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

Brad Aagaard, *U.S. Geological Survey*.
Jean Paul Ampuero, *ETH*.
Joe Andrews, *U.S. Geological Survey*.
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*.

USGS SOUTHERN CALIFORNIA EARTHQUAKE CENTER SCEC

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	

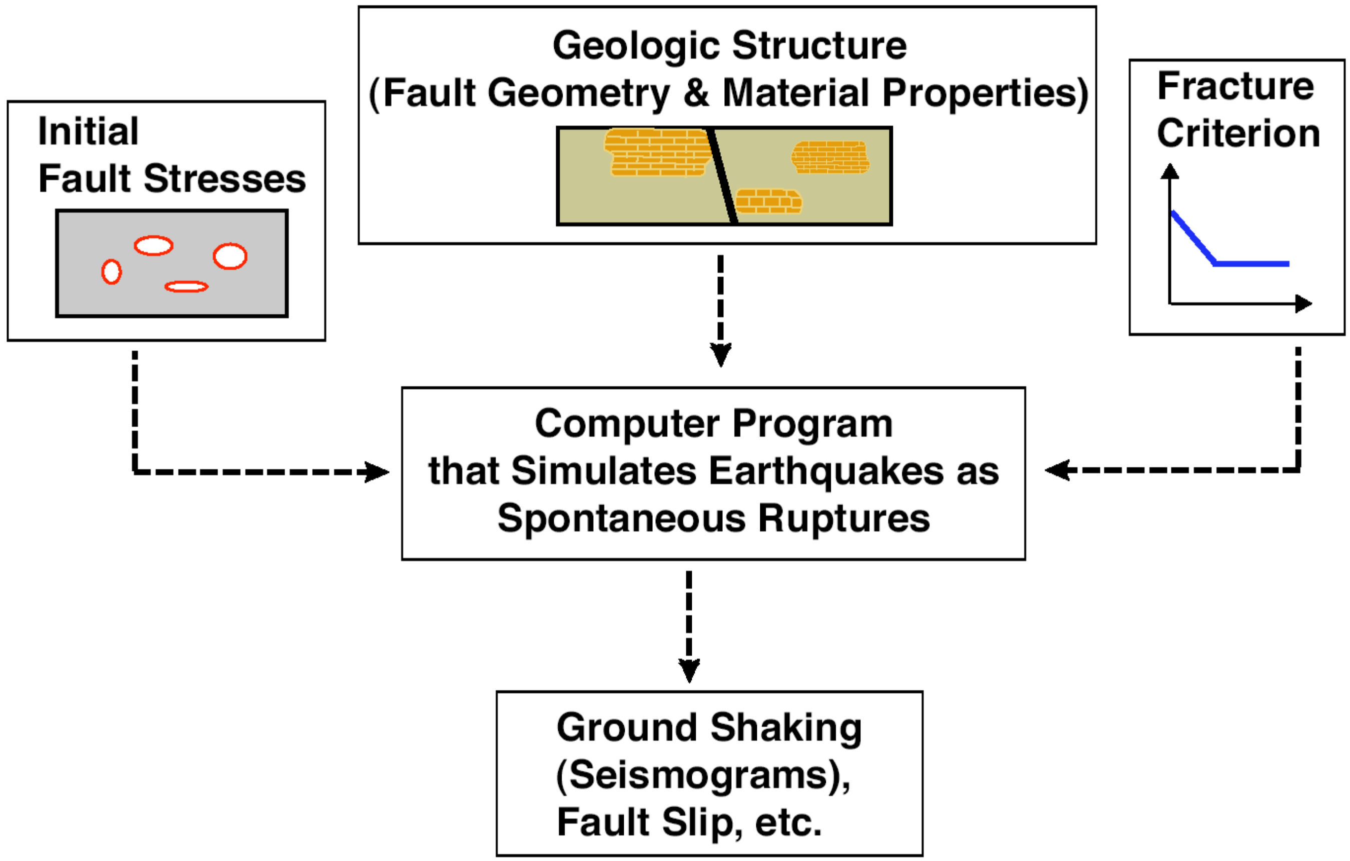
Overall Goal of the SCEC Code Validation Group

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

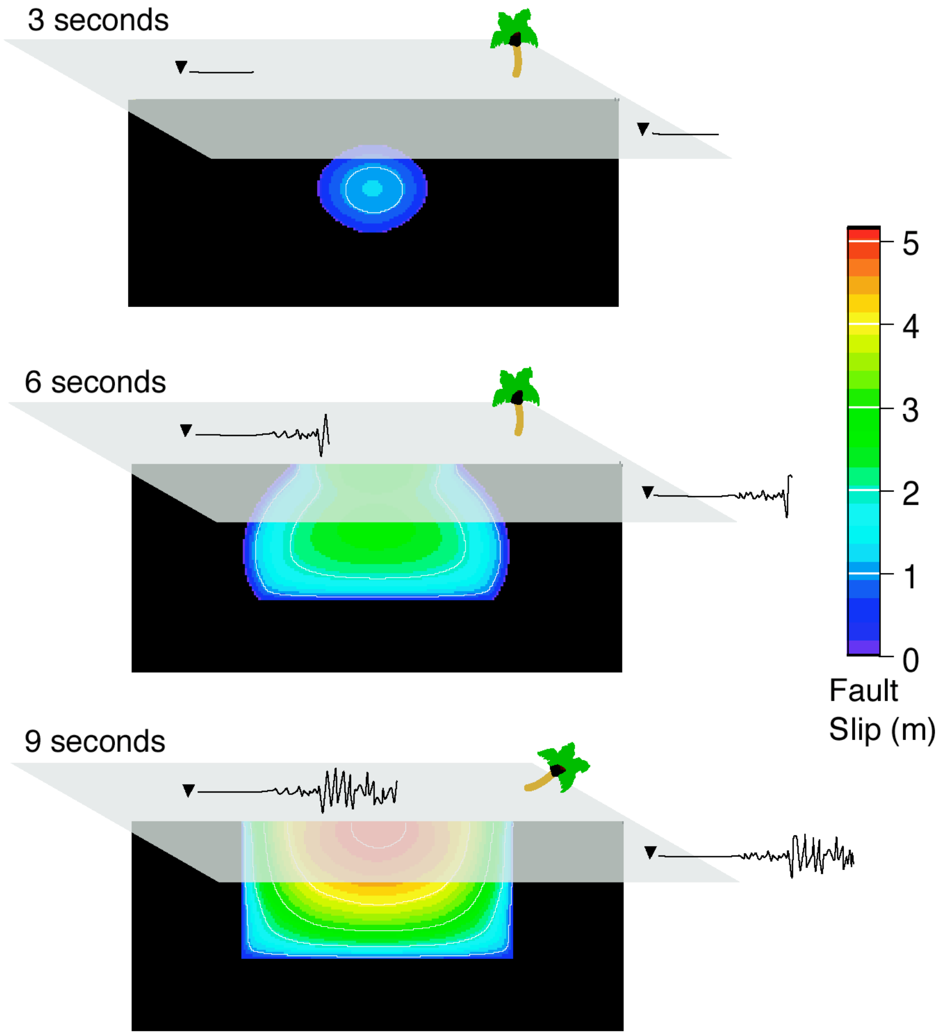
Some Specific Objectives

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

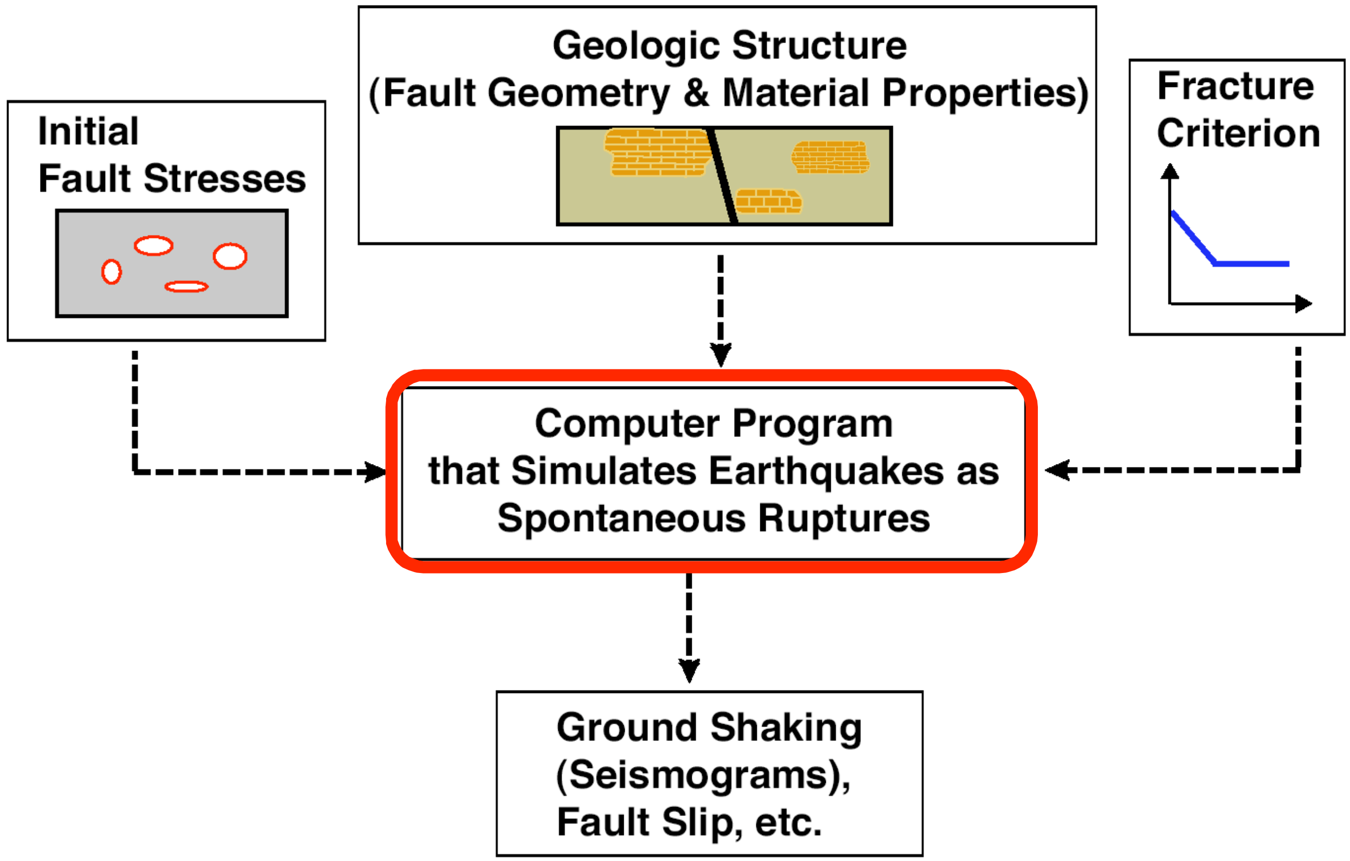
Produce results for the "Joe Andrews" Yucca Mountain normal-faulting benchmark, to compare with Joe's 2D simulations.



