2007 SCEC Annual Report

Project Title:

A Collaborative Project:
3D Rupture Dynamics, Validation of the Numerical Simulation Method

Coordinating Principal Investigator:

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Co-Principal Investigators:

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2007 Annual Report to SCEC
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*A "free collaborator" who didn't request SCEC funds for 2007

Overview:

Numerical (computer) simulations of earthquake rupture are used by SCEC researchers for a variety of purposes. These range from the very applied tool of ground motion prediction at specific sites, such as in the Extreme Ground Motion and PetaSHA DynaShake projects, to the basic research goal of a better scientific understanding of earthquake source physics, an ultimate objective for the SCEC3 FARM and Ground Motion Prediction groups. Whether these simulations are used in a purely applied setting or a more theoretical setting, it is critical for the simulations to be numerically accurate and reproducible. For some types of geophysics and seismology problems, tests of numerical accuracy are simple, since the codes can be compared with analytical solutions. For dynamic earthquake rupture simulations however, there are no analytical solutions. Instead the code testing must be performed by other means, such as presented here, with a code comparison exercise.

Within SCEC, rupture dynamics modelers who consider the physics of earthquakes have used and will continue to use a range of 3D computational methods to simulate earthquake behavior. To date no single numerical method or code has been shown to be superior for all of the types of problems SCEC researchers need to tackle. Therefore a number of numerical codes are currently being used, each with its own advantages. These methods include finite-difference, finite-element, spectral element, and boundary integral techniques. Whereas some of the methods are extremely accurate and computationally efficient at certain types of problems, for example investigating a range of earthquake friction mechanisms, other types of methods are better at simulating geologically reasonable fault geometry or the propagation of waves through the surrounding heterogeneous rocks. This knowledge that there is no 'optimal' code available to SCEC researchers, combined with the fact that none of these codes is testable by an analytical solution, leads us to the critical need for code validation and comparison.

To date the code comparison exercise has led to significant advances. For example some visible SCEC research products of the past have not been matching other SCEC researcher's findings on the same topic. In the past the differences would have remained an earthquake source physics/ground motions prediction puzzle, but now, because of the collaborative code comparison exercise, we understand that the anomalous science result is often solely due to the difference in how faults or friction are represented in the different codes (e.g. Dalguer and Day, 2006). Success stories so far include a major upgrade to the code that was used in the highly visible SCEC2 TeraShake simulations and is being used in the PetaSHA DynaShake simulations.

Over the past three years we have worked at the intersection of code abilities, where all types of the SCEC codes could produce results. Therefore the benchmarks, The Problem, 1,2,3,4,5,6,7 have been rupture on a vertical strike-slip fault. We have learned much from these exercises (for example, Day et al., JGR [2005] is an in-depth comparison of two of the codes) and explored the added complexity of stress heterogeneity on the fault plane. At the beginning of our validation exercise, there were codes that could not handle off-fault complexity, or any asymmetry, including the earth's free surface, but now all participating codes are able to tackle these types of problems.

Both the dipping fault problem and the friction problem are of high relevance to SCEC research goals, and so understanding how the different codes handle variations on fault geometry and friction appears an essential exercise. We are embarking on these exercises with TPV8,9,10,11,12, and TPV101, 102 in FY08.

We need to mention that this collaborative SCEC effort is serving more than just the SCEC internal community. It is also a means of testing the USGS/CIG 3D finite-element rupture code of Brad Aagaard, which is being linked to the CIG/SCEC geodynamics 3D finite-element code of Charles Williams for fault rupture/geodynamics problems. In a USGS Northern California project parallel to SCEC's efforts, 3D finite-element codes are being used to simulate large northern California earthquakes, including Hayward fault rupture scenarios and their effects on San Francisco Bay area ground motion. The SCEC Code Validation effort is also being followed closely by ExGM participants Matt Purvance and Peter Cundall and is being followed by members of the European Union (now former) SPICE collaboration, under the auspices of the Slovakian code validation group led by Peter Moczo. Our SCEC work is setting the stage for numerous international efforts, with scientists from at least 6 other countries (Japan, Switzerland, Italy, France, Germany, Slovakia) closely following our progress and using our results for their own code-testing. As a specific example, the EU SPICE program in FY06 and FY07 was using our benchmarks and closely following our SCEC code validation website.

In 2007 we were also invited to present our methodology to the SCEC/GNS Earthquake Simulators group, and they are investigating if they can directly use our comparison-website-approach to assist them with the rigor of their investigations.

