such, the assessment of the statistical uncertainty of the fault zones, requiring a number of different stochastic realisations to be generated, is a time consuming task. However, as part of this presentation a geostatistical analysis of the upscaled fault zone properties has been prototyped to provide an understanding of the variability in effective properties and to enable the generation of realisations of the planar fault zone model expediently. Computationally, the method is light and enables a number of realisations to be created without the need to regenerate the underling fracture network and upscale. Such models are believed to be especially useful in performance/safety assessment applications where multiple realisations typically may be required. It is also noted that the upscaled transport properties (porosity and flow wetted surface) may be used directly within the ECPM in order to provide consistent upscaling of the underlying DFN model, even if we here focus on the representation of these properties on fault mid-planes.

For the generic methodologies detailed above, the presentation includes comparison / confirmatory tests within the framework of Posiva's latest DFN models for reducing the detailed description of fault damage zones, and their individual fault related fractures to a more conventional hydrogeological property model of transmissivity, porosity and flow wetted surface on the fault mid-planes.

Figure 1: A slice at z = –420 m through the fault associated fractures (brown) around the base of the ONKALO.

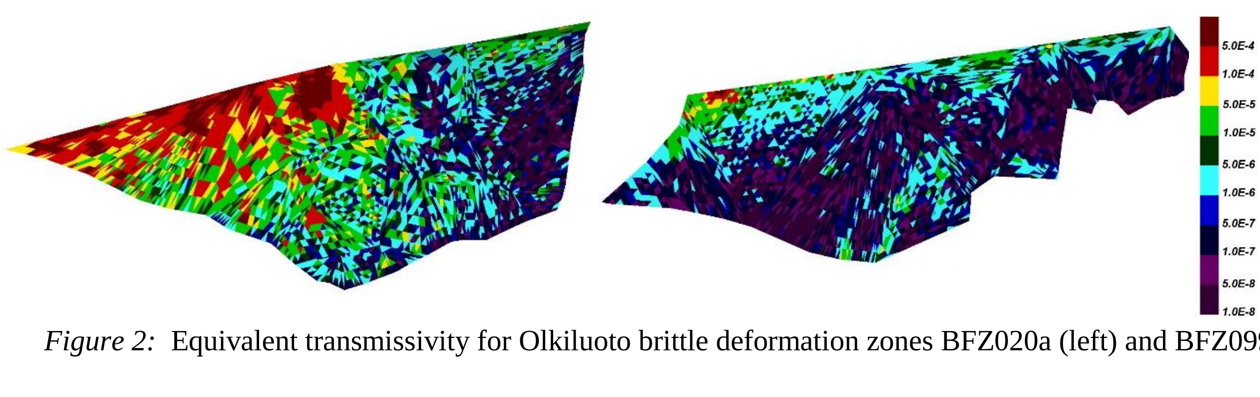

Figure 2: Equivalent transmissivity for Olkiluoto brittle deformation zones BFZ020a (left) and BFZ099 (right).