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Challenges and best practices for modelling fractures in geological repositories

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Challenges and Best Practices for Modelling Fractures in Geological Repositories

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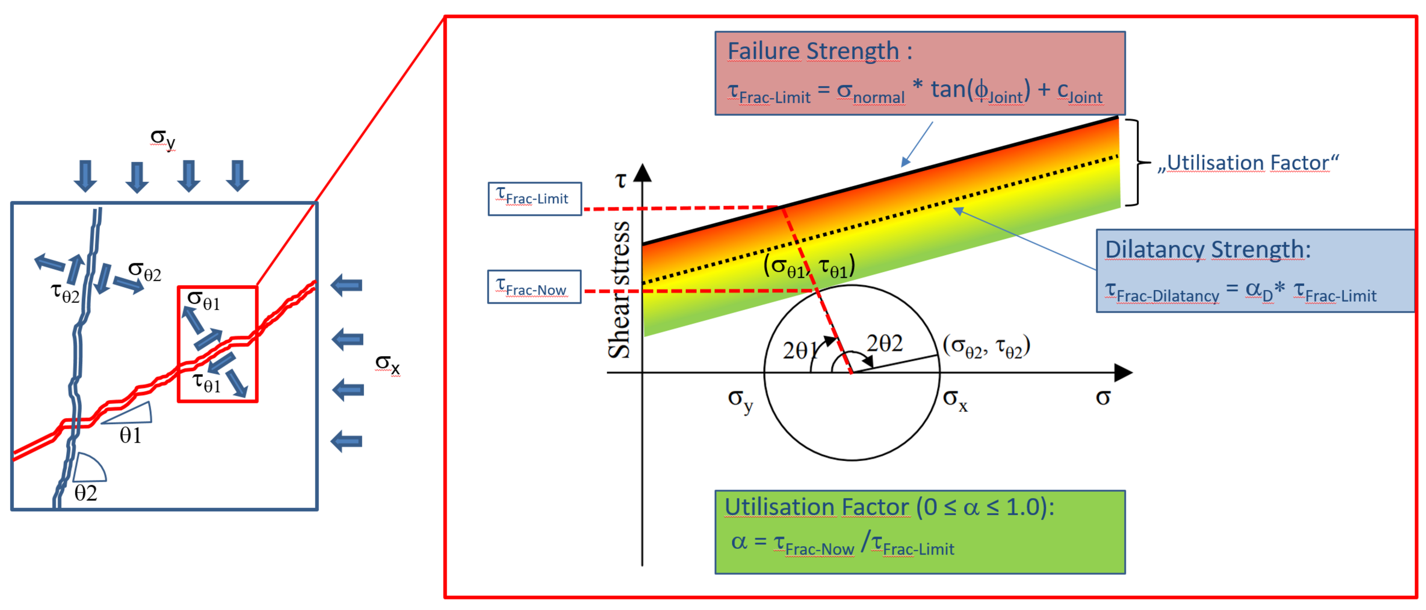
I Introduction

Fractures in host rock complicate safety assessment models for geological repositories. Accurately incorporating these fractures into numerical models poses a challenge due to their complexity. To address this, we evaluated modelling approaches for their accuracy and efficiency via benchmarks. Our focus spans two R&D projects: PRECODE emphasises mechanical integrity of the geological barrier, while SUSE addresses fluid flow and transport.

