MPM with DEM homogenized constitutive laws

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This talk presents the groundwork for the development a double-scale MPM×DEM concurrent model (Ozenda et al., 2023). It has been specifically developed with the aim of simulating cohesive geophysical flows such as avalanches and landslides. We highlight some subtleties and difficulties in the implementation that are frequently overlooked in other studies, because of the recentness of the approach. In this respect, the fact that both the MPM and DEM codes are developed in-house tools represents a vast advantage, since all the intricacies can be precisely mastered. Figure 1 shows a schematic diagram that summarize the main ingredients involved.

We make use of three-periodic DEM elementary volumes so that deformation increments coming from the MPM are applied as an affine displacement field to the DEM particles. Dynamic effects are considered at both the macro- and micro-scale thanks to the explicit-in-time nature of both coupled methods. Hence, time has the same physical meaning at both scales and deformation increments are applied on the DEM cells over time increments that correspond to the MPM time step. As a result, both scales share strain velocity in addition with strain direction and amplitude that are only shared in classical non inertial methods (Desrues et al., 2015). The response of the DEM cell is evaluated at the end of this time increment even if it has not reached static equilibrium. This contrasts with most other implementations of hierarchical methods (*e.g.*, FEM×DEM or FE^2), in which a static macroscopic computation (no inertia) is performed and the response of the DEM cells is computed after stabilization. These specificities of the coupled model led us to introduce particular stability conditions related to cross-scale communications, with the need to adjust several ratio parameters involved in the definition of the time steps related to MPM and DEM.

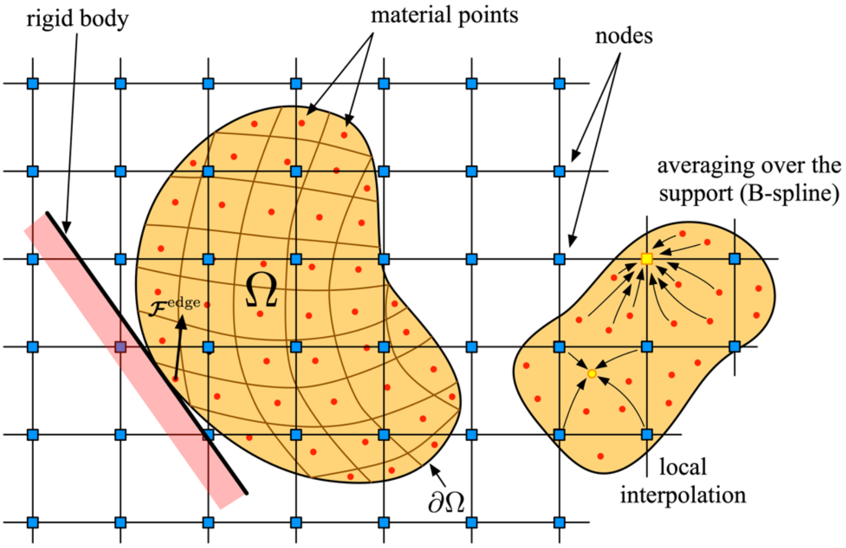

Figure 1. The classical principle of the MPM. In a less usual way, a rigid body, whose motion can be time integrated (by assigning it a mass) or simply fixed, is used for representing various boundary conditions including repulsion, frictional resistance and viscous dissipation.

Benchmark simulations of a column collapse of a dense cohesive granular material were performed to assess the potential the method; Figure 2. Particular attention needed to be paid to the preparation of the DEM cells, *i.e.*, the generation of the initial microstructure, and the stabilization of the cells under gravity inside the column. In this example, the material points are all associated to the same initial microstructure before stabilization. Cohesive-brittle interactions are considered between the particles through a viscous-damped frictional contact law superimposed to elastic-brittle solid bonds. The preliminary results clearly show that Computationally Homogenized Constitutive Laws (CHCL) obtained from DEM periodic cells with only a limited number of particles result in a rich mechanical behavior at the macroscopic scale. In particular, the independent evolution of the microstructure in each DEM cell can capture subtle memory effects and result in, *e.g.*, spontaneous symmetry breaking in the overall flow pattern. The DEM simulations also provide unique insights into the coupling between microstructure evolution and macroscopic deformation processes. Hence, besides damage, more sophisticated micro- or mesoscopic features such as reorganizations of force chains and grain could be followed in future works.

To get closer to the mechanical behavior of real geomaterials, such as soil or snow, further work will also be devoted to implementing additional complexity into the DEM cells such as grain size polydispersity, non-spherical particles, or loose microstructures. This latter feature, in particular, should allow us to reproduce “naturally”, *i.e.*, without additional material parameters, the large volume changes and collapse processes involved in the release of snow avalanches (see talk of Guillaume Chambon in this workshop).

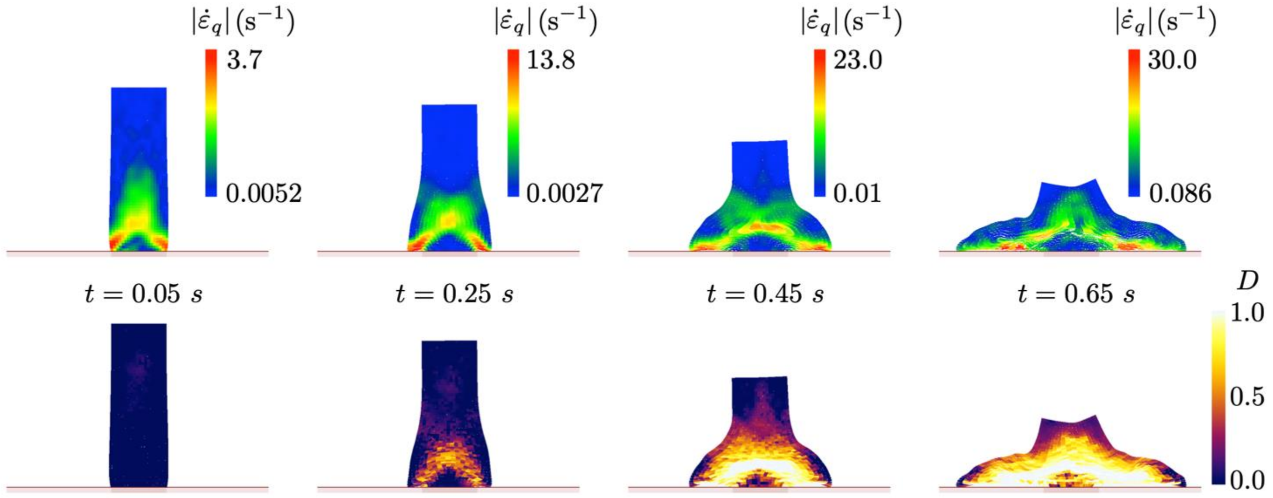

Figure 2. Evolution of deviatoric strain rate (top line) and damage (bottom line) inside the collapsing column at different times.

References

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