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Non-linear hydro-mechanics of fluid-filled deformable fractures

Patrick Schmidt (1) and Holger Steeb (2)

(1) Stuttgart, Chair of Continuum Mechanics, Civil Engineering, Germany (patrick.schmidt@mechbau.uni-stuttgart.de), (2) Stuttgart, Chair of Continuum Mechanics, Civil Engineering, Germany (holger.steeb@mechbau.uni-stuttgart.de)

Determination of properties concerning underground fluid storage and heat transport in e.g. complex reservoir geometries require numerical investigations of flow processes coupled with the pressure-induced deformation of fractured porous media. The deterministic workflow is composed of hydraulic stimulation tests providing transient field data and inverse numerical simulations. Commonly un-coupled diffusion based models are applied throughout numerical calculations which fail to reproduce hydro-mechanical phenomena even by using extended formulations. Pressure-diffusion in the fluid filled fracture acts at a slower pace than immediate non-local volumetric, pressure-induced changes caused by the (elastic) deformation and result in inverse water level fluctuations on the reservoir scale also known as Noordbergum effect. Aside from volumetrically triggered phenomena local permeability changes might be induced by fracture deformation. In case of high aspect ratio fractures (length vs. aperture, i.e. $\delta > 1000$) these deformations lead to effective fracture permeability changes that have an immediate impact on the diffusion process, i.e. the characteristic diffusion time.

In the present contribution, a highly non-linear fracture flow model for deformable fractures is proposed to capture coupled local and non-local phenomena. Creeping flow conditions within the fractures motivates a hybrid-dimensional model and allows the assumption of pressure-driven Poiseuille-type flow leading to a numerically efficient dimension-reduction of the fracture domain. Monolithically solved systems built by interface element formulations guarantee numerical stability and efficiency. The discussion of numerical results concerning large (non-linear) aperture changes indicating qualitative changes of pressure-flux relationships to the non-linear regime closes the work.