2003 SCEC Annual Report for the SHA Focus Group

Introduction:

The goal of seismic hazard analysis (SHA) is to state the probability that something of concern related to earthquake shaking will occur over some specified time span. SHA relies on three types of models: 1) an Earthquake Rupture Forecast (ERF) that gives an inventory of all possible (and significant) faulting events in a region over a given time span; 2) a ground motion model that gives the level of shaking at a site for a given faulting event; and 3) an engineering model that predicts the amount of damage given the level of ground shaking. The latter two models are usually combined into one that predicts the probability that and engineering "Intensity Measure" will exceed a specified value at a particular site given a fault rupture event; this combined model is referred to as and Intensity-Measure Relationship (IMR). Traditional IMRs have been based on empirical regression of observed data (so-called attenuation relationships), although IMRs could also be based on full-waveform modeling from first principles of physics.

A strong motivating force within SCEC is the belief that improvements in SHA will require a more physics-based approach to modeling. For example, SCEC's Phase III report (e.g., Field et al., 2000) demonstrated that traditional IMRs (empirical attenuation relationships) have inherent limitations with respect to precision (i.e., there will always be significant uncertainty). The Yucca Mountain Repository project also demonstrated that a lack of physics in attenuation relationships can lead to ground-motion predictions that far exceed actual strength of rock (McGarr, 2003). Thus, the key to improved IMRs is to utilize waveform modeling from first principles of physics.

Similarly, while the ERF applied in our National Hazard Maps is a time-independent Poisson model, where the likelihood of each faulting event is completely independent of all others, there presently exists a flood of papers and meeting abstracts on stress-interaction and time-dependent earthquake effects. In other words, there is clear consensus that the time-independent model is inadequate, but no consensus on what type of model should replace it. In fact, the range of views is so wide that it's highly unlikely that consensus will be reached anytime soon. Should we continue to use the time-independent Poisson model until consensus is reached? The scientific approach might say yes – keep the model simple until and alternative is proven to be superior. However, proper SHA actually requires that all *viable* models be considered in the analysis (SSHAC, 1995). Therefore, what we need is a suite of alternative, perhaps physics-based models to be developed and applied. This is the primary goal of SCEC's working group for the development of **R**egional **E**arthquake **L**ikelihood **M**odels (RELM; http://www.relm.org), This project, which constitutes the lead activity of the SHA focus group, is discussed more below.

The need to consider all viable models in SHA applies to IMRs as well. This is why the NGA project that SCEC is involved with is developing multiple attenuation relationships, some of which will utilize waveform modeling to fill in where empirical data are lacking. In addition, part of SCEC's ITR project (Pathway 2) is developing a more routine, community-accessible waveform modeling capability, and there will certainly be multiple ways of doing these simulations as well.

One problem we previously faced was the lack of a SHA computational infrastructure capable of handling the wide range of models currently under development. As discussed more below, our solution to this potential dilemma is OpenSHA – an emerging community-modeling environment for SHA.

It's import to note that almost all activities taking place in SCEC's SHA focus group are indistinguishably coupled with activities in the other focus and interdisciplinary groups, What's given below, therefore, is merely outline of the two main projects (RELM and OpenSHA).

RELM (http://www.RELM.org):

RELM is the working group for the development of **R**egional **E**arthquake **L**ikelihood **M**odels. Our goal is to develop, evaluate, and test a variety of more physics-based ERFs than that currently applied in the National Hazard Maps. This will help define existing uncertainties in seismic hazard analysis, identify the research topics needed to reduce these uncertainties, and identify which models are exportable to other regions where the options are fewer. We plan to publish our results as a special issue of a peer-reviewed journal (such as BSSA). Perhaps the best overview of this project is the list of anticipated publications:

Papers on Models

Blanpied et al.	The Working-Group 2002 forecast model for the San Francisco Bay area
Ward	Different models based on geologic, seismic, and geodetic constraints.
Ward	Standard Physical Earthquake Model for so. California (simulation based model).
Tiempo et al.	A Earthquake Forecast Based on Pattern Informatics (previously known as PDPC)
Jackson et al.	Different models based on geologic and geodetic constraints
Gerstenberger et al.	Short-Term Earthquake Probability (STEP) model
Helmstetter et al. ????	Epidemic Type Aftershock Sequence (ETAS) model
Anderson	Southern California regional earthquake probability estimated from geodetic data
Petersen et al.	The California model used in the 2002 USGS/CGS National Hazard Maps
Schorlemmer, Jackson, et al.	Seismicity based forecasts w/ spatial & temporal variability in mag-freq dist. params.
Rundle et al.	The Virtual California earthquake simulation model
Bowman et al.	A model that incorporates accelerating moment release and coulomb stress change
Field et al.	The SCEC system-level, CFM-based ERF

