Kellogg West Conference Center
January 8, 2020

SCEC Dynamic Rupture TAG

The 2019-2020 Ingredients Workshop:

Fault Friction

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Michael Barall (Invisible Software)

Our group uses dynamic rupture simulation codes to examine how earthquakes work.

So far, we have successfully tested these codes for a variety of
** fault geometries **
** friction formulations **
** initial stress conditions **
rock properties
(See our group paper Harris et al., SRL, 2018)

We have demonstrated that we can simulate dynamic earthquake rupture in a wide range of settings.

But, are we using the appropriate assumptions (ingredients) for our simulations?

That is the purpose of this workshop:
Investigate Ingredient #2: Fault Friction

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How Dynamic Earthquake Rupture Simulations Work

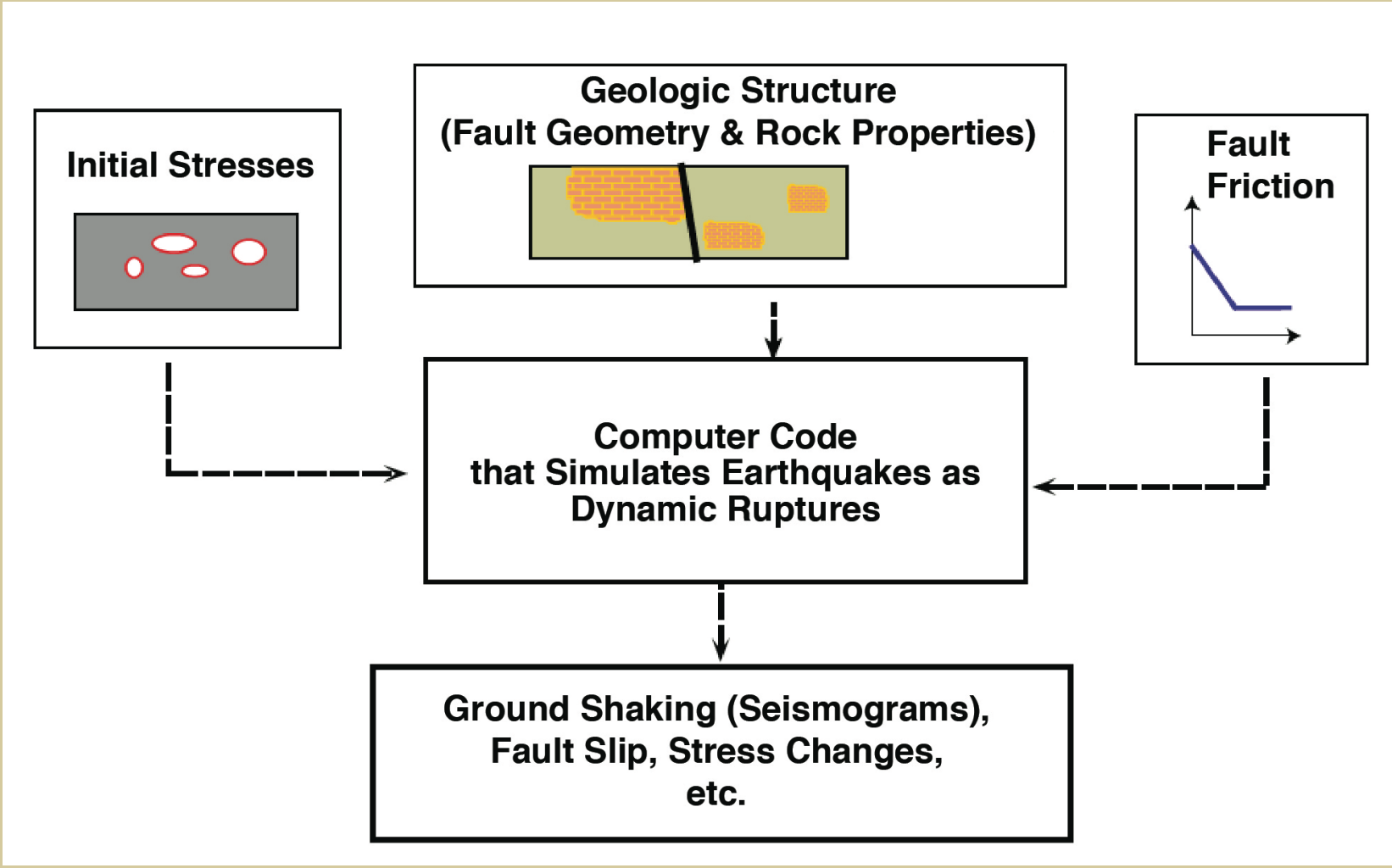

figure from Harris et al., SRL, 2018
(and earlier related Harris publications)

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List of many of our group's tested dynamic earthquake rupture codes
