Diffuse thick fault representation in 2D SEM for earthquake dynamic rupture simulations

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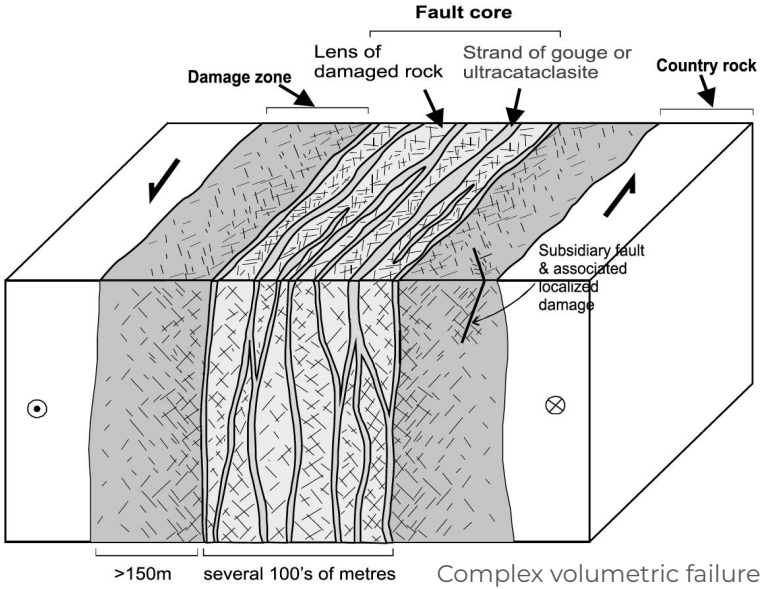
Fault zone complexity

- Observed at multiscale natural earthquakes (Cheng, Y. et al., 2018; Klinger, Y. et al., 2018) and laboratory experiments (Passelègue, F.X., et al., 2016)
- Earthquake dynamic rupture simulations often treat faults as infinitesimally thin planes with distinct on- versus off-fault rheologies
- Efforts collapsing the dynamics of earthquakes to single interfaces may miss important physical aspects governing fault system behaviour



Complex volumetric failure patterns of fault networks. (Mitchell, T. M. et al., 2009)

Within the TEAR project (https://www.tear-erc.eu), we aim to model **how faults slip** in extended fault zones based on models with increased material and geometrical complexities.

se2dr (https://bitbucket.org/dmay/se2wave)

A **PETSc** (Balay, S. et al., 1997, 2019, 2020) **spectral element adaption of the stress-glut method** (Andrews, D.J., 1976, 1999).

Diffuse interface method for earthquake rupture dynamics based on a phase-field approach

Fault zone representation

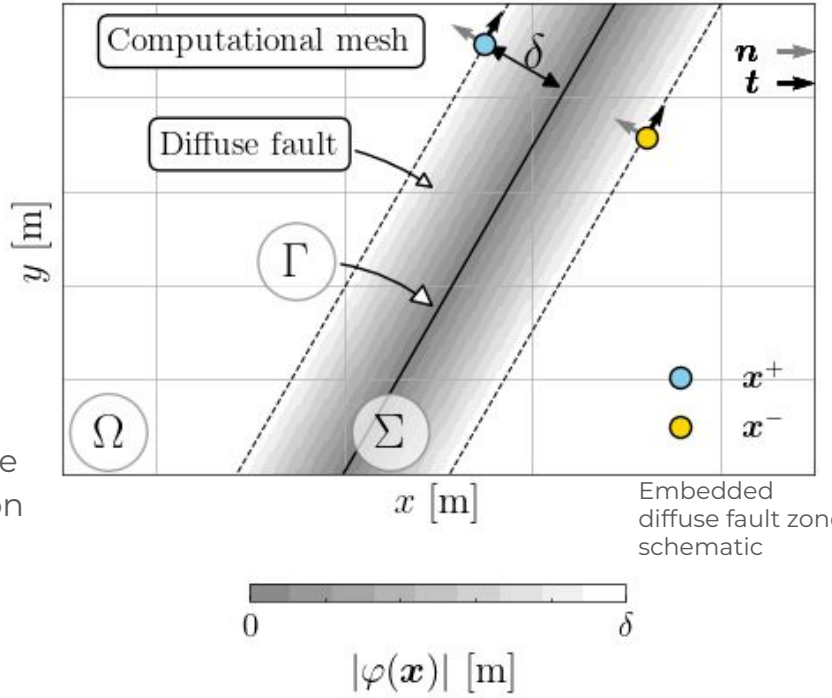
Described via a signed distance function (SDF).