(Harris & Archuleta,
EOS, August 24, 2004)



(Harris & Archuleta,
EOS, August 24, 2004)

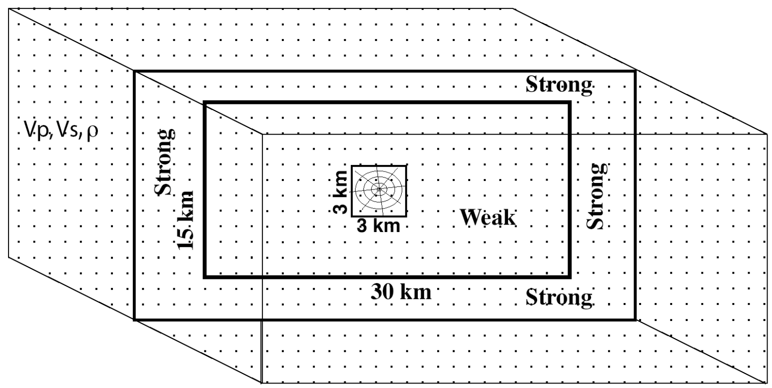


(Harris & Archuleta,
EOS, August 24, 2004)

Code Comparison Strategy

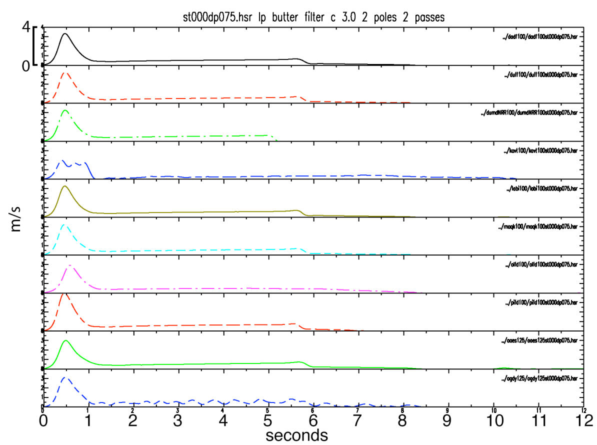
Start simply

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

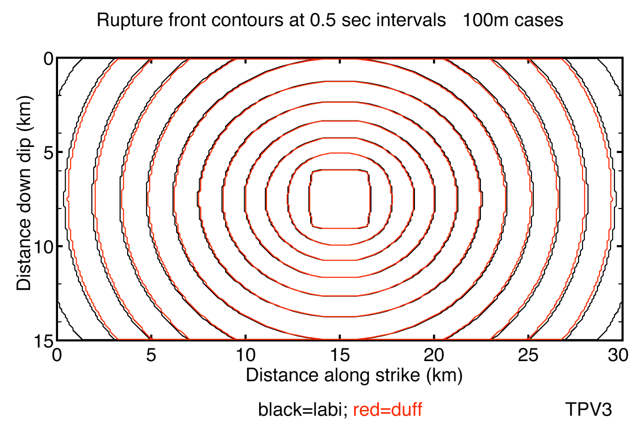


homogeneous initial stresses

slip-weakening friction



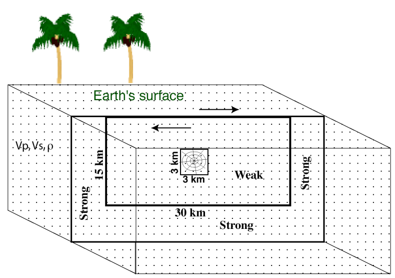
Some Results



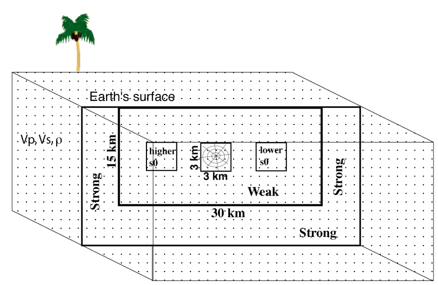
Code Comparison Strategy

Incrementally add complexity

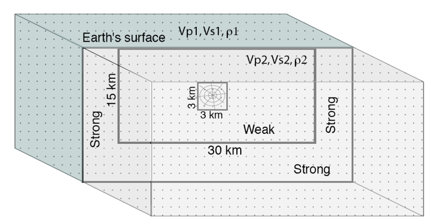
Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) **Halfspace**, Homogeneous initial stresses, Slip-weakening friction →



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

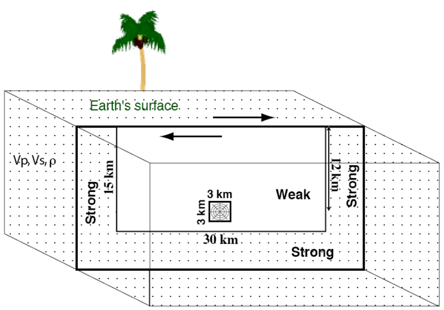
Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, **Depth-dependent Initial Stresses**, Slip-weakening friction

→

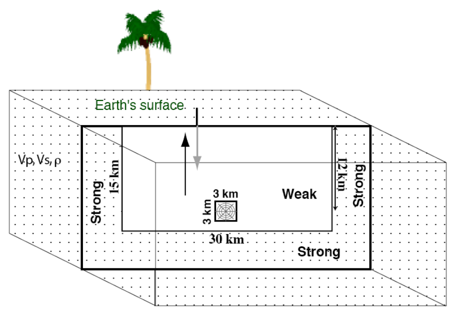
Rupture on a Vertical **Dip-Slip** fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction

→

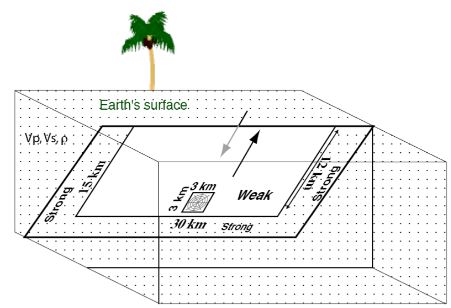
Rupture on a **Dipping** Dip-slip fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction



TPV8



TPV9



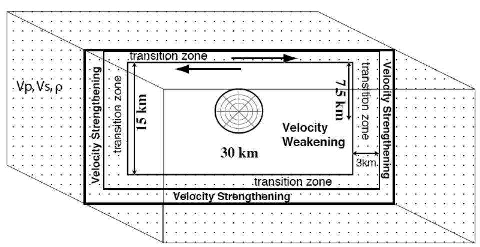
Code Comparison Strategy

Incrementally add complexity

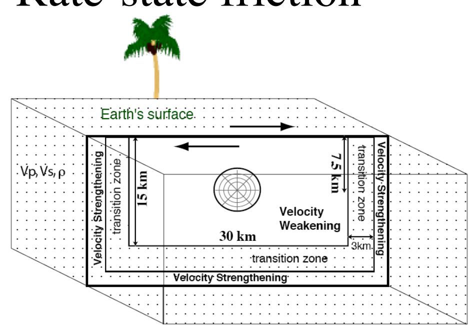
Rupture on
a vertical
strike-slip fault
set in a
Homogeneous
(materials)
Fullspace,
Homogeneous
initial stresses,
Rate-state friction

→

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



TPV101



TPV102

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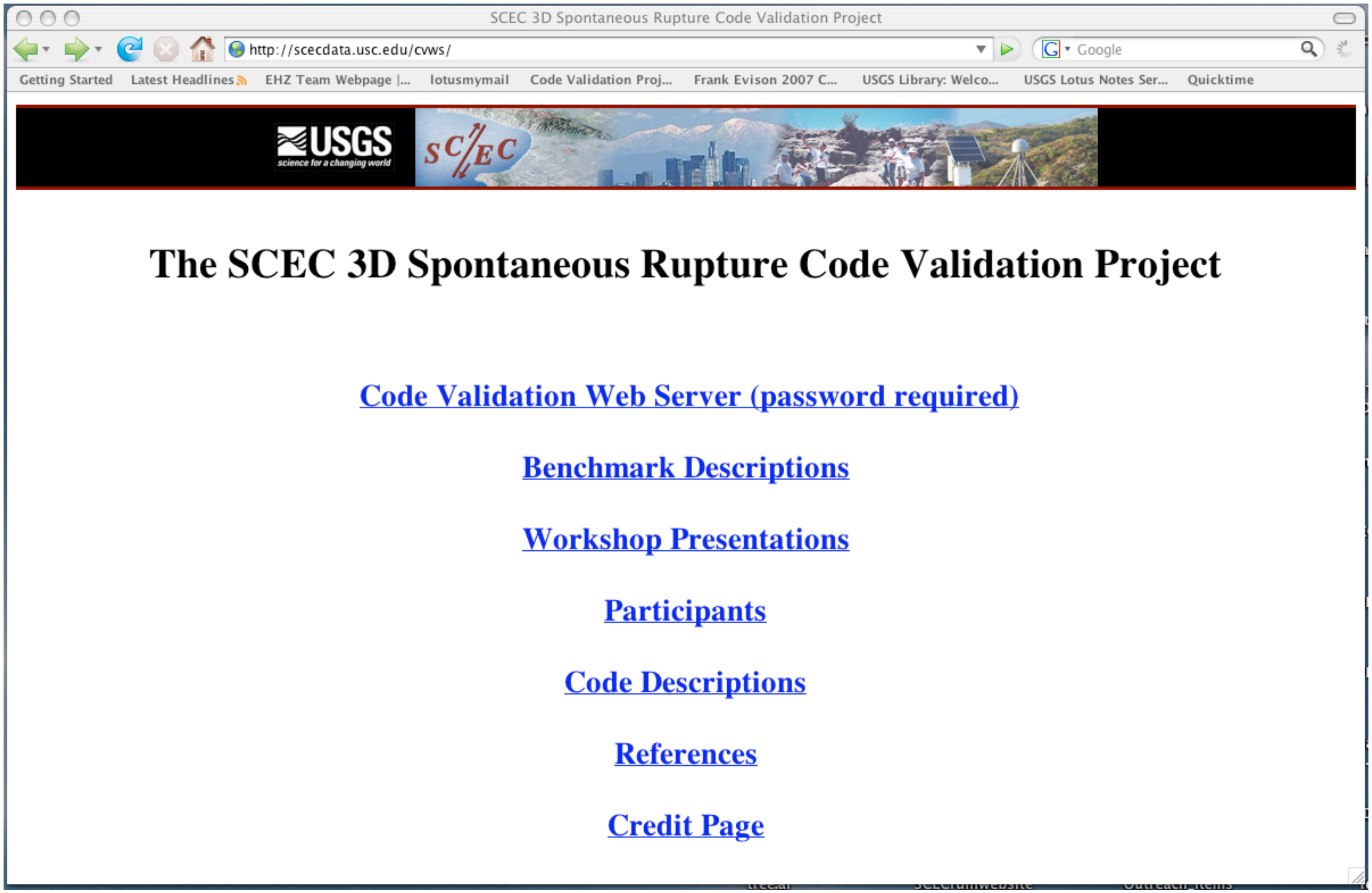
The SCEC Code Validation Website*

http://scecdata.usc.edu/cvws/



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

http://scecdata.usc.edu/cvws/code_descriptions.html

Spontaneous Rupture Code Descriptions

Aagaard - Finite Element Code (EqSim)

Ampuero - Spectral Element Code (SPECFEM3D)

Andrews/Song - Dynelf

Barall - Finite Element Code (FaultMod)

Cruz-Atienza - 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)

3D Benchmark Descriptions

http://scecdata.usc.edu/cvws/benchmark_descriptions.html

Getting Started Latest Headlines EHZ Team Webpage |... lotusmymail Code Validation Proj... Frank Evison 2007 C... USGS Library: Welco... USGS Lotus Notes Ser... Quicktime

