Presentation for April 23, 2018
Kellogg West Conference Center, Pomona, CA

A Joint SCEC Workshop:

Rupture Dynamics Code Validation and Comparing Simulations of Earthquake Sequences and Aseismic Slip (SEAS)

Ruth A. Harris (U.S. Geological Survey)
Brittany Erickson (Portland State University)
Junle Jiang (University of California, San Diego)

INTRODUCTION

Welcome!

Thank you very much to Tran and Deborah for making our workshops happen!

Plans for this workshop

Day 1: 10:00 a.m. – 2:15 p.m. Dynamic Rupture Studies
Day 1: 2:30 p.m. – 5:30 p.m. Earthquake Cycle Studies
Day 2: 8:30 a.m. – 3:00 p.m. Earthquake Cycle Studies

*Introduce ourselves

*Learn about exciting dynamic rupture research frontiers

*Learn about ideas for dynamic rupture code validation

*Learn about exciting SEAS research frontiers

*Discuss SEAS benchmark #1 results

*Discuss next steps

Harris April 2018

Day 1 (Monday April 23)

10:00 **Ruth**: Welcome to the workshop, overview of dynamic rupture group activities
10:15 **Everyone** (remote and in-room): Workshop participants self-introductions
10:30 **Thomas Ulrich** (remote): Dynamic viability of the 2016 Mw 7.8 Kaikoura earthquake cascade on weak crustal faults
10:45 **Daniel Roten**: Off-fault deformations and shallow slip deficit from dynamic rupture simulations with fault zone plasticity
11:00 **Michael Barall**: What does validation look like?
11:15 **Brad Aagaard** (remote): Validation: Why getting the same answer may be bad
11:30 **Shuo Ma** (remote): Further validation of the Andrews & Ma (2016) heterogeneous stress model & some preliminary results
11:45 **Luis Dalguer**: GMPEs and dynamic rupture models: Which direction to go for validation

12:00 Lunch

13:15 **Eric Daub**: SCEC dynamic rupture benchmarks in the classroom
13:30 **Ben Duan**: From single-event dynamics to multi-cycle dynamics of geometrically complex faults
13:45 **All**: Group Discussion about dynamic rupture code validation, etc.

14:15 Break

14:30 **Brittany Erickson/Junle Jiang**: Introduction to SEAS activities
15:00 **Nadia Lapusta**: SEAS: on resolution, complexity, and dynamic effects
15:15 **Yoshi Kaneko** (remote): Modeling of the nucleation process of laboratory and crustal earthquakes
15:30 **Ahmed Elbanna**: Coupling spectral boundary integral and volume-based models for high resolution fault zone physics
15:45 **Yuval Tal**: Modeling the rupture process on rough faults during multiple slip events with the mortar finite element method

16:00 Break

16:15 **Jeremy Kozdon**: Discontinuous Galerkin methods for earthquake cycle simulations
16:30 **Kayla Kroll** (remote access): RSQSim modeling and applications
16:45 Discussion
17:30 Adjourn for the day

18:00 Dinner

Day 2 (Tuesday April 24)

07:00 Breakfast

08:30 **Kali Allison**: The effect of shear heating on the earthquake cycle
08:45 **Brittany Erickson**: Time stepping for earthquake cycles with plasticity
09:00 **Pranger Casper Cornelis** (remote): Modelling frictional faults as plastic shear bands in nonlinear media
09:15 **Paul Segall**: FDRA — Fault Dynamics with Radiation damping Approximation: history and capabilities
09:30 **Sylvain Barbot**: The spectrum of rupture styles at subduction zones governed by geometry & rheology of the upper plate
09:45 **Yajing Liu**: Modeling of slow slip events on a non-planar subduction fault
10:00 **Matt Wei**: Numerical simulation of dynamic triggering of slow slip events in California and New Zealand

