Modeling Dynamic Ruptures with High Resolution Fault Zone Physics

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Introduction

- Fault zone has multiscale spatio-temporal complexity.
  
  **Spatial scales**: microns to kilometers
  
  **Temporal scales**: fractions of a second to years

- The multiscale feature is a challenge for numerical method.
Introduction

Many important examples incorporated fault zone complexities have shown that fault zone has geometric or material nonlinearities, but they tend to be relatively local.

Damage and localization in fault zones (https://www.emaze.com)  Plasticity distribution with rough fault [Dunham et al. 2011]
Hybrid Methodology

We apply a staggered coupling approach, in which the FEM and SBI share nodes at the (virtual) boundary:

- Solve full time step within the FEM domain.
- Set interface tractions in the SBI equal to the nodal forces from FEM.
- Solve full time step within SBI.
- Set displacements of the shared nodes in FEM equal to displacement in SBI.
- Return to Step 1 to advance to the next time step.

[Ma et al., IJNAMG, 2018]
Effect of small scale branches on rupture dynamics

Patterns of off-fault secondary failures induced by the dynamic rupture on a main fault plane have been extensively investigated [Works by J.R.Rice, Bhat, Dmwoiska, Dunham, Kame, and others].

However, the majority of prior work has focused primarily on conditions under which the rupture may jump or terminate.

Off-fault damage has been routinely modeled either using isotropic plasticity or scalar continuum damage theories.

We hypothesize that small scale fractures may influence rupture characteristics as well as near source radiation fields in ways not captured by the continuum inelasticity approaches above.

Johnson Valley 1992 rupture, at start of the Landers 1992 earthquake, bending along the Kickapoo (or Landers) fault zone [Poliakov et al. 2003].
Effect of small scale branches on rupture dynamics

Model Setup

- A planar main fault is in a linear elastic medium under plane strain condition.
- The secondary fault branches are explicitly modeled.
- The shear and normal stress along the faults are consistently resolve from the background stress.
- All fault are governed by the slip weakening friction model.

\[ R = \frac{\mu D_c}{r_s - r_d} \]

Uenish and Rice, 2003

[Ma and Elbanna, 2018, in preparation]
Effect of small scale branches on rupture dynamics

Model Setup (Cont’d)

\[ R = \frac{\mu D_c}{\tau_s - \tau_d} \]

- Length of the secondary fault is \( R \), the spacing is \( 0.5R \). The main fault length is \( 100R \).
- Width of the virtual strip \( W_H = 4R \)
- \( R = 500m \) from the parameter choice

[Ma and Elbanna, 2018, in preparation]
Heterogeneity distribution after rupture events

[Ma and Elbanna, 2018, in preparation]
Slip and Slip rate variation

- The fish bone case accumulates less slip than the homogeneous case.
- The fish bone structure slows down the main fault rupture.

[Ma and Elbanna, 2018, in preparation]
The fish bone structure significantly reduce the peak slip rate. With fish bone structure, the peak slip rates shows increased high frequency oscillations.

[Ma and Elbanna, 2018, in preparation]
Stress Heterogeneity on the Main fault

- Significant stress heterogeneity caused by the fish bone structure.
- The normal stress variation caused by the fish bone structure interaction has potential in promoting fault opening.
- These stress variation can not be captured if an isotropic plasticity or scalar continuum damage models are used.

[Ma and Elbanna, 2018, in preparation]
High frequency generation

- Concentric fringes due to high frequency scattering are observed.
- These high frequency scatterings are emerging from the interference between seismic radiation from the main and secondary faults.

[Ma and Elbanna, 2018, in preparation]
High frequency generation (Cont’d)

- Large amount of high frequency wave generated due to the existence of fish bone structure.

[Ma and Elbanna, 2018, in preparation]
The Drucker-Prager plasticity model is used to consider the effect of inelastic processes at scales smaller than the scale of the secondary faults.

\[ \sqrt{J_2} = A + BI_1 \]

[Ma and Elbanna, 2018, in preparation]
Conclusion and Outlook

- The Hybrid Spectral Boundary Integral – Finite Element method may provide a pathway for efficiently modeling earthquake ruptures in complex fault zones.

- Explicit representation of short faults using the hybrid scheme suggests new dynamical phenomena that are not captured by continuum damage or plasticity theories such as extreme post-event stress heterogeneity and high frequency generation.

- Future work would be focus on a thorough parametric study on the secondary branches distribution effect on the rupture dynamic such as:
  - Length of the secondary fault
  - Angle of the secondary faults between the main fault
  - The spacing between the secondary fault.
REFERENCES


