**Zoom**

**December 2, 2025**

*Statewide California Earthquake Center*

Dynamic Rupture Group Workshop

# A Workshop to Improve our Understanding of (Coseismic) Fault Friction


*Ruth A. Harris*

*(U.S. Geological Survey)*

**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

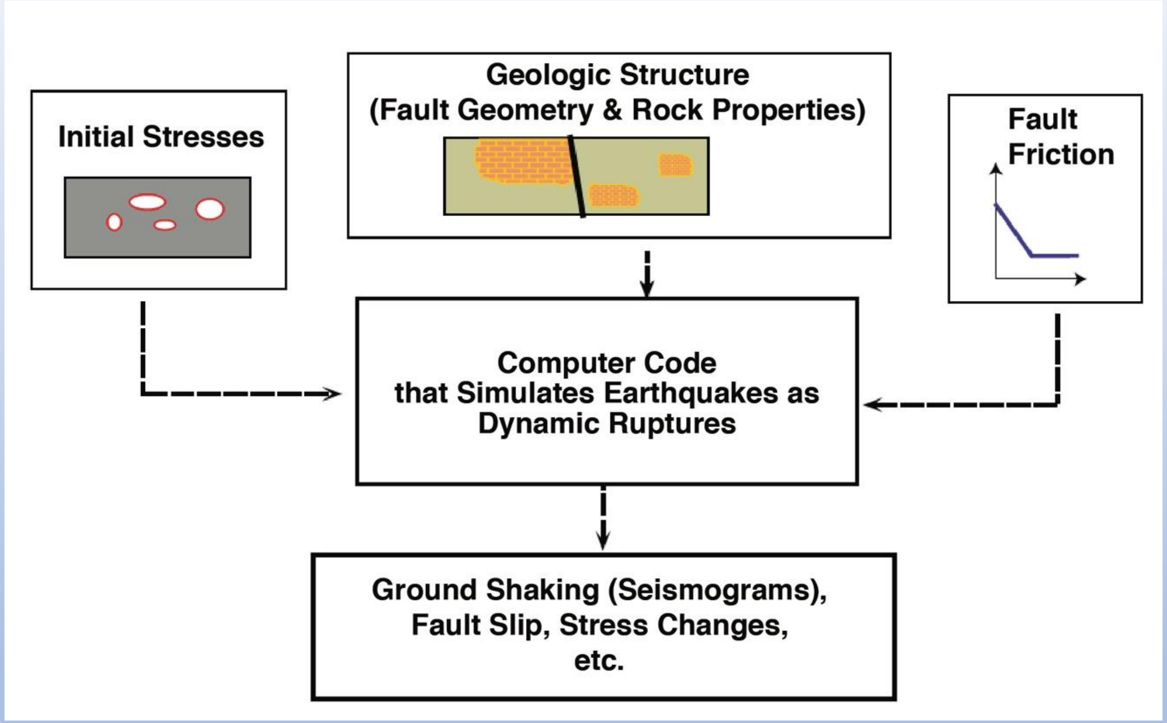



figure from Harris et al., SRL, 2018
(and earlier related Harris publications)

