Zoom

November 4, 2024

Statewide California Earthquake Center

Dynamic Rupture Group Workshop

Getting to the Surface of the Problem:

A Dynamic Rupture Benchmark for Shallowly-Dipping Faults Near Earth's Surface

Ruth A. Harris

(U.S. Geological Survey)

THANK YOU

Tran and Edric!

Our group uses dynamic rupture simulation codes

to do exciting and innovative science.

This includes our investigations into earthquakes

and how they operate.

How Dynamic Earthquake Rupture Simulations Work

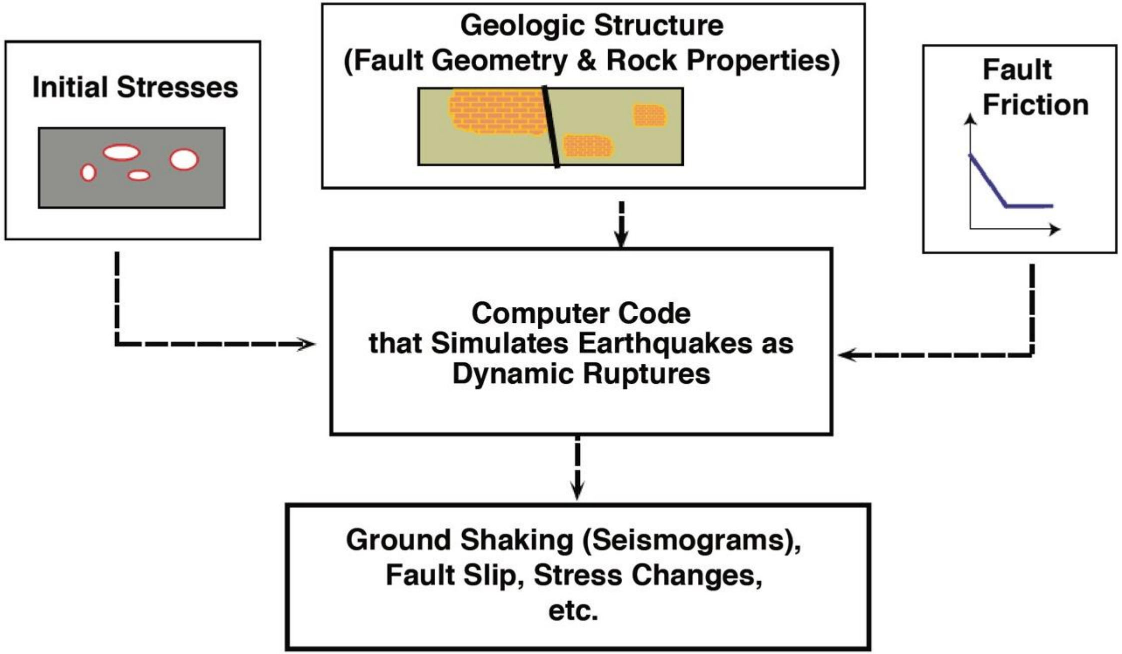
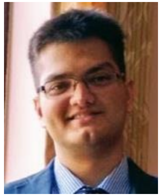
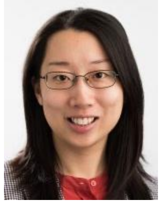


figure from Harris et al., SRL, 2018
(and earlier related Harris publications)

Highly Recommended 2022 Paper Describing How the Simulations Work





Working with Dynamic Earthquake Rupture Models: A Practical Guide

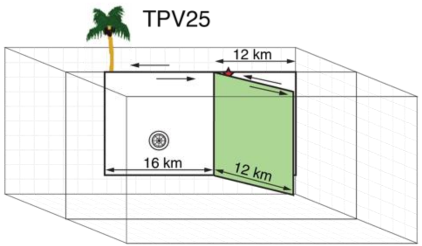
Marlon D. Ramos*[1,2], Prithvi Thakur[1], Yihe Huang[1], Ruth A. Harris[3], and Kenny J. Ryan[2]