(Table 1 of 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EqSim	finite element	Aagaard et al., 2001	superseded by PyLith	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

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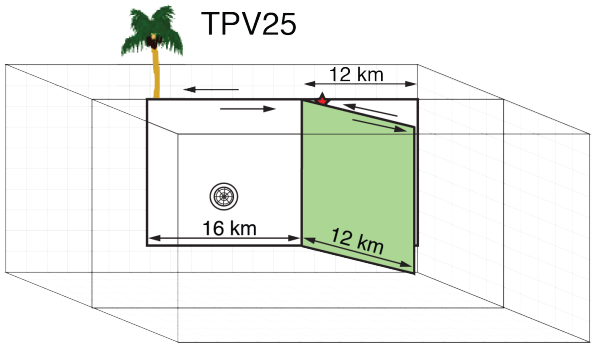
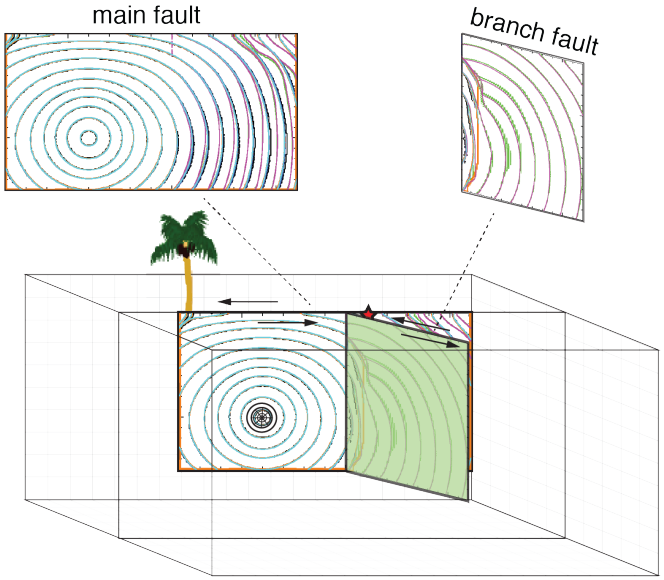
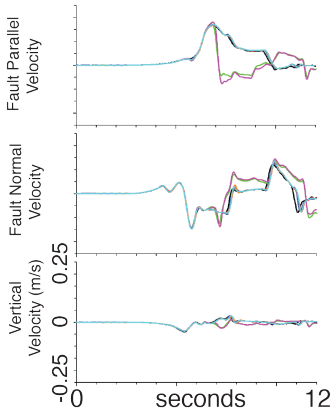
How it works – dynamic earthquake rupture and a fault branch







aagaard.2 (Brad Aagaard - PyLith v1.9.0a - Tet4 100m)	disconnected
barall.2 (Michael Barall - Finite Element - FaultMod - 50 m)	disconnected
daub (Eric Daub - Finite Difference - fdfault)	connected
duan.2 (Benchun Duan - Finite Element - EQdyna - 50 m)	disconnected
ma (Shuo Ma - Finite Element - MAFE (100 m))	disconnected
ulrich (Thomas Ulrich - DG - SeisSol -fault 150m - o5 -0.15c - no gap)	connected
ulrich.2 (Thomas Ulrich - DG - SeisSol -fault 150m - o5 -0.15c - 25m gap)	disconnected

Lightly rearranged figure 14
from Harris et al., SRL, 2018

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Simulated Seismic Waves at Earth's surface produced by a 2004 M6 Parkfield earthquake rupture simulation

