Presentation for the March 10, 2008 SCEC Workshop
Pomona, CA

SCEC
3D Rupture Dynamics
Code Validation Workshop
Project Coordinator
Ruth Harris, U.S. Geological Survey.

Software Engineer
Michael Barall, U.S. Geological Survey and Invisible Software.

Modelers
Jean Paul Ampuero, ETH.
Ralph Archuleta, UC Santa Barbara.
Victor Cruz Atienza, Universidad Nacional Autonoma de Mexico.
Luis Dalguer, San Diego State University.
Steve Day, San Diego State University.
Ben Duan, Texas A&M.
Eric Dunham, Harvard University.
Geoff Ely, UC San Diego.
Yoshi Kaneko, Caltech.
Yuko Kase, Geological Survey of Japan.
Nadia Lapusta, Caltech.
Yi Liu, Caltech.
Shuo Ma, Stanford University.
David Oglesby, UC Riverside.
Kim Olsen, San Diego State University.
Arben Pitarka, URS Corporation.
Daniel Roten, San Diego State University.
Seok-Goo Song, URS Corporation.
Elizabeth Templeton, Harvard University.

http://scecdata.usc.edu/cvws/participants.html
# SCEC 3D Rupture Dynamics Code Validation Workshop

**Monday, March 10, 2008**

Kellogg West Conference Center, Pomona, CA

Valley Vista Room

### Convener: Ruth Harris

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<thead>
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<th>Session</th>
<th>Speaker</th>
</tr>
</thead>
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<tr>
<td>10:30-10:45</td>
<td>Introduction</td>
<td>Ruth Harris</td>
</tr>
<tr>
<td>10:45-11:15</td>
<td>New Code – FaultMod</td>
<td>Michael Barall</td>
</tr>
<tr>
<td>11:15-12:15</td>
<td>Rate-State Benchmarks: Description, Results &amp; Discussion</td>
<td>Eric Dunham</td>
</tr>
<tr>
<td>12:15-1:15</td>
<td>Lunch</td>
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<tr>
<td>1:15-2:00</td>
<td>Slip-Weakening Benchmarks: Description, Results &amp; Discussion</td>
<td>Ruth Harris</td>
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<tr>
<td>2:00-2:30</td>
<td>Benchmark Boundary Assumptions: Implications for Results</td>
<td>Brad Aagaard</td>
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<tr>
<td>2:30-3:00</td>
<td>Numerical Convergence: Implications for Results</td>
<td>Yoshi Kaneko</td>
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<td>3:00-3:30</td>
<td>Break</td>
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<td>3:30-5:00</td>
<td>General Discussion</td>
<td>All</td>
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<td>5:00</td>
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Code Workshop March 2008
Overall Goal of the SCEC Code Validation Group

Compare the 3D methods currently being used by SCEC scientists to simulate (spontaneous) rupture dynamics

Some Specific Objectives

Understand if our methods are producing the same results when using the same assumptions about friction, crustal structure, fault geometry, etc.

Produce results for the “Joe Andrews” Yucca Mountain normal-faulting benchmark, to compare with Joe’s 2D simulations.
(Harris & Archuleta, EOS, August 24, 2004)
(Harris & Archuleta, EOS, August 24, 2004)
Initial Fault Stresses

Geologic Structure (Fault Geometry & Material Properties)

Fracture Criterion

Computer Program that Simulates Earthquakes as Spontaneous Ruptures

Ground Shaking (Seismograms), Fault Slip, etc.

(Harris & Archuleta, EOS, August 24, 2004)
Code Comparison Strategy

Start simply

Spontaneous rupture on a vertical strike-slip fault set in a homogeneous (materials) Fullspace

homogeneous initial stresses

slip-weakening friction

Some Results

Rupture front contours at 0.5 sec intervals 100m cases

black=lab; red=duff

TPV3

Code Workshop March 2008
Code Comparison Strategy

Incrementally add complexity

Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) **Halfspace**, Homogeneous initial stresses, Slip-weakening friction

Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, **Heterogeneous Initial stresses**, Slip-weakening friction

Rupture on a Vertical Strike-Slip fault set in a **Heterogeneous (Materials) halfspace**, homogeneous initial stresses, Slip-weakening friction
Code Comparison Strategy

Incrementally add complexity

Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, **Depth-dependent Initial Stresses**, Slip-weakening friction

Rupture on a Vertical **Dip-Slip** fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction

Rupture on a **Dipping** Dip-slip fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction

TPV8  TPV9
Code Comparison Strategy

Incrementally add complexity

Rupture on a vertical strike-slip fault set in a Homogeneous (materials) **Fullspace,** Homogeneous initial stresses, **Rate-state friction**