## 2022 Paper Describing How the Simulations Work

# Working with Dynamic Earthquake Rupture Models: A Practical Guide

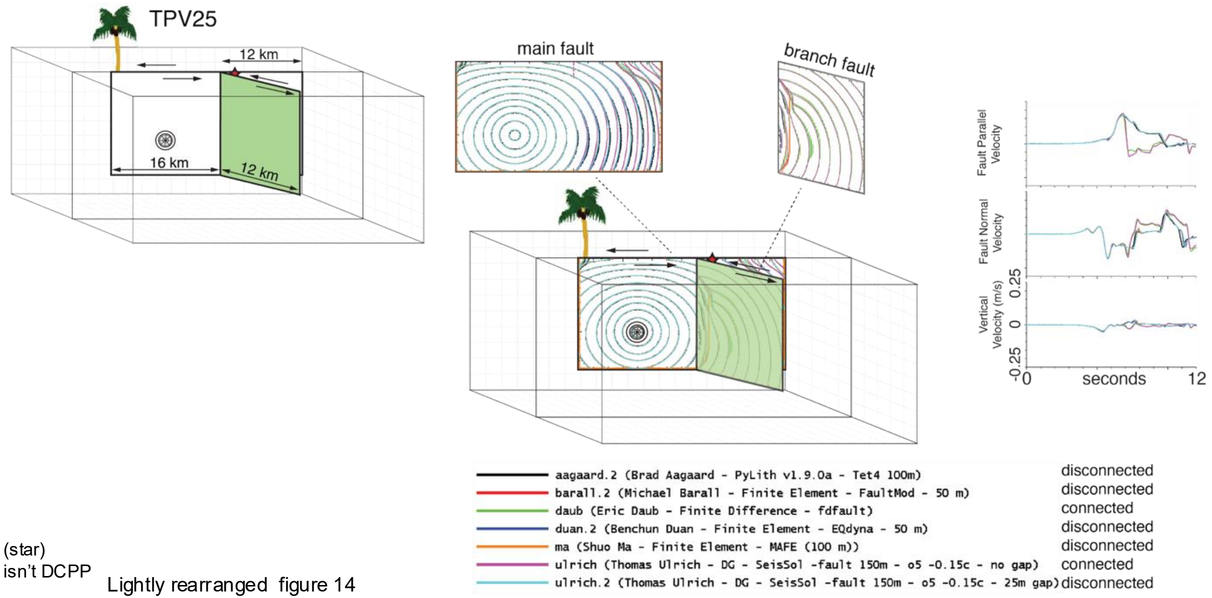
Marlon D. Ramos*[1,2], Prithvi Thakur[1], Yihe Huang[1], Ruth A. Harris[3], and Kenny J. Ryan[2]

**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

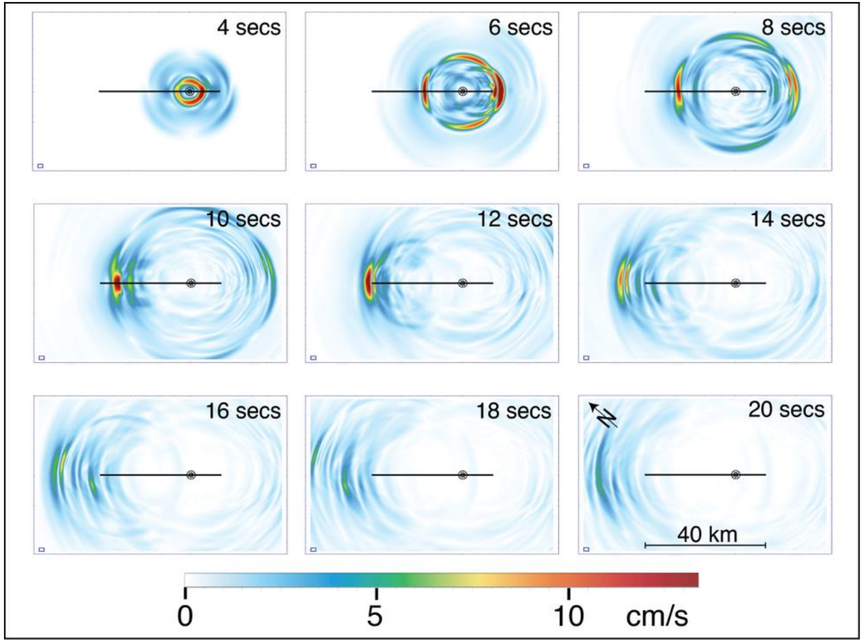
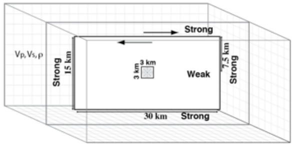



