SCEC Dynamic Rupture TAG

The 2020 Ingredients Workshop:

Rock Properties

Ruth A. Harris (U.S. Geological Survey)
Michael Barall (Invisible Software)
Our group uses dynamic rupture simulation codes to examine earthquakes and how they behave.
<table>
<thead>
<tr>
<th>Code Name</th>
<th>Code Type</th>
<th>References</th>
<th>Notes</th>
<th>Code Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWP-ODC</td>
<td>Finite difference</td>
<td>Roten et al., 2016; Dalguer &amp; Day, 2007</td>
<td></td>
<td>contact author Roten</td>
</tr>
<tr>
<td>beard</td>
<td>DG finite element</td>
<td>Kozdon et al., 2015</td>
<td></td>
<td>contact author Kozdon</td>
</tr>
<tr>
<td>CG-FDM</td>
<td>Finite difference</td>
<td>Zhang et al., 2014</td>
<td></td>
<td>contact author Zhang</td>
</tr>
<tr>
<td>EqSim</td>
<td>Finite element</td>
<td>Aagaard et al., 2001</td>
<td>superseded by PyLith</td>
<td></td>
</tr>
<tr>
<td>DFM</td>
<td>Finite difference</td>
<td>Day &amp; Ely, 2002</td>
<td></td>
<td>contact author Dalguer</td>
</tr>
<tr>
<td>DGCrack</td>
<td>DG finite element</td>
<td>Tago et al., 2012</td>
<td></td>
<td>contact authors Tago or Cruz-Alienza</td>
</tr>
<tr>
<td>EQdyna</td>
<td>Finite element</td>
<td>Duan &amp; Oglesby, 2006</td>
<td></td>
<td>contact author Duan</td>
</tr>
<tr>
<td>FaultMod</td>
<td>Finite element</td>
<td>Barall, 2009</td>
<td></td>
<td>contact author Barall</td>
</tr>
<tr>
<td>Fdfault</td>
<td>Finite difference</td>
<td>Daub, 2016</td>
<td></td>
<td><a href="https://github.com/egdaub/fdfault">https://github.com/egdaub/fdfault</a></td>
</tr>
<tr>
<td>Kase code</td>
<td>Finite difference</td>
<td>Kase &amp; Kuge, 2001</td>
<td></td>
<td>contact author Kase</td>
</tr>
<tr>
<td>MAFE</td>
<td>Finite element</td>
<td>Ma et al., 2008; Ma &amp; Andrews, 2010</td>
<td></td>
<td>contact author Ma</td>
</tr>
<tr>
<td>PyLith</td>
<td>Finite element</td>
<td>Aagaard et al., 2013</td>
<td></td>
<td><a href="https://geodynamics.org/cig/software/pylith">https://geodynamics.org/cig/software/pylith</a></td>
</tr>
<tr>
<td>SeisSol</td>
<td>DG finite element</td>
<td>Pelties et al., 2012; Pelties et al., 2014</td>
<td></td>
<td><a href="https://github.com/SeisSol/SeisSol/wiki">https://github.com/SeisSol/SeisSol/wiki</a></td>
</tr>
<tr>
<td>SESAME</td>
<td>Spectral element</td>
<td>Galvez et al., 2014</td>
<td>same as SPECFEM3D</td>
<td></td>
</tr>
<tr>
<td>SORD</td>
<td>Finite difference</td>
<td>Ely et al., 2009; Shi &amp; Day, 2013</td>
<td></td>
<td>contact author Shi</td>
</tr>
<tr>
<td>SPECFEM3D</td>
<td>Spectral element</td>
<td>Galvez et al., 2014</td>
<td></td>
<td><a href="https://geodynamics.org/cig/software/specfem3d">https://geodynamics.org/cig/software/specfem3d</a></td>
</tr>
<tr>
<td>SPECFEM3D-old</td>
<td>Spectral element</td>
<td>Kaneko et al., 2008</td>
<td>superseded by SPECFEM3D</td>
<td></td>
</tr>
<tr>
<td>WaveQLab3D</td>
<td>Finite difference</td>
<td>Duru &amp; Dunham, 2016</td>
<td></td>
<td><a href="https://bitbucket.org/ericmdunham/waveqlab3d">https://bitbucket.org/ericmdunham/waveqlab3d</a></td>
</tr>
</tbody>
</table>
How Dynamic Earthquake Rupture Simulations Work

- Initial Stress
- Geologic Structure (Fault Geometry & Rock Properties)
- Fault Friction
- Computer Code that Simulates Earthquakes as Dynamic Ruptures
- Ground Shaking (Seismograms), Fault Slip, Stress Changes, etc.

