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Transition Of Dynamic Rupture Modes In Elastic Media

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Although seismic inversions of earthquake sources show dominantly pulse-like rupture behavior, i.e. the fault heals shortly behind the rupture front leading to short rise times, laboratory experiments and theoretical models indicate that earthquakes can operate either in pulse- or crack-like rupture mode. In fact, recent near-source ground motion shows signatures of crack like-ruptures (e.g., the Mw 8.8 2010 Chile earthquake). This suggests, that earthquakes may not be restricted to only one type of rupture mode but rather show multiple rupture patterns. Motivated by these considerations, we develop numerical experiments to study different rupture mode regimes and their transitions to gain an understanding of the conditions to trigger a given rupture type and of what controls it's dynamics.

We apply the 2D spectral element method of Ampuero (2008) to simulate spontaneous dynamic rupture propagation under strong velocity-and-state-dependent friction in a fully homogeneous elastic 2D in-plane model. Depending on initial stresses and nucleation procedure the generated ruptures approach distinct regimes of stable self-similar behavior: decaying, steady-state, growing pulse-like and crack-like ruptures, in both, sub- and super-shear regimes, which are bordered by highly sensitive transitional zones. We characterize these general rupture modes as a function of background shear stress and nucleation procedure and provide phase diagrams of the covered parameter space. The asymptotic behavior of self-similar ruptures is independent of nucleation details, unlike the transient approach to that asymptotic solution. The transitional rupture modes correspond to previous analytical work and are determined by competing critical propagation length scales. Interestingly, the pulse-crack transition involves re-activation of the previously healed rupture due to gradual stress build-up near the hypocenter.

This work demonstrates the general existence of sub- and super-shear ruptures in pulse- and crack-like rupture regimes and their systematic transitions with fault pre-stress but also with nucleation conditions. In homogeneous elastic media with homogeneous pre-stress steady-state pulses are found as first sustainable rupture mode at low stress states and minimal nucleation energies, but are highly sensitive to model parametrization. Subsequent transitional modes are equally sensitive to small perturbations in background stress and other initial conditions. These results lead to the conjecture that non-homogeneous conditions, as found in nature as signature of heterogeneities present at all scales in time and space, can trigger any self-similar and dynamically stable rupture regimes described above. Identifying the effective rupture mode may have important implications for the energy balance and heat generation during earthquakes, for scaling laws and macroscopic earthquake features, as the slip duration on the fault, which are affecting the resulting ground motion.