Final Report

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March 1, 2017 Workshop
Rupture Dynamics Code Validation Workshop
(SCEC Project 16184)

Co-Principal Investigators:

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The SCEC Rupture Dynamics Code Validation Workshop was held March 1, 2017, at SCEC Headquarters on the campus of the University of Southern California, in Los Angeles. A total of 38 people participated, including 23 in the meeting room and 15 remote-access. This year our workshop attendees, both remote and in-person, included scientists from five countries (Germany, Japan, New Zealand, Switzerland, U.S.A.). More than one-half (20) of our workshop participants were either students or postdocs. Many thanks to Tran Huynh and her team for all of their work that helped make this workshop happen.

The workshop agenda and participant list are on the last page of this report.

Ruth Harris (U.S. Geological Survey) introduced the SCEC workshop to the participants, and explained what our SCEC/USGS Dynamic Rupture Code group does to test computer codes that simulate earthquakes as spontaneous ruptures, how we do this work, and why we do this work. Harris then summarized the wide range of spontaneous rupture code benchmark exercises performed by the group to date. These benchmarks enable the codes to be tested for their flexibility in modeling various earthquake-source scenarios, including variations in fault geometry, variations in fault friction, variations in initial stress conditions on and off the faults, and variations in off-fault rock structure (e.g., see Harris, PAGEOPH, 2004, and Harris et al., SRL, 2009 for the framework). She next showed where our group currently is in its scientific investigations, and mentioned the group's goals for the rest of 2017, including the code-validation work proposed for 2017. Following this introduction to the code comparison/validation project, the workshop attendees, both remote and in-person, introduced themselves.

The rest of the workshop consisted of an intellectually stimulating selection of science talks, discussions of the benchmark assignment that had been completed by the SCEC/USGS code-comparison group members in preparation for this March 2017 workshop, an introduction to the 2004 Parkfield earthquake, models for this earthquake and its recorded data, and discussions about proceeding with code validation. Please note that there is also a separate report to SCEC that describes the recent year's progress of the SCEC/USGS dynamic rupture code comparison group (SCEC project 16056).

In the second talk of the morning, postdoc Betsy Madden (Ludwig Maximilians-Universitat, Munich), presented an overview of the modeling that LMU, Munich lead P.I., postdocs and students, who are members of the Dynamic Rupture Code group, have conducted using their code, SeisSol. She started with a description of the flexibilities of the SeisSol code itself, then showed that the simulations using the code span a wide range of earthquake investigations and include studies of geometrically complex faults, complex velocity structures, and in addition, tsunami modeling. She presented detailed overviews of dynamic rupture simulations of the 1992 Landers earthquake and the great 2004 Sumatra earthquake.

For the third talk of the morning, Dynamic Rupture Code Group member Brad Aagaard (USGS) introduced his refurbished 3D finite-element code, PyLith that is anticipated to be ready for use by the community in the summer of 2017. He also highlighted and discussed modeling frameworks and strategies implemented within CIG, the NSF-funded Computational Infrastructure for Geodynamics.

For the fourth talk of the morning, the workshop participants learned about the 2004 M6 Parkfield earthquake, and a one-code validation exercise conducted by Dynamic Rupture Code Group member Arben Pitarka (Lawrence Livermore National Laboratory) testing if he was able to match the Parkfield time-series data with dynamic rupture models. He pointed out where there might be challenges in using dynamic rupture simulations to match seismic time-series data in general, and he presented his models for the 2004 M6 Parkfield earthquake source. This theme of time-series data being difficult to impossible to match with dynamic (or kinematic) rupture simulations continued throughout the rest of the workshop.

This concluded the morning session.

The first talk of the afternoon was by Dynamic Rupture Code Group member Shuo Ma (San Diego State University). Shuo presented the details of his 2004 M6 Parkfield earthquake spontaneous rupture model, that was published in Ma et al. [2008]. This is the model that was used for the group's current TPV35 benchmark exercise, and Shuo described the initial conditions for the model, including the initial stress assumptions on the fault, and the 3D velocity structure. He also described how this model was tested using geodetic data that were not used in the original dynamic rupture simulation efforts. Shuo presented two possible spontaneous rupture models for the M6 2004 Parkfield earthquake, both of which were based on a kinematic source inversion for that earthquake by Custodio et al. [2005]. Shuo noted that his favored spontaneous rupture model, which is what was used for our Dynamic Rupture Code Group's TPV35, is consistent with the idea that the 2004 Parkfield earthquake was physically confined in depth extent, and did not coseismically reach the Earth's surface.

The second talk of the afternoon was by Dynamic Rupture Code Group member Michael Barall (Invisible Software), who showed the results of the code-group benchmark exercise, TPV35, which was based on Shuo Ma's [Ma et al., 2008] favored 2004 M6 Parkfield earthquake spontaneous-rupture model. Michael noted that 8 of the 9 codes participating in the benchmark exercise produced results with excellent agreement among the codes, as demonstrated via both qualitative and quantitative [Barall and Harris, 2015] metrics. He also showed however that we have some challenges ahead if we are contemplating matching time-series data. This was demonstrated by clear mismatches between the simulations and the velocity time-series data. To add to the challenge, he also showed clear mismatches among the velocity time-series data themselves, that he had obtained from two different sources. This then led to a discussion about how these two sets of data had been processed, and what the best sources might be from which to obtain data for future code validation work. Please see our group project report 16056, our SCEC website scecdata.usc.edu/cvws, and in particular, Michael's workshop presentation *http://scecdata.usc.edu/cvws/download/mar1_2017/Barall_TPV35_Results_v09.pdf* for more information about this dynamic-rupture code-comparison benchmark exercise.