Figure from Harris et al., SRL, 2018 (and earlier related Harris publications)

Harris Oct. 2020
How it works – dynamic earthquake rupture and a fault branch

Lightly rearranged figure 14 from Harris et al., SRL, 2018
Simulated Seismic Waves at Earth’s surface produced by a 2004 M6 Parkfield earthquake rupture simulation

figure from Harris et al., SRL, 2018
So far, we have successfully tested the codes for a variety of "ingredients"

** fault geometries **

** friction formulations **

** rock properties**

** initial stress conditions **

(See our group paper Harris et al., SRL, 2018)
Code Comparison Benchmarks – Incrementally added complexity

**TPV3**
Homogeneous fullspace

**TPV4**
Dipping dip-slip fault, subshear, **bimaterial**

**TPV5, 205**
Light stress heterogeneity

**TPV6-7**

**TPV8**
Depth-dependent initial stresses

**TPV9**
Vertical dip-slip fault, subshear

**TPV10, 210, 11**
Dipping dip-slip fault, subshear, supershear

**TPV12**
Dipping dip-slip fault super-supershear, elastic

**TPV13**
Dipping dip-slip fault super-supershear, **plastic**
Code Comparison Benchmarks – Incrementally added complexity

TPV101
Rate-state friction using an ageing law

TPV102
Rate-state friction using a slip law with strong rate-weakening

TPV103

TPV104

TPV105-2D
Thermal pressurization, rate-state friction, slip-law, strong rate-weakening
Code Comparison Benchmarks – Incrementally added complexity

**Fault Branches:** elastic, **plastic**

**Fault Stepovers**

**Elastic, Viscoelastic**

**Slightly rough fault**

**Rough fault: elastic, viscoelastic**

**Discontinuous, Continuous 1D horizontal velocity structure**

**1D vertical velocity structure**

**3D CVM-Hish velocity structure**

Harris Oct. 2020
Code Comparison Benchmarks – Incrementally added complexity

vertical planar planar fault, **3D-ish velocity structure**, Elastic, slip-weakening friction

Figures lightly modified from Harris et al., 2018
Initial shear stress & station map from Ma et al., 2008
Code Comparison Benchmarks – Incrementally adding complexity

TPV105-3D

Thank you to Thomas, Jagdish, Alice, Michael for designing the new TPV105-3D benchmark, and the Gold Star Modelers who used their codes to run TPV105-3D:

- Jagdish, Thomas, Alice
- Dunyu
- Zhenguo
- Yongfei
- Michael

3D Thermal pressurization
We have demonstrated that we can simulate dynamic earthquake rupture in a wide range of settings.

But, are we using the appropriate assumptions (ingredients) for our simulations?

That is the purpose of this series of workshops:
Investigate each of our dynamic rupture ingredients.

In November 2018, we examined Ingredient #1, Fault Geometry
In January 2020, we examined Ingredient #2, Fault Friction
Today, in October 2020 we examine Ingredient #3, Rock Properties
Next year we hope to examine Ingredient #4, Stress Conditions
Code Comparison Benchmarks – Testing Rock Structure Implementations

Some of our benchmark exercises implemented complex structure:

TPV6,7 (bimaterials)
TPV31,32 (1D vertical layering, discontinuous, continuous)
TPV33 (low velocity fault zone)
TPV34 (3D Imperial Valley)
TPV35 (Parkfield, 2 1D structures)

Some of our benchmark exercises implemented non-elastic yielding:

TPV13 (extreme ground motion, plasticity)
TPV19, 21 (branching faults, plasticity)
TPV27 (planar fault, viscoplasticity)
TPV30 (rough faults, viscoplasticity)

Detailed benchmark descriptions are available at:
strike.scec.org/cvws
For More Information about our group, including code verification exercises:

Please see our website: strike.scec.org/cvws

and our group’s papers:


Harris Oct. 2020
Today’s Workshop – Effects of the Rock Properties Ingredient

Initial Stresses

Geologic Structure (Fault Geometry & Rock Properties)

Fault Friction

Computer Code that Simulates Earthquakes as Dynamic Ruptures

Ground Shaking (Seismograms), Fault Slip, Stress Changes, etc.

figure from Harris et al., SRL, 2018 (and earlier related Harris publications)
Some questions to consider:

What is (are) the most appropriate assumptions about rock properties for dynamic rupture modeling applications?

Do we need to include rock property heterogeneity at all scales?

What happens if we assume elastic behavior?

What happens if we assume plastic behavior?

How do the effects of the rock property structure assumptions compare with the other ingredients (fault geometry, fault friction, stress)?
## Dynamic Rupture TAG – The 2020 Ingredients Workshop - Rock Properties

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>Introduction to the workshop</td>
<td>Ruth Harris</td>
</tr>
<tr>
<td>9:15</td>
<td>Self-introductions by all participants</td>
<td>All</td>
</tr>
<tr>
<td>9:35</td>
<td>Thermal pressurization 3D benchmark and results</td>
<td>Alice Gabriel</td>
</tr>
<tr>
<td>10:00</td>
<td>SCEC Community Velocity Model (CVM)</td>
<td>Andreas Plesch</td>
</tr>
<tr>
<td>10:30</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>3D velocity structures, effects on ground motion and ruptures</td>
<td>Kim Olsen</td>
</tr>
<tr>
<td>11:30</td>
<td>Effects of off-fault inelasticity on near-fault directivity pulses</td>
<td>Yongfei Wang</td>
</tr>
<tr>
<td>11:50</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>12:05</td>
<td>How do near-fault low-velocity structures affect dynamic rupture and ground motion?</td>
<td>Yihe Huang</td>
</tr>
<tr>
<td>12:30</td>
<td>Discussion and wrap-up</td>
<td>All</td>
</tr>
<tr>
<td>13:15</td>
<td>Adjourn</td>
<td></td>
</tr>
</tbody>
</table>