Adaptive refinement for discrete models of coupled mechanics and transport in concrete

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Mesoscale mechanical models represent a reliable and robust approach to modeling of pre- and post-critical mechanical response of concrete structures. The composite material is represented by an assembly of rigid bodies interconnected by cohesive contacts. The kinematics of the model is derived from the rigid body motion, as proposed in [1]. These models are capable of capturing discrete jumps in the displacement field and therefore are suited for simulating of fracture. At the contact facets, a vectorial constitutive formulation is used, providing a simpler approach than the traditional tensorial formulation. Inherently, this formulation also yields the orientation of cracks.

In this work, an adaptive refinement algorithm for steady state discrete mesoscale models is presented, accounting for the coupled mechanics and mass transport in concrete. The coupling is based on two phenomena: (i) the Biot's theory and (ii) the influence of cracks on the material permeability. The model kinematics is derived from rigid body motion of the Voronoi polyhedra resulting from the tessellation of the model volume.

Initially, the model is represented by a coarse non-physical discretization and during the solution, its selected regions are refined to meso-scale discretization as they approach the nonlinear regime. At the solution beginning, only an elastic behavior is assumed and therefore it is not necessary to keep track of the loading history or state variables. The density of the particles (Voronoi generator points) is adaptively refined during the numerical solution. Whenever the state of any of the rigid particles starts to approach a selected threshold, the neighborhood of the particle is refined.

The refinement criteria and the size of the neighborhood are input parameters. Various failure/refinement criteria can be found in the literature, see e.g. [2] and [3]. As a suitable refinement criterion, we propose using e.g. 70% of the material tensile strength as used in [4]. Once a region has been refined to the fine (mesoscale) discretization, another refinement is prohibited as nonlinear behavior is expected to develop.

In [4], an adaptive refinement was proposed for mechanical models. In the presented work, we extend this concept for two-way coupled models of mechanics and mass transport in saturated heterogeneous solids such as concrete.

The adaptive geometry update provides a major decrease of the number of degrees of freedom. A comparison of solution performance is presented using various numerical models representing diverse modeling use-cases. Typically, a speedup of about 10-12x can be achieved depending on the specific modeling scenario. It is shown that the adaptive refinement algorithm can be employed for coupled discrete mesoscale models and provides a significant solution speedup.

References

[1] Takayasu, Hideki. "A deterministic model of fracture." Progress of theoretical physics 74.6 (1985): 1343-1345.

[2] Ottosen, Niels Saabye. "A failure criterion for concrete." Journal of the Engineering Mechanics Division 103.4 (1977): 527-535.

[3] Boswell, L. F., and Z. Chen. "A general failure criterion for plain concrete." International journal of solids and structures 23.5 (1987): 621-630.

[4] Eliáš, Jan. "Adaptive technique for discrete models of fracture." International Journal of Solids and Structures 100 (2016): 376-387.