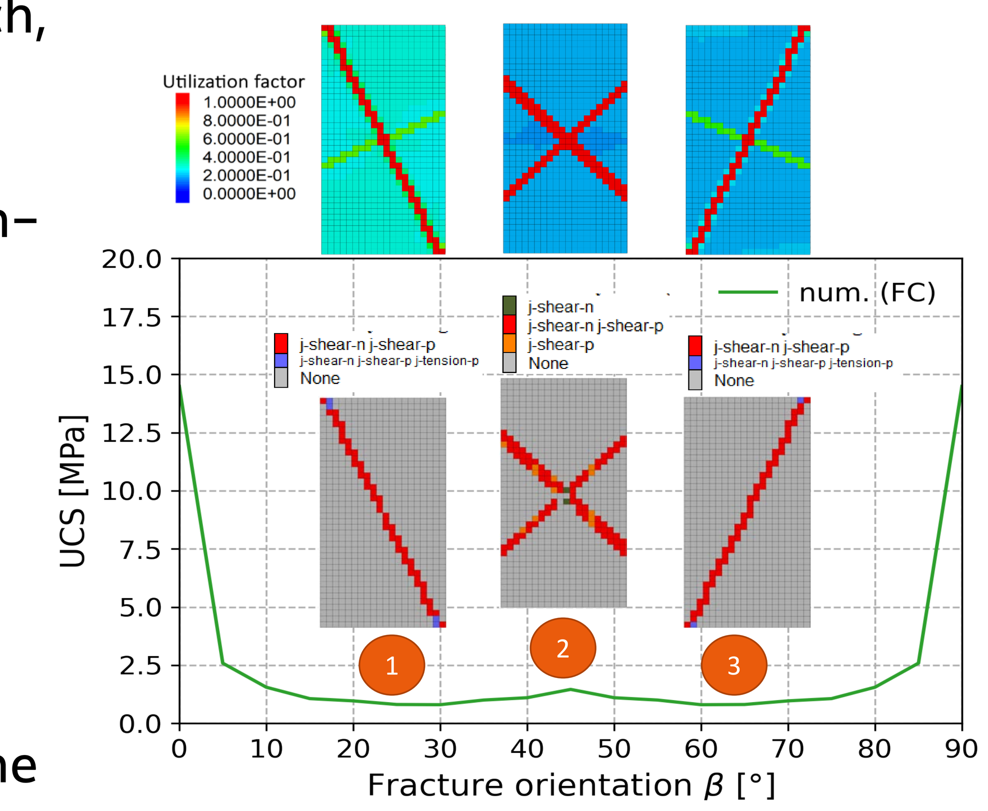
II Mechanical Processes (Project PRECODE)

If the host rock acts as a geological barrier, it must be proven that the expected stresses stay below the dilatant strength and fluid pressure criterion. In fractured rocks, variable joint orientations influence the activation of pre-existing failure patterns due to stress interactions, as indicated by Mohr circle analyses. This yields heterogeneous fracturing, where poorly aligned fractures fail earlier, contributing to complex rock behaviour.



Various approaches have been examined, encompassing both explicit fracture representation and attempts to upscale heterogeneous fracture properties. The Fractured Continuum (FC) approach addressed here explicitly incorporates fractures into a continuum mesh, assigning corresponding fracture properties to each element representing a fracture. Intact rock follows the Mohr-Coulomb behaviour, while fractures adhere to the Ubiquitous Joint (UJ) model, which describes anisotropic behaviour dependent on fracture orientation ("ubiquitous joint" weakness is confined to fracture zones).

To assess the FC approach, a straightforward uniaxial compression test was numerically simulated using orthogonal fractures of different orientations.