In the third talk of the afternoon, Dynamic Rupture Code Group member (and student) Kangchen Bai (Caltech) presented his work simulating earthquakes rupturing multiple strike-slip faults. He focused on the particular case of an earthquake jump between strike-slip faults. He showed that the likelihood of an earthquake jumping across a fault stepover is related to a number of factors, including the depth extent of the faults.

In the fourth talk of the afternoon, Dynamic Rupture Code Group member Yoshi Kaneko (GNS Science, New Zealand) introduced the group to the 2016 M7.8 Kaikoura, New Zealand earthquake. This impressive event ruptured the earth's surface along at least 180 km, and involved at least 12 major fault segments. The maximum observed surface slip was at least 12 m, and the nearby subduction zone also participated, although apparently over a smaller region than was involved in the multi-fault rupture closer to the Earth's surface. He also showed his kinematic rupture simulations of this earthquake that he has been working on using the code SPECFEM3D, and demonstrated that his results appear to show re-rupture of the Kekerengu fault during the earthquake.

During the discussion time of the workshop at the end of the day, Dynamic Rupture Code Group member Luis Dalguer (swissnuclear, Switzerland) and Christine Goulet (SCEC) made presentations. Luis mentioned that in May 2018 there will be a workshop about using empirical predictions (Ground Motion Prediction Equations) along with dynamic and kinematic rupture simulations, for application to nuclear power plant earthquake-resilience. Christine talked about dynamic rupture code validation in general, and procedures that the dynamic rupture group should consider, based on successful experiences from kinematic rupture modeling with the SCEC Broadband Platform [Goulet et al., 2015]. She recommended starting with the mean of the ground motions, then adding variation later. She also proposed that site effects, which are sometimes challenging to dynamic rupture modelers due to their low velocities and non-linear rock response, could be managed separately from the main dynamic rupture earthquake source simulations, using a simplified site-corrections technique.

The workshop participants learned much during the day's events, and more discussions will ensue to decide how best to conduct dynamic rupture code validation.

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March 1, 2017
SCEC Rupture Dynamics Code Validation Workshop
SCEC Boardroom, USC, Los Angeles, CA

Workshop Conveners: *Ruth Harris and Ralph Archuleta*

SUMMARY: The purpose of the March 1, 2017 SCEC Rupture Dynamics Code Validation Workshop is to discuss our first foray into code validation, particularly the results of our group's new Parkfield earthquake benchmark and to plan our next code validation steps for 2017. We will also learn about new science results in our field. For more information about our code group and the benchmarks, please see the SCEC/USGS Spontaneous Rupture Code Verification Project website. *http://scecdata.usc.edu/cvws*.

09:30	Breakfast	
10:00	Introduction	*Ruth Harris*
10:20	Unraveling earthquake dynamics with SeisSol: Megathrust ruptures, off-fault plasticity and rough faults	*Betsy Madden*
10:50	Meet a New Code - PyLith	*Brad Aagaard*
11:20	Parkfield Model 1	*Arben Pitarka*
11:50	Parkfield Model 2	*Shuo Ma*
12:20	*Lunch*	
13:30	Parkfield benchmark results	*Michael Barall*
14:15	Seismogenic zone depth control on the likelihood of fault stepover jumps	*Kangchen Bai*
14:45	*Break*	
15:15	Complex rupture process during the 2016 M7.8 Kaikoura (New Zealand) earthquake	*Yoshi Kaneko*
15:45	Discussion and planning for code validation in 2017	*All*
17:30	Adjourn	

38 Total Participants (15 Remote-Access):
Ruth Harris (USGS), Ralph Archuleta (UCSB), Tran Huynh (USC), Brad Aagaard (USGS), Sabber Ahamed (U of Memphis), Khurram Aslam (U of Memphis), Kangchen Bai (Caltech), Michael Barall (Invisible Software), Sam Bydlon (Stanford), Luis Dalguer (swissnuclear, Switzerland), Eric Daub (U of Memphis), Ben Duan (Texas A&M), Kenneth Duru (LMU, Germany), Alice Gabriel (LMU, Germany), Christine Goulet (USC), Evan Hirakawa (LLNL), Zhifeng Hu (SDSU), Junle Jiang (UCSD), Yoshihiro Kaneko (GNS Science, New Zealand), Yuko Kase (GSJ Japan), Dunyu Liu (Texas A&M), Shuo Ma (SDSU), Betsy Madden (LMU, Germany), Shiying Nie (SDSU), Jack Norbeck (USGS), David Oglesby (UC Riverside), Kim Olsen (SDSU), Arben Pitarka (LLNL), Daniel Roten (SDSU), Kenny Ryan (USGS), Bill Savran (UCSD), Zheqiang (Sam) Shi (TMT), Nan Wang (SDSU), Yongfei Wang (SDSU), Kyle Withers (USGS), Stephanie Wollherr (LMU, Germany), Baoning Wu (UC Riverside), Te-Yang Yeh (SDSU)