2008 Science Plan Overview (note that this collaborative work will be covered by 2008 SCEC funding, but that our March 2008 workshop will be covered by carryover 2007 funding, and so I report on the details for this upcoming March 2008 workshop:

The Problem, Versions 8, 9 Vertical Fault rupture with depth-dependent stresses

For our 2008 collaborative work and 2008 workshops (with the first, March 2008 workshop supported with SCEC 2007 funding) we are starting our visit of the 3D dipping fault scenario, with benchmarks "The Problem, Versions 8, 9" (TPV8, TPV9). By the end of FY08 our goal is to produce the "Joe Andrews Extreme Ground motion Yucca Mountain dipping-fault benchmark" that we will then compare with Joe's (2D) results. Our current strategy is to get to this benchmark step-wise, by incrementally varying each component until we get to the final objective. As part of our step-wise process, for the March 2008 workshop in 2 weeks, we are simulating 2 vertical fault cases that include for the first time depth-dependent initial shear and normal stresses. We are also considering both strike-slip (TPV8) and dip-slip (TPV9) rupture. At the workshop, we will be comparing the time-series (e.g., ground motions, and deeper motions) generated by the modelers. We will also be comparing the rupture front behavior, in both time and space, since this seems to be most indicative of overall comparative behavior.

The Problem, Versions 101, 102 Vertical Fault rupture with rate-state friction

For our 2008 collaborative work, and the 2007-funded March 2008 workshop, we are also varying some of our simulation comparisons by moving away from the slip-weakening friction used in our "Series X and XX" previous benchmarks, to a rate-state formulation in our Series XXX benchmarks. This effort, with benchmark selection by co-PI Eric Dunham, is to satisfy a longtime request by the FARM PI's who would like to test their implementations of rate-state friction in dynamic rupture simulations. This rate-state comparison effort will be presented and discussed at the March 2008 (2007 funded) code-validation workshop.

Note -
Our funding for code validation is partly from the DOE ExGM project, so at least part of our work has a goal of providing to DOE ExGM a recommendation about the best 2-3 codes to go forward with more intense YM-related simulations in 2009 and 2010. Most likely this will occur near the end of 2008.

The Code Validation Website (CVWS)

Over the past year we have benefited greatly from our code comparison website, CVWS. This has been a big enhancement to our process of comparing the codes and has also allowed the project leader to delegate more of the day-to-day operations to others. Michael Barall, our contract programmer, has been the source of this improved functionality for the SCEC rupture dynamics code validation group.

Our rupture dynamics code validation website is
http://scecdata.usc.edu/cvws/

This website lists the benchmark descriptions, the participants, and many of the codes being used by the modelers, all in an easy-to-use format that is open to the entire SCEC community, as well as being available to scientists outside SCEC.

The website is also where we now do our comparisons, online, in a password protected section. If any reviewer /reader would like to see the password protected part of our website, just let me know and I will happily provide a username and password.

Current Participants

This following list shows our current "modeler" participants, and their institutional affiliations. Our group involves and encourages SCEC students, postdoctoral associates, junior faculty, and established researchers as equal participants, and this approach has served us well.

We include at our workshops, and as part of our mailings, the lead PI's, our core modelers, and other members of the SCEC and ExGM ground motions and FARM communities that are interested in our progress.

Current SCEC Rupture Dynamics Code Validation Modelers

Project Coordinator	
Ruth Harris	U.S. Geological Survey
Software Engineer	
Michael Barall	U.S. Geological Survey and Invisible Software
Modelers	
Brad Aagaard	U.S. Geological Survey
Jean Paul Ampuero	ETH
Joe Andrews	U.S. Geological Survey
Ralph Archuleta	UC Santa Barbara
Victor Cruz Atienza	UNAM
Luis Dalguer	San Diego State University
Steve Day	San Diego State University
Ben Duan	Texas A&M
Eric Dunham	Harvard University
Geoff Ely	UC San Diego
Yoshi Kaneko	Caltech
Yuko Kase	Geological Survey of Japan
Nadia Lapusta	Caltech
Yi Liu	Caltech
Shuo Ma	Stanford University
David Oglesby	UC Riverside
Kim Olsen	San Diego State University
Arben Pitarka	URS Corporation
Seok-Goo Song	URS Corporation
Elizabeth Templeton	Harvard University