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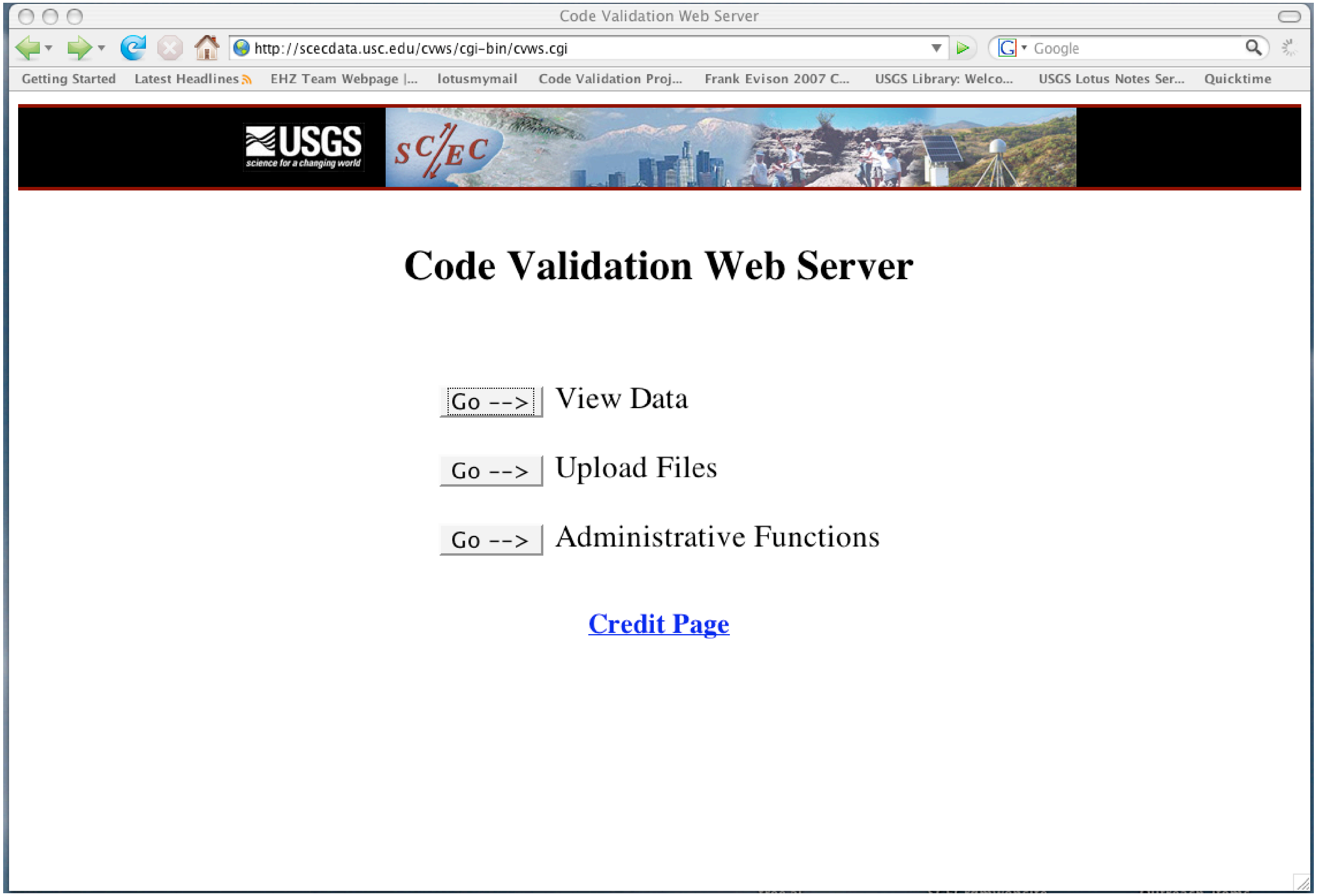
3D Benchmark Descriptions

TPV3	Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous fullspace.
TPV4	Nucleation followed by spontaneous rupture on a slightly stress-heterogeneous vertical strike-slip fault in a homogeneous fullspace.
TPV5	Nucleation followed by spontaneous rupture on a slightly stress-heterogeneous vertical strike-slip fault in a homogeneous halfspace. Detailed description and instructions to modelers for TPV5.
TPV6	Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a bimaterial halfspace, with high shear modulus contrast across the fault (a "well-posed" problem). Detailed description and instructions to modelers for TPV6.
TPV7	Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a bimaterial halfspace, with low shear modulus contrast across the fault. Detailed description and instructions to modelers for TPV7.
TPV8	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. Detailed description and instructions to modelers for TPV8.
TPV9	Nucleation followed by spontaneous rupture on a vertical dip-slip fault in a homogeneous halfspace. Initial stress conditions are linearly dependent on depth. Subshear rupture conditions. Detailed description and instructions to modelers for TPV9.
TPV10	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.
TPV11	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.
TPV12	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.
TPV101	Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous fullspace. Rate-state friction, using an ageing law. Detailed description and instructions to modelers for TPV101.
TPV102	Nucleation followed by spontaneous rupture on a vertical strike-slip fault in a homogeneous halfspace. Rate-state friction, using an ageing law. Detailed description and instructions to modelers for TPV102.


Code Validation Web Server
http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi
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Getting Started
Latest Headlines
EHZ Team Webpage |...
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Code Validation Proj...
Frank Evison 2007 C...
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Go --> View Data
Go --> Upload Files
Go --> Administrative Functions
Credit Page

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http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi

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Select Problem

Problems

Name	Date	Description	Action
tpv101	2/11/2008 5:15 AM	The Problem, Version 101	Select
tpv102	2/11/2008 5:15 AM	The Problem, Version 102	Select
tpv5	10/4/2007 7:32 PM	The Problem, Version 5	Select
tpv6	8/10/2007 5:20 AM	The Problem, Version 6	Select
tpv7	8/10/2007 5:21 AM	The Problem, Version 7	Select
tpv8	2/8/2008 7:56 PM	The Problem, Version 8	Select
tpv9	2/8/2008 7:56 PM	The Problem, Version 9	Select

Logout

Today’s Benchmarks

The Problem,

Versions 101 and 102

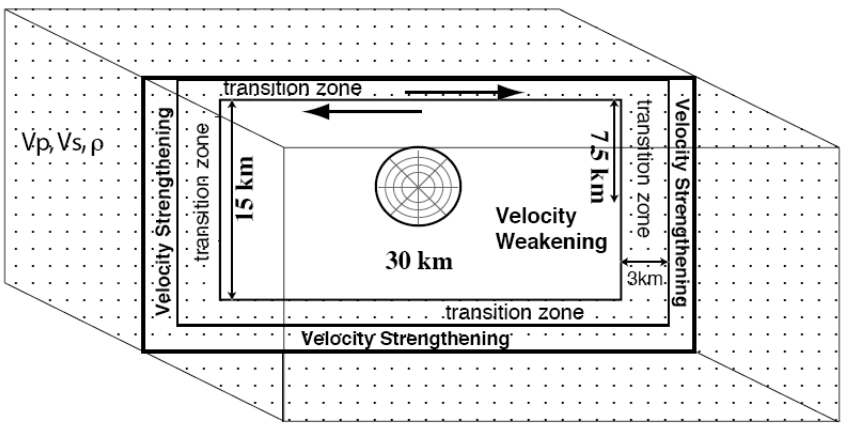
The Problem,

Versions 8 and 9

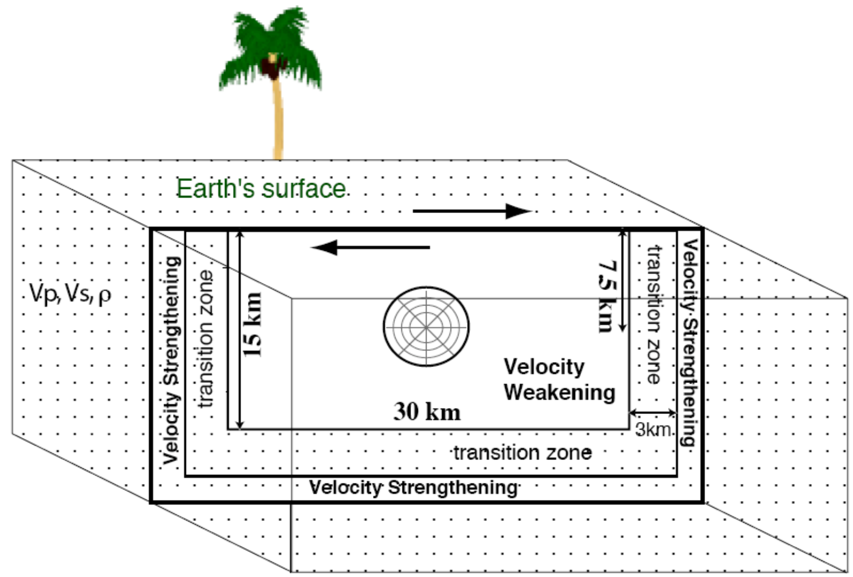
Courtesy of Eric Dunham

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

Rate-State Friction Dynamic Rupture



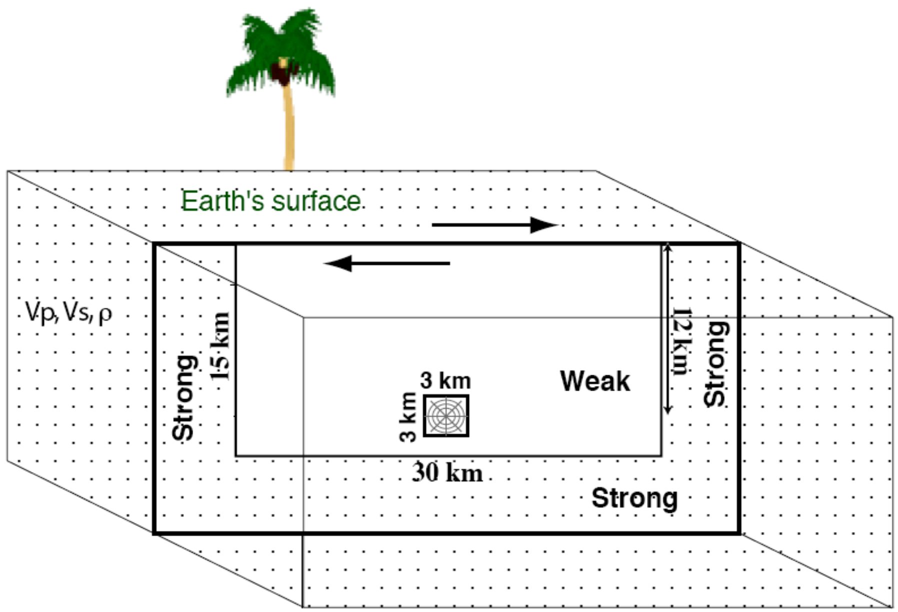
whole-space



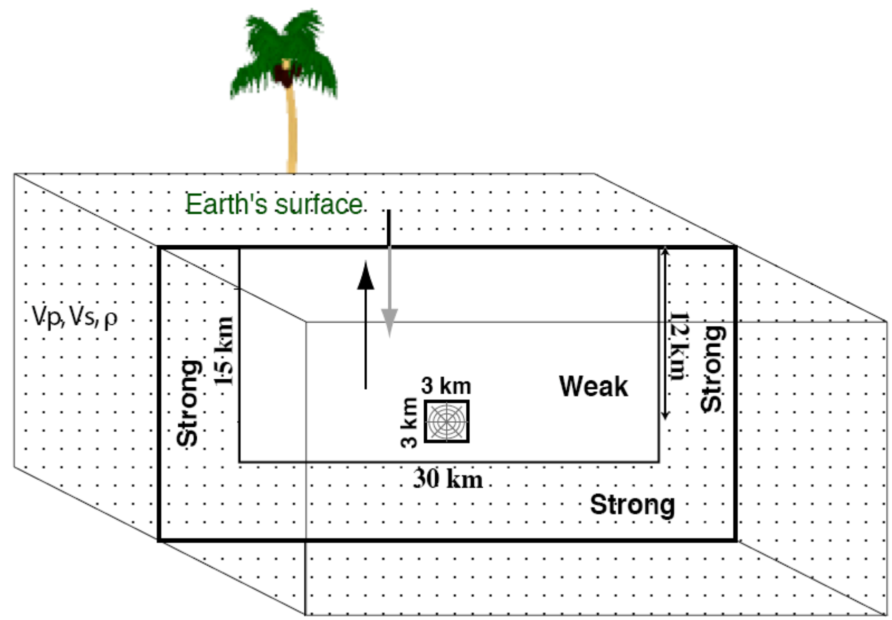
half-space

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

SCEC 3D Rupture Dynamics Code Validation Workshop

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Convener: *Ruth Harris*

10:30-10:45	**Introduction**	***Ruth Harris***
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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	

The Problem, Versions 8 and 9

Pathway to YM

Code Comparison Strategy

Incrementally add complexity

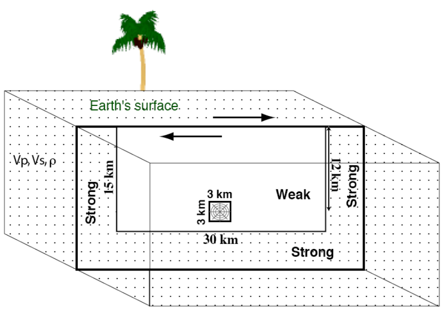
Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, **Depth-dependent Initial Stresses**, Slip-weakening friction

→

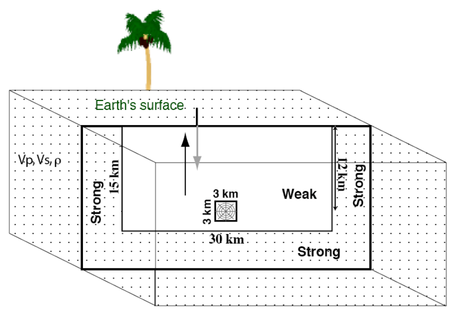
Rupture on a Vertical **Dip-Slip** fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction

