



Modeling earthquake rupture dynamics across diffuse deforming fault zones

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Earthquakes are a multi-scale, multi-physics problem. For the last decades, earthquakes have been modeled as a sudden displacement discontinuity across a simplified (potentially heterogeneous) surface of infinitesimal thickness in the framework of linear elastodynamics. Thus, earthquake models are commonly forced to distinguish artificially between on-fault frictional failure and the off-fault response of rock.

While complex volumetric failure patterns of fault networks are observed from well-recorded large earthquakes (e.g., the 2016 M_w 7.8 Kaikōura event, *Klinger et al. 2018*) and small earthquakes (e.g., events in the San Jacinto Fault Zone, *Cheng et al. 2018*) as well as in laboratory experiments (e.g., in high-velocity friction experiments, *Passelègue et al., 2016*) inelastic deformation within a larger volume around the fault is generally neglected when studying kinematics, dynamics and the energy budget of earthquakes. Fault behaviour is then dominantly controlled by lab-derived friction on a surface. Recent 2D collapsing of material properties, stresses, geometry, and strength conditions from seismo-thermo-mechanical models to elastodynamic frictional interfaces illustrated resulting earthquake complexity and modeling challenges (*van Zelst et al., 2019*).

To understand the mechanics of slip in extended fault zones the ERC project **TEAR** (<https://www.tear-erc.eu>) aims to solve the governing equations of earthquake sources based on the conservation of mass, momentum and energy and rheological models for generalized visco-elasto-plastic materials. We here present (i) 2D numerical experiments of rupture dynamics and displacement decoupling under loading for varying fault zone properties resembling observations from the San Jacinto Fault Zone in a weak discontinuity approach using a diffuse fault representation (adapted stress-glut approach, Madariaga et al., 1998) within a *PETSc* spectral element discretisation of the seismic wave equation; (ii) Verification of modeling rupture dynamics using a novel diffuse interface approach using *ExaHyPE* (www.exahype.eu, *Reinartz et al. 2019*) that allows spontaneous, finite crack formation (*Tavelli et al., in prep.*) and adaptive mesh refinement (AMR) zooming into the process zone at the rupture tip.

By this means, we start exploring scalable software for modelling shear rupture across extended, spontaneously developing fault systems for testing the hypothesis, that earthquake dynamics in fault zones can be jointly captured based on the theory of generalized visco-elasto-plastic

materials.

References:

- Cheng, Y. et al. Diverse volumetric faulting patterns in the San Jacinto fault zone. *JGR: Solid Earth*, 123.6, 5068-5081 (2018). <https://doi.org/10.1029/2017JB015408>
- Klinger, Y. et al. Earthquake damage patterns resolve complex rupture processes. *GRL*, 45, 10,279– 10,287 (2018). <https://doi.org/10.1029/2018GL078842>
- Madariaga, R. et al. Modeling dynamic rupture in a 3D earthquake fault model. *BSSA*, 88.5 (1998): 1182-1197.
- Passelègue, F. X. et al. Frictional evolution, acoustic emissions activity, and off-fault damage in simulated faults sheared at seismic slip rates. *JGR: Solid Earth*, 121(10), 7490-7513 (2016). [doi:10.1002/2016JB012988](https://doi.org/10.1002/2016JB012988)
- Reinarz, A. et al. ExaHyPE: An Engine for Parallel Dynamically Adaptive Simulations of Wave Problems. *arXiv preprint* (2019), [arXiv:1905.07987](https://arxiv.org/abs/1905.07987).
- Tavelli, M. et al. Space-time adaptive ADER discontinuous Galerkin schemes for nonlinear hyperelasticity with material failure, in prep.
- Van Zelst, I. et al. Modeling Megathrust Earthquakes Across Scales: One-way Coupling From Geodynamics and Seismic Cycles to Dynamic Rupture. *JGR: Solid Earth*, 124, 11414–11446 (2019). <https://doi.org/10.1029/2019JB017539>