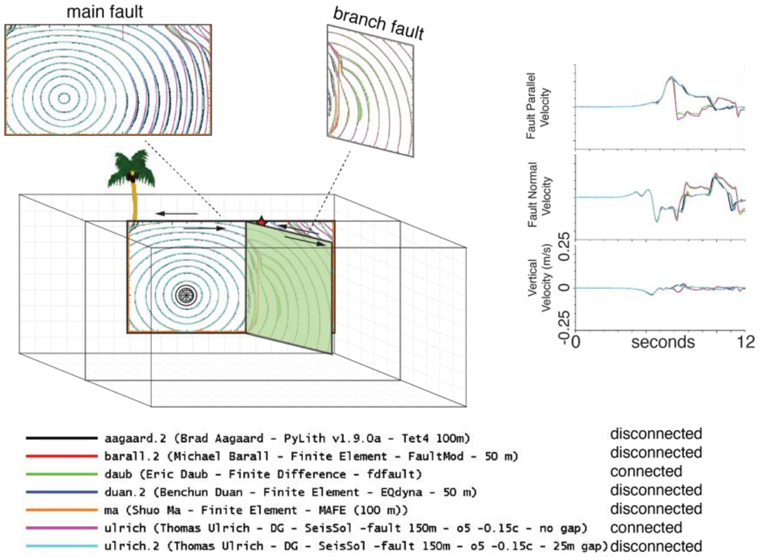
Abstract

Dynamic rupture models are physics-based simulations that couple fracture mechanics to wave propagation and are used to explain specific earthquake observations or to generate a suite of predictions to understand the influence of frictional, geometrical, stress, and material parameters. These simulations can model single earthquakes or multiple earthquake cycles. The objective of this article is to provide a self-contained and practical guide for students starting in the field of earthquake dynamics. Senior researchers who are interested in learning the first-order constraints and general approaches to dynamic rupture problems will also benefit. We believe this guide is timely given the recent growth of computational resources and the range of sophisticated modeling software that are now available. We start with a succinct discussion of the essential physics of earthquake rupture propagation and walk the reader through the main concepts in dynamic rupture model design. We briefly touch on fully dynamic earthquake cycle models but leave the details of this topic for other publications. We also highlight examples throughout that demonstrate the use of dynamic rupture models to investigate various aspects of the faulting process.

Cite this article as Ramos, M. D., P. Thakur, Y. Huang, R. A. Harris, and K. J. Ryan (2022). Working with Dynamic Earthquake Rupture Models: A Practical Guide, *Seismol. Res. Lett.* **93**, 2096–2110, doi: 10.1785/0220220022.

How it works – dynamic earthquake rupture and a fault branch





(star)
isn't DCPP

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

TPV35

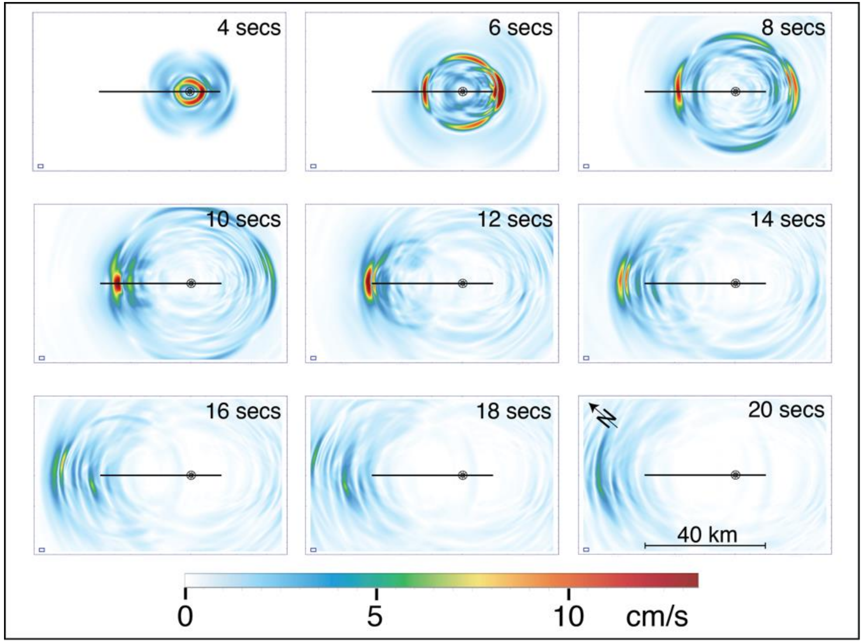


figure from
Harris et al.,
SRL, 2018

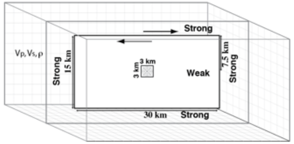
Many of our group's tested dynamic earthquake rupture codes (Table 1 of our group paper, Harris et al., SRL, 2018)

