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Quantitative relations between earthquake source properties from dynamic rupture simulations incorporating off-fault plasticity

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High stress concentrations at earthquake rupture fronts may generate inelastic off-fault response around the rupture tip, leading to increased energy absorption in the damage zone. Accounting for off-fault plasticity in earthquake rupture simulations imposes physical limits on extreme ground motion as plastic dissipation limits the rupture speed and peak slip rate of pulses.

We present physics-based relations between earthquake source parameters derived from analytic considerations and from a consistent set of 2D dynamic rupture models that incorporate severe velocity-weakening friction and off-fault plasticity assuming homogeneous initial conditions. Specifically, we deduce a non-linear relation between the peak slip velocity and rupture speed, which holds for sub- and super-shear, crack- and pulse-like ruptures. We find that these relations are statistically consistent with the correlation of peak slip rate and rupture speed in 3D dynamic rupture models under linear slip weakening friction and highly heterogeneous initial stress. Furthermore the closeness to failure (CF) parameter introduced by Templeton and Rice (2008) is an adequate predictor of rupture speed for slow ruptures, whereas rupture speeds larger than $\sim$80% S-wave speed have a more complicated dependence on stress orientation and the relative strength of the fault.

These relations, combined with the limits on rupture speed imposed by off-fault plasticity, may encapsulate a major influence of plastic deformation on near-field ground motions. Our study captures fundamental processes governing dynamic rupture propagation coupled to self-similar off-fault energy dissipation. Thus, our results may be a suitable starting point to develop new pseudo-dynamic source parametrizations for source inversion and ground motion prediction that account for off-fault plasticity. We will report on the suitability of these relations in the presence of other sources of rupture complexity, e.g. coalescing rupture fronts.