Friction and yielding criteria

We use a time weakening / slip weakening friction law to calculate the **critical shear strength** and **modify the shear traction component** of the stress accordingly.

Diffuse description

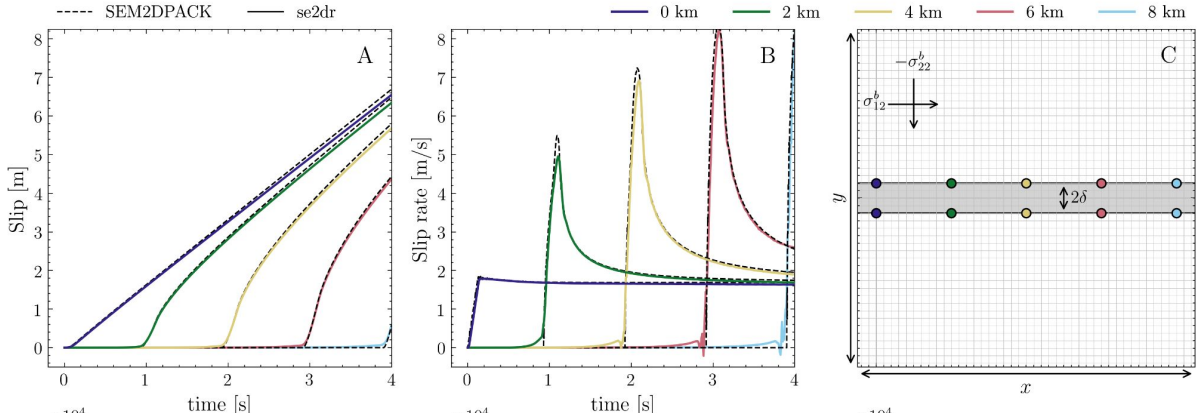
We include a **diffuse interface description** of the modified stress motivated by steady-state representation of phase-field models (Sun, Y. et al., 2007).



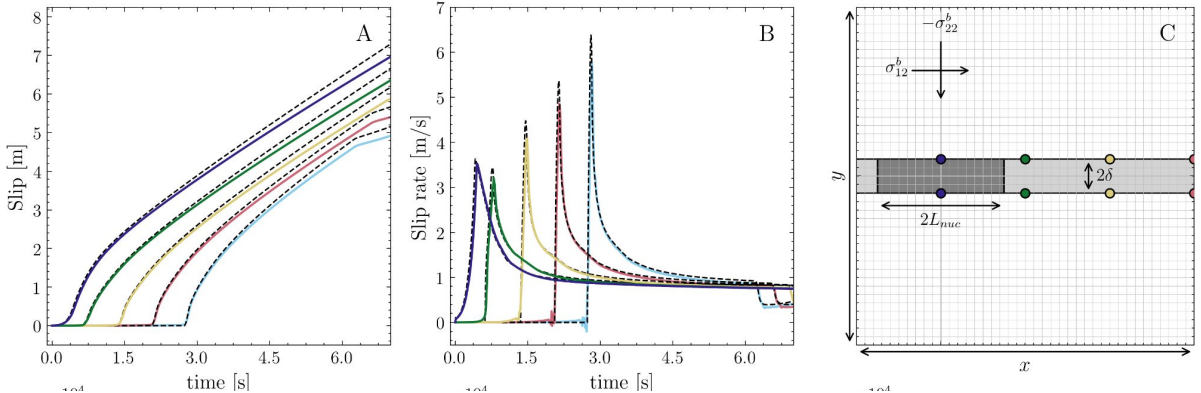
Embedded diffuse fault zone schematic

Classical rupture models

Kinematic Kostrov-like crack (Kostrov, B. V. 1964)



