Geophysical Research Abstracts
Vol. 13, EGU2011-11806, 2011
EGU General Assembly 2011

Macroscopic Source Properties From Dynamic Rupture Simulations With Off-Fault Plasticity

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High stress concentrations at earthquake rupture fronts may generate inelastic off-fault response at the rupture tip leading to increased energy absorption in the damage zone. Furthermore, the induced asymmetric plastic strain field in in-plane rupture modes may produce bimaterial interfaces that can increase the radiation efficiency and reduce the frictional dissipation. Off-fault inelasticity thus plays an important role for realistic predictions of near-fault ground motion. For steady-state pulse dynamics analytical relations between cohesive zone properties, background stresses, fracture energy and rupture speed are available, but do not account for the energy dissipated by off-fault inelastic processes.

We apply the 2D spectral element method of Ampuero (2008) to model spontaneous rupture under strong velocity-and-state-dependent friction in a 2D in-plane model with Coulomb off-fault plasticity. Depending on initial parametrization and nucleation procedure the generated ruptures approach distinct zones of stable self-similar behavior: decaying, steady-state, growing pulse-like and crack-like ruptures, in both, sub- and super-shear regimes, bordered by sensitive transitional zones. The introduction of off-fault inelasticity quantitatively modifies the conditions to obtain each rupture mode, depending on the angle of maximum compressive initial stress and background shear stress level. Additionally, the considerable amount of induced off-fault energy dissipation alters macroscopic source properties, e.g. leads to slower rupture velocities, lower peak slip rates and lower shear stress levels on the fault with respect to the purely elastic case.

Our simulations provide quantitative relations between off-fault energy dissipation and macroscopic source properties.These relations provide a self-consistent theoretical framework for the study of the earthquake energy balance based on observable earthquake source parameters.