Code Name	Code Type	References	Notes	Code Availability
AWP-ODC	Finite difference	Roten et al., 2016; Dalguer & Day, 2007		contact author Roten
beard	DG finite element	Kozdon et al., 2015		contact author Kozdon
CG-FDM	finite difference	Zhang et al., 2014		contact author Zhang
EqSim	finite element	Aagaard et al., 2001	superseded by PyLith	
DFM	finite difference	Day & Ely, 2002		contact author Dalguer
DGCrack	DG finite element	Tago et al., 2012		contact authors Tago or Cruz-Atienza
EQdyna	finite element	Duan & Oglesby, 2006		contact author Duan
FaultMod	finite element	Barall, 2009		contact author Barall
Fdfault	finite difference	Daub, 2016		https://github.com/egdaub/fdfault
Kase code	finite difference	Kase & Kuge, 2001		contact author Kase
MAFE	finite element	Ma et al., 2008; Ma & Andrews, 2010		contact author Ma
PyLith	finite element	Aagaard et al., 2013		https://geodynamics.org/cig/software/pylith
SeisSol	DG finite element	Pelties et al., 2012; Pelties et al., 2014		https://github.com/SeisSol/SeisSol/wiki
SESAME	spectral element	Galvez et al., 2014	same as SPECFEM3D	
SORD	finite difference	Ely et al., 2009; Shi & Day, 2013		contact author Shi
SPECFEM3D	spectral element	Galvez et al., 2014		https://geodynamics.org/cig/software/specfem3d
SPECFEM3D-old	spectral element	Kaneko et al., 2008	superseded by SPECFEM3D	
WaveQLab3D	finite difference	Duru & Dunham, 2016		https://bitbucket.org/ericmdunham/waveqlab3d

+ new codes we will learn about today

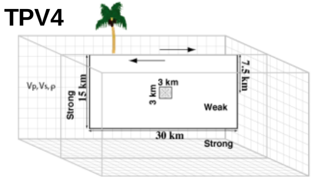
Code Comparison Benchmarks – Incrementally added complexity

TPV3



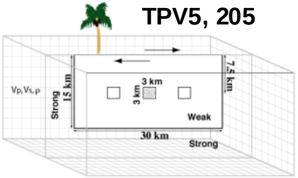
Homogeneous full space

TPV4



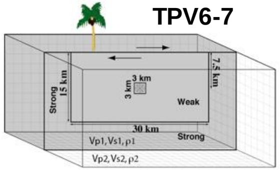
Homogeneous half-space

TPV5, 205



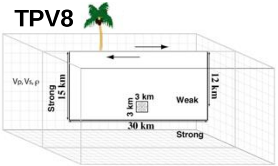
light stress heterogeneity

TPV6-7



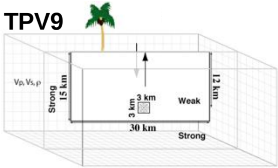
bimaterial

TPV8



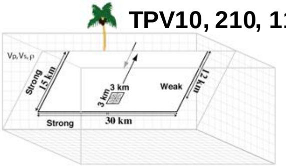
Depth-dependent initial stress

TPV9



Vertical dip-slip fault, subshear

TPV10, 210, 11

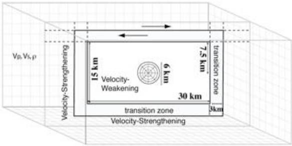


Dipping dip-slip fault, subshear, supershear

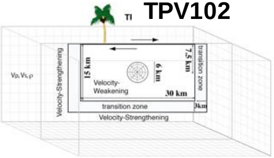
TPV12, 13

Dipping dip-slip fault super-supershear, elastic, plastic

TPV101

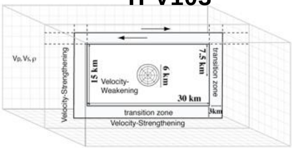


TPV102

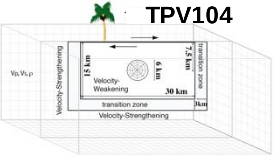


Rate-state friction with ageing law

TPV103

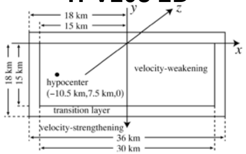


TPV104

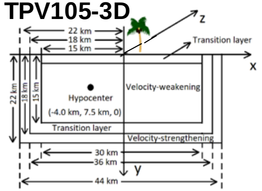


Rate-state friction with slip law with strong rate-weakening

TPV105-2D



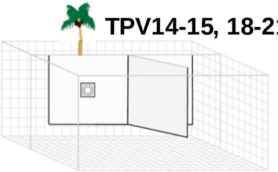
TPV105-3D



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

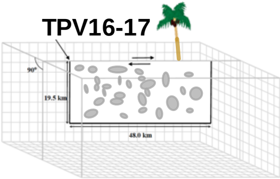
Code Comparison Benchmarks – Incrementally added complexity

