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Application of an extended finite element method for modeling fully coupled hydromechanical processes in discrete fracture-rock matrix systems

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Analysis of mechanics related coupled processes in fractured rock, such as hydromechanical (HM) processes, is important in assessment of deep geothermal reservoirs, because of their strong influence on flow and subsequent transport systems in subsurface. Various numerical HM models, e.g. interface elements (IE) approach, have been developed and applied to geotechnical applications (Jing 2003, Rutqvist & Stephansson 2003 and Segura & Carol 2008). However, a challenge still remains in explicit representation of complex fracture geometries in a computer model.

In this study, we propose a numerical method partially using an enrichment technique, i.e. an extended finite element method (XFEM), to include pre-existing fractures for modelling coupled HM processes. The XFEM theory has been developed for crack analysis (Belytschko & Black 1999) and it treats the discontinuities directly in an approximation space with jump functions. Hence there is no need to represent them in a mesh. This significantly reduces a cost for remeshing when geometry changes. The XFEM has been applied to rock mechanics such as a tunnel stability analysis (Belytschko et al. 2001, Deb & Das 2010). To author's knowledge, there are few studies to apply it for modeling coupled HM processes in fractured rock.

Our proposed method is based on an XFEM theory presented by Belytschko et al. (2001) which has capability of handling arbitrary discontinuities. Modeling a fully coupled HM model becomes possible by (1) representing fractures as lower dimensional elements, (2) applying enrichment only at the fracture elements and (3) modeling mechanical behaviour of fractures as spring systems. Although the XFEM does not require including fracture geometries into a mesh, we do it to use a same mesh for both flow and mechanical processes. This is feasible because we concern only pre-existing fractures and assume no fracture growth. We introduce a spring model so as to be able to include well-known fracture closure laws such as Barton-Bandis model.

For verification of the method, we have conducted simulations of a 2D fluid injection problem into a single fracture where fracture aperture varies depending on fluid pressure. The study shows that the proposed method can produce very similar results as the semi-analytical solution. Ongoing works are solving more complex fracture geometries such as fracture intersection and higher-dimensional spaces.