2004 SCEC SHA Focus Group Report
(RELM & OpenSHA)

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(note – this is the same as the report written for NSF in Oct. 2004)

The goal of seismic-hazard analysis (SHA) is to state the probability that some Intensity Measure Type (any measure of earthquake shaking found to correlate with damage) will exceed a specified level at a site over a particular time span (e.g., the lifetime of a building). The two main model components needed for SHA are an Earthquake Rupture Forecast (ERF), which gives the probability of all possible fault-rupture events over the time span of interest, and an Intensity-Measure Relationship (IMR), which gives the exceedance probability at a site given the occurrence of an arbitrary fault-rupture event.

There is consensus that significant improvements in SHA will require a more physics-based approach to modeling. This applies to forecasting both where and when faults will rupture (an ERF), as well as predicting the consequent ground shaking and exceedance probabilities (an IMR). Unfortunately there is no consensus on how to construct more physics-based models, which explains, in part, why our national seismic hazard maps are based on both a time-independent ERF (where each event is completely independent of all others) and empirically-based IRMs. This lack of consensus means that we will need to accommodate alternative models, and in fact, proper SHA requires that all viable models be included in the analysis (to adequately represent "epistemic" uncertainties). To reach this very challenging goal of accommodating multiple, perhaps physics-based models, we clearly need a computational infrastructure for SHA that enables both users and modelers to "plug in" without creating additional demands on their time or abilities.

The SCEC SHA focus group has two major activities aimed at improving SHA: RELM (to develop alternative, physics-based ERFs), and OpenSHA (a community modeling environment for SHA). Both of these activities are detailed below. There are also related efforts in the Ground Motions focus group and the Implementation Interface. These include the "NGA" project to develop empirically-based IMRs (know as attenuation relationships) and waveform modeling efforts that could someday form the basis of more accurate, physics-based IMRs. Please see the reports from those focus groups for details.

RELM:

RELM stands for the working Group for the development of Regional Earthquake Likelihood Models (http://www.RELM.org). The goal is to develop a variety of viable Earthquake-Rupture Forecasts (ERFs) rather than one consensus model (the latter being approach taken in previous working groups). Those currently under development range in sophistication from simple Poisson models (e.g., based on smoothed historical seismicity), to models that include foreshock/aftershock statistics, to physical earthquake simulators that track stress changes throughout the system. A list of models currently slated for publication can be seen by clicking "Models" at the RELM website given above.

Part of the effort is to establish and implement formal test of each model (e.g., compare predicted earthquakes to those that actually occur). This activity has become particularly important in light of recent claims of success with respect to earthquake prediction. We also want to evaluate the hazard implications of each ERF using the

OpenSHA tools discussed below, which will not only give us a better idea of the true uncertainty of hazard, but will also suggest studies needed to reduce those uncertainties. This activity will also indicate which models may be exportable to other regions where the options are fewer. Our web site (http://www.RELM.org) can be used to monitor progress in this ongoing effort.