Rupture on a vertical strike-slip fault set in a Homogeneous (materials) **Halfspace** Homogeneous initial stresses, **Rate-state friction**

TPV101

TPV102
The SCEC Code Validation Website*
http://sceCDATA.usc.edu/cvws/

*Funding from the U.S. Dept. of Energy
Extreme Ground Motion Project
Spontaneous Rupture Code Descriptions

Aagaard - Finite Element Code (EqSim)

Ampuero - Spectral Element Code (SPECTFM3D)

Andrews/Song - Dynelf

Barall - Finite Element Code (FaultMod)

Cruz-Alienza - Finite Volume Code

Day - Finite Difference Code (DFM)

Duan - Finite Element Code (EQdyna)

Dunham - MultiDimensional Spectral Boundary Integral Code (MDSBI)

Ely - Support Operator Code (SORD)

Kase - Finite Difference Code

Lapusta - Boundary Integral Code

Ma - Finite Element Code (MAFE)

Oglesby - Finite Element Code (DYNA3D)

Olsen - Finite Difference Code (AWM)

Pitarka - Finite Difference Code (FDMSPLIT)

Templeton - Finite Element Code (ABAQUS)
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>TPV3</td>
<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous halfspace.</td>
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<tr>
<td>TPV4</td>
<td>Nucleation followed by spontaneous rupture on a slightly stress-heterogeneous vertical strike-slip fault in a homogeneous halfspace.</td>
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<tr>
<td>TPV5</td>
<td>Nucleation followed by spontaneous rupture on a slightly stress-heterogeneous vertical strike-slip fault in a homogeneous halfspace. <a href="#">Detailed description and instructions to modelers for TPV5.</a></td>
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<tr>
<td>TPV6</td>
<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a bimaterial halfspace, with high shear modulus contrast across the fault (a &quot;well-posed&quot; problem). <a href="#">Detailed description and instructions to modelers for TPV6.</a></td>
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<tr>
<td>TPV7</td>
<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a bimaterial halfspace, with low shear modulus contrast across the fault. <a href="#">Detailed description and instructions to modelers for TPV7.</a></td>
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<td>TPV8</td>
<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous halfspace. Initial stress conditions are linearly dependent on depth. Subshear rupture conditions. <a href="#">Detailed description and instructions to modelers for TPV8.</a></td>
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<td>TPV9</td>
<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous halfspace. Initial stress conditions are linearly dependent on depth. Subshear rupture conditions. <a href="#">Detailed description and instructions to modelers for TPV9.</a></td>
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<tr>
<td>TPV10</td>
<td>Nucleation followed by spontaneous rupture on a 45 degree dipping dip-slip fault (normal fault) in a homogeneous halfspace. Initial stress conditions are linearly dependent on depth. Subshear rupture conditions.</td>
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<td>TPV11</td>
<td>Nucleation followed by spontaneous rupture on a 60 degree dipping dip-slip fault (normal fault) in a homogeneous halfspace. Initial stress conditions are linearly dependent on depth. Subshear rupture conditions.</td>
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<td>Nucleation followed by spontaneous rupture on a 60 degree dipping dip-slip fault (normal fault) in a homogeneous halfspace. Initial stress conditions are linearly dependent on depth. Supershear rupture conditions.</td>
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<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous halfspace. Rate-state friction, using an ageing law. <a href="#">Detailed description and instructions to modelers for TPV101.</a></td>
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<tr>
<td>TPV102</td>
<td>Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous halfspace. Rate-state friction, using an ageing law. <a href="#">Detailed description and instructions to modelers for TPV102.</a></td>
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Code Validation Web Server

Go --> View Data

Go --> Upload Files

Go --> Administrative Functions

Credit Page
Select Problem

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Logout
Today’s Benchmarks

The Problem,
Versions 101 and 102

The Problem,
Versions 8 and 9
The Problem, Versions 101 and 102 (February-March 2008)

Rate-State Friction Dynamic Rupture

whole-space

half-space

Code Workshop March 2008
The Problem, Versions 8 and 9 (February-March 2008)
Slip-weakening Dynamic Rupture with Depth-Dependent Stresses
Pathway to the YM Simulations

Strike-Slip

Dip-Slip

Code Workshop March 2008
SCEC 3D Rupture Dynamics Code Validation Workshop

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                  Yoshi Kaneko

3:00-3:30       Break

3:30-5:00       General Discussion  
                  All

5:00            Adjourn
The Problem, Versions 8 and 9

Pathway to YM
Code Comparison Strategy

Incrementally add complexity

Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, Depth-dependent Initial Stresses, Slip-weakening friction