10:15 Break

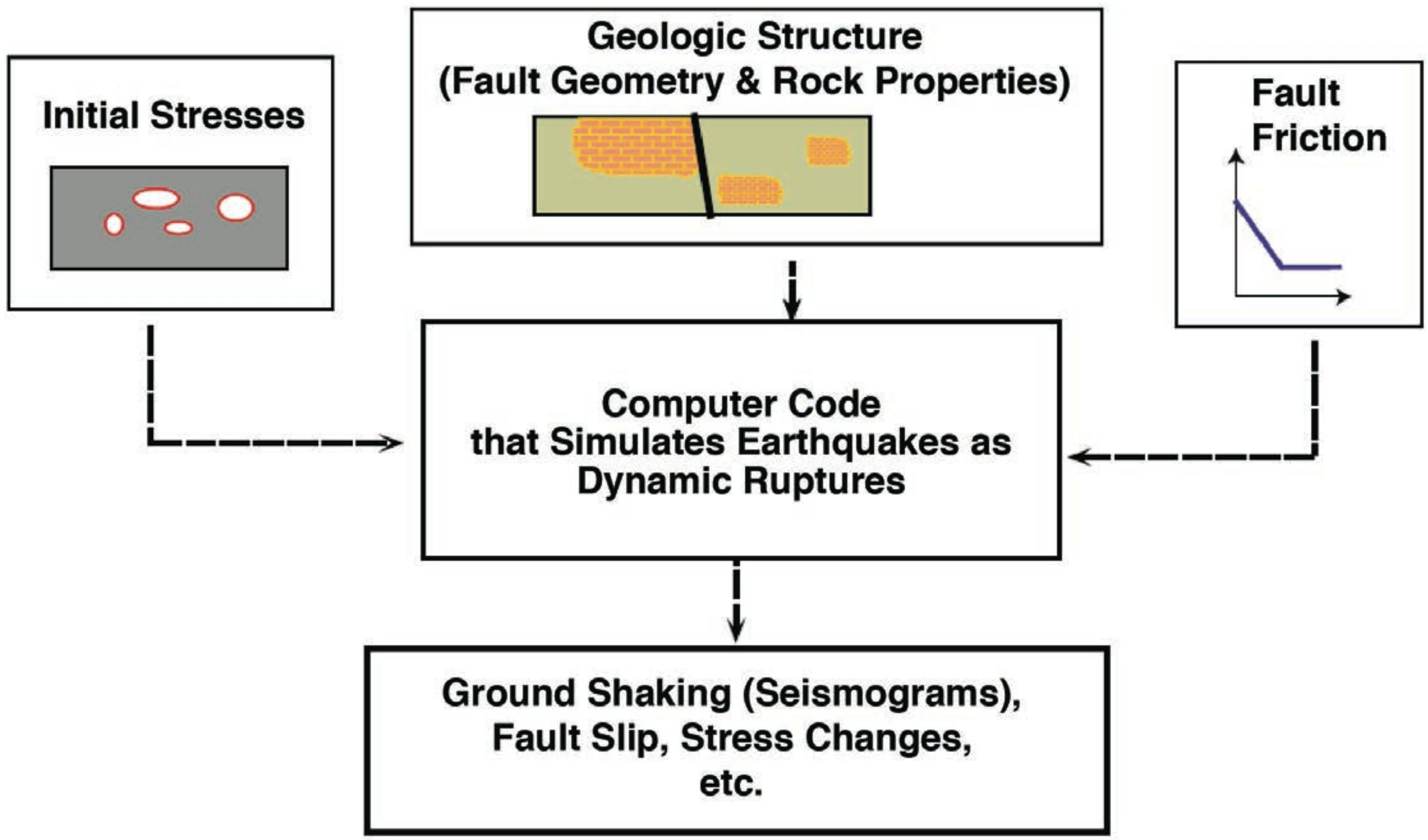
10:30 **Junle Jiang/Brittany Erickson**: Benchmark results and discussions

