# NONLINEAR COSEISMIC OFF-FAULT DAMAGE IN 3D DYNAMIC RUPTURE SIMULATIONS: DELAYED TRIGGERING, HIGH-FREQUENCY RADIATION, AND SEISMIC WAVE SPEED REDUCTION

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Off-fault materials can be subject to significant co-seismic damage (moduli reduction) near major faults according to the field and seismic observations (e.g. Sibson, 1977; Mitchell and Faulkner, 2009; Allam et al., 2014). To analyze the effects of non-linear off-fault damage on the dynamic rupture process, as well as the co-seismic interplay of earthquake rupture dynamics in complex fault systems, we implement the Continuum Damage Breakage (CDB) model of Lyakhovsky et al. (2016) in the 3D open-source dynamic rupture and seismic wave propagation solver SeisSol. The localized damage zones (see Fig. 1b) from our numerical simulations originate from a rapid transition from the solid phase to the granular phase of rocks. The damage patterns in the simulation also align with the weak surfaces predicted by the CDB model. Such a phase transition process generates high-frequency seismic energy radiation (see Fig. 1a). We in addition quantify how the energy dissipated due to thermodynamically irreversible off-fault rock damage depends on the parameters of the CDB model.

In strike-slip step-over dynamic rupture simulations, we find that the damage-induced moduli reduction around a rupturing fault can facilitate dynamic triggering ('rupture jumping') of an adjacent fault (see Fig. 1c to 1e). Depending on the accumulation rate of damage, we observe delayed triggering by a variable time interval (from seconds to minutes). These results demonstrate how the mechanical moduli reduction due to a time-dependent damage evolution process in off-fault rocks can contribute to rupture triggering on adjacent faults. Our implementation of the non-linear model in SeisSol also provides the tool to quantify this physical process with 3D regional scale physics-based numerical simulations.

*Note: Figure is on the next page.*

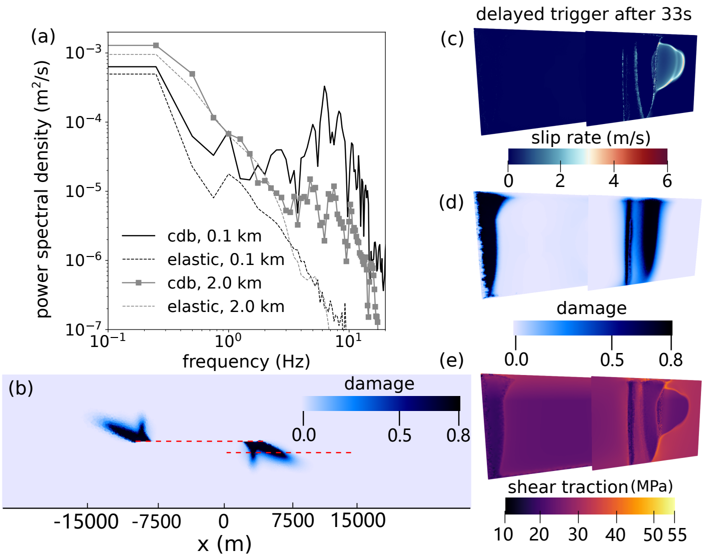


Fig. 1: (a) The power spectral density of velocity time series recorded at 0.1 km and 2.0 km away from the fault plane. (b) The fault localized damage zones (in dark blue) at depth of 7.5 km that follows the weak planes according to the model from Lyakhovsky et al. (2016). The two dashed red lines mark the locations of the two neighboring fault planes, separated by 3 km. We show the slip rate (c), damage (d) and shear traction (e) on the two faults. The nucleation of rupture on the second fault is delayed by 33 s in this example.