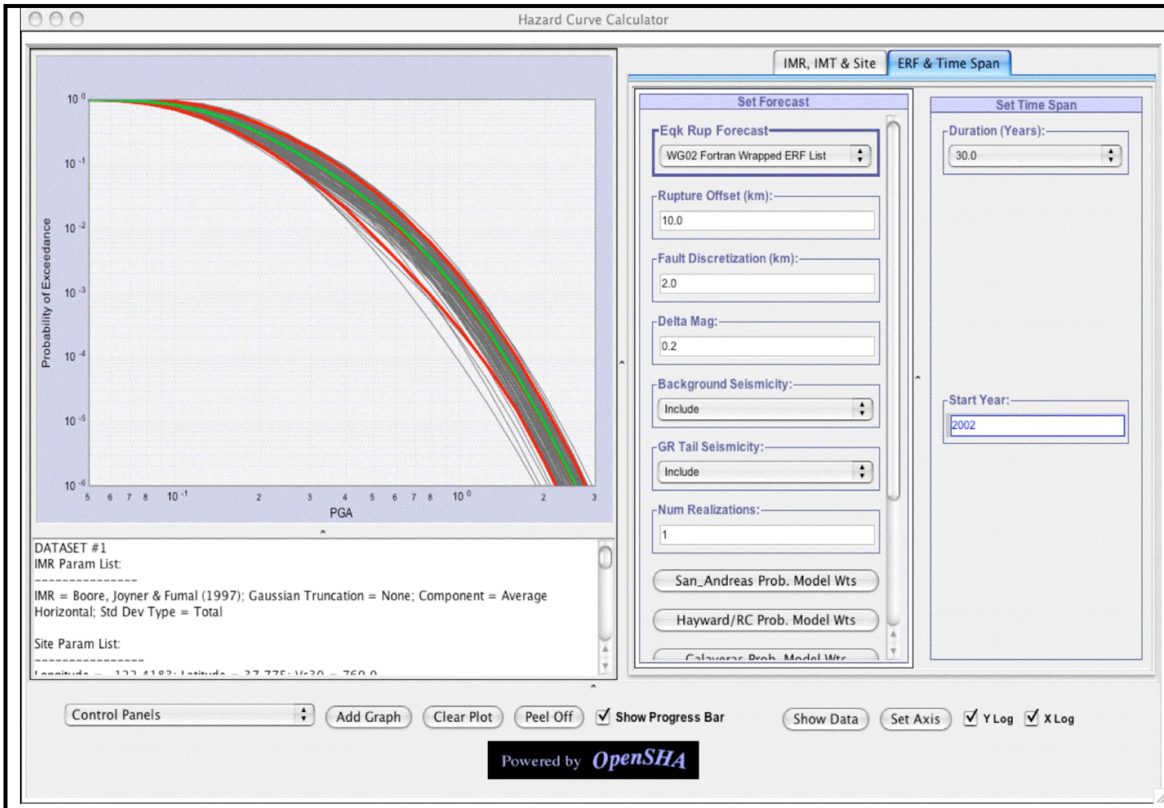
OpenSHA:

As discussed above, we need a computational infrastructure for SHA that can accommodate a rapid proliferation of new, alternative, and more physics-based models (e.g., new ERFs from RELM or new IMRs from the NGA effort mentioned above). Our answer to this need is OpenSHA (http://www.OpenSHA.org) – a modular, open-source, and web-based "community-modeling environment" or "collaboratory" for SHA. The idea is to enable any arbitrarily sophisticated ERF or IMR to "plug in" for analysis without having to change what is being plugged into (without rewriting existing code).

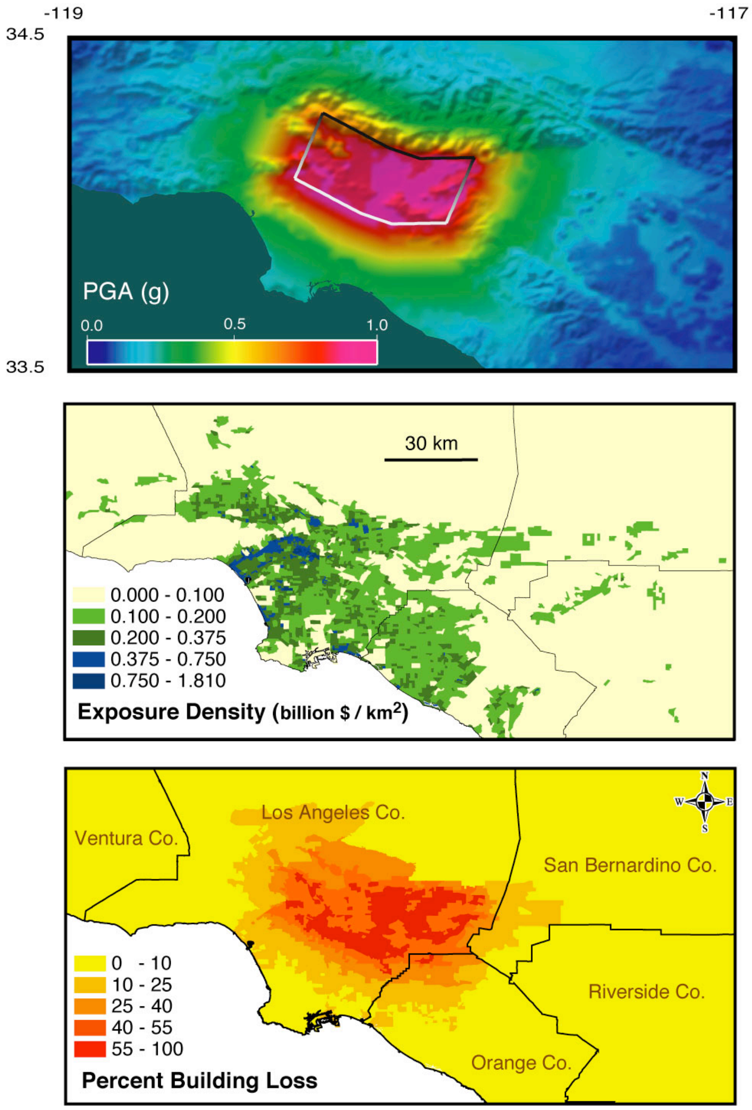
We currently have web-accessible tools for doing various types of SHA. These include a Hazard Curve Calculator (exemplified in Box 1), a Scenario ShakeMap Calculator (Box 2), and a full Hazard Map Data Calculator and Viewer (Box 3). Again, it's important to emphasize that these applications have not been customized for any particular ERFs or IMRs, so that plugging other models in will not require changing the applications at all. In fact, we eagerly await the availability of RELM ERFs and NGA IMRs.

