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Hydro-mechanical coupling strategies for fluid-filled fractures using a hybrid dimensional formulation

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Numerical investigations of subsurface flow in fractured porous media provide information about properties connected to underground matter and heat transport just as characteristics of fluid underground storage capacity. Many diffusion-based models in the literature precisely describe subsurface flow. Nevertheless, pronounced hydro-mechanically-coupled phenomena like inverse water level fluctuations (Noordbergum effect) cannot be reproduced by diffusion-based models alone. Direct Numerical Simulations of surface-coupled fluid-solid (fracture) interaction or coarse-grained continuum descriptions like Biot's theory are theoretically capable to reproduce such phenomena. However, in case of investigations of fractures with high aspect ratios (length vs. aperture, i.e. $1/\delta > 1000$) methods using explicit discretization of the fluid domain tend to fail due to technical discretization issues. By assuming a parabolic velocity profile, the hybrid dimensional approach avoids an explicit discretization of the fracture domain. Thus, the fluid domain's dimension is reduced by one and solved for the pressure as the only primary variable. The mass balance within the fracture is modified to take volume changes into account and realizes the interaction between both domains, namely the hybrid-dimensional and surrounding solid domain. The characteristics of the coupled system vary with the ratio of the compressibility of the fluid within the fracture and the dimension of the elastic moduli of the surrounding matrix. Principally, when the ratio of fluid compressibility and bulk modulus tend to one the coupled system becomes stiff. The challenge are consistent numerical implementations that guarantee conservation of global mass and convergence for the full bandwidth of property ratios. A staggered-iterative scheme is presented for systems using moderate fluid compressibilities. Both systems are solved independently, hence it allows the use of non-conformal meshes and achieves an increase in efficiency. For stiff systems, a fully coupled model formulation that uses coupled boundary elements in an implicit fashion is introduced. The fully coupled problem allows the modelling of complex fracture geometries since only one mesh for both formulations is needed. In the course of this work, two consistent coupling schemes using the hybrid-dimensional formulation coupled to a surrounding elastic bulk material are proposed. The work closes with a discussion of the numerical solution scheme by means of relevant simulations to validate the methods compared to a poroelastic formulation and investigations of different fracture patterns.

References

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