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TWO-SCALE MODELS FOR FRACTURE IN FLUID-SATURATED POROUS MEDIA

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ABSTRACT

The proper computation of fluid flow in deforming porous media is crucial for predicting the physical behaviour of many systems of interest, for example, in geotechnical and petroleum engineering, but also for soft tissues. Because of the complicated structure and functioning of human tissues, the classical two-phase theory has been extended to three and four-phase media, taking into account ion transport and electrical charges.

The presence of damage, such as cracks, faults, and shear bands, can markedly change the physical behaviour. Furthermore, the fluid can transport contaminants which can dramatically reduce the strength of the solid skeleton. To account for such phenomena, the fluid flow must be studied also in the presence of discontinuities in the solid phase. Indeed, the physics of the flow within such discontinuities can be very different from that of the interstitial fluid in the deforming bulk material. These differences affect the flow pattern and therefore also the deformations in the vicinity of the discontinuity. As we will show, the local differences in flow characteristics can even influence the flow and deformations in the entire body of interest.

In this contribution, we will describe a general numerical methodology to capture deformation and flow in progressively fracturing porous media, summarising and unifying the work recently reported in [1–4]. The modelling allows for flow inside an evolving crack to 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 can be modelled in various ways, e.g. as a Stokes flow in an open cavity, or using a Darcy relation for a damaged porous material. 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.

Numerically, 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 micromechanics of the flow within the cavity require that the flow

normal to the cavity is discontinuous, and in conformity with Darcy's relation which, at the macroscopic scale, 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 discretisations, these requirements can be satisfied by exploiting the partition-of-unity property of finite element shape functions.

To provide a proper setting, we will first 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 micromechanical flow model properly. This micromechanical flow model is discussed next, and it will be demonstrated how the momentum and mass couplings of the micromechanical flow model to the surrounding porous medium can be accomplished in the weak formulation. Time integration and a consistent linearisation of the resulting equations, which are nonlinear due to the coupling terms and the cohesive crack model complete the numerical model. Finally, example calculations are given of a body with stationary and propagating cracks.

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