The Simulations of Sequences of Earthquake and Aseismic Slip (SEAS) project

Brittany Erickson, Valère Lambert, Junle Jiang

Talk given in the Dynamic Rupture Simulation Workshop
January 12, 2023
Talk outline:

● Brief history and update on SEAS activities.
● Ongoing SEAS science targets and context within the larger scientific community.
● Latest benchmark results.
● SEAS activities in 2023 and beyond.
History of SEAS:

- Held 1st workshop with dynamic rupture group in April, 2018 (thanks Ruth!)
- 1st SEAS-specific meeting was held in November, 2018; we acquired SCEC funding that same year.
- Have held 6 SEAS-related (SCEC-funded) workshops, the most recent in November 2022.
History of SEAS:

- Launched SEAS platform in 2018 (Michael Barall)
  - https://strike.scec.org/cvws/seas/index.html

- Have completed 8 benchmark problems; 3 papers published
  - Erickson et al., SRL (2020): 24 co-authors
  - Jiang et al., JGR (2022): 19 co-authors
  - Erickson et al., BSSA (2023): 33 co-authors!
History of SEAS:

- First two benchmarks, BP1-QD and BP2-QD involving 11 modeling groups...
History of SEAS:

- … and focused on a fundamental problem in crustal faulting based on Rice (1993), done in 2D with quasi-dynamic rupture.

- Our follow up benchmarks focused on 3D problems, full dynamics and dipping fault geometries.
  - Most recent benchmarks including different treatments of fault friction and effects of changes in fault pore fluid pressure.
History of SEAS:

- Our most recent publication (Erickson et al., 2023) further developed SEAS-specific quantitative metrics to assess model outcome agreements.

- *Short term metrics inspired by Barall and Harris (2014) and Day et al. (2005)*
SEAS Science Targets:

- Advancing robust predictive models of earthquake source processes.
- Determining what physical processes explain observables.
- Complimenting and informing dynamic rupture simulations and earthquake simulators.
Advancing SEAS models

Different rupture styles on low-stress faults with shear heating and thermal pressurization of pore fluids (Lambert et al., 2021)

Ongoing efforts:

- Shear heating and enhanced dynamic weakening (e.g. Lambert et al. 2021)
- Fault roughness and non-planar geometries (e.g. Romanet and Ozawa, 2022)
- Pore fluid effects (e.g. Zhu et al. 2021)
- Heterogenous and inelastic bulk (e.g. Thakur et al. 2020, Harvey et al. 2023)
Context for SEAS modeling
Persistent Numerical Challenges in SEAS modeling

- Variable time-stepping
- Choices in computational domain size and boundary conditions
- Problem nonlinearity and round-off errors
- How to determine legitimate solution differences?
- Resolution of important spatial/temporal scales
- Numerical efficiency and computational performance
Current Science Targets:

● Verifying SEAS models with increased complexity (e.g., full dynamics, dipping geometries, free surface, pore fluid effects).
● Developing robust, quantitative metrics to assess differences in SEAS model outcomes.
● Maintain relevance to SCEC research priorities.
Scientific Community Context for SEAS

AN NSF+USGS CENTER

Computational Infrastructure for Geodynamics (CIG)

CASCADIA REGION
EARTHQUAKE SCIENCE CENTER

Modeling Collaboratory for Subduction
Research Coordination Network

Reports and other docs
Past Meetings
Latest benchmark comparisons (Nov. 2022)

Focus on aseismic processes and nucleation of unstable slip including different treatments of fault friction, inertial effects and changes in pore fluid pressure.

**BP6-QD-A/S/C**  Many thanks to Eric Dunham!

- 2D problem of fault with velocity-strengthening or constant friction with fluid injection and along-fault pore fluid diffusion.

**BP7-QD/FD-A/S**

- 3D problem with a circular velocity-weakening asperity with repeating seismic and aseismic events.
Summary of results for BP7 and BP6

- 6 participating codes for BP7-QD-A and 2 for BP7-FD-A
  - BEM codes show good overall agreement in BP7-QD-A, including SBEM codes with sufficiently large domain sizes
  - Results from SBEM codes agree with each other for similar domain sizes in BP7-FD-A
  - Simulations of BP7-A with full treatment of inertial effects result in different sequences of repeating seismic and aseismic event, compared to quasi-dynamic problems
    - Different stress evolution results in larger slip in seismic events and different aseismic transients
    - Correspondingly longer recurrence time between seismic events

- Good agreement among results from 6 groups for BP6
  - Some small differences in rupture timing (~4 days - 2 weeks) and slip (< 0.01 m) potentially due to differences in variable time-stepping?
Group planning for 2023

- Maximize participation!
- Submitted 2023 SCEC proposal
- Continue analyzing benchmark results for BP6 and BP7
  - Potential workshop in Winter/Spring 2023
- Design exercises focused on examining sensitivity of numerically-determined source (including slow-slip events) properties and observables (e.g. rupture speed, duration, ground motions) to numerical procedures (e.g. discretization, velocity thresholds, QS-dynamic switching schemes)
- Continued development of SEAS-specific quantitative metrics
- Verification efforts for subduction zones and relation to other community efforts?
- Inspection and development of online platform with SCEC developers

Contact: bae@uoregon.edu

Thanks!