12:00 Lunch

13:00 **All**: Discussion and future plans

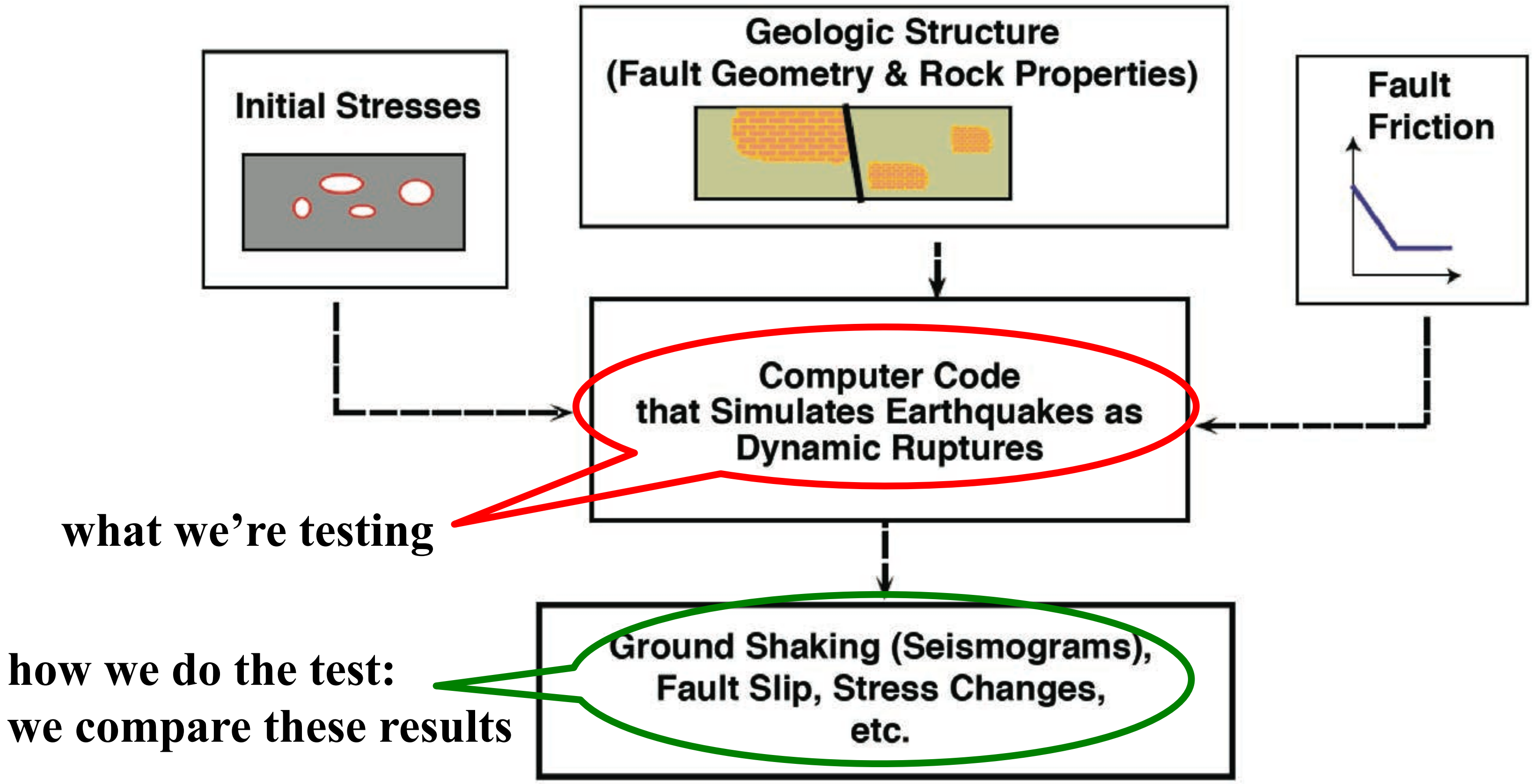
15:00 Adjourn

Ingredients and Results for Dynamic Rupture Simulations



Harris et al., SRL, 2018

What our Dynamic Rupture Code Verification Group Does:
We Test Computer Codes Used to Simulate Earthquakes



