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Dynamics of fluid flow in natural fracture networks

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In complex fracture networks, dynamic fluid-flow patterns arise already at flow velocities in the centimetre-per-second (cm/s) range. Yet, these phenomena get ignored or underestimated when such flows are modelled using Stokes'equation or steady-state approximations of the Navier Stokes equation (NSE) are used.
Here we apply the Detached-Eddy Simulation technique to solve the NSE in rock fractures, carrying out an investigation of the flow dynamics and flow micro-transitions in particular. Following verification and validation of this approximative model with data collected from physical flow experiments involving single Y- and X-shaped channel intersections, we have performed transient simulations on discrete fracture models constructed of tens-of-metre sized natural patterns with millimeter-wide open fractures. Our new results obtained on highly refined two-dimensional fracture meshes with tens of cells spanning the width of each fracture reveal that fracture flow, that is typically represented by streamlines and pressure distribution patterns, becomes unsteady at cm/s velocities. Dynamic eddies emerge at various scales, occupying a substantial volume of the fracture channels, increasing the tortuosity of the flow and fluid distribution in fracture branches. Associated pressure fluctuations do not average out at the model scale but are detectable there, possibly reaching magnitudes of ~10% of the total pressure drop across the network. The contribution of inertial losses to the hydraulic head gradient across the network is substantially increased with the onset of non-stationary eddies, confirming that they are the primary source of flow nonlinearity.

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