Workshop Final Report: Numerical Modeling of Crustal Deformation Associated with Earthquake Faulting

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Introduction and Motivation

Over the past several years, we have implemented a program to coordinate development and validation of 3D quasi-static, finite-element codes for modeling crustal deformation; with the aim of developing deformation models consistent with observed topography, fault geometries, rheological properties, geologic slip rates, geodetic motions, and earthquake histories; and use these models to infer fault slip, rheologic structure, and fault interactions through stress transfer. We have helped specify and catalyze the development of community-modeling packages that are engineered with software evolution and growth as design requirements, developing code able to run on multiple platforms, including Beowulf PC clusters and GRID-computing systems. An ultimate goal of our modeling community is to derive physically based models of the distribution of lithospheric stress in space and time, to simulate deformation spanning the entire earthquake cycle, as well as the integrated affect of many earthquake cycles over the past 300,000 yrs to compare to geologic determinations of earthquake clustering and statistical studies of seismicity.

The CIG short-term crustal deformation modeling (CDM) community developed into a cohesive group with the following Mission Statement:

1. Build tools to understand the response to single earthquakes, and make geodetic comparisons, infer rheology, and constrain structures;
2. Build tools to simulate fault system interaction, regional strain and stress field evolution and produce results that assist in the estimation or modeling of fault slip and constrain physics;
3. Develop understanding of transient stress interaction among faults; and
4. Determine realistic predictions of geologic features (e.g., topography, fault slip).

History of the Workshops

An essential part of our strategy for community building, as well as building software, has been a series of workshops that involve the SCEC CDM community and others. The first CDM workshop at Caltech (June, 2002) focused on assessing the accuracy, speed, and ability to modify software in use by members of the community. The second (August, 2003) was expanded in both length and participation. The workshop was hosted by Los Alamos National Laboratory, enabling SCEC scientists to benefit from attendance by Lab experts, particularly those with expertise in meshing. By leveraging SCEC, NASA, and LANL support, we were able to increase the number of students and senior researchers attending, as well as meet for a longer time. A highlight of the workshop was intense discussion of Computational Frameworks. Because members of the NASA-sponsored SERVO Quakesim group participated in the workshop, there was significant interchange of ideas and software.

The third annual workshop (August, 2004) was again at LANL. Based on the success of previous workshops, the funding base was expanded to include NSF EarthScope, as well as SCEC, LANL IGPP, and NASA. 30 scientists from 12 universities, the USGS, JPL, Los Alamos National Laboratory, and Sandia National Laboratory participated. This workshop had a "hands-on" emphasis. The goals of the workshop were

- to leave the workshop knowing how to do more with basic tools than before the workshop;
- to use Southern California and Benchmarks as convenient and important examples for developing the next generation of crustal deformation modeling tools;

- to focus on the meshing problem, learning how to use LAGriT; and
- to learning to use GeoFest and Lithomop (aka TECTON) - what does it take to get these up and running, what can they do, how can they be modified.

The fourth annual workshop (July, 2005) followed the pattern of the previous years quite closely. SCEC, LANL IGPP, NASA, and CIG jointly provided funding for the workshop. We had 42 participants, many of whom were new to the computational crustal deformation modeling community. The underlying goal of this workshop was to have all participants leave with a working FEM code on their home machine to get them over the start-up hurdle. This goal was reasonably successful. In addition, this workshop focused on defining the tools necessary for end-to-end modeling from concept, through structural models, meshes, and finally to solvers and visualization. Because modest support from SCEC has enabled our community to organize and articulate its priorities and plans, this community is able to take advantage from its beginning of the more substantial support of the new NSF-IT CIG initiative. This last workshop spent significant time defining our communitys priorities and needs with respect to CIG activities.

The fifth workshop was held the summer of 2006 on the campus of the Colorado School of Mines in Golden, Colorado. For details of the workshop, please see CFEM 2006. This was our most successful workshop with over 60 participants, the majority of whom were students and postdocs. This workshop included the tutorial and software introduction sessions of previous years, but had many more science application presentations. With this workshop, we began befriending the FARM community with talks on laboratory friction laws and on dynamic slip modeling. This represents a concerted effort by the community to merge the modeling codes to hand time scales of seconds to thousands of years truly a daunting task, but an important one if we want to make progress in understanding the impact of 3D variations in crustal stress. A post workshop survey was completed by most participants (see web site listed above), and the response was extremely positive, with strong enthusiasm for yet another incarnation to be held again at the School of Mines. We plan to expand the scope of the workshop a bit in two ways: The first is bringing a closer tie to the FARM type of modeling, and the 2nd is to bring in new blood from the international modeling community in particular from Japan and Europe.

Our Most Recent Workshop

The 6th workshop (June 25-29, 2007) was also held in Golden, Colorado at the Colorado School of Mines. We had 63 attendees, 31 of whom were postdocs/students, and 32 of whom where faculty. For further logistical details, agenda, and list of attendees, please see the CFEM 2007 workshop web pages. As in previous years, we continue to have a hands-on emphasis. A primary goal of the workshop is for participants to leave the workshop knowing how to do more with state-of-the-art modeling tools than before the workshop. This is done by using Southern California and our benchmark suite as convenient and important examples for using the next generation of crustal deformation modeling tools. We continue our focus on meshing issues, including how to create models using the SCEC structural representations combined with Cubit and/or LAGriT. Participants learned to use GeoFest and/or PyLITH - what the codes can do, how to use them, and how can they be customized. We will also address issues associated with running these codes on PC clusters and other parallel systems. In addition, this workshop is the occasion for our community to provide guidance to code developers as to what we want and what our priorities our. It is also the time to identify deficiencies in our physical models.

This year we continued our linkage with the rock mechanics and FARM communities with talks from Nadia Lapusta, Eric Dunham, Brad Aagaard, Jim Dietrich, and David Kohlstedt. This linkage is now manifesting itself in the features being requested for development in PYLITH. Another new aspect of the

workshop was the discussion of FEM models to calculate Green functions from 3D models for input in parameter inversion studies.

A continuing priority is the comparison of results for a small number of benchmark problems to verify codes and ascertain their strengths and weaknesses. For the FEM models, the effects of irregular computational meshes are being explored. The models will eventually be extended to include postseismic relaxation for viscoelastic and rate-state friction. The ability to accurately model body forces will be investigated by considering test problems with explicit topography. Primary goals of these benchmarking exercises are to assess accuracy/basis function/parallelism issues, and to separately assess commercial/SCEC-funded options for both mesh generation and simulation. We are relying on CIG to provide the necessary benchmarking software environment.

The post workshop survey suggests that people found the workshop to be extremely useful. There was unanimous desire and expectation for yet another workshop next year at the same place and same general time of year. We expect that next year we will have more emphasis on particular applications, and less on detailed code development. We also expect to continue this balance of pedagogical aspects for nascent modelers and the more cutting edge discussions desired by the hardcore.