→

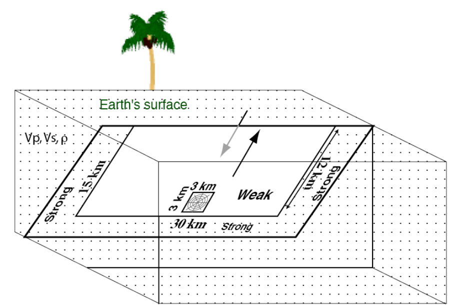
Rupture on a **Dipping** Dip-slip fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction



TPV8

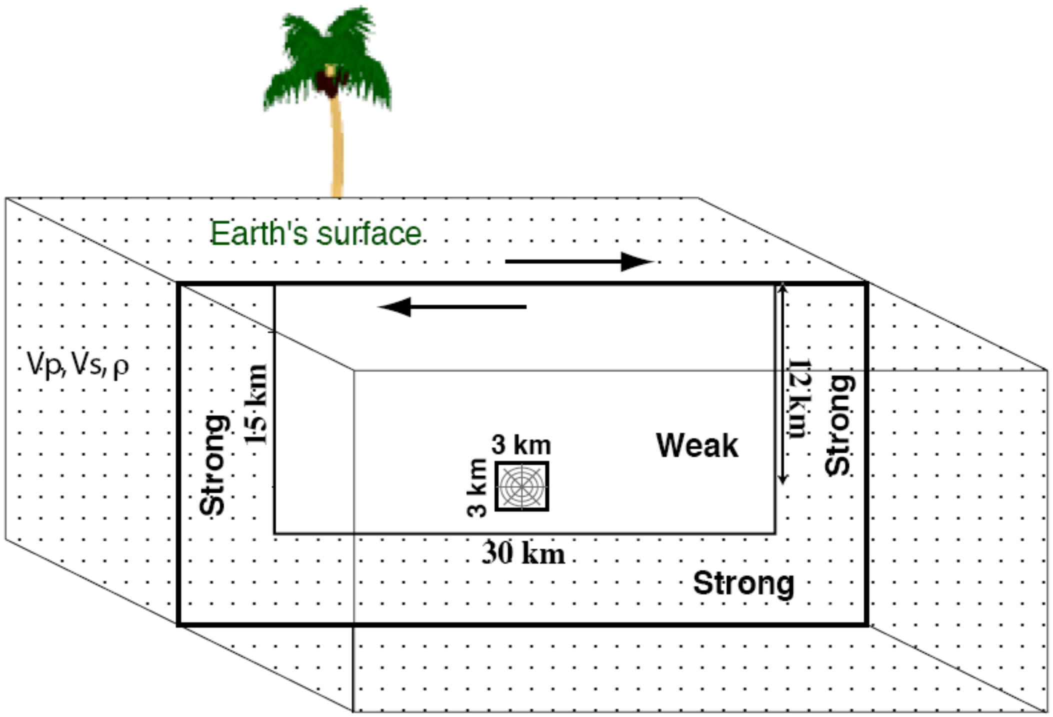


TPV9

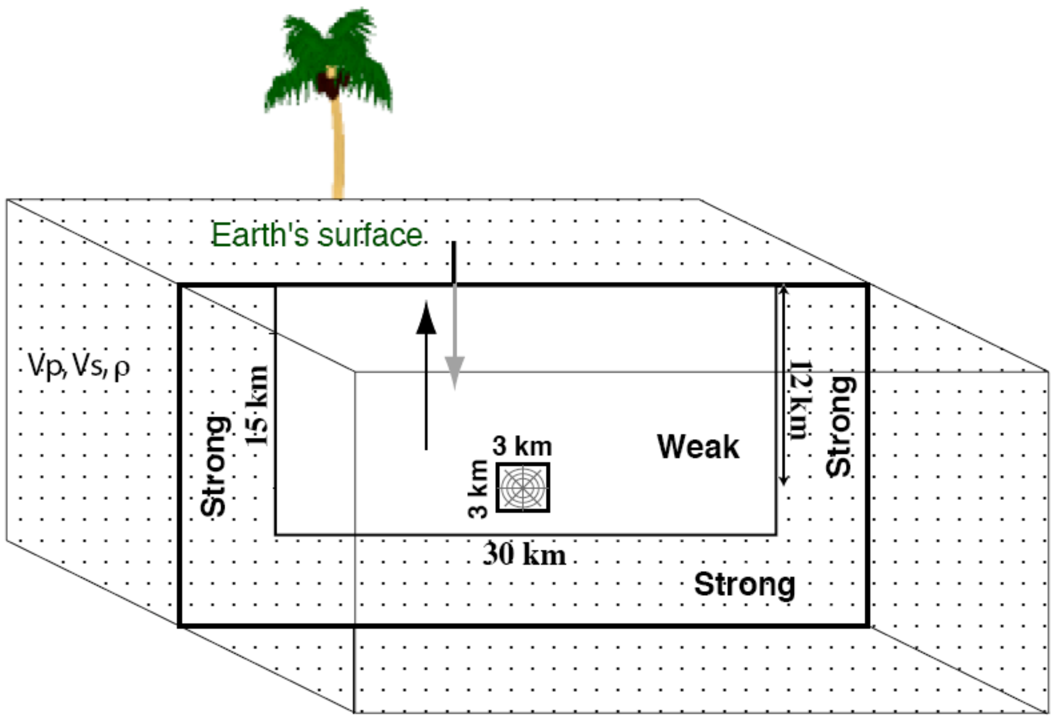


TPV10-12

The Problem, Version 8



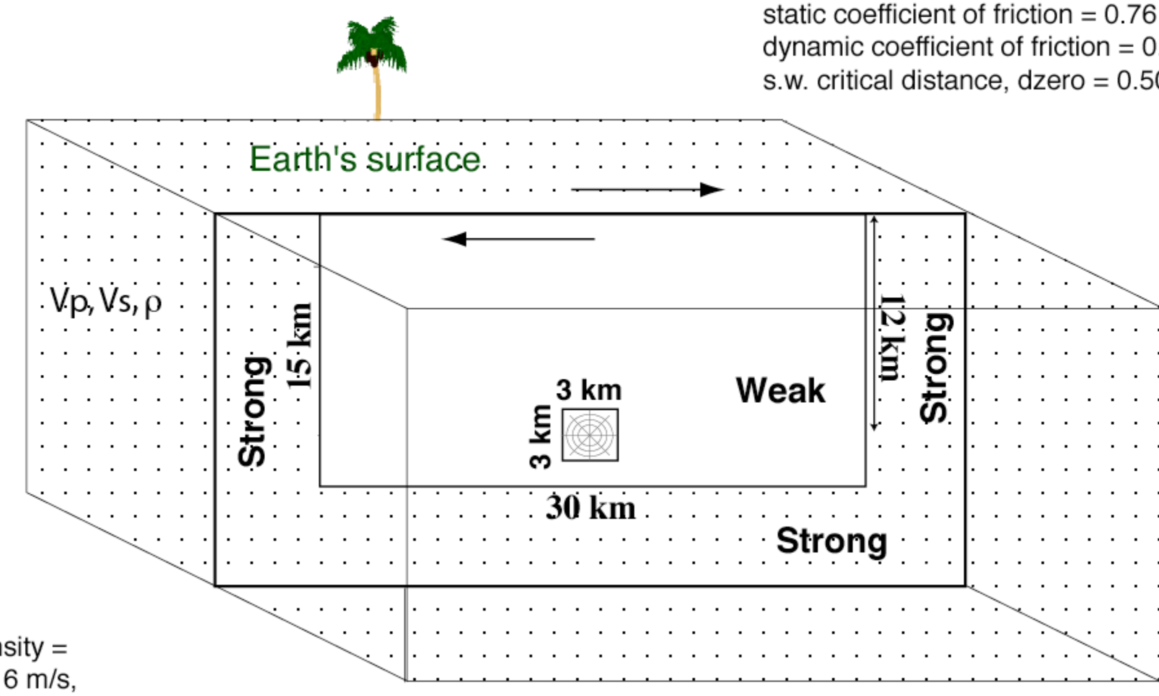
The Problem, Version 9



Source Physics for The Problem, Version 8

TPV8

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



vp,
vs,
density =
5716 m/s,
3300 m/s,
2700 kg/m3

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

TPV9

slip-weakening friction everywhere
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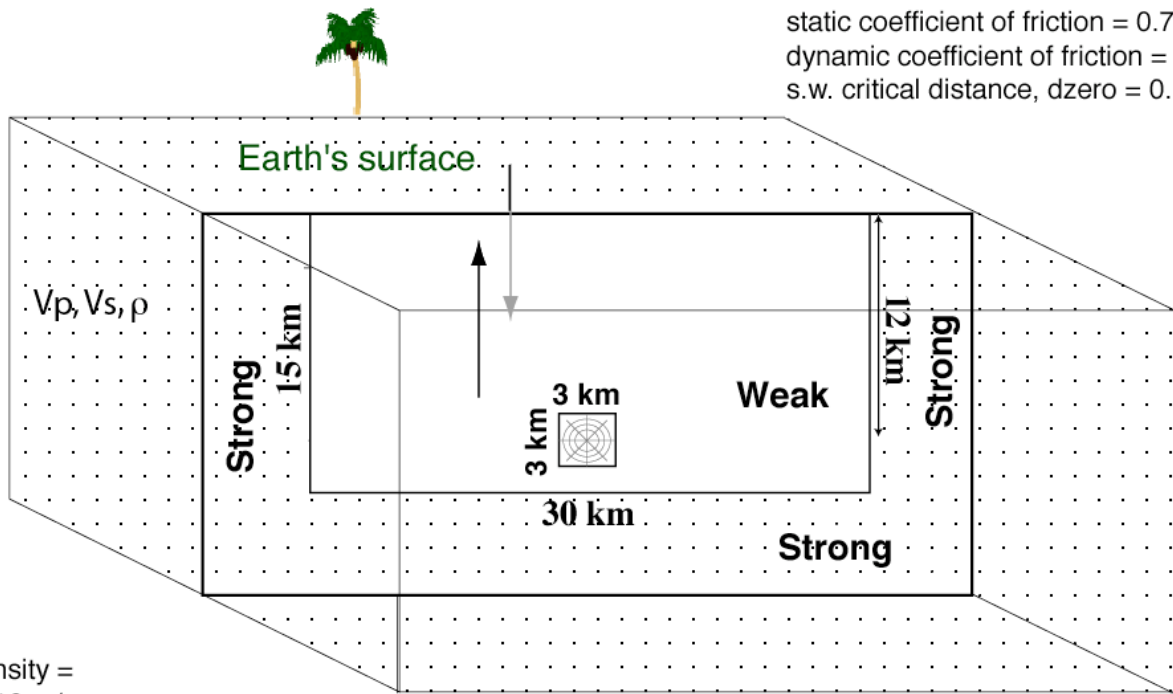

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Rupture Dynamics Code Validation

On-Fault Station Locations for **T**he **P**roblem, **V**ersions **8** and **9**

3 Stations on the Earth's surface are at :

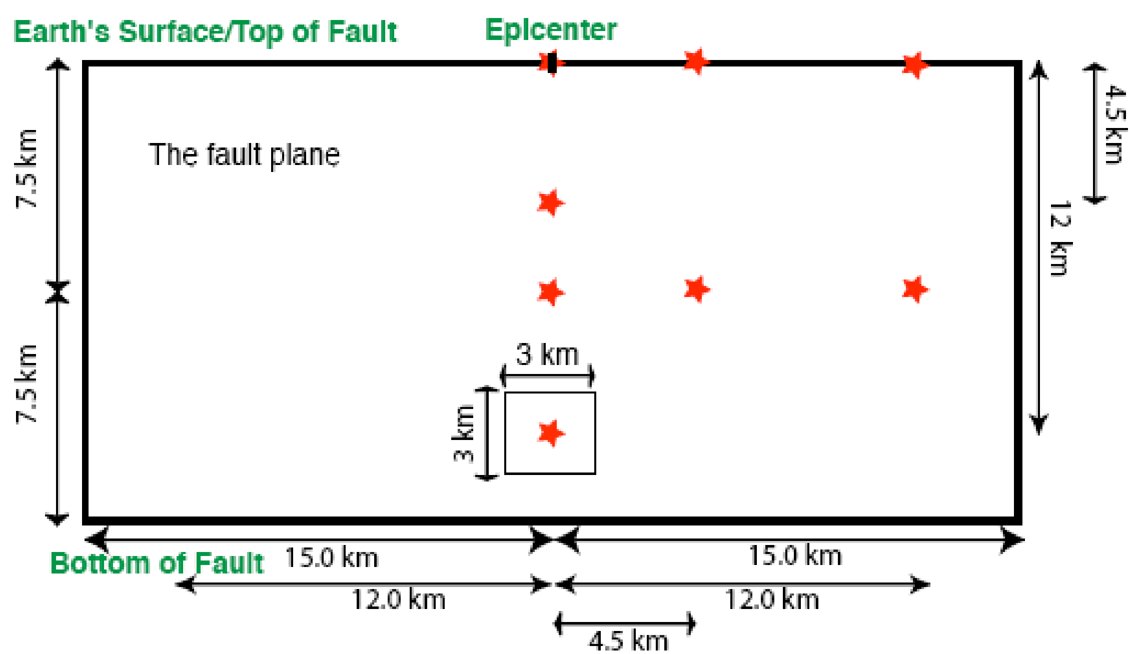
0, +4.5 km, +12.0 km along-strike distance, and 0 km down-dip distance

