A bulk damage model for modeling dynamic fracture in rock

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Abstract

Brittle materials are rate-dependent, meaning that the failure criterion envelope and failure patterns depend on the rate at which the loads are applied. The main reason is their microstructure characteristics. Brittle materials, especially rock materials, have significant microcracks and microdefects in their underlying microstructure. This has a direct effect on macroscopic fracture energy and fracture strength. The main energy dissipation mechanism for these materials is generating fracture surfaces in macroscale response or coalescing of microcracks and microdefects in mesoscale response. The dynamic features of failure response come from interactions between these two scales. We expect more coalescing in microscopic mechanism for a high rate of loading, but we expect fractures creation in macroscopic mechanism for a low rate of loadings. Therefore, it is crucial to investigate the rate effects in brittle materials on both fracture energy and failure capacity.

There are various methods to model failure response of brittle materials. Fracture mechanics and damage mechanics are two popular methods in this area. Tracking fractures in fracture models is very sophisticated, but the most challenging and questionable problem of fracture models is the initiation of fractures from a continuum level to an entirely explicit discontinuous fracture. Damage mechanics resolves most of the arising problems in fracture models by approximating fracture zones with an implicit weak area as damage zones. Besides of the desired properties, software implementation of damage mechanics is more straightforward.

In the present article, we will utilize a damage mechanics approach to model failure mechanism of rock. The damage model is rate-dependent, and the corresponding damage evolution is a dynamic equation which introduces a timescale to the problem. The introduced time scale preserves the convexity of the damage formulation as a non-local phenomenon. Therefore, the damage formulation incorporates rate-dependent failure mechanisms in the numerical analysis, and it does not suffer from mesh dependency drawbacks with much less computational efforts than conventional non-local formulations. The damage model is coupled with the elastodynamics equation of motion based on linear elasticity and infinitesimal strain definition. The final system of coupled equations is discretized in both time and space by an asynchronous spacetime discontinuous Galerkin method (aSDG) which is well-suited for the solution of hyperbolic systems of equations. We use the Newton-Raphson method to linearize the nonlinear system of discrete equations. The aSDG method is a robust method to capture elastic wave fronts for a wide range of loading rates, and so the proposed toolbox can track the failure history for highly dynamic loads, correctly. The final goal of the study is investigating the rate effects on failure mechanism of rock materials in high rates to low rates of loading. A dual adaptivity error indicator approach control both the energy dissipation in the bulk and error associated with the satisfaction of damage evolution law. Numerical results will be compared with those obtained by an interfacial damage model, i.e. a sample interfacial fracture model.