Papers on Supporting Developments

Plesch et al.	The Digital 3D SCEC Community Fault Model (CFM) of Southern California
Plesch et al.	Formalization of alternative source models from the SCEC CFM
Perry et al.	The SCEC/USGS Fault Activity Database (FAD) and the Fault Information System (FIS)
Gould et al.	A method for populating paleoseismic databases using non-expert readers
Maechling et al.	The SCEC, distributed community modeling environment and its support of RELM

Papers on Evaluations/Implications of the Models

Schorlemmer, Jackson, et al.	Standardized tests for any ERF and their application to RELM models
Field et al.	Evaluation of hazard implications of the various RELM models using OpenSHA
Campbell et al.	Risk/Loss implications of the RELM models
Stirling et al.	Use of the historical intensity data to test probabilistic seismic hazard models
Bowman et al.	Testing arbitrary RELM forecast scenarios for accelerating moment release
A panel of independent, authoritative experts	Evaluation of RELM models for practical use (independent evaluation of the complete suite of models)

Our goals for the next year are to get most of the above submitted for publication. Particular effort will be devoted to SCEC's system-level, Community-Fault-Model-based ERF, both because we now have the ingredients necessary to build it, and because it will be the closest thing to a logical extension of previous Working Group on California Earthquake Probability models (WGCEP, 1988, 1990, 1995, 2002). Significant effort will also be devoted to assembling the panel of independent experts needed evaluate the RELM models and to make recommendations for potential users and public policy officials (hopefully forming the basis of a WGCEP-200X report).

OpenSHA (http://www.OpenSHA.org):

As discussed above, SHA requires two types of models – an Earthquake Rupture Forecast (ERF) and an Intensity-Measure Relationship (IMR). OpenSHA is an effort to build a computational infrastructure, or community-modeling environment, capable of handling the wide range of ERFs and IMRs currently under development. The goal is to enable any such model to plug in for analysis without having to change what's being plugged into. We also want to accommodate the rapidly evolving needs of the engineering community and other user groups.

Figure 1 shows the basic elements of the OpenSHA framework. The output of the analysis is the probability that an intensity-measure type, which represents any functional of ground motion found by engineers to correlate with earthquake damage, will exceed a specified intensity-measure level.

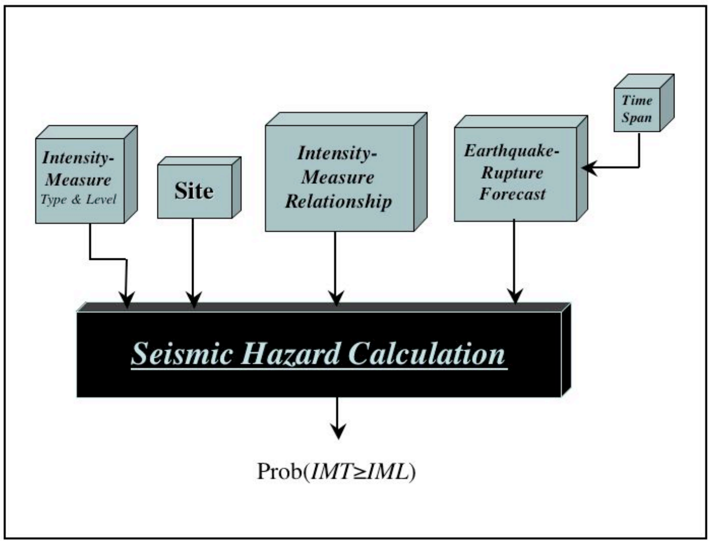

Figure 1. The fundamental elements needed for a hazard calculation in OpenSHA. Although the figure portrays computing the exceedance probability of a single *Intenity-Measure Level (IML)*, the analysis can be repeated over different *IML*s to generate a hazard curve, over different *Intensity-measure Types (IMT*s) to generate a hazard spectrum (if considering spectral acceleration), or over different *Sites* to generate a hazard map.

The computational framework is object oriented, web and GUI enabled, platform independent, open source, and freely available. We also have a thorough and aggressive code evaluation and testing process (e.g., we are participating in a code validation exercise initiated by PEER). Although most of the code is written in Java, the overall framework is programming-language independent, and some of the existing components are legacy code (e.g., written in Fortran) with a Java wrapper.