5 Deeper Stations are at:

0 km along-strike distance, and +4.5 km, +7.5 km, +12.0 km down-dip distance

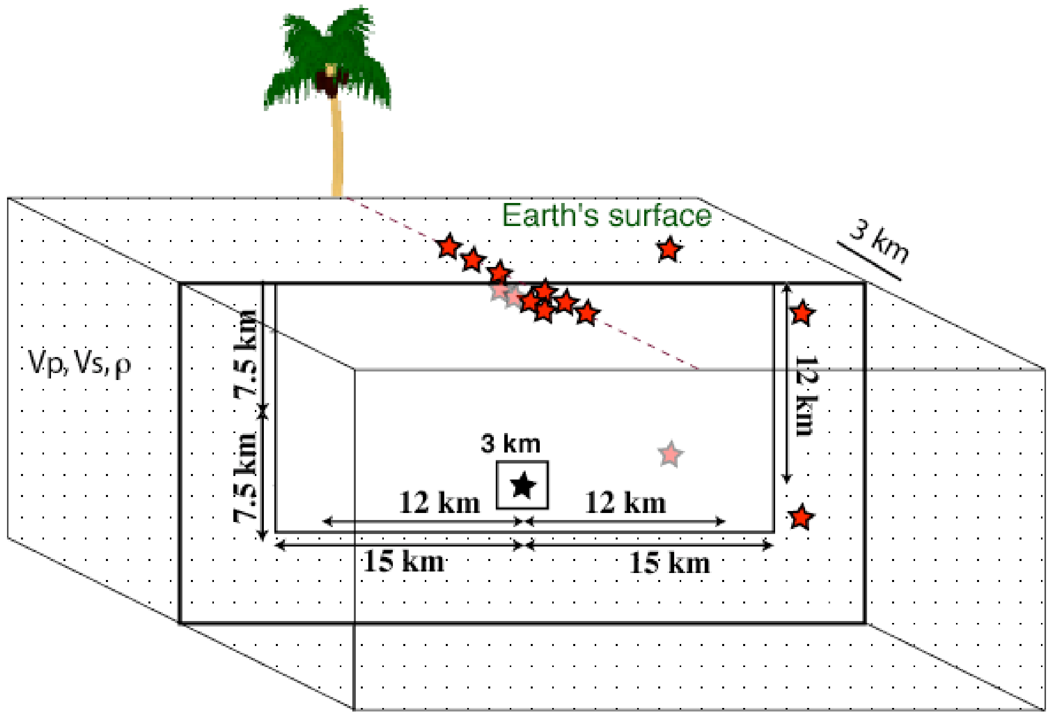
4.5 km along-strike distance, and 7.5 km down-dip distance

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

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TPV8

Modelers & Codes

Results submitted by 03/09/08

Select User(s)

http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi

Select User(s)

Problem: tpv8 (The Problem, Version 8)

Users | Select Checked | Select All

	Name	Description	Action
☐	aagaard	Brad Aagaard - Finite Element - EqSim	Select
☐	atienza	Victor Cruz Atienza - Finite Difference - AWM	Select
☐	barall	Michael Barall - Finite Element - FaultMod	Select
☐	dalguer	Luis Dalguer - Finite Difference - DFM	Select
☐	dalguer2	Luis Dalguer - Finite Difference - DFM	Select
☐	duan	Benchun Duan - Finite Element - EQdyna	Select
☐	kaneko	Yoshihiro Kaneko - Spectral Element - SPECFEM3D	Select
☐	kaneko2	Yoshihiro Kaneko - Spectral Element - SPECFEM3D	Select
☐	kase	Yuko Kase - Finite Difference	Select
☐	liu	Yi Liu - Boundary Integral	Select
☐	ma	Shuo Ma - Finite Element - MAFE	Select
☐	oglesby	David Oglesby - Finite Element - DYNA3D	Select
☐	pitarka	Arben Pitarka - Finite Difference - FDMSPLIT	Select
☐	song	Seok Goo Song - Dynelf	Select
☐	templeton	Elizabeth Templeton - Finite Element - ABAQUS	Select

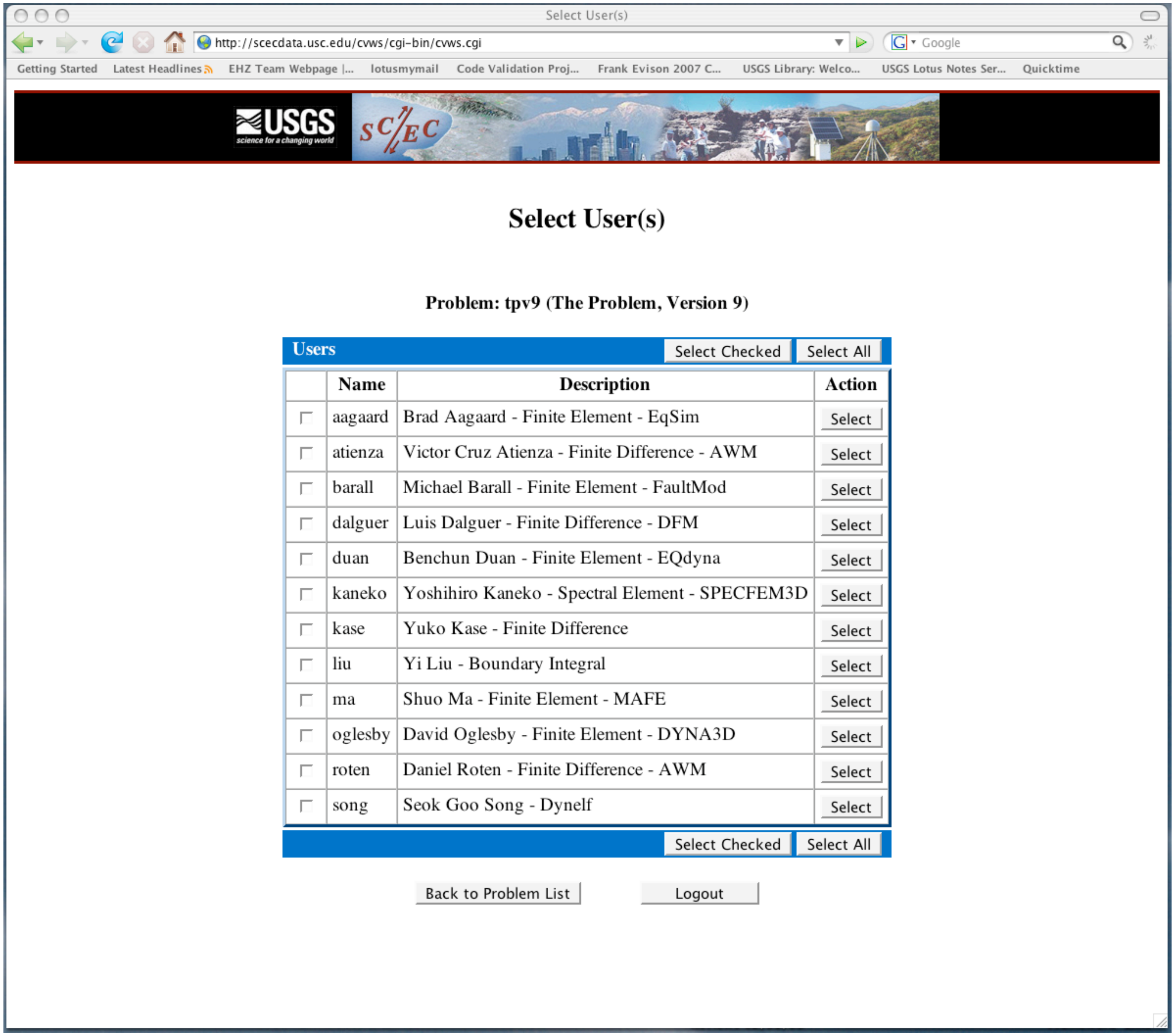
Select Checked | Select All

Back to Problem List | Logout

TPV9

Modelers & Codes

Results submitted by 03/09/08



Select User(s)

Problem: tpv9 (The Problem, Version 9)

Users — Select Checked | Select All

	Name	Description	Action
	aagaard	Brad Aagaard - Finite Element - EqSim	Select
	atienza	Victor Cruz Atienza - Finite Difference - AWM	Select
	barall	Michael Barall - Finite Element - FaultMod	Select
	dalguer	Luis Dalguer - Finite Difference - DFM	Select
	duan	Benchun Duan - Finite Element - EQdyna	Select
	kaneko	Yoshihiro Kaneko - Spectral Element - SPECFEM3D	Select
	kase	Yuko Kase - Finite Difference	Select
	liu	Yi Liu - Boundary Integral	Select
	ma	Shuo Ma - Finite Element - MAFE	Select
	oglesby	David Oglesby - Finite Element - DYNA3D	Select
	roten	Daniel Roten - Finite Difference - AWM	Select
	song	Seok Goo Song - Dynelf	Select

