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# A new method for modeling of coupled brittle - ductile deformation

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The combined deformation of brittle and ductile materials plays a role in a number of important geological processes. One such process which is of particular importance is the brittle deformation of carbonate of anhydrite layers embedded in a viscous salt body during tectonics.
We are proposing a method where both the viscous and the brittle material are modeled using mesh-less, particle based Lagrangian methods. In this approach the viscous or fluid material is represented by a Smoothed Particle Hydrodynamics (SPH) model and the brittle solid is represented by a Discrete Element Method (DEM) model. Both approaches are well tested in their respective domain and due to the similarities between them it is possible to couple the two approaches to develop a hybrid method.
In both methods the material is represented by particles, which are carrying mass, momentum and other physical properties. The particles interact with other particles in their vicinity and move due to the forces resulting from these interactions. The difference between the two methods is the way in which these interactions are calculated and the particle positions are updated. In DEM models particles interact with their nearest neighbors by, e.g., frictional or brittle-elastic interactions and the motion of the particles is calculated by updating the velocities of each particles from the sum of the forces exerted on that particle using Newton's law.
SPH is an interpolation method and the integral interpolant of any function is calculated using a special smoothing function, called kernel. The SPH formulation is derived by discretizing the Navier-Stokers equations spatially; leading to a set of ordinary differential equations with respect to time, which then can be solved via time integration.
The coupling between the viscous (SPH) and the brittle-elastic (DEM) material, i.e. between the two types of particles, is implemented using "hybrid" particles which interact with SPH particles according to the SPH discretization of the Navier-Stokes equation and with DEM particles according to the DEM nearest-neighbor interactions. The forces due to both types of interactions are combined and the hybrid particles are then moved according to Newton's law.
Initial tests show that the combined DEM-SPH approach provides a way towards a simulation approach which can naturally combine brittle and viscous materials in the same model.