TPV35

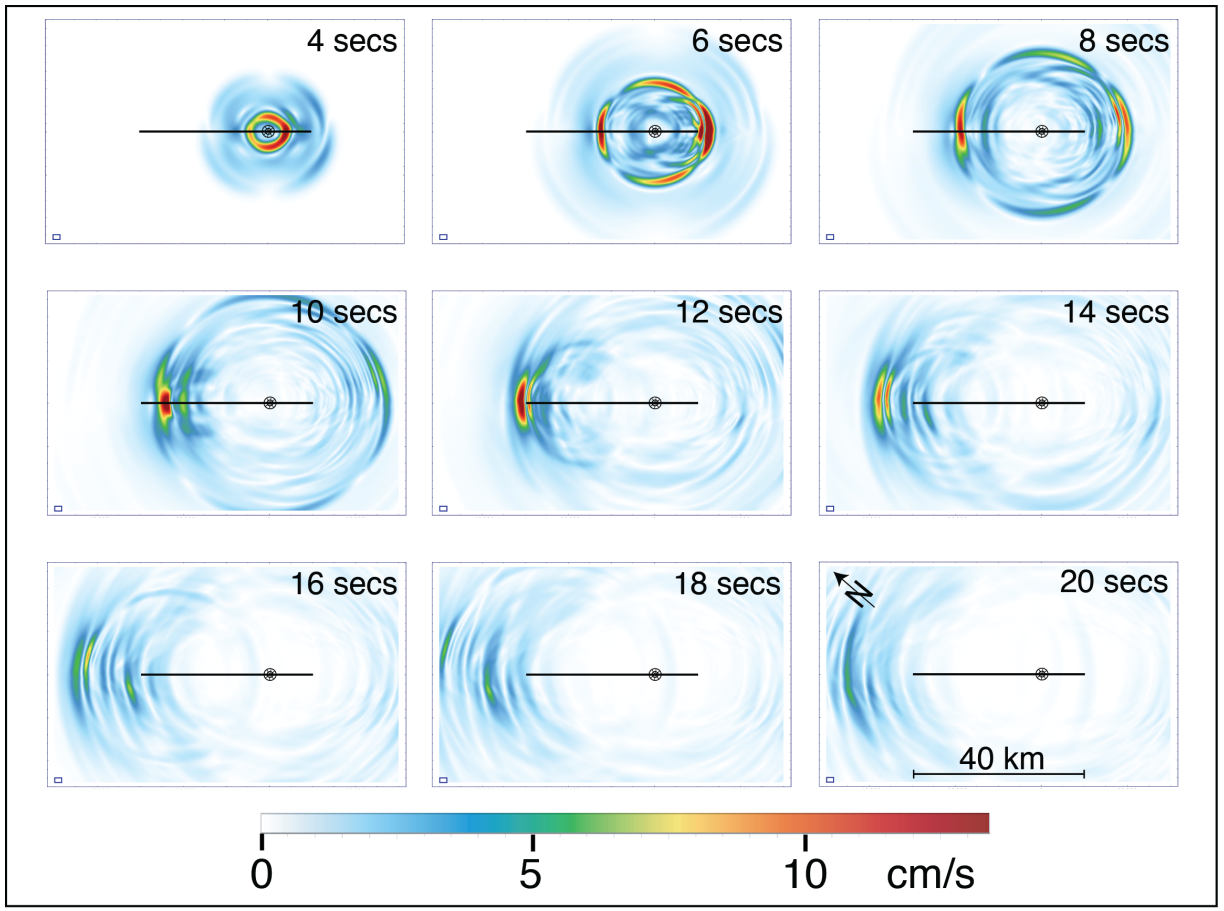

figure from
Harris et al.,
SRL, 2018

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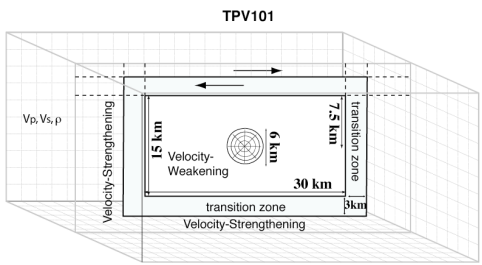
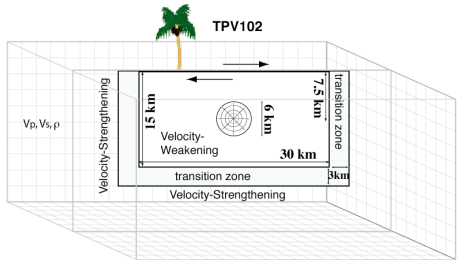
Code Comparison Benchmarks – Testing Fault Friction Implementations

TPV101

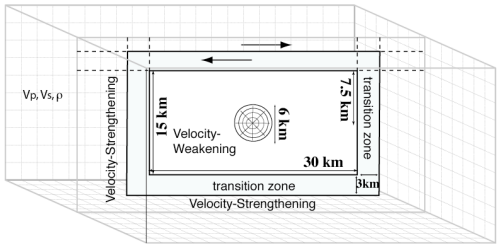


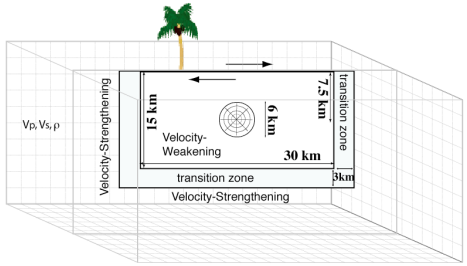


TPV102

Rate-state friction using an ageing law

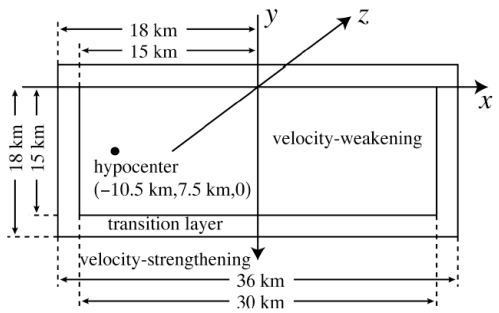
TPV103





TPV104

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



TPV105-2D

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

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

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

and our group's 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**.

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Today's Workshop – How to Choose the Fault Friction Ingredient