figure from
Harris et al.,
SRL, 2018

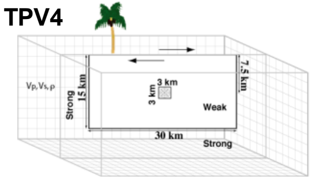
# Many of our group's tested dynamic earthquake rupture codes (updated Table 1 from our group paper, Harris et al., SRL, 2018)

| Code Name | Code Type | References | Notes | Code Availability |
|---|---|---|---|---|
| **AWP-ODC** | Finite difference | Roten et al., 2016; Dalguer & Day, 2007 | | contact authors Roten, Olsen, Cui |
| **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 | | https://code.usgs.gov/esc/faultmod |
| **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 |

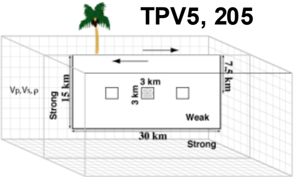
# Code Comparison Benchmarks – Incrementally added complexity

TPV3


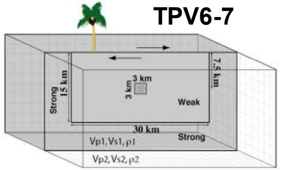
Homogeneous full space

TPV4


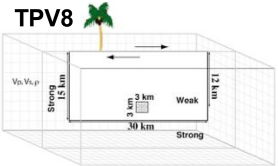
Homogeneous half-space

TPV5, 205


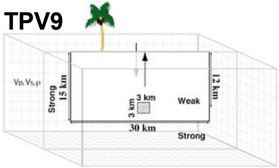
light stress heterogeneity

TPV6-7


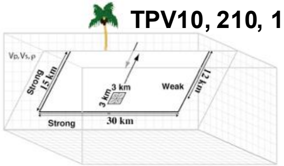
bimaterial

TPV8


Depth-dependent initial stress

TPV9


Vertical dip-slip fault, subshear

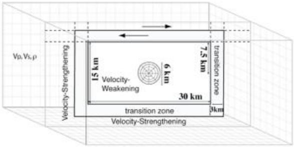
TPV10, 210, 11


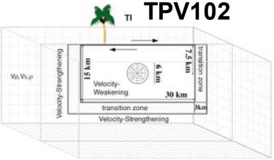
Dipping dip-slip fault, subshear, supershear

TPV12, 13

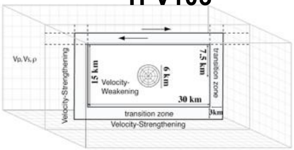

Dipping dip-slip fault super-supershear, elastic, plastic

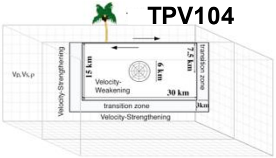
benchmark described in group manuscript in prep.

TPV101


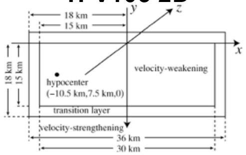

TPV102


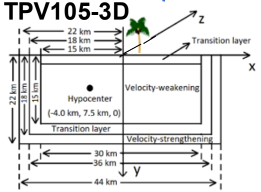
Rate-state friction with ageing law

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

# Benchmarks not encircled used slip-weakening

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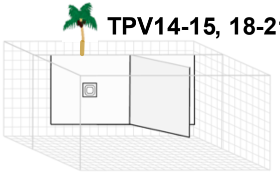
# Code Comparison Benchmarks – Incrementally added complexity