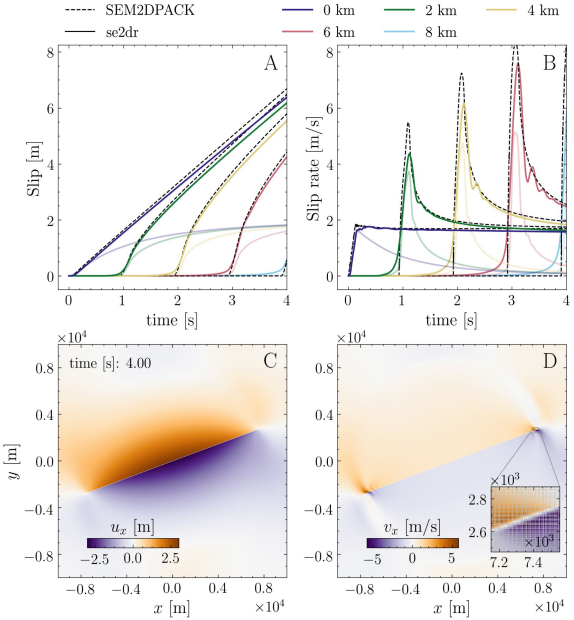
Spontaneous dynamic rupture: TPV3 Benchmark (Harris, R. A., et al 2018)



Comparison of the se2dr vs. the SEM split-node reference solution of SEM2DPACK (Ampuero, J.P., 2012, https://github.com/jpampuero/sem2dpack)

Fault geometry independent of the mesh geometry

Kinematic Kostrov-like crack

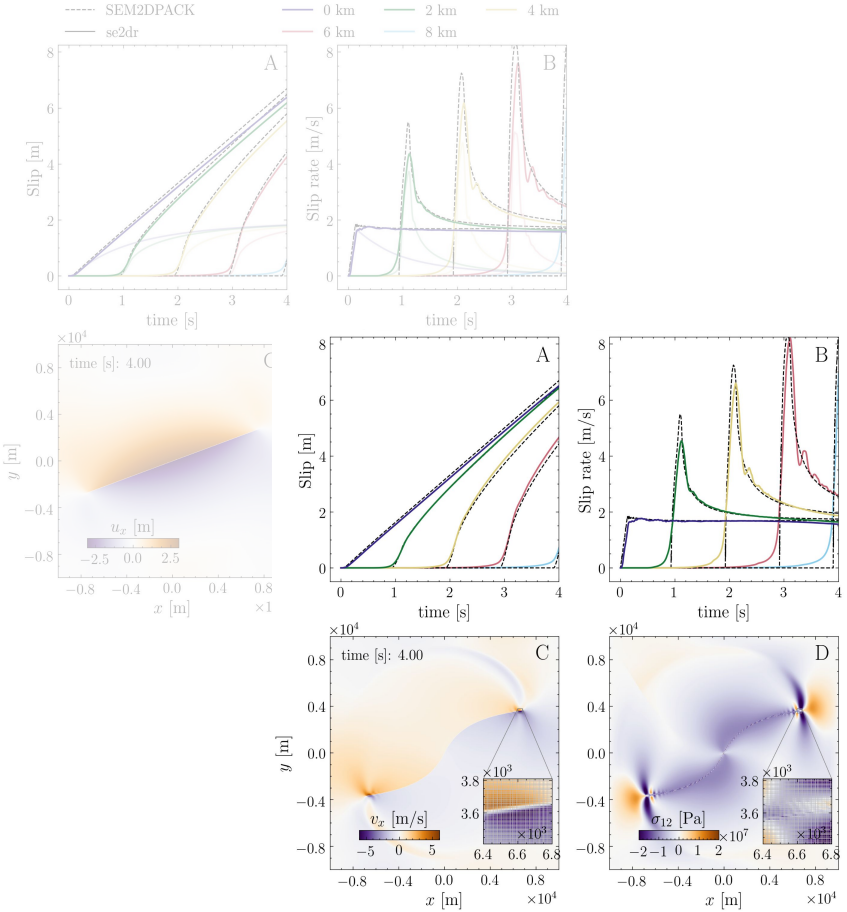


Tilted fault kinematics

- Significant reduction in the slip rate profiles when applying only tilting to the conditions in the previous mesh-aligned kinematic test.
- When increasing fault zone resolution, we obtain results closer to the reference solution.