Please see our website http://scecdata.usc.edu/cvws

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Goal of our Code Group

Compare and validate the computational methods currently used by SCEC and USGS scientists to simulate (spontaneous) earthquake rupture dynamics and the resulting ground motion

Some Specific Objectives

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

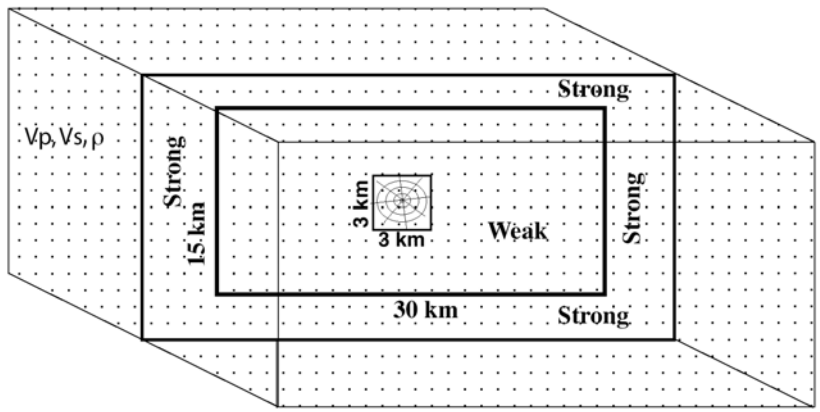
Funding

This project has received funding from SCEC, the USGS, and PG&E

Code Comparison Strategy

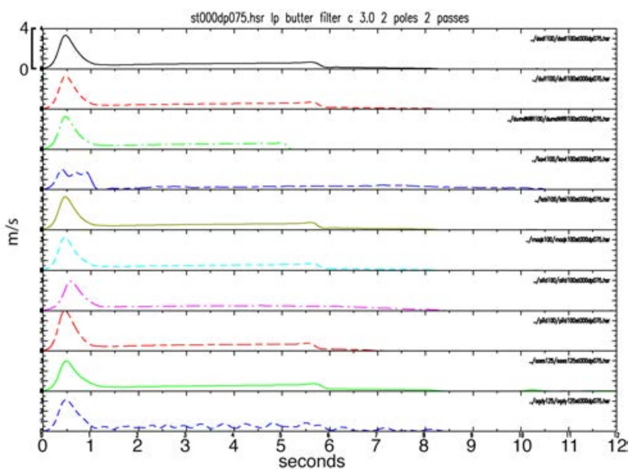
Start simply

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

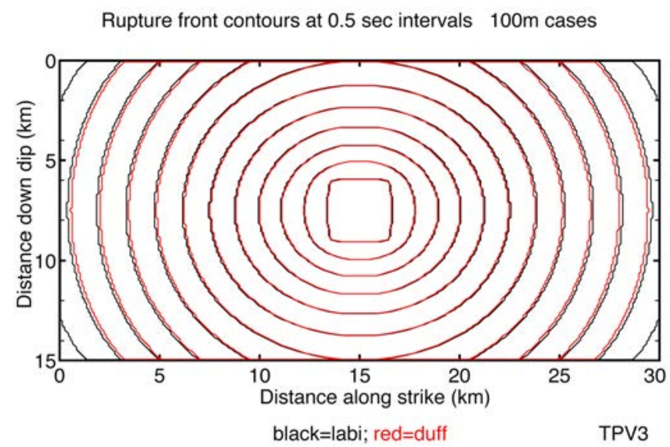


homogeneous initial stresses

slip-weakening friction

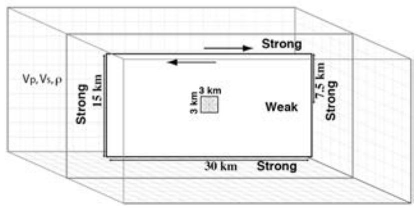


Some Results



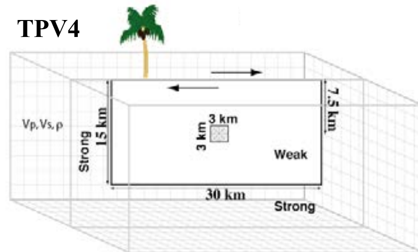
Code Comparison Benchmarks – Incrementally add complexity