Rupture on a Vertical Dip-Slip fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction

Rupture on a Dipping Dip-slip fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction
The Problem, Version 8

Earth's surface

$V_p, V_s, \rho$

15 km

3 km

30 km

Strong

Weak

12 km
Source Physics for The Problem, Version 8

**slip-weakening friction** everywhere
- cohesion = 1 MPa
- static coefficient of friction = 0.76 or 10000
- dynamic coefficient of friction = 0.448
- s.w. critical distance, dzero = 0.50 m

**Initial normal stress** = 7378 Pa/m x depth (m)
- outside nucleation patch: initial shear stress = 0.55 x initial normal stress
- nucleation patch: initial shear stress = cohesion + (1.005 x mu-s x initial normal stress)
Source Physics for The Problem, Version 9

slip-weakening friction everywhere
cohesion = 1 MPa
static coefficient of friction = 0.76 or 10000
dynamic coefficient of friction = 0.448
s.w. critical distance, dzero = 0.50 m

Initial normal stress = 7378 Pa/m x depth (m)

outside nucleation patch:
initial shear stress = 0.55 x initial normal stress

nucleation patch:
initial shear stress = cohesion + (1.005 x mu-s x initial normal stress)
Rupture Dynamics Code Validation

On-Fault Station Locations for The Problem, Versions 8 and 9

3 Stations on the Earth's surface are at:
0, +4.5 km, +12.0 km along-strike distance, and 0 km down-dip distance

5 Deeper Stations are at:
0 km along-strike distance, and +4.5 km, +7.5 km, +12.0 km down-dip distance
4.5 km along-strike distance, and 7.5 km down-dip distance
12 km along-strike distance, and 7.5 km down-dip distance
Rupture Dynamics Code Validation

Off-Fault Station Locations for The Problem, Versions 8 and 9

14 Off-fault Station Locations

8 stations at the earth's surface:
0 km along strike, 0 km depth, and +/- 1.0, +/- 2.0, +/- 3.0 km perpendicular-distance from the fault trace
+12 km along strike, 0 km depth, and +/- 3.0 perpendicular-distance from the fault trace

6 deeper stations:
0 km along strike, 0.3 km depth, and +/- 0.5 and +/- 1.0 horizontal perpendicular-distance from the fault plane
+12 km along strike, +12 km down-dip, and +/- 3.0 km horizontal perpendicular-distance from the fault plane
TPV8

Modelers & Codes

Results submitted by 03/09/08

Select User(s)

Problem: tpv8 (The Problem, Version 8)

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<td>Brad Aagaard - Finite Element - EqSim</td>
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<td>Victor Cruz Atienza - Finite Difference - AWM</td>
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<td>Arben Pitarka - Finite Difference - FDMSPLIT</td>
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<td>song</td>
<td>Seok Goo Song - Dynelf</td>
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Code Workshop March 2008
### TPV9 Modelers & Codes

Results submitted by 03/09/08

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**Problem: tpv-9 (The Problem, Version 9)**

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Code Workshop March 2008
Comparisons

The Problem,
Versions 8 and 9
The SCEC Code Validation Website*

*Funding from the U.S. Dept. of Energy
Extreme Ground Motion Project

Code Workshop March 2008
The Problem, Version 8
TPV8
Rupture
Front
Contours
0.5 sec
Intervals from
12/13
modelers

aagaard (Brad Aagaard - Finite Element - EqSim)
atienza (Victor Cruz Atienza - Finite Difference - ANM)
dalgueir (Luis Dalgueir - Finite Difference - DFM)
duan (Benchun Duan - Finite Element - EQdyna)
kaneko (Yoshiiro Kaneko - Spectral Element - SPECFEM3D)
kase (Yuko Kase - Finite Difference)
lau (Yi Liu - Boundary Integral)
ma (Shuo Ma - Finite Element - MAFE)
oglesby (David Oglesby - Finite Element - DYN3D)
pitarka (Arben Pitarka - Finite Difference - FDMSPRIT)
song (Seok Goo Song - Dynef)
templeton (Elizabeth Templeton - Finite Element - ABAQUS)
TPV8
Rupture
Front
Contours
0.5 sec
Intervals
from
2/13
modelers
Synthetic Seismograms
### On-Fault Time Series

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### Off-Fault Time Series

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Rupture Dynamics Code Validation