We have thus far implemented nine different attenuation-relationship-type IMRs that are applicable to southern California. We have also implemented a variety of ERFs, including: 1) a generic single-fault forecast; 2) the ERF used in the current National Hazard Maps; 3) a variety of ERFs needed to implement the code-validation test cases defined by a PEER working group; 4) the Short-Term Earthquake Probability (STEP) model for southern California which makes a real-time forecast based on recent seismicity and foreshock/aftershock statistics; and 5) the Working-Group 2002 forecast model for the San Francisco bay area (WGCEP, 2002), which is the most sophisticated time-dependent ERF ever developed and one for which no other code can currently handle.

We presently have applications that allow the calculation of hazard curves (Figure 2), hazard spectra, scenario ShakeMaps (Figure 3), and full hazard maps (see the "Applications" section at http://www.OpenSHA.org). It's important to note that none of these applications have been hard coded for any particular IMRs or ERFs (new ones can be added, or old ones removed, without rewriting any code).

A study following the November 3, 2002 Denali earthquake exemplifies the current capability and flexibility of the OpenSHA framework. During the main shock, the Alaskan oil pipeline was offset where it crosses the fault to within a few feet of its design limit. The USGS was asked to assess the likelihood that aftershocks would threaten the structure, given its diminished capacity to accommodate additional offset and the time lag in making repairs. The aftershock-forecast technique of Wiemer and Katsumata (1999) was used to build an appropriate ERF, and a new IMR based on a new intensity-measure type (fault displacement) was developed and quickly implemented in the OpenSHA (Figure 2). This study demonstrates the extensibility of OpenSHA with respect to accommodating arbitrary model components.

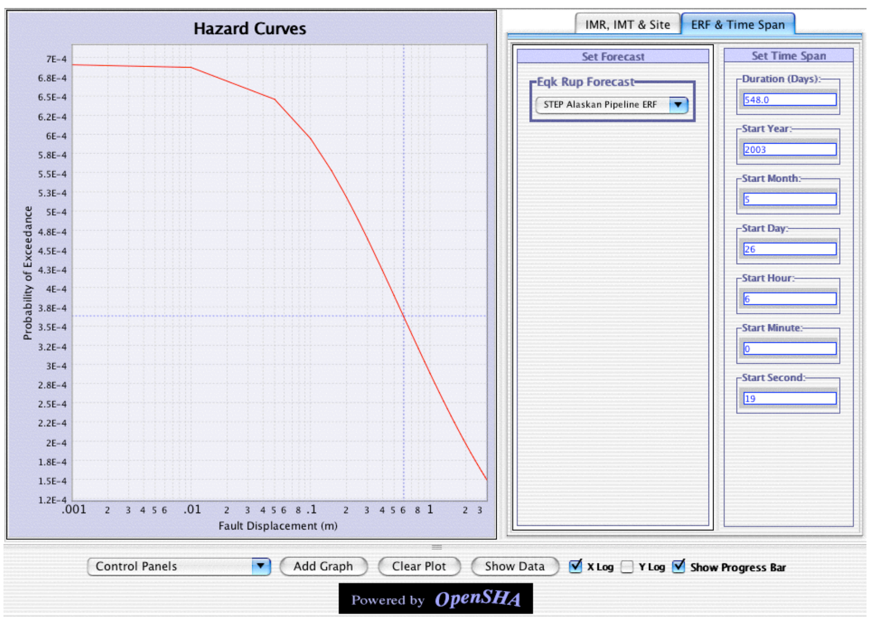

Figure 2. A screen-shot of the OpenSHA GUI, giving the probability of exceeding a given displacement in meters on the Denali fault at the site of the Alaska pipeline in the 540 days from May 26, 2003 (Jones et al., 2003).