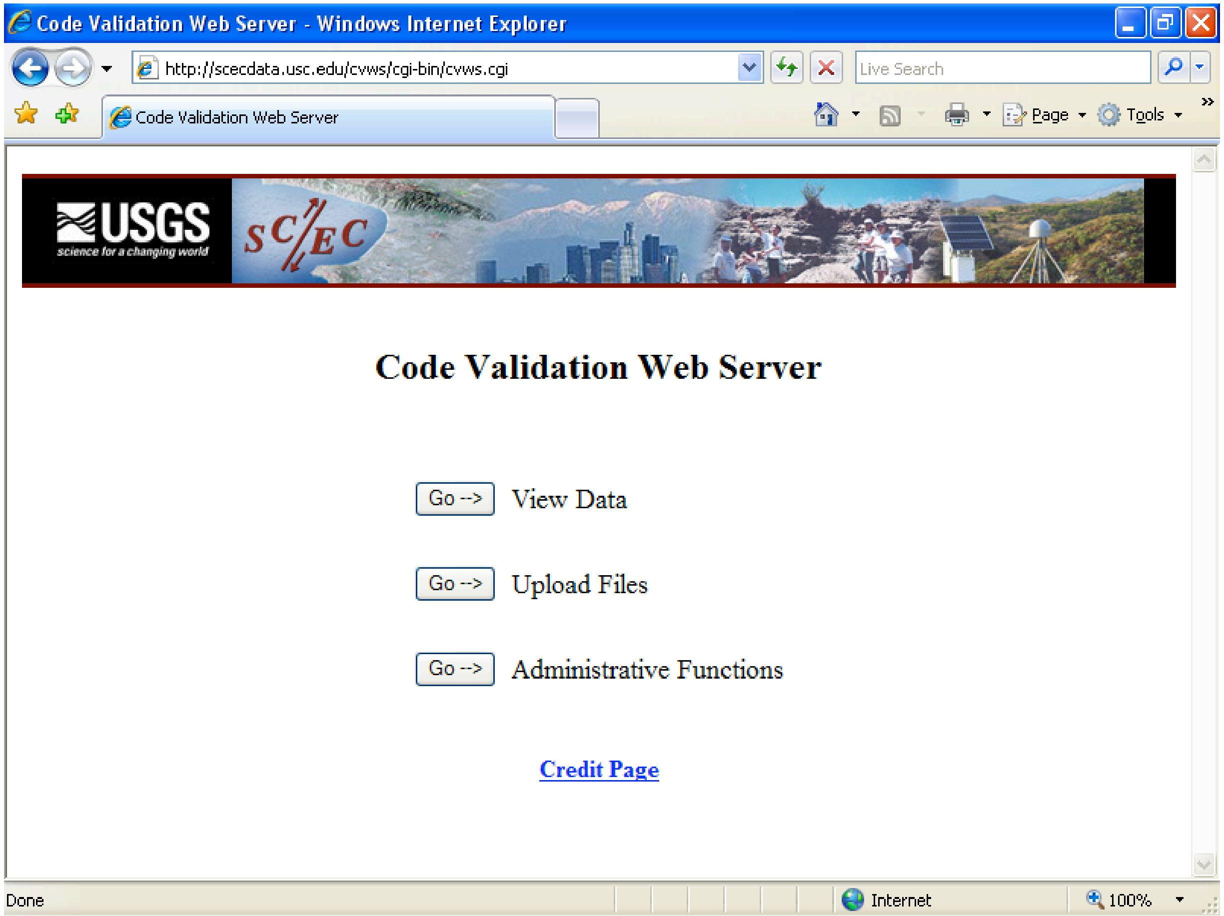
Select Checked | Select All

Back to Problem List | Logout

Comparisons

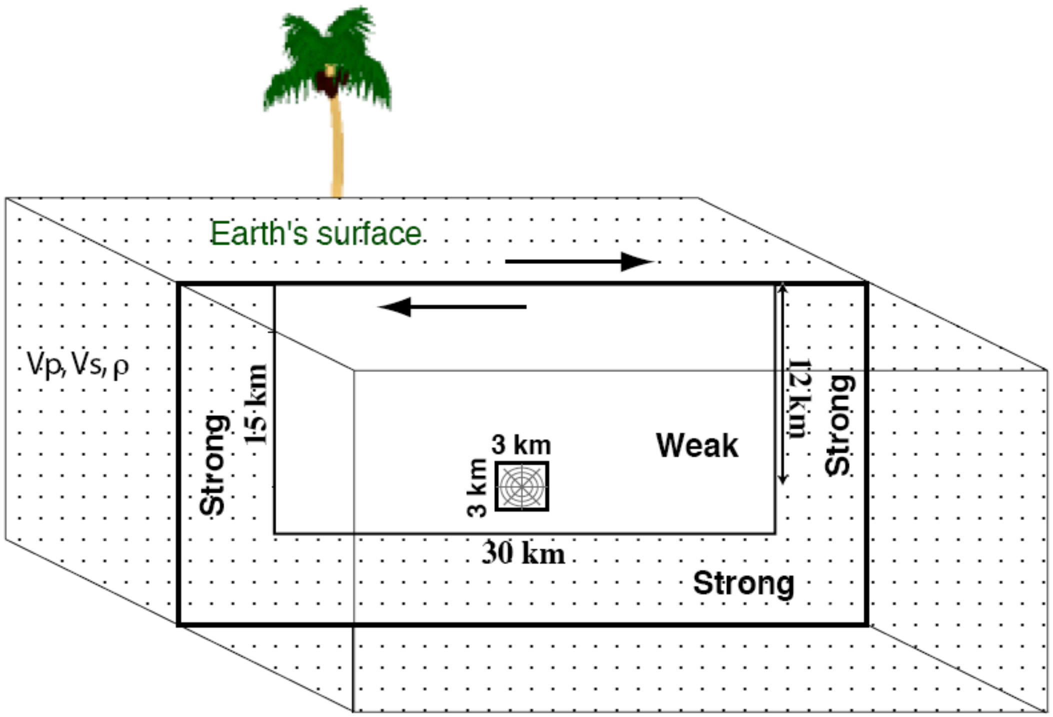
The Problem,
Versions 8 and 9

The SCEC Code Validation Website*



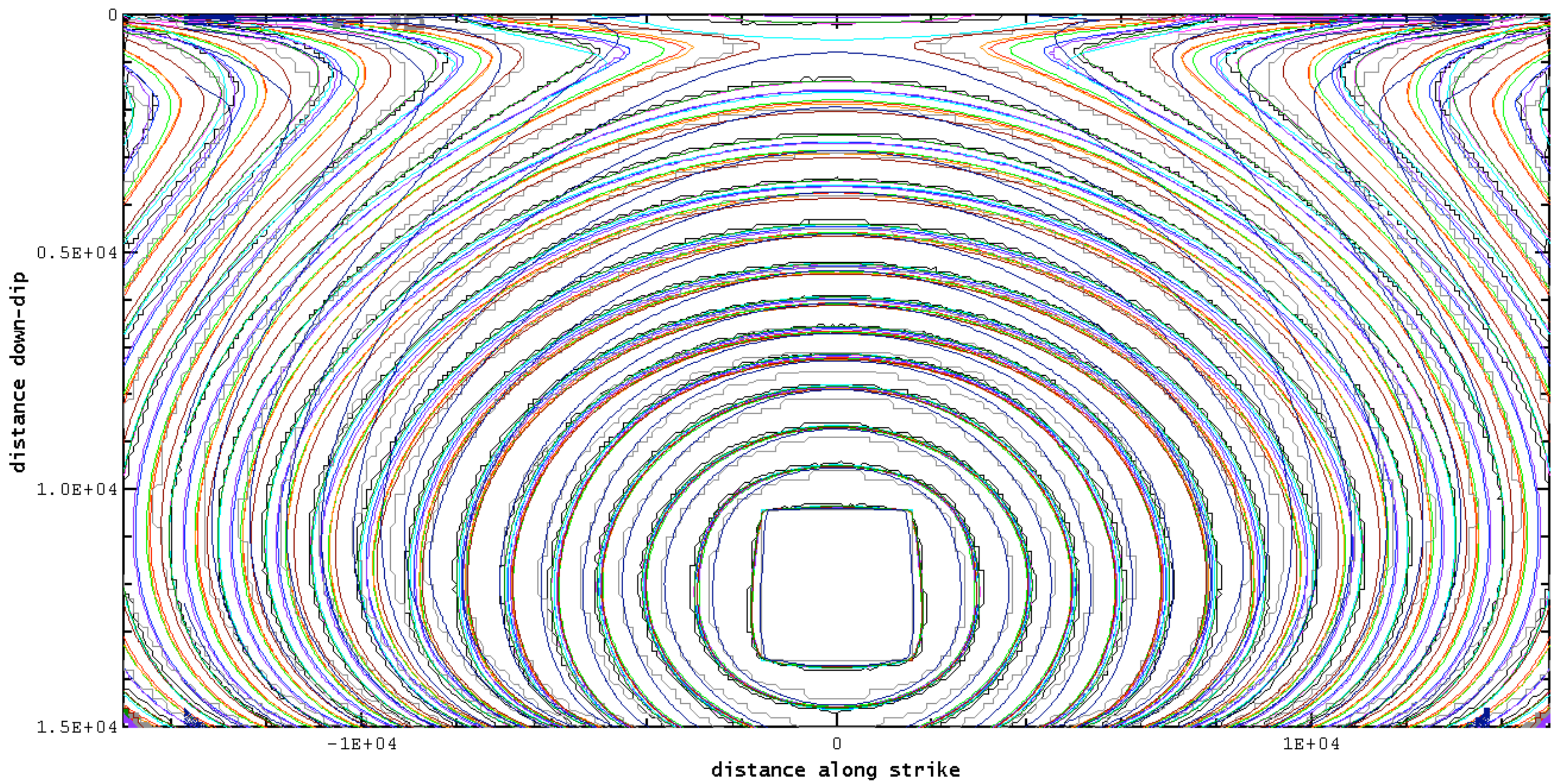
*Funding from the U.S. Dept. of Energy
Extreme Ground Motion Project

The Problem, Version 8



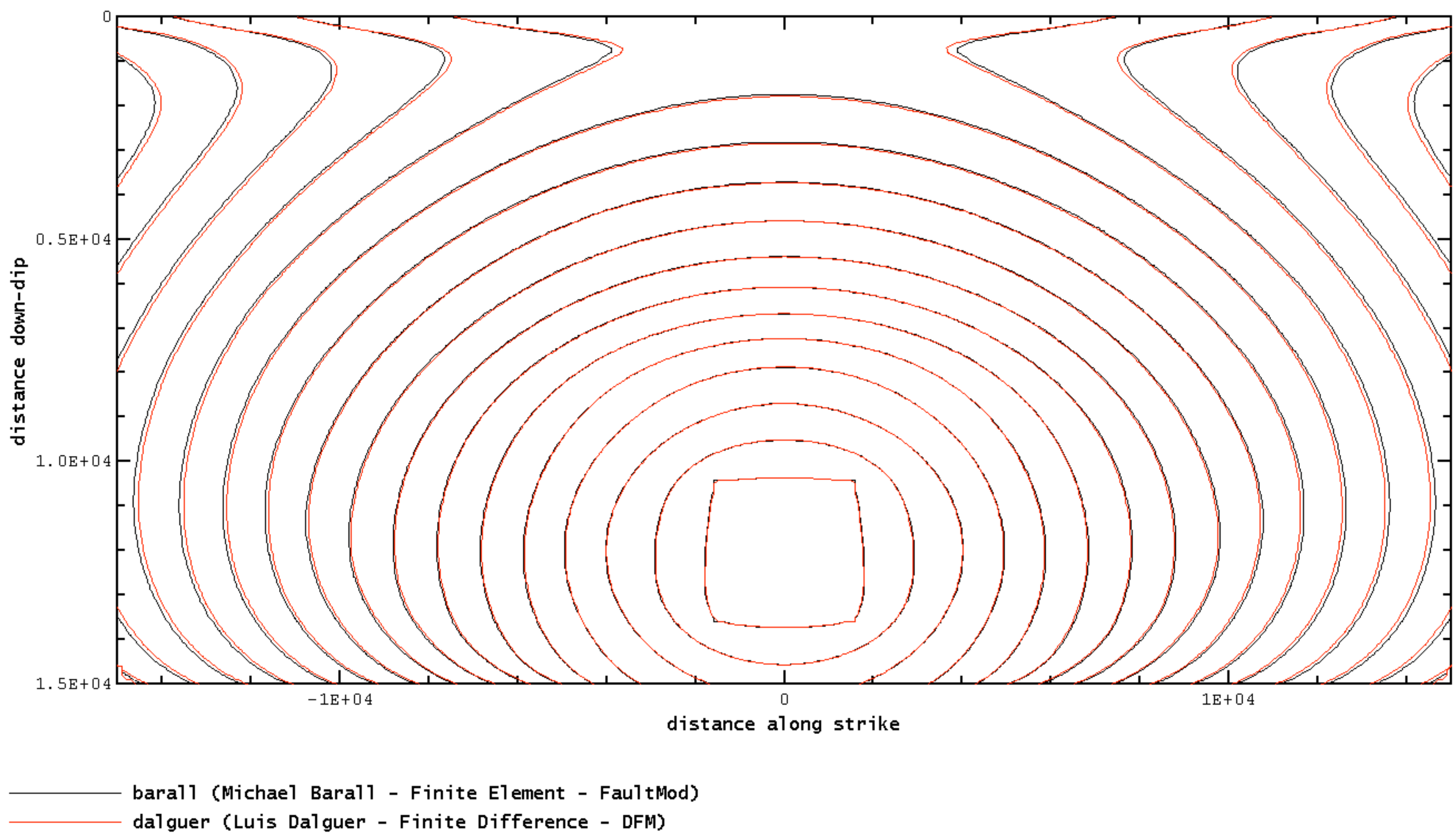
Rupture Front Times

TPV8
Rupture
Front
Contours
0.5 sec
Intervals
from
12/13
modelers



aagaard (Brad Aagaard - Finite Element - EqSim)
atienza (Victor Cruz Atienza - Finite Difference - AWM)
dalguer (Luis Dalguer - Finite Difference - DFM)
duan (Benchun Duan - Finite Element - EQdyna)
kaneko (Yoshihiro Kaneko - Spectral Element - SPECFEM3D)
kase (Yuko Kase - Finite Difference)
liu (Yi Liu - Boundary Integral)
ma (Shuo Ma - Finite Element - MAFE)
oglesby (David Oglesby - Finite Element - DYNA3D)
pitarka (Arben Pitarka - Finite Difference - FDMSPLIT)
song (Seok Goo Song - Dynelf)
templeton (Elizabeth Templeton - Finite Element - ABAQUS)