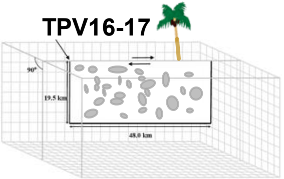


TPV14-15, 18-21, 24-25



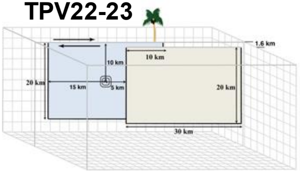
Fault Branches: elastic, plastic

TPV16-17



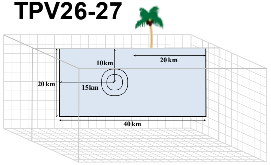

Heterogeneous random initial stress

TPV22-23



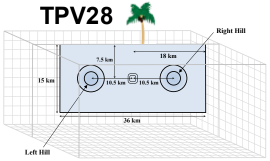

Fault Stepovers

TPV26-27



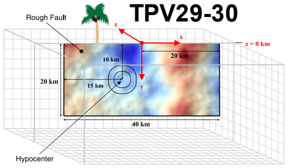

Elastic, Viscoplastic

TPV28



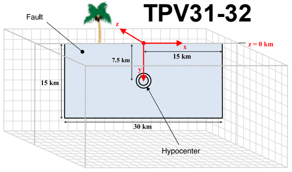

Slightly rough fault

TPV29-30



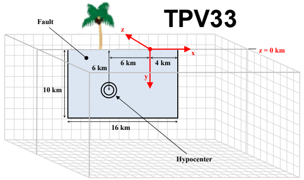

Rough fault: elastic, viscoplastic

TPV31-32



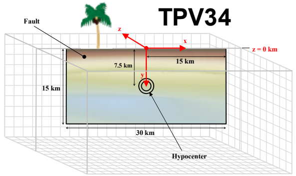

Discontinuous, Continuous
1D horizontal velocity structure

TPV33



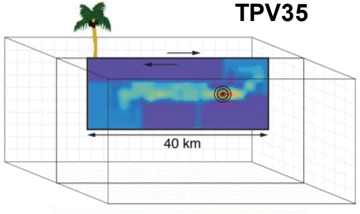

1D vertical velocity structure

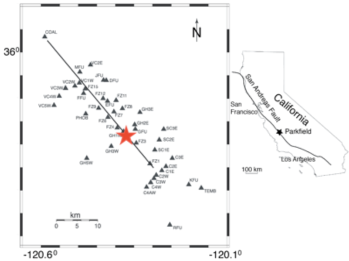
TPV34




3D CVM-Hish velocity structure

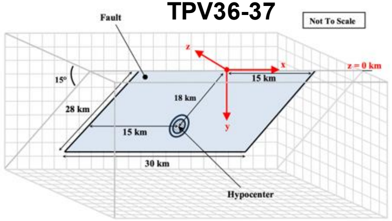
TPV35




2004 Parkfield

TPV36-37




Shallowly dipping fault reaching Earth's surface

2024 benchmark discussed in our group manuscript in preparation

## These benchmarks all used slip-weakening

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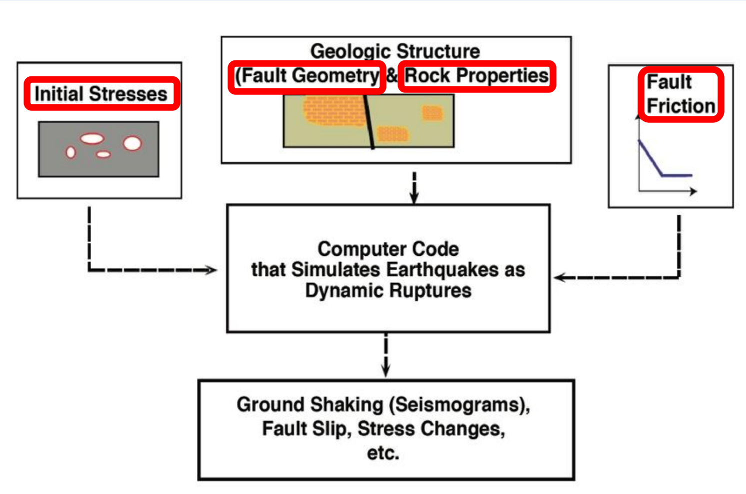
So far, we have successfully tested the codes for a variety of ”ingredients”

** fault geometries **

** friction formulations **

** rock properties **

** initial stress conditions **




(See our group paper Harris et al., SRL, 2018.
We are currently writing a new group paper about our two most recent benchmarks.)