TPV14-15, 18-21, 24-25



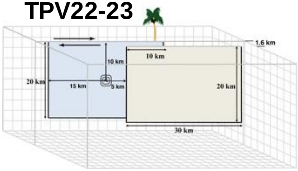
Fault Branches: elastic, plastic

TPV16-17



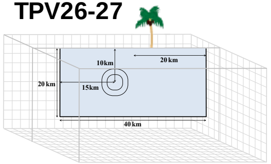
Heterogeneous random initial stress

TPV22-23



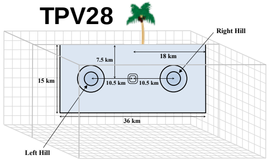
Fault Stepovers

TPV26-27



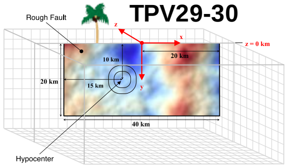
Elastic, Viscoplastic

TPV28



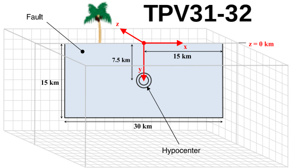
Slightly rough fault

TPV29-30



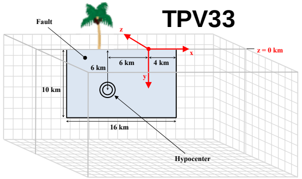
Rough fault: elastic, viscoplastic

TPV31-32



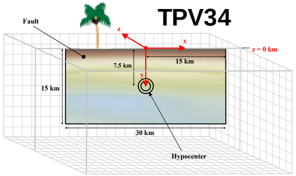
Discontinuous, Continuous
1D horizontal velocity structure

TPV33



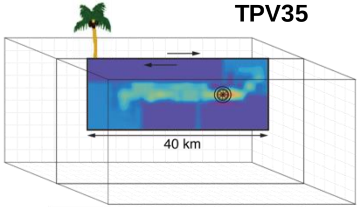
1D vertical velocity structure

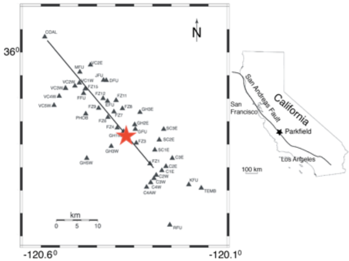
TPV34



3D CVM-Hish velocity structure

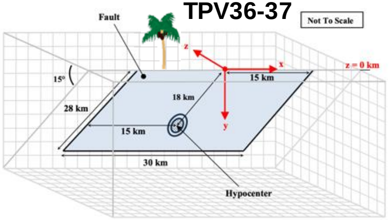
TPV35





2004 Parkfield

TPV36-37



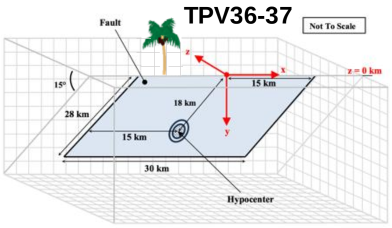
Shallowly dipping fault reaching Earth's surface

New
2024
benchmark

Harris November 2024

New 2024 Benchmarks **TPV36 and TPV37**

Thank you to our modelers!



Shallowly dipping fault reaching Earth's surface

Code	Modeler Teams
drdg3d	Wenqiang Zhang, Yajing Liu, Xiaofei Chen
EQdyna	Dunyu Liu, Ben Duan
FaultMod	Michael Barall
MAFE	Shuo Ma
PyLith	Di Deng, Hongfeng Yang, Suli Yao
SeisSol	Alice Gabriel, Fabian Kutschera, Duo Li, Zihua Niu, David Schneller, Thomas Ulrich

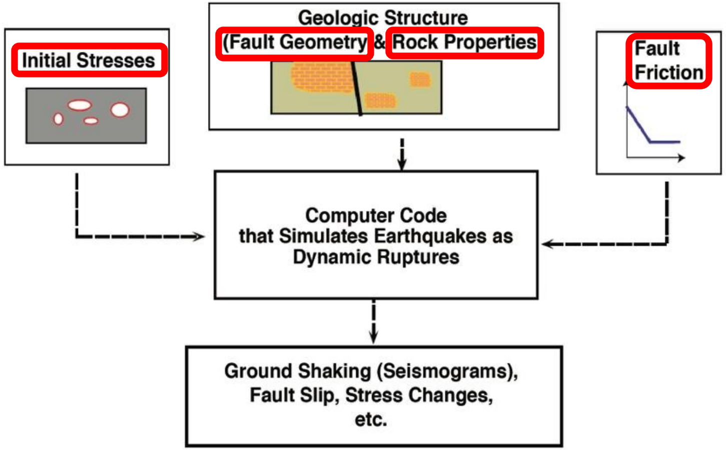
So far, we have successfully tested the codes for a variety of ”ingredients”