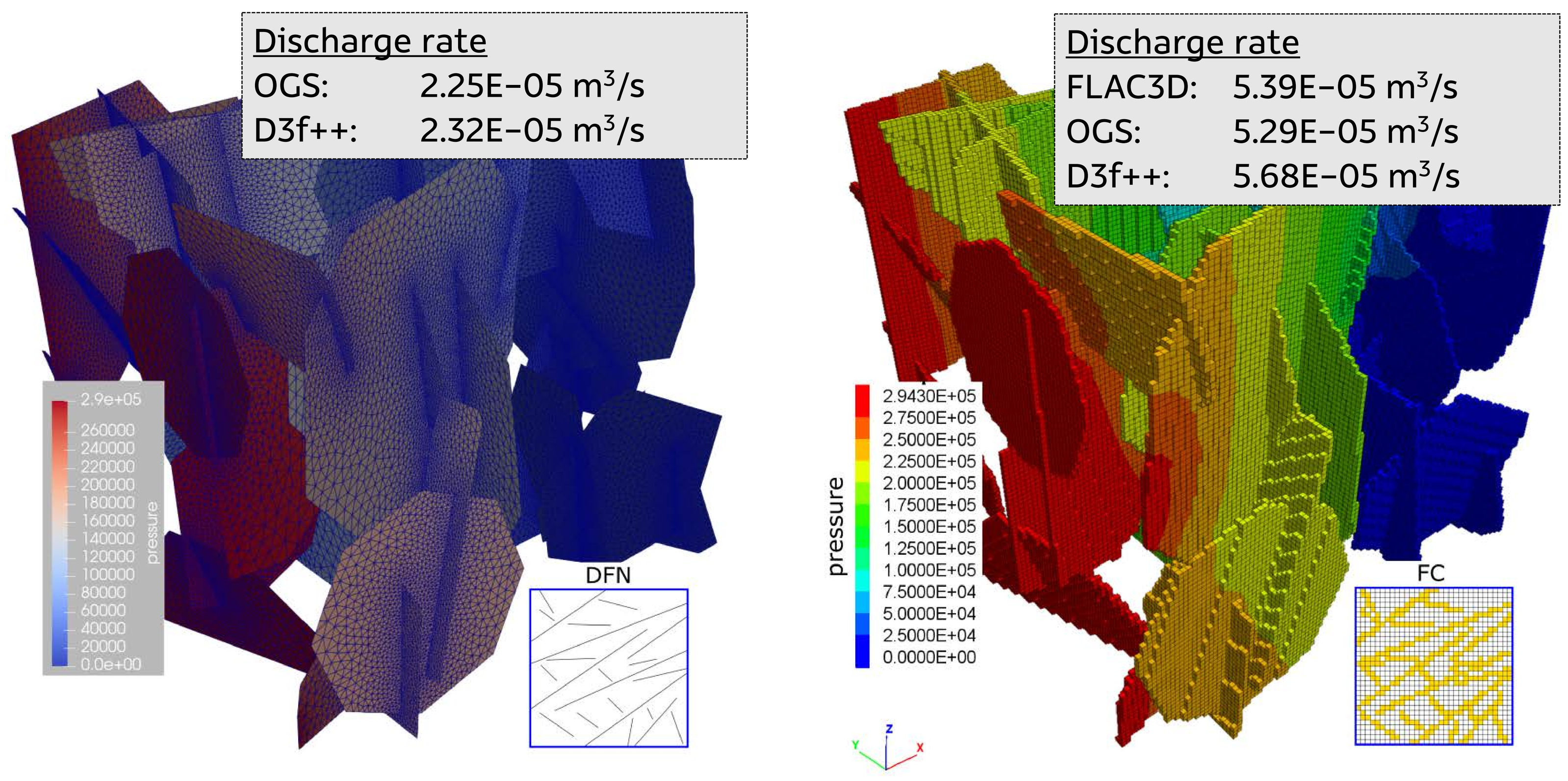


This test illustrates how material strength varies concerning the fracture orientation relative to the loading direction. When introducing a utilisation factor, which is the ratio of actual shear stresses to maximum shear stresses, the stress condition of both intact rock and fractures can be evaluated. Depending on orientation, both fractures (at 45°) or only one of the fractures can fail under shear stress. Additional details and preliminary results can be found in the poster presented by Ajmal et al. (2023) at this meeting.

III Fluid Flow / Transport Processes (Project SUSE)

Fractures are potential radionuclide transport pathways, crucial for accurate performance assessment. Simplifying fractures through methods like Equivalent Porous Media (EPM) may be inadequate for simulating fluid flow and transport. Thus, diverse approaches have been tested, including explicit fracture representation and upscaling heterogeneous properties, and compared via benchmark cases.

The benchmark addressed here focuses on groundwater flow and considers a 1000-m cube containing 50 disc-shaped fractures with varied sizes and orientations. A hydraulic gradient in the x-direction was assumed. The matrix is impermeable.



Different codes were used: FLAC3D (FVM), d3f++ (FVM), OGS (FEM). The Discrete Fracture Network (DFN) approach explicitly represents fracture properties (position, orientation, size, aperture), offering accuracy but lower efficiency. It serves as a reference for discharge rate calculations. The FC approach maps fractures onto a regular continuum mesh, assigning each zone an equivalent conductivity. Traditional porous media flow simulators are used. However, the stair-stepped mapping pattern (FC approach) can distort fluid velocities and the effective flow area locally within the fracture, resulting in discharge values more than twice the reference value.

IV Conclusions

- Fractures challenge safety assessments in geological repositories, demanding accurate incorporation into models despite complexities.
- Comparative benchmarks reveal trade-offs between accuracy and computational efficiency in modelling fluid flow through fractures.
- Integrating intact rock and fractures into numerical models highlights the fracture orientation's role in material strength. Utilisation factors visualise shear stress/strength ratios and contribute to understanding complex rock behaviour and safety.

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