TPV3



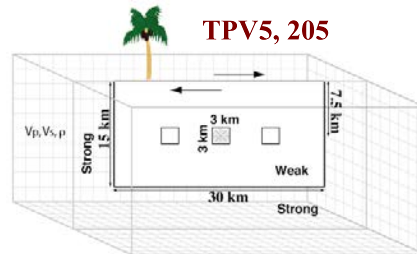
Homogeneous fullspace

TPV4



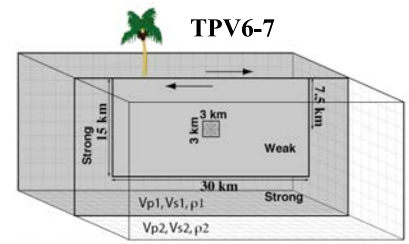
Homogeneous halfspace

TPV5, 205



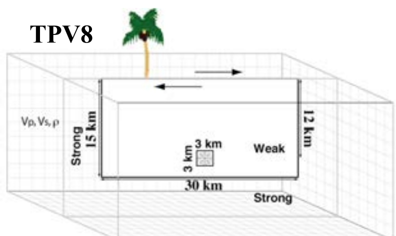
light stress heterogeneity

TPV6-7



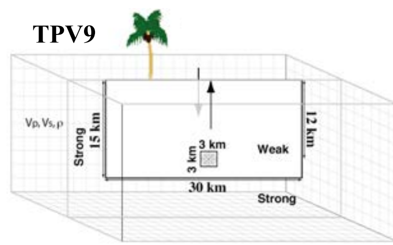
bimaterial

TPV8



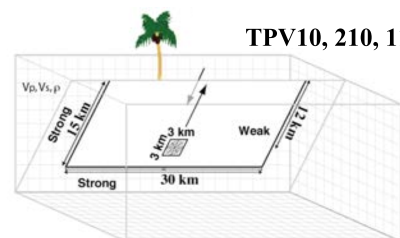
Depth-dependent initial stresses

TPV9



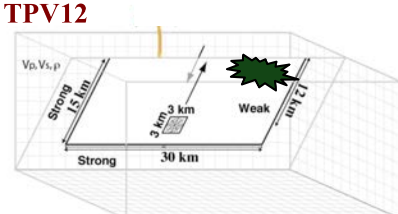
Vertical dip-slip fault, subshear

TPV10, 210, 11



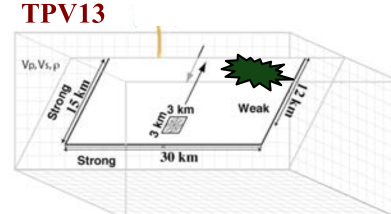
Dipping dip-slip fault, subshear, supershear

TPV12



Dipping dip-slip fault super-supershear, elastic

TPV13



Dipping dip-slip fault super-supershear, plastic

Extreme Ground Motion

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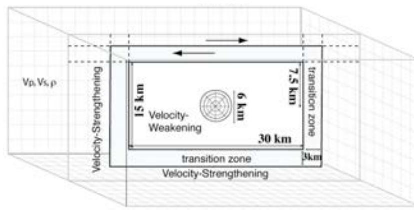
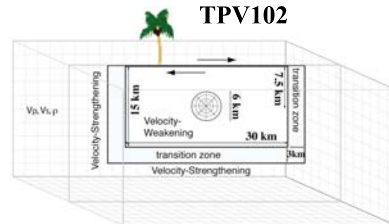
Code Comparison Benchmarks – Incrementally add complexity