Fault geometry independent of the mesh geometry

Kinematic Kostrov-like crack

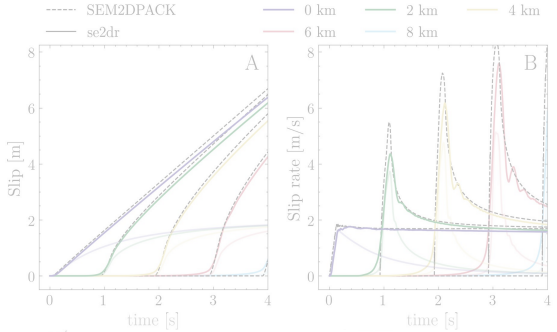


Sigmoid kinematics

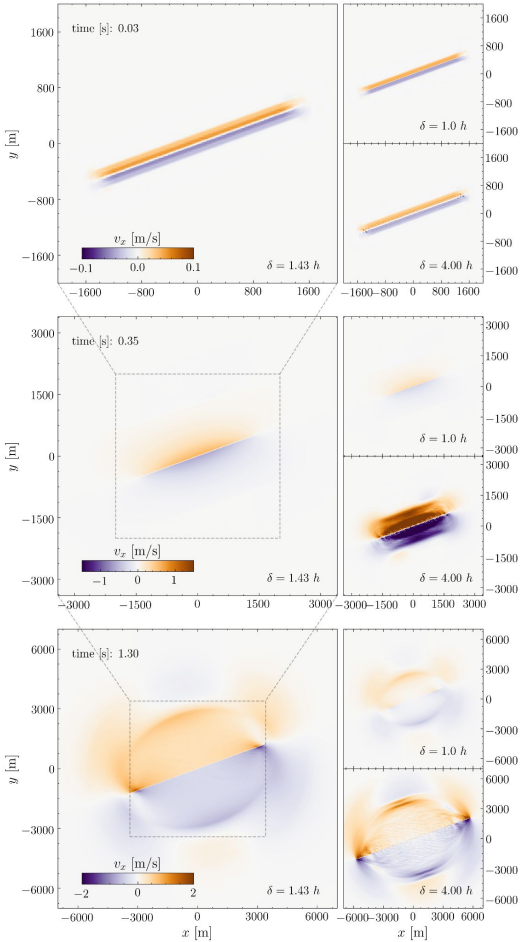
- We prescribe the rupture velocity along the geometrically complex sigmoid fault and the stress conditions follow a fault local reference frame
- Fault local slip and slip rate profiles match the TSN reference model

Fault geometry independent of the mesh geometry

Kostrov crack

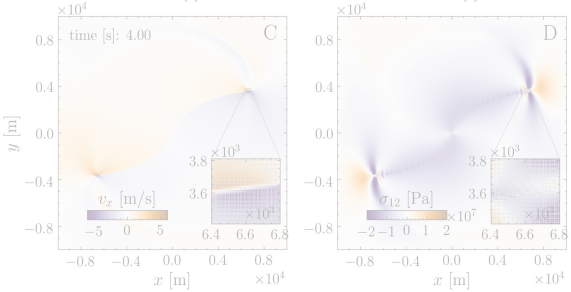


TPV3 Benchmark



Tilting the spontaneous dynamic rupture model

- We tilt the dynamic test configuration
- Our choice of fault and nucleation zone width affect the rupture initiation process.



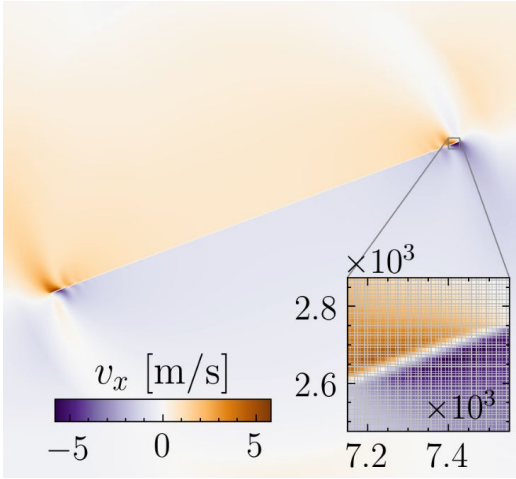
Summary

Our diffuse fault zone description represents fault volumetric complexities as a distribution instead of the traditional planar interface.

The mesh-aligned kinematic and dynamic benchmark solutions of our modified stress glut implementation match the discrete fault split-node spectral element reference solution.

Solutions with a fault geometry independent of the mesh geometry require higher fault zone resolution.

Our modification does not stray away from the original logical simplicity in the method formulation and thus keeps its flexibility regarding implementation within wave propagation codes.



Diffuse interface method for earthquake rupture dynamics based on a phase-field approach

Thank you for your attention!

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