TPV8 Rupture Front Contours 0.5 sec Intervals from 2/13 modelers



Synthetic Seismograms

On-Fault Time Series

Name	Description	Action
faultst000dp000	strike 0.0 km, dip 0.0 km	Select
faultst000dp045	strike 0.0 km, dip 4.5 km	Select
faultst000dp075	strike 0.0 km, dip 7.5 km	Select
faultst000dp120	strike 0.0 km, dip 12.0 km	Select
faultst045dp000	strike 4.5 km, dip 0.0 km	Select
faultst045dp075	strike 4.5 km, dip 7.5 km	Select
faultst120dp000	strike 12.0 km, dip 0.0 km	Select
faultst120dp075	strike 12.0 km, dip 7.5 km	Select

Off-Fault Time Series

Name	Description	Action
body-005st000dp003	body -0.5 km, strike 0.0 km, dip 0.3 km	Select
body-010st000dp000	body -1.0 km, strike 0.0 km, dip 0.0 km	Select
body-010st000dp003	body -1.0 km, strike 0.0 km, dip 0.3 km	Select
body-020st000dp000	body -2.0 km, strike 0.0 km, dip 0.0 km	Select
body-030st000dp000	body -3.0 km, strike 0.0 km, dip 0.0 km	Select
body-030st120dp000	body -3.0 km, strike 12.0 km, dip 0.0 km	Select
body-030st120dp120	body -3.0 km, strike 12.0 km, dip 12.0 km	Select
body005st000dp003	body 0.5 km, strike 0.0 km, dip 0.3 km	Select
body010st000dp000	body 1.0 km, strike 0.0 km, dip 0.0 km	Select
body010st000dp003	body 1.0 km, strike 0.0 km, dip 0.3 km	Select
body020st000dp000	body 2.0 km, strike 0.0 km, dip 0.0 km	Select
body030st000dp000	body 3.0 km, strike 0.0 km, dip 0.0 km	Select
body030st120dp000	body 3.0 km, strike 12.0 km, dip 0.0 km	Select
body030st120dp120	body 3.0 km, strike 12.0 km, dip 12.0 km	Select

Rupture Dynamics Code Validation

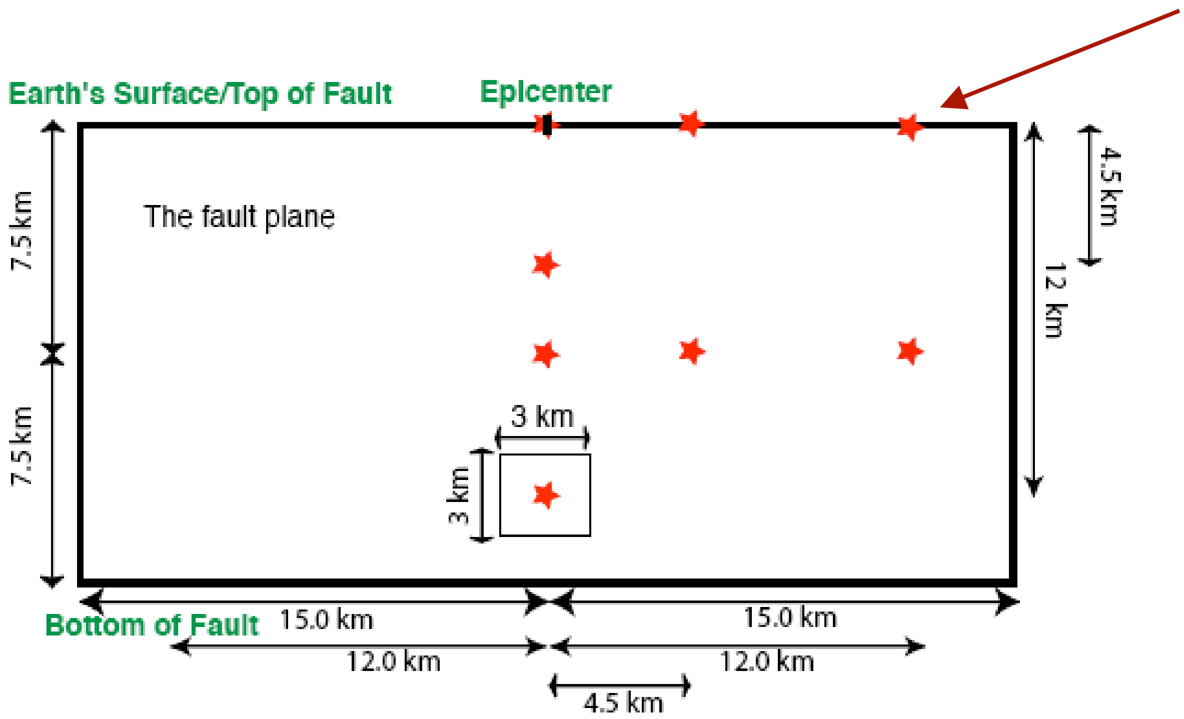
On-Fault Station Locations for **T**he **P**roblem, **V**ersions **8** and **9**

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



S O U T H E R N   C A L I F O R N I A   E A R T H Q U A K E   C E N T E R

File: faultst120dp000 (strike 12.0 km, dip 0.0 km)

Field: h-slip-rate (horizontal slip rate)

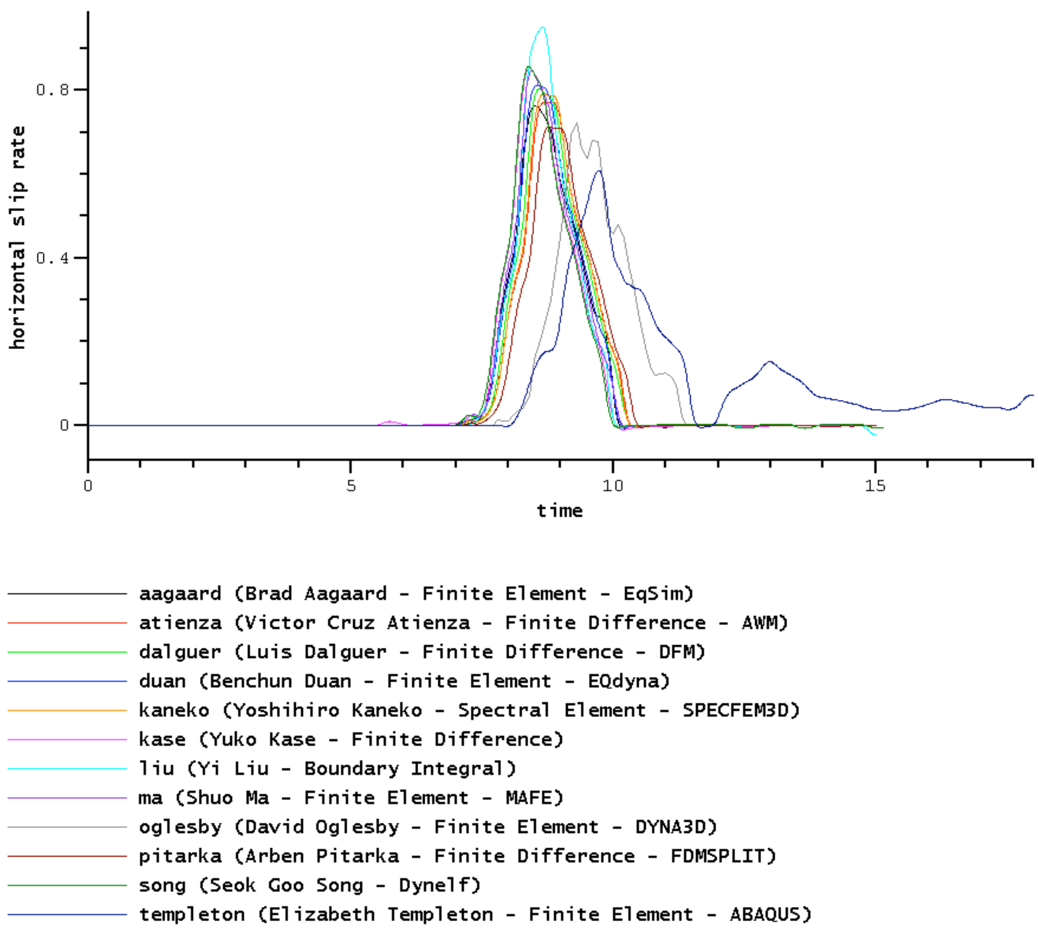
Back to Field List   Logout

<< < Page 1 of 1 > >>

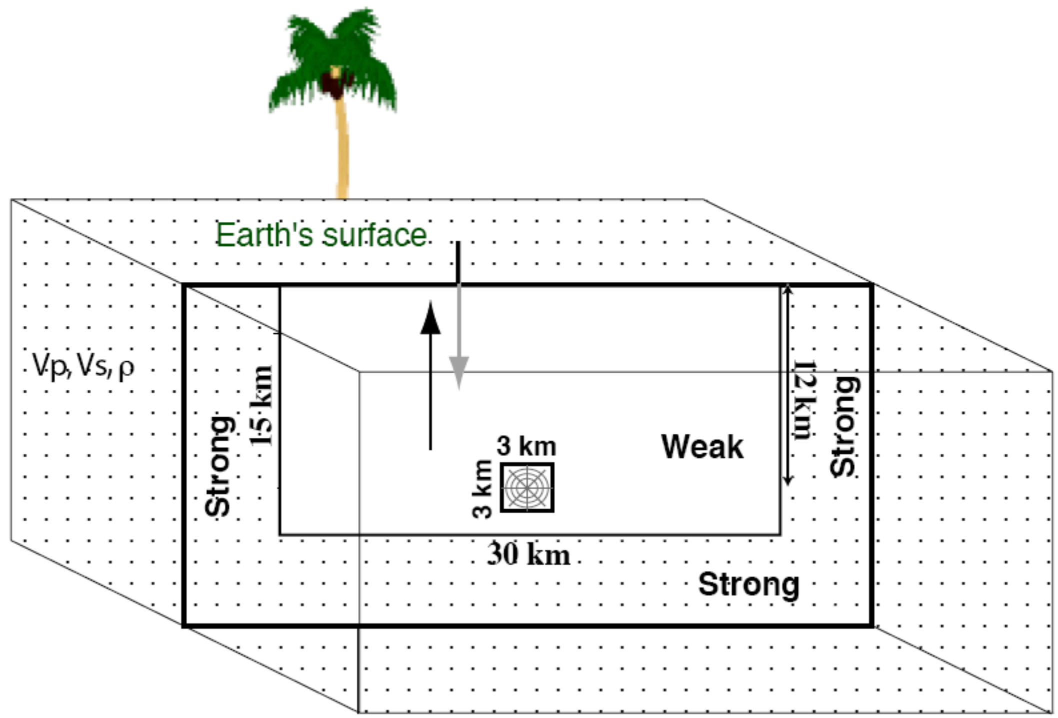
Horizontal
Slip rate
(m/s)

