Linking direct and continuum fluid flow models for fractured media: The intersection problem

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Finding an adequate bridge between direct and continuum modeling approaches has been the fundamental issue of upscaling fluid flow in rock masses. Typically, numerical simulations of direct fluid flow (e.g. Stokes or Lattice-Boltzmann) in fractured or porous media serve as small-scale building blocks for larger-scale continuum flow simulations (e.g. Darcy). For fractured rock masses, the discrete-fracture-network (DFN) modeling approach is often used as an initial step to upscale flow properties by parameterizing the permeability of each fracture with its hydraulic aperture and solving steady-state flow equations within the fracture system. However, numerical simulations of Stokes flow in small fracture networks (FN) indicate that, depending on the orientation of the applied pressure gradient, fluid flow tends to localize at places where fractures intersect. This effect causes discrepancies between direct and equivalent continuum flow modeling approaches, which ought to be taken into account when modeling flow at the network scale.

In this study, we compare direct flow simulations of small fracture networks to their continuum representation obtained with several techniques in order to find an upscaling approach that takes these intersection effects into account. Direct flow simulations are conducted by solving the Stokes equations in 3D using our open-source finite-difference software LaMEM. Continuum flow simulations are realized with a newly developed parallel finite-element code, which solves fully anisotropic 3D Darcy flow with specific permeability tensors for each voxel. The direct flow simulations serve as benchmarks to optimize the continuum flow models by comparing resulting permeabilities. We tested two different schemes to generate the equivalent continuum representation:

1. Fully resolved isotropic permeability discretizations (fracture permeability is obtained from a refined cubic law) where voxel sizes are a fraction of the minimal hydraulic aperture of the FN or
2. Coarse anisotropic permeability discretizations (permeability tensors are rotated according to fracture orientation) with voxel sizes larger than the minimal hydraulic aperture of the FN.

We then assess different scenarios to incorporate the intersection effects by adding, averaging and/or multiplying the permeabilities of the intersecting fractures within intersection voxels. Preliminary results for scheme 1 suggest that a simple addition of both intersecting fracture permeabilities delivers the best fit to the results of the direct flow simulations, if the voxel size is
about 68% of the minimal hydraulic aperture. Scheme 2 systematically underestimates the direct flow permeabilities by about 26%.