TPV101

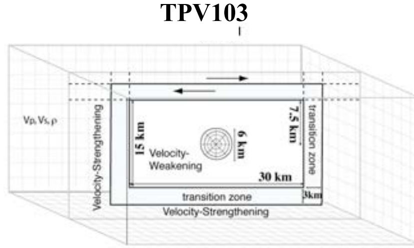


TPV102

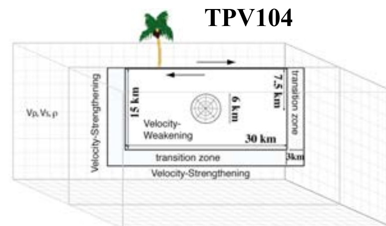


Rate-state friction using an ageing law

TPV103

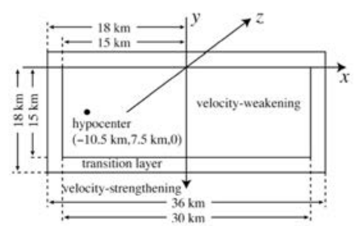


TPV104



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

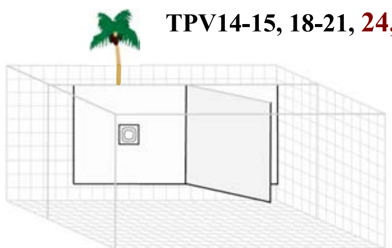
TPV105-2D



Thermal pressurization, rate-state friction, slip-law, strong rate-weakening

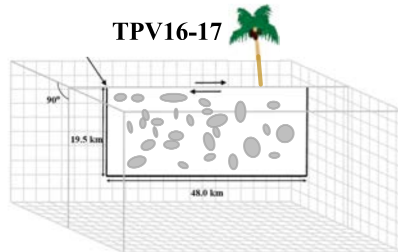
Code Comparison Benchmarks – Incrementally add complexity