surface
station
12 km
from
hypocenter

2 hz
lowpass
filter
applied

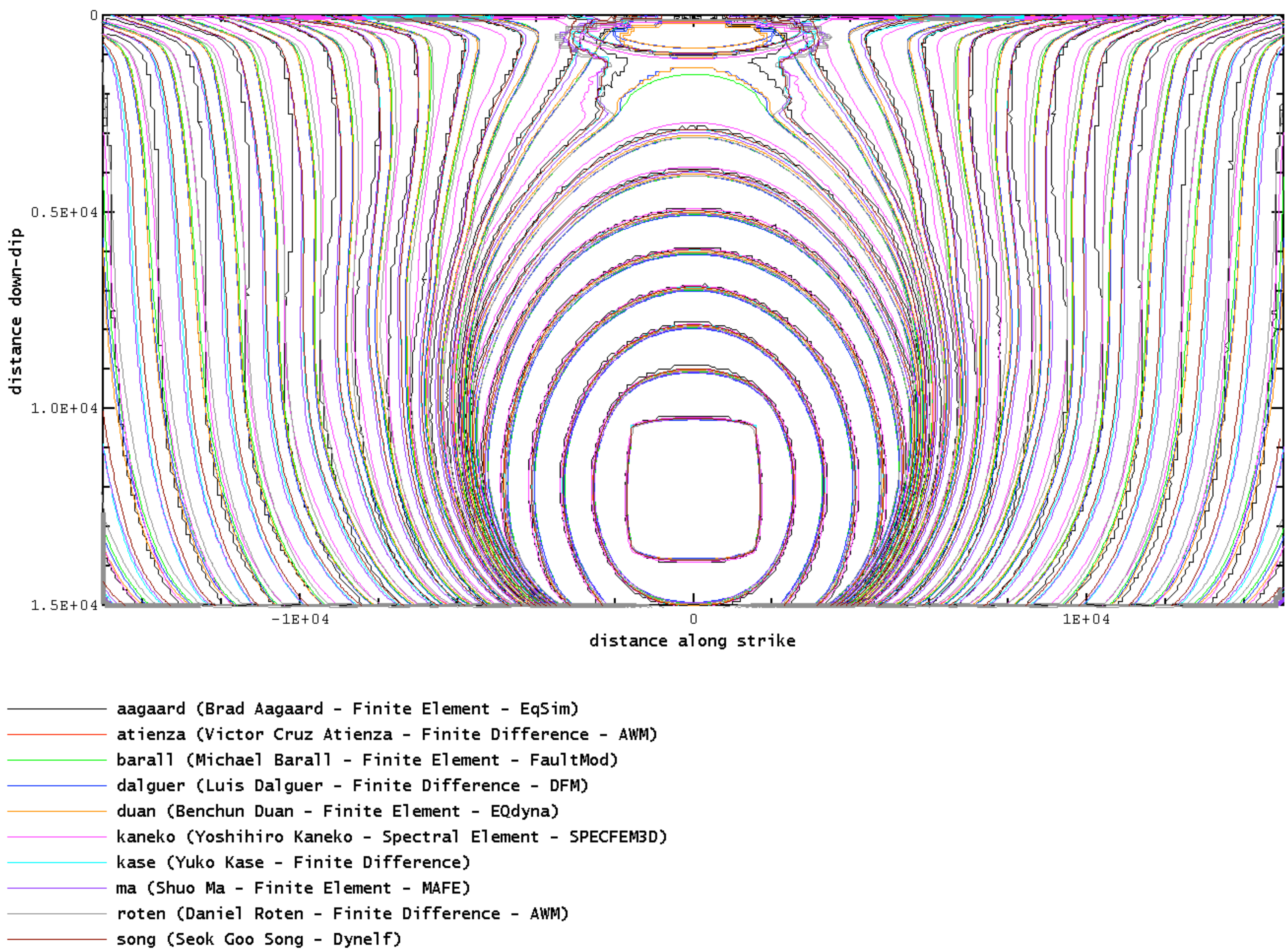


The Problem, Version 9



Rupture Front Times

TPV9 Rupture Front Contours 0.5 sec Intervals from 10 modelers



Synthetic Seismograms

On-Fault Time Series

Name	Description	Action
faultst000dp000	strike 0.0 km, dip 0.0 km	Select
faultst000dp045	strike 0.0 km, dip 4.5 km	Select
faultst000dp075	strike 0.0 km, dip 7.5 km	Select
faultst000dp120	strike 0.0 km, dip 12.0 km	Select
faultst045dp000	strike 4.5 km, dip 0.0 km	Select
faultst045dp075	strike 4.5 km, dip 7.5 km	Select
faultst120dp000	strike 12.0 km, dip 0.0 km	Select
faultst120dp075	strike 12.0 km, dip 7.5 km	Select

Off-Fault Time Series

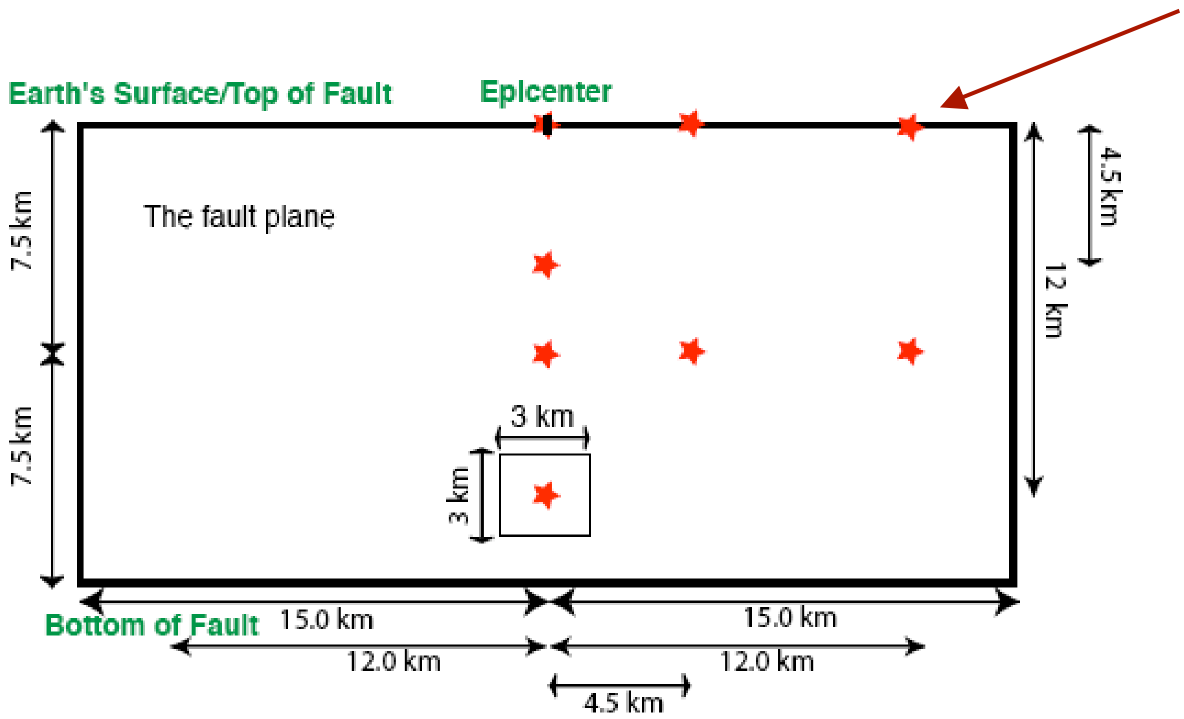
Name	Description	Action
body-005st000dp003	body -0.5 km, strike 0.0 km, dip 0.3 km	Select
body-010st000dp000	body -1.0 km, strike 0.0 km, dip 0.0 km	Select
body-010st000dp003	body -1.0 km, strike 0.0 km, dip 0.3 km	Select
body-020st000dp000	body -2.0 km, strike 0.0 km, dip 0.0 km	Select
body-030st000dp000	body -3.0 km, strike 0.0 km, dip 0.0 km	Select
body-030st120dp000	body -3.0 km, strike 12.0 km, dip 0.0 km	Select
body-030st120dp120	body -3.0 km, strike 12.0 km, dip 12.0 km	Select
body005st000dp003	body 0.5 km, strike 0.0 km, dip 0.3 km	Select
body010st000dp000	body 1.0 km, strike 0.0 km, dip 0.0 km	Select
body010st000dp003	body 1.0 km, strike 0.0 km, dip 0.3 km	Select
body020st000dp000	body 2.0 km, strike 0.0 km, dip 0.0 km	Select
body030st000dp000	body 3.0 km, strike 0.0 km, dip 0.0 km	Select
body030st120dp000	body 3.0 km, strike 12.0 km, dip 0.0 km	Select
body030st120dp120	body 3.0 km, strike 12.0 km, dip 12.0 km	Select

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



File: faultst120dp000 (strike 12.0 km, dip 0.0 km)

Field: v-slip-rate (vertical slip rate)

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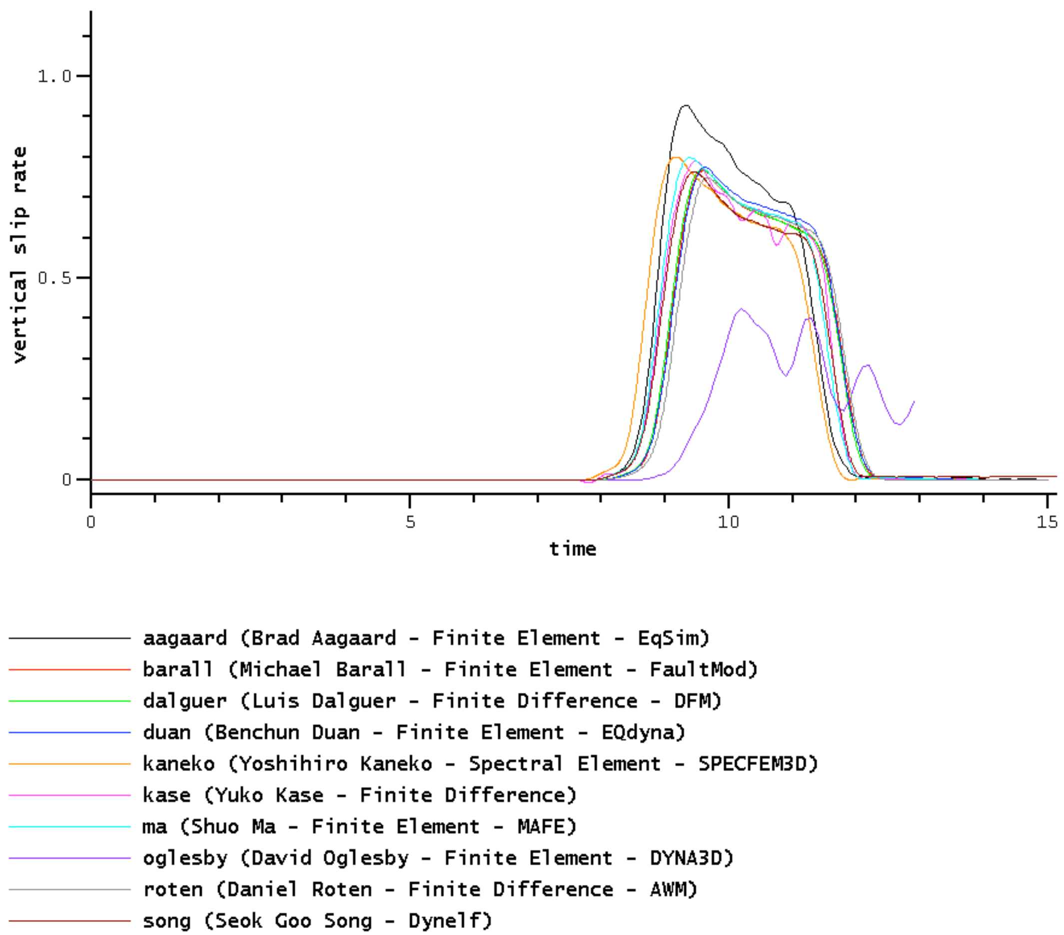
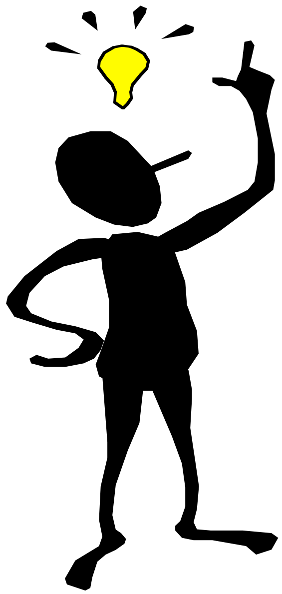
Vertical
Slip rate
(m/s)

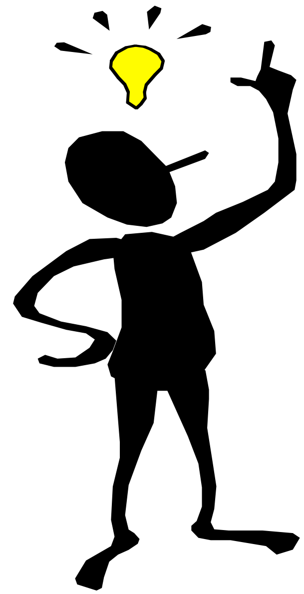
surface
station
12 km
from
hypocenter

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	