A multi-scale approach to fluid flow in fracturing porous media

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ABSTRACT

We will develop a general numerical model for fluid flow in progressively fracturing porous media.The theory includes flow inside stationary and propagating cracks. The flow inside the evolving crack can be in the tangential direction. This is achieved by a priori adopting a two-scale approach. At the fine scale the flow in the cavity created by the (possibly cohesive) crack is modelled using a sub-grid scale model. Since the cross-sectional dimension of the cavity is small compared to its length, the flow equations can be averaged over the width of the cavity. The resulting equations provide the momentum and mass couplings to the standard equations for a porous medium, which are assumed to hold on the macroscopic scale.

The two-scale model which ensues, imposes some requirements on the interpolation of the displacement and pressure fields near the discontinuity. The displacement field must be discontinuous across the cavity. Furthermore, the micro-mechanics of the flow within the cavity require that the flow normal to the cavity is discontinuous, and in conformity with Darcy's relation which is assumed to hold for the surrounding porous medium, the normal derivative of the fluid pressure field must also be discontinuous from one face of the cavity to the other. For arbitrary discretizations, these requirements can be satisfied by exploiting the partition-of-unity property of finite element shape functions.

To provide a proper setting, we will briefly recapitulate the governing equations for a deforming porous medium under quasi-static loading conditions. The strong as well as the weak formulations will be considered, since the latter formulation is crucial for incorporating the micro-mechanical flow model properly. This micro-mechanical flow model will be treated next, and it will be shown how the momentum and mass couplings of the micro-mechanical flow model to the surrounding porous medium can be accomplished in the weak formulation. Time integration and consistent linearization of the resulting equations, which are non-linear due to the coupling terms and because of the cohesive crack model, complete the numerical model. Example calculations are given of a body with stationary cohesionless cracks and with a propagating cohesive crack. The calculations show that the influence of the presence of discontinuities on flow and deformation patterns can be significant.

The final part will involve two more recent developments. First, the extension of the theory to large deformations will be considered. Secondly, the suitability of splines to be used as basis functions for the analysis of fluid-saturated porous media will be explored.