TPV14-15, 18-21, 24, 25



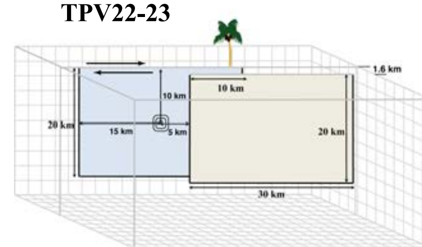
Fault Branches: elastic, viscoplastic

TPV16-17



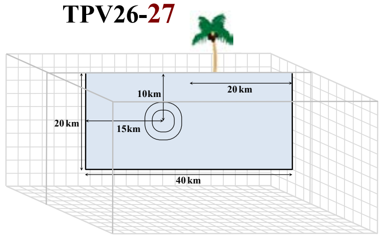
Heterogeneous initial stress

TPV22-23



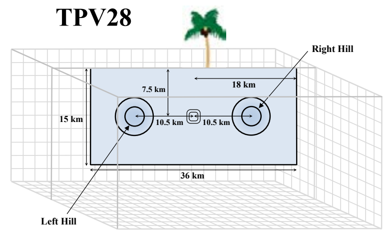
Fault Stepovers

TPV26-27



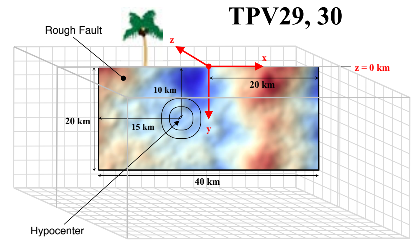
Elastic, Viscoplastic

TPV28



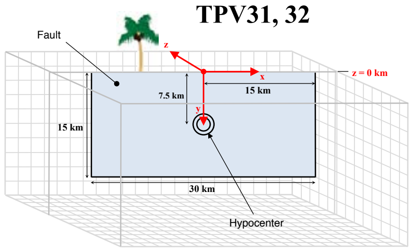
Slightly rough fault

TPV29, 30



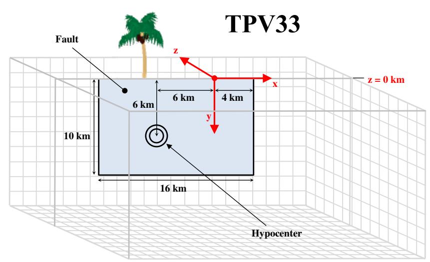
Rough fault: Elastic, viscoplastic

TPV31, 32



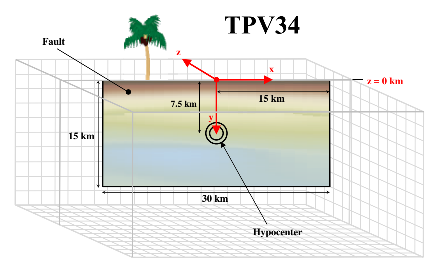
Discontinuous, Continuous 1D horiz. vel. structure

TPV33



1D vertical Velocity structure

TPV34



3D CVM-Hish Velocity structure

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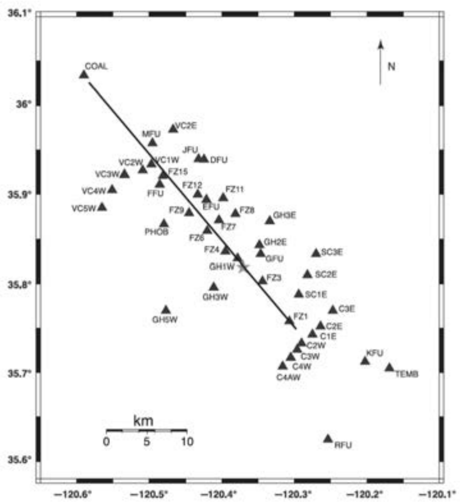
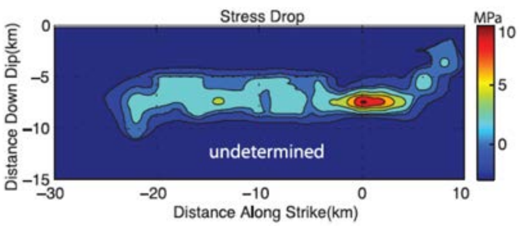
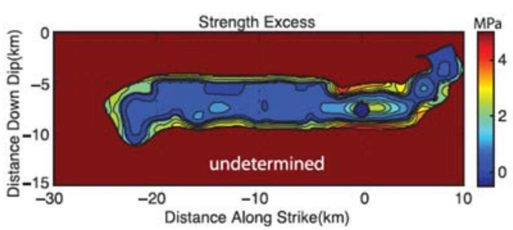
Code Comparison Strategy, Aiming Towards Validation

TPV35: Real Earthquake: 2004 Parkfield M6.0

Rupture on a vertical planar strike-slip fault set in a 3D-ish velocity structure, Elastic, Slip-weakening friction







Ma et al., JGR 2008, Figs. 10, 4

Figure 37. Oblique aerial photograph of the San Andreas fault, town of Parkfield, Stop 7 (marked with red dot), and abundant geomorphic evidence for the presence of an active fault. View is northeastward; photograph taken March 2003.

Rymer et al., GSA Field Guide, 2006, Fig. 37

Results:
Synthetic seismograms matched each other well,
matching real 1 Hz data is hard
(for all EQ's and all codes)

A field guide to the central, creeping section of the San Andreas fault

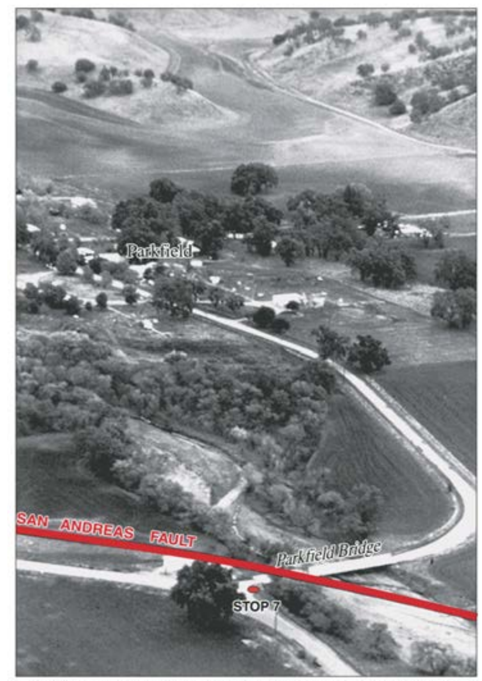


Figure 39. Oblique aerial view of the San Andreas fault and Parkfield (in midground); location of Stop 7 is at bridge (Parkfield Bridge) in lower right. View is northeastward; photograph taken in 1984 by W.H. Bakun.

