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Non-planar dynamic rupture modelling across diffuse, deforming fault zones using a spectral finite element method with a non-mesh aligned embedded diffuse discontinuity

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Faults in earthquake rupture dynamic simulations are typically treated as infinitesimally thin planes with distinct on- versus off-fault rheologies. These faults are prescribed and can be explicitly accounted for with hexahedral or unstructured tetrahedral meshing approaches.
We present a diffuse interface alternative to dynamic rupture modelling on non-mesh aligned faults and, by design, permits modelling of non-planar faults and time-dependent fault geometries. We use se2dr, a spectral finite element (continuous Galerkin) method with a non-mesh aligned embedded diffuse discontinuity for dynamic rupture simulations.

Natural fault systems are characterised by fault zone complexity, e.g. the frictional strength and spatio-temporal slip localisation may change drastically from the outer damage zone to the fault core. Complex volumetric failure patterns are observed in well-recorded large complex earthquakes (e.g., the 2016 Mw7.8 Kaikōura event, Klinger et al. 2018), small events (e.g., in the San Jacinto Fault Zone, Cheng et al. 2018), and laboratory-scale experiments (e.g., in high-velocity friction experiments, Passelègue et al., 2016).

We develop a diffuse description of fault slip to better understand complex volumetric failure patterns and the mechanics of slip in diffuse fault zones. The fault is defined via a signed distance function ($s(x)$), which is in turn used to define a fault indicator function with compact support H. If $s(x) > H$ the material behaves as a pure elastic solid - otherwise the tangential stress is governed by a frictional sliding law.
Our approach is implemented on a structured hexahedral mesh using a spectral finite element (continuous Galerkin) method for wave propagation using PETSc. Our diffuse fault SEM method is inspired by the stress-glut method of Andrews, 1999. A non-mesh aligned embedded diffusive discontinuity allows for complex dynamic rupture simulations. We present 2D numerical experiments of kinematically driven rupture and spontaneous dynamic rupture on non-planar and non-mesh aligned complex fault geometries. The method can be used to model earthquake rupture dynamics on specifically complex and evolving fault faults such as the San Jacinto, CA, fault, or shallowly dipping megathrusts and splay faulting structures in subduction zones.