** fault geometries **

** friction formulations **

** rock properties **

** initial stress conditions **



And in a suite of SCEC workshops, we investigated the dynamic rupture ingredients.

In November 2018, we examined Ingredient #1, Fault Geometry

In January 2020, we examined Ingredient #2, Fault Friction

In October 2020 we examined Ingredient #3, Rock Properties

In December 2021, we examined Ingredient #4, Stress Conditions

For More Information about our group, including code verification exercises:

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

and our group papers:

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, Seism. Res. Lett., 89(3), 1146-1162, **2018**.

Harris, R.A., M. Barall, D.J. Andrews, B. Duan, E.M. Dunham, S. Ma, A.-A. Gabriel, Y. Kaneko, Y. Kase, B. Aagaard, D. Oglesby, J.-P. Ampuero, T.C. Hanks, N. Abrahamson, Verifying a computational method for predicting extreme ground motion, Seism. Res. Lett., 82(5), 638-644, **2011**.

Harris, R.A., M. Barall, R. Archuleta, E. Dunham, B. Aagaard, J.P. Ampuero, H. Bhat, V. Cruz-Atienza, L. Dalguer, P. Dawson, S. Day, B. Duan, G. Ely, Y. Kaneko, Y. Kase, N. Lapusta, Y. Liu, S. Ma, D. Oglesby, K. Olsen, A. Pitarka, S. Song, E. Templeton, The SCEC/USGS dynamic earthquake rupture code verification exercise, Seism. Res. Lett., 80(1), 119-126, **2009**.

Our next step is to learn more about new codes and new ideas in EQ source mechanics, including *newly modeled earthquakes* which have occurred, *scenarios of future earthquakes*, and how well we might do modeling shallow crustal thrust faulting and subduction zone earthquakes.

We also have opportunities to improve our modeling approaches.

Questions we hope to answer in this workshop include:

1. Are there new computational methods we can use to help us do our work more easily?
2. Can we do o.k. simulating EQ's on shallowly dipping thrust faults near Earth's surface?
3. Is there cool new EQ science happening that we should know about?
4. What are related SCEC and outside groups working on?
5. What should our group do next?

Session 1: Workshop Overview and Introductions

09:00-09:15 Introduction to the Workshop (Ruth Harris)

09:15-09:30 Participant Introductions (All)

Session 2: New Codes Joining Us and Benchmark Results (15-minute live talks including Q&A)

09:30-09:45 Mixed-Flux DG Code (Wenqiang Zhang)

09:50-10:05 MOOSE FARMS (Chunhui Zhao)

10:10-10:50 TPV36 and TPV37 Descriptions and Results (Michael Barall)

10:55-11:10 Lightning Talks - 100-second pre-recorded talks about new science

11:10-11:25 ***Break***

Session 3: New Science Ideas (15-minute live talks including Q&A)

11:25-11:40 Putting 3D dynamic rupture modeling in the context of 3D earthquake cycle simulations (Ben Duan)

11:45-12:00 Earthquake faults, stress and rheology from novel 3D strike-slip geodynamic models (Alice Gabriel)

12:00-12:15 *Group Discussion* (All)

12:15-13:00 ***Break***

13:00-13:15 Where and when does aseismic creep stop rupture propagation? From dynamic rupture simulations to passing probabilities (Julian Lozos)

13:15-13:25 *Group Discussion* (All)

Session 4: Updates from related SCEC groups (7-minute live talks including Q&A)

13:30-13:37 The SEAS Project (Brittany Erickson)

13:42-13:49 The Community Stress Drop Validation Study (Annemarie Baltay)

13:54-14:01 The Dynamic Rupture Code Validation Project (Kyle Withers)

14:06-14:13 The CRESCENT DET group (Alice Gabriel)

14:18-14:33 *Group Discussion* (All)

14:38-14:53 Lightning Talks - 100-second pre-recorded talks about new science

14:53-15:15 ***Break***

Session 5:

15:15-16:00 *Group Discussion - planning our next steps (All)*