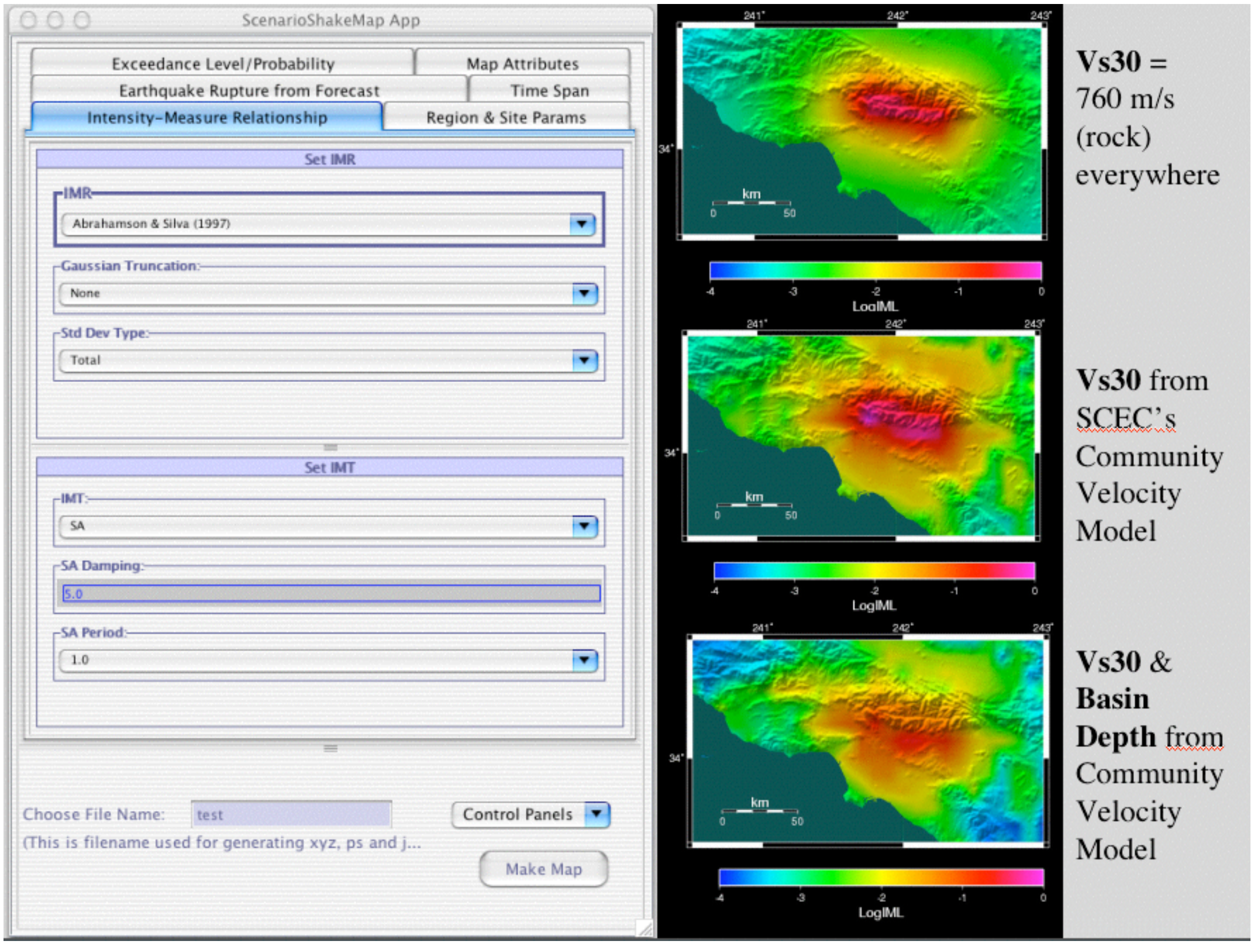

Figure 3. Snapshot of the *OpenSHA* application for computing scenario earthquake maps. This example is for the Sierra Madre fault rupture as defined by the ERF used in the 1996 National Hazard Maps. The three images show results for different assumption regarding site conditions (the average 30-meter shear-wave velocity ("Vs30") and depth of sediments to basement rock ("Basin Depth")).

ITR Collaboration Contributions:

We anticipate a large number of potentially complex IMRs and ERFs, almost all of which will evolve over time as assumptions change and new data become available. We also anticipate that some models will be implemented in programming languages (e.g., Fortran) that are not easily ported across platforms. To make this infrastructure manageable, therefore, a high priority is to enable the ERFs and IMRs, as well as any data resources upon which they depend, to be geographically distributed and run-time accessible over the Internet as "web services". Thus, rather bundling each ERF inside an application, for example, we instead access each ERF over the Internet at runtime. This has the added convenience of making our applications relatively lightweight and putting the maintenance onus directly on the host of each model.

Elements that have thus far been implemented as web services include: 1) several ERFs, including the WGCEP-2002 model where their Fortran code is configured and run in real time during a hazard calculation; 2) access to the SCEC community velocity model (CVM) for the purpose of defining site attributes for an arbitrary latitude and longitude; and 3) the making of GMT maps (written in the C programming language). These latter two were utilized in making the maps in Figure 3.

We are also beginning to utilize GRID computing, where the computational burden is distributed among any idle computers that are available during the calculation. Our first tests of this reduced the time needed to make a hazard map from about 7 hours to about 30 minutes. This is a very significant achievement, as it effectively means we will be able to consider more alternative models in our analysis, as required for "proper" SHA (SSHAC, 1995).

Our goals for the next year are to continue implementing and optimizing these capabilities in order to make them routine and automatic in the community modeling environment. We also want to implement the other ERFs being developed by the RELM working group, not the least of which is SCEC's system-level ERF. Finally, we will be adding the new IMRs (attenuation relationships) coming out the NGA project, and any other IMRs such as the vector-valued intensity-measure type being pursued by some SCEC researchers.

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