Rymer et al., GSA Field Guide, 2006, Fig. 39

Many of our Tested Codes (see Table 1 of Harris et al., SRL, 2018)

Code Name	Code Type	Code Availability	Notes
AWP-ODC	finite difference	contact author Roten	
beard	discontinuous Galerkin f.e.	contact author Kozdon	
CG-FDM	finite difference	contact author Zhang	
DFM	finite difference	contact author Dalguer	
DGCrack	discontinuous Galerkin f.e.	contact authors Tago or Cruz-Atienza	
EQdyna	finite element	contact author Duan	
FaultMod	finite element	contact author Barall	
fdfault	finite difference	https://github.com/egdaub/fdfault	
Kase code	finite difference	contact author Kase	
MAFE	finite element	contact author Ma	
PyLith	finite element	https://geodynamics.org/cig/software/pylith	supercedes EqSim
SeisSol	discontinuous Galerkin f.e.	https://github.com/SeisSol/SeisSol/wiki	
SESAME	spectral element		same as SPECFEM3D
SORD	finite difference	contact author Shi	
SPECFEM3D	spectral element	https://geodynamics.org/cig/software/specfem3d	supercedes old SPECFEM3D
WaveQLab3D	finite difference	https://bitbucket.org/ericmdunham/waveqlab3d	

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Our group 2018 SRL article

Harris, R.A., M. Barall, B. Aagaard, S. Ma, D. Roten, K. Olsen, B. Duan, B. Luo, D. Liu, K. Bai, J.-P. Ampuero, Y. Kaneko, A.-A. Gabriel, K. Duru, T. Ulrich, S. Wollherr, Z. Shi, E. Dunham, S. Bydlon, Z. Zhang, X. Chen, S.N. Somala, C. Pelties, J. Tago, V.M. Cruz-Atienza, J. Kozdon, E. Daub, K. Aslam, Y. Kase, K. Withers, and L. Dalguer, **A suite of exercises for verifying dynamic earthquake rupture codes**, Seismological Research Letters, vol. 89, 2018.

2015 Barall Metrics SRL article

Barall, M., and R.A. Harris, **Metrics for comparing dynamic earthquake rupture simulations**, Seismological Research Letters, vol. 86, 223-235, 2015.

Our group 2011 SRL article

Harris, R.A., M. Barall, D.J. Andrews, B. Duan, S. Ma, E.M. Dunham, A.-A. Gabriel, Y. Kaneko, Y. Kase, B.T. Aagaard, D.D. Oglesby, J.-P. Ampuero, T.C. Hanks, and N. Abrahamson, **Verifying a Computational Method for Predicting Extreme Ground Motion**, Seismological Research Letters, vol. 82, 638-644, 2011.

Our group 2009 SRL article

Harris, R.A., M. Barall, R. Archuleta, B. Aagaard, J.-P. Ampuero, H. Bhat, V. Cruz-Atienza, L. Dalguer, P. Dawson, S. Day, B. Duan, E. Dunham, G. Ely, Y. Kaneko, Y. Kase, N. Lapusta, Y. Liu, S. Ma, D. Oglesby, K. Olsen, A. Pitarka, S. Song, and E. Templeton, **The SCEC/USGS Dynamic Earthquake-Rupture Code Verification Exercise**, Seismological Research Letters, vol. 80, 119-126, 2009.

links available on our website **http://scecdata.usc.edu/cvws**

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