SEAS Benchmark BP3 Results

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Outline

• Design of 2D Dynamic Benchmark BP3
• Results of slip profiles: general features
• Results of time series: long- and short-term behavior
• Conclusions
2D anti-plane shear motion. The fault is a vertical strike-slip fault in a homogeneous half-space. Friction is regularized rate-and-state friction with the aging law.
Benchmark Problem BP3

Same set-up at BP1 except with full dynamics
Benchmark Problem BP3

**Similarity** - The problem set-up for this second benchmark is identical to that of the first benchmark problem (BP1), except with full dynamics.

**Difference** - Dynamics, total simulation time is halved (from 3,000 to 1,500 years) from BP1.

**Objectives** - Understand how to properly resolve dynamic problems and interpret model results. Gain insight into the differences between quasi-dynamic and full dynamic effects.
Modeling groups/codes participating in BP3

- BICyclE: **jiang** (Jiang), **lambert** (Lambert/Lapusta)

- Hybridized BEM-FEM: **abdelmeguid** (Abdelmeguid/Elbanna)

- SEM: **thakur** (Thakur/Huang)
Slip profiles: quasi-dynamic (BP1) and fully dynamic (BP3)

quasi-dynamic (BP1), $\text{j}i\text{a}ng$, $L_z = 80$ km, $dz = 25$ m

fully-dynamic (BP1), $\text{j}i\text{a}ng$, $L_z = 80$ km, $dz = 25$ m

Differences with full dynamics: longer recurrence times, more slip with each event (alternating?), prominent surface reflection
Co-seismic time series fully dynamic vs quasi-dynamic:

$z = 0 \text{ km}$

- Fully dynamic: higher peak values in surface shear stress and slip rate

$z = 7.5 \text{ km}$

- Fully dynamic: faster rupture speed
Domain-size comparisons:

\[ L_z = \infty \text{ unless specified} \]

9 modelers; \( \approx 76 \) model runs

\( \text{jiang } L_z = 80 \text{ km, } dz = 25 \text{ m} \)

\( \text{jiang } L_z = 160 \text{ km, } dz = 25 \text{ m} \)

\( \text{jiang } L_z = 320 \text{ km, } dz = 25 \text{ m} \)

\( \text{jiang } L_z = 160 \text{ km, } dz = 25 \text{ m} \)
Across-group comparisons:

**Liang** $L_z = 80$ km, $dz = 25$ m

**Thakur** $L_z = 80$ km, $L_x = 40$ km, $dz = 25$ m

**Liang** $L_z = 160$ km, $dz = 25$ m

**Thakur** $L_z = 160$ km, $L_x = 40$ km, $dz = 50$ m
Coseismic fault shear stress (4th event):

\[
\text{jiang } L_z = 80 \text{ km}, \ dz = 25 \text{ m}
\]

\[
\text{thakur } L_z = 80 \text{ km}, L_x = 40 \text{ km}, dz = 25 \text{ m}
\]

Plotted every 1 second, time fading from blue to red
Time-series Comparisons:

$z = 0 \text{ km}$. Blue is outlier - differences could stem from differences in spin-up, computational domain size choices.
Within-group time-series:

Effect of computational domain depth - reasonable choices of $L_z$ - 160, 320 km?
Across-group time-series:

On small domains, need smaller cell size (12.5 m) than on larger domains where \( dz = 25 \) m appear sufficient.
Coseismic time series:

4th event, $z = 0$ km, offset

4th event, $z = 7.5$ km
Summary/Discussion

- Codes based on BEM show qualitative agreement, with convergence (?) to periodic events at $L_z = 160, 320$ km with $dz = 25$ m. Smaller $dz$?

- Discrepancies with volume method (SEM) likely related to choices in computational domain size. Need to do more exploration of dependencies on both $L_z$ and $L_x$.

- Good matches between BEM models with a 25-m cell-size, poorer matches between models with a 50-m cell-size

- Full dynamics yields higher peak values in surface shear stress and slip rate, faster rupture speeds, longer recurrence times, more slip with each event compared with quasi-dynamic counterpart.
Additional issues/questions:

• Spin-up of models: generally easy for BP1/BP2

• The effect of numerical procedures, e.g. variable grid spacing, solvers?

• How should we compare results (verification metrics)?
  • do we only accept results that show independence of domain size?
  • the most important model characteristics? e.g. coseismic rupture, recurrence times
  • normed errors in time series/slip profiles?

• What constitutes a successful verification exercise? (how much discrepancy/matching do we expect/allow?)
  • define a tolerance on error between model results?
  • convergence as a function of resolution?
Conclusions and Lessons

- The qualitatively similar model behavior and divergence of models with increased cell sizes agree well with our expectations.

- The convergence of models with the decrease in cell sizes seems clear for some model groups (SBEM and some BEM). Need followups on other models in smaller groups.

- Small event patterns are highly sensitive to cell sizes.

- Large event occurrence times are sensitive to cell sizes; time shift and long-term error accumulation are present in models even with the smallest cell sizes.

- Coseismic rupture behavior are in overall excellent agreements; surface reflected phase (prestress & rupture speed) is probably influenced by the model spin-up process (for early events) and long-term error accumulation (for later events).