NUMERICAL SIMULATION OF DIRECTIONAL TENSILE FAILURE IN THE EULERIAN GODUNOV FRAMEWORK.

I. Lomov

Lawrence Livermore National Laboratory,
Livermore, CA 94550
lomov1@llnl.gov

High order Eulerian Godunov methods are well known to give high quality solutions for compressible fluid dynamics problems. Combination of this numerical approach with volume of fluid and interface reconstruction techniques has been shown to be successful for simulating multimaterial problems including liquids and solids when strength effects are insignificant. An Eulerian frame of reference provides the significant advantage of relative ease of incorporation of adaptive mesh refinement (AMR) into the algorithm. AMR provides significant speed advantages for a wide range of problems where a large region needs to be calculated, and it is necessary to resolve small portions with very fine zoning. Considering all these factors, it was very attractive to apply these methods for the solution of solid mechanics problems where strength effects are important. The full system of equations had to be formulated as a first order system of hyperbolic partial differential equations. On top of the usual conservation laws for mass, momentum and energy, and the equations for volume fraction, there need to be equations for the calculation of elastic shear deformation and history dependant variables like porosity, plastic strain, damage, etc. We also store the symmetric unimodular tensor of elastic distortional deformation; then we calculate the velocity gradient tensor (based on the Riemann solver) and update elastic distortional deformation tensor in nondivergent formulation. Characteristics analysis and the Riemann solver play a significant role in the accuracy of Godunov codes. Characteristics tracing for the full system of equations, including shear stresses, was performed similar to hydrodynamics. The Riemann solver calculates shear waves in the acoustic approximation and longitudinal waves without compromising the quality of solution for strong shock waves and rarefaction fans. Properties are distributed and averaged within multimaterial cells based on the bulk modulus of the corresponding material. The velocity gradient required for updating shear deformations is distributed between materials based on the shear modulus. The shear stress is also averaged based on the shear modulus. The described implementation of material strength was used to simulate rate-dependent inelastic behavior in the framework of porosity and general plasticity models, including effects of pressure and strain dependent hardening, Lode angle, thermal and structural softening, bulking and dilatancy.

It is especially challenging for Eulerian or ALE (Arbitrary Lagrange-Euler) type of codes to model the fact that although a brittle material (like rock) can fail in one direction, it may retain virgin strength to tensile failure in a perpendicular direction. In order to overcome this difficulty a new continuum model has been developed that can simulate weakening and void formation due to directional tensile failure. The model is developed within the context of a properly invariant nonlinear thermomechanical theory. A second order damage tensor is introduced which allows simulation of weakening to tension applied in one direction, without weakening to subsequent tension applied in perpendicular directions. This damage tensor can be advected using standard methods in ALE (Arbitrary Lagrangian Eulerian) computer codes. Porosity is used as an isotropic measure of volumetric void strain and its evolution is influenced by tensile failure. Furthermore, instead of introducing a void strain tensor, the inelastic effects of directional void opening and closing are modeled by introducing their effects on the rate of evolution of elastic deformation. The rate of dissipation due to directional tensile failure takes a particularly simple form which can be analyzed easily. Specifically, the model can be combined with general constitutive equations for porous compaction and dilation, as well as viscoplasticity. The constitutive equations for inelasticity due to tensile failure are specified by rate-dependent evolution equations which are shown to satisfy the second law of thermodynamics. A robust non-iterative numerical scheme for integrating these evolution equations is proposed. A number of simulations of fracture of rock of under explosive loading have been performed These simulations will be presented to show that directionality of damage can play a significant role in material failure.