On-Fault Station Locations for The Problem, Versions 8 and 9

3 Stations on the Earth's surface are at:
- 0, +4.5 km, +12.0 km along-strike distance, and 0 km down-dip distance

5 Deeper Stations are at:
- 0 km along-strike distance, and +4.5 km, +7.5 km, +12.0 km down-dip distance
- 4.5 km along-strike distance, and 7.5 km down-dip distance
- 12 km along-strike distance, and 7.5 km down-dip distance
Horizontal Slip rate (m/s)

surface station 12 km from hypocenter

2 hz lowpass filter applied
The Problem, Version 9
TPV9
Rupture Front
Contours 0.5 sec
Intervals from 10 modelers

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aagaard (Brad Aagaard - Finite Element - EqSim)
atienza (Victor Cruz Atienza - Finite Difference - AWM)
barall (Michael Barall - Finite Element - FaultMod)
dalguer (Luis Dalguer - Finite Difference - DFM)
duan (Benchun Duan - Finite Element - Eddynea)
kaneko (Yoshihiro Kaneko - Spectral Element - SPECFEM3D)
kase (Yuko Kase - Finite Difference)
ma (Shuo Ma - Finite Element - MAFE)
roten (Daniel Roten - Finite Difference - AWM)
song (Seok Goo Song - Dynelf)
Synthetic Seismograms
### On-Fault Time Series

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>faultst000dp000</td>
<td>strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst000dp045</td>
<td>strike 0.0 km, dip 4.5 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst000dp075</td>
<td>strike 0.0 km, dip 7.5 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst000dp120</td>
<td>strike 0.0 km, dip 12.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst045dp000</td>
<td>strike 4.5 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst045dp075</td>
<td>strike 4.5 km, dip 7.5 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst120dp000</td>
<td>strike 12.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>faultst120dp075</td>
<td>strike 12.0 km, dip 7.5 km</td>
<td>Select</td>
</tr>
</tbody>
</table>

### Off-Fault Time Series

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>body-005at000dp003</td>
<td>body -0.5 km, strike 0.0 km, dip 0.3 km</td>
<td>Select</td>
</tr>
<tr>
<td>body-010at000dp000</td>
<td>body -1.0 km, strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body-010at000dp003</td>
<td>body -1.0 km, strike 0.0 km, dip 0.3 km</td>
<td>Select</td>
</tr>
<tr>
<td>body-020at000dp000</td>
<td>body -2.0 km, strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body-030at000dp000</td>
<td>body -3.0 km, strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body-030st120dp000</td>
<td>body -3.0 km, strike 12.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body-030st120dp120</td>
<td>body -3.0 km, strike 12.0 km, dip 12.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body005st000dp003</td>
<td>body 0.5 km, strike 0.0 km, dip 0.3 km</td>
<td>Select</td>
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<tr>
<td>body010st000dp000</td>
<td>body 1.0 km, strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
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<td>body010st000dp003</td>
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</tr>
<tr>
<td>body020st000dp000</td>
<td>body 2.0 km, strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body030st000dp000</td>
<td>body 3.0 km, strike 0.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body030st120dp000</td>
<td>body 3.0 km, strike 12.0 km, dip 0.0 km</td>
<td>Select</td>
</tr>
<tr>
<td>body030st120dp120</td>
<td>body 3.0 km, strike 12.0 km, dip 12.0 km</td>
<td>Select</td>
</tr>
</tbody>
</table>
Rupture Dynamics Code Validation

On-Fault Station Locations for The Problem, Versions 8 and 9

3 Stations on the Earth's surface are at:
0, +4.5 km, +12.0 km along-strike distance, and 0 km down-dip distance

5 Deeper Stations are at:
0 km along-strike distance, and +4.5 km, +7.5 km, +12.0 km down-dip distance
4.5 km along-strike distance, and 7.5 km down-dip distance
12 km along-strike distance, and 7.5 km down-dip distance
Vertical Slip rate (m/s)
surface station 12 km from hypocenter
2 hz lowpass filter applied
Scintillating Discussion
Upcoming Benchmarks

Dipping faults

YM fault
SCEC 3D Rupture Dynamics Code Validation Workshop

Monday, March 10, 2008
Kellogg West Conference Center, Pomona, CA
Valley Vista Room

Convener: Ruth Harris

10:30-10:45  Introduction  Ruth Harris
10:45-11:15  New Code – FaultMod  Michael Barall
11:15-12:15  Rate-State Benchmarks: Description, Results & Discussion  Eric Dunham
12:15-1:15  Lunch
1:15-2:00  Slip-Weakening Benchmarks: Description, Results & Discussion  Ruth Harris
2:00-2:30  Benchmark Boundary Assumptions: Implications for Results  Brad Aagaard
2:30-3:00  Numerical Convergence: Implications for Results  Yoshi Kaneko
3:00-3:30  Break
3:30-5:00  General Discussion  All
5:00  Adjourn