In a suite of SCEC workshops, we investigated the dynamic rupture ingredients in detail

**In November 2018, we discussed Fault Geometry**
**In January 2020, we discussed Fault Friction**
**In October 2020 we discussed Rock Properties**
**In December 2021, we discussed Stress Conditions**

**but we still have so much to learn (!)**

**TODAY WE RETURN TO THE FAULT FRICTION THEME**

**How does Coseismic Fault Friction Work?**

**What is the current thinking**
**about this all-important ingredient of dynamic earthquake rupture?**

**SW (17)**

SW + inelasticity proxy

SW if matches observations

SW with variable dzero

SW + cohesion

**RS(11)**

Lab = RS

RS + temperature effects

RS + thermal weakening

RS + flash heating

RS + fluid and temp effects

Fast-velocity weakening RS (2)

RS with strong weakening

TP with dilatancy hardening

Lab RS + bulk rheology

Multi-mechanism (2)

Melt-producing friction

Physical processes models

Byerlee friction

friction proxies

Rheology model

SW & RS - both too simple – assumes localized FZ

DJA velocity toughening

Keep testing ideas

Questions we hope to answer in this workshop include:

1. What do results from the lab tell us about coseismic fault friction?
2. What do field observations tell us about coseismic fault friction?
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 dynamic rupture group do next?

**Session 1: Workshop Overview and Introductions**

| | |
|---|---|
| 09:00-09:15 | Introduction to the Workshop (Ruth Harris) |
| 09:15-09:20 | Participant Introductions (All, zoom chat) |

**Session 2: Introduction to the Science and New Discoveries** (Talk times include Q&A)

| | |
|---|---|
| 09:25-10:00 | Coseismic fault friction: Recent lab observations and links to natural faults (**Monica Barbery**) |
| 10:05-10:20 | 2025 SCEC rheology workshop and new fault slip results for minerology and fabric (**Alexis Ault**) |
| 10:25-10:40 | Lab results for stress drop and fault slip: near-field stress measurements (**Eric Burdette**) |
| 10:45-11:00 | *Lightning Talks - 100-second pre-recorded talks about new science* |
| 11:05-11:20 | Break |
| 11:25-11:40 | Lab results for fault healing and asperity partitioning (**Jun Young Song**) |
| 11:45-12:00 | Lab results for thermal pressurization on rough faults (**Yuval Tal**) |
| 12:05-12:20 | Fault pseudotachylytes: recent advances and open questions (**Eric Ferre**) |
| 12:25-13:00 | Break |
| 13:05-13:20 | Lab results for strain and conductivity due to fault formation in stepovers (**Sara Beth Cebry**) |
| 13:25-13:40 | Evolution of fault strength in granite under hydrothermal conditions (**Tamara Jeppson**) |
| 13:45-14:00 | Group Discussion |
| 14:05-14:20 | *Lightning Talks - 100-second pre-recorded talks about new science* |
| 14:20-14:40 | Break |

**Session 3: Updates from related groups**

| | |
|---|---|
| 14:40-14:55 | CRESCENT - 3D fully coupled earthquake and tsunami benchmarks (**Fabian Kutschera**) |
| 15:00-15:07 | SCEC SEAS Project (**Valère Lambert**) |
| 15:12-15:19 | SCEC Community Stress Drop Validation Study (**Rachel Abercrombie/Annemarie Baltay**) |

**Session 4:**

| | |
|---|---|
| 15:24-16:00 | *Group Discussion and planning our next steps (**All**)* |