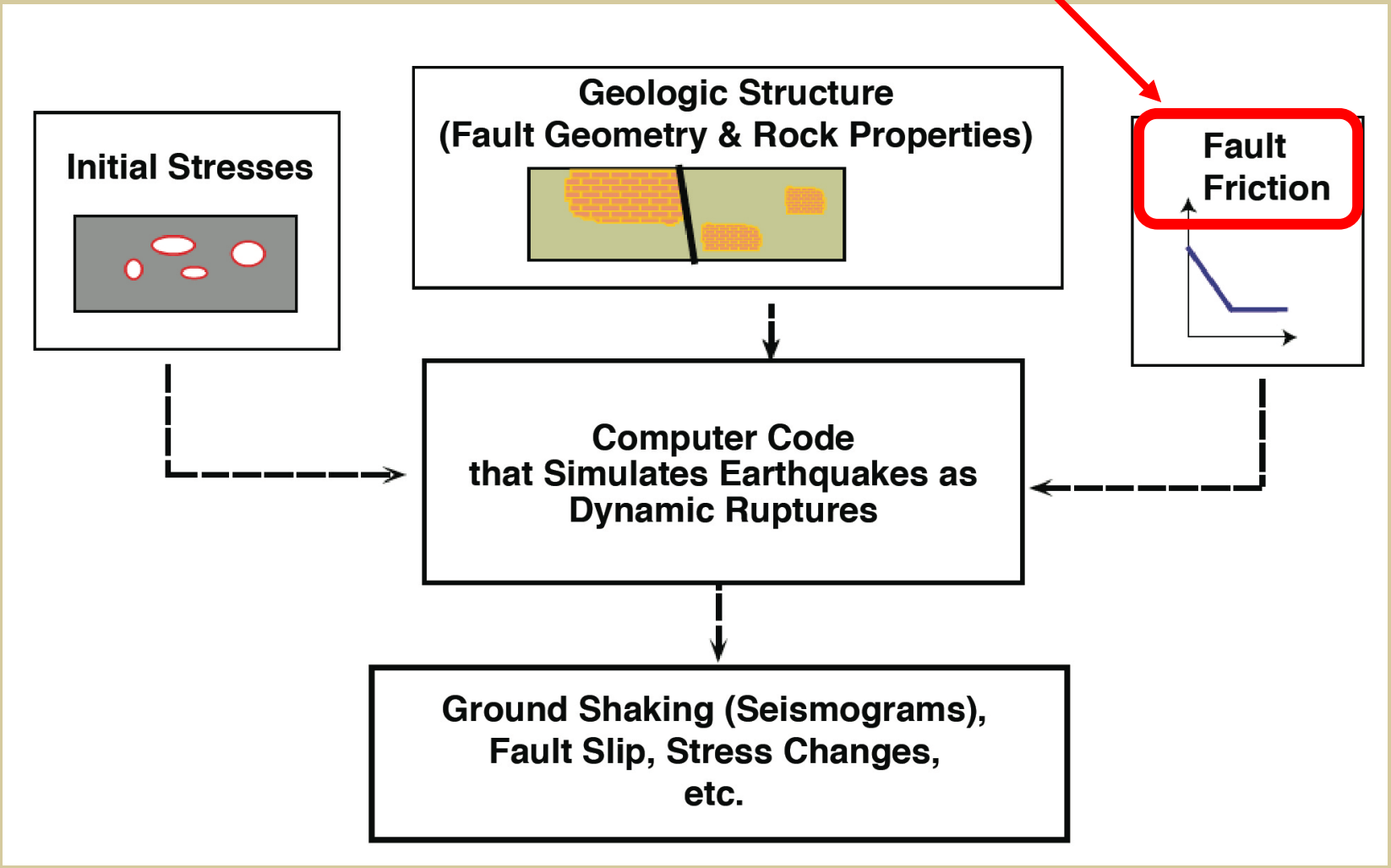

figure from Harris et al., SRL, 2018
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	SCEC Dynamic Rupture Fault Friction Workshop January 8, 2020	
09:00	Welcome and Overview of Workshop Objectives, Introductions	Ruth Harris
	Session 1: Views of Coseismic Friction from the Lab and Field	
09:20	Overview, friction in the lab and field	Fred Chester
09:45	Thermal pressurization in laboratory experiments	Nir Badt
10:05	Insights from deep drilling – case studies	Tamara Jeppson
10:25	Discussion	All
10:45	Break	
11:00	The frictional strength of rocks before, during, and following earthquakes: Insights from the field and lab experiments	Noah Phillips
11:20	Recent lab observations concerning stability of hydraulically isolated faults	David Lockner
11:40	Discussion	All
12:00	Lunch	
	Session 2: Views of Coseismic Friction from the Lab, Field, and Modeling	
13:10	Constraining physical conditions for the low-stress, low-heat operation of mature faults	Valere Lambert
13:30	Probing frictional properties on seismogenic faults with constraints from near-field data	Hongfeng Yang
13:50	Update – dynamic rupture code validation project Update - surface rupture project	Kyle Withers Christine Goulet
14:15	Discussion	All
15:10	Break	
	Session 3: Dynamic Rupture Simulations and Friction – Current Practice	
15:30	Overview: Friction currently used in dynamic rupture simulations	Eric Dunham
15:55	Friction law and level matter in dynamic ruptures of earthquake gates	Ben Duan
16:15	Dynamic rupture simulations of recent earthquakes	Alice Gabriel
16:35	**Discussion**	All
17:30	**Adjourn**	

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Some questions to consider:

What is (are) the most appropriate assumptions about coseismic fault friction mechanism(s) for dynamic rupture modeling applications?

Are there any coseismic fault friction ideas that can be disproved, due to incompatibility between experimental or computational simulations and field observations?

Is coseismic fault friction EQ-magnitude dependent?

Is coseismic fault friction depth-dependent?

Is coseismic fault friction tectonic-setting dependent?

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