This community-modeling environment for SHA has benefited greatly by involvement in the SCEC Information Technology Research (ITR) collaboration. Specifically, this collaboration has enabled any of the model components (e.g., the ERFs) to be geographically distributed and runtime accessible over the Internet. This conveniently puts the maintenance onus directly on the host of the componenet, and makes our applications relatively lightweight and portable (e.g., the same version can be downloaded an run on any computer platform). The ITR collaboration has also enabled us to significantly reduce the computation time for hazard maps. Specifically, using the Condor GRID at USC, which automatically distributes the computation task among any idle UNIX workstations across the university, we have reduced the time needed to make hazard maps by more than an order of magnitude. This is very important in that it will now enable us to compute and compare the hundreds to thousands of hazard maps needed for proper SHA (because all viable models need to be considered). Thus, we are poised to make dramatic improvement in SHA by accommodating alternative and more physics based model components.

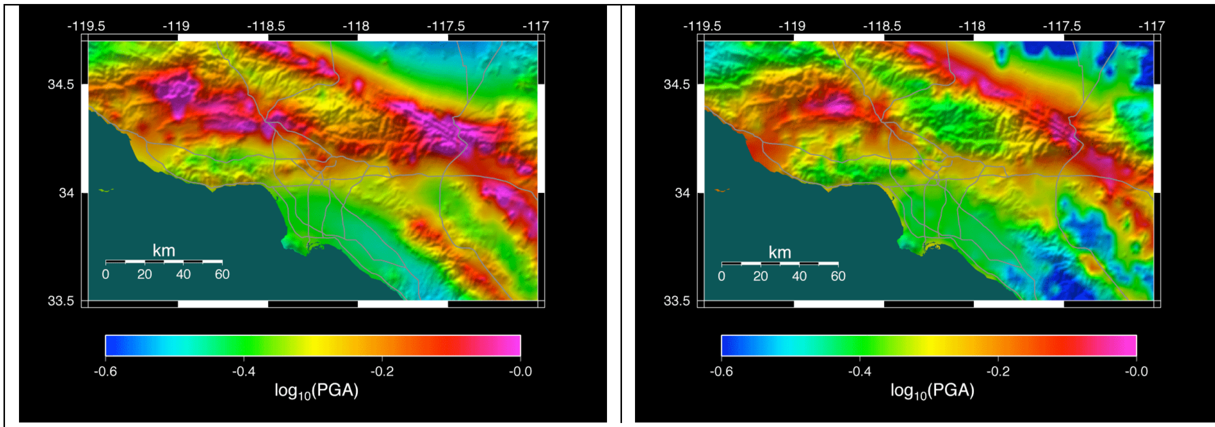
More details on OpenSHA accomplishments can be found at our web site (e.g., click "Accomplishments" or "Publications" at http;//www.OpenSHA.org).



Box 1. This is a screenshot from the OpenSHA hazard curve calculator, showing 30-year PGA hazard curves for downtown San Francisco based on the ERF from the 2002 Working Group on California Earthquake Probabilities. This ERF is the most sophisticated forecast model ever developed, both in terms of it being time dependent and in accounting for numerous epistemic uncertainties. The gray lines represent the range of values given these uncertainties, the red curves represent 90% confidence bounds, and the green curve is the mean or "best" estimate. This ERF is deployed as Java-wrapped Fortran code that resides on a server and can be accessed by the application from anywhere over the Internet. The Boore et al. (1997) IMR (attenuation relationship) was used for this calculation, although any of the other supported models could have been chosen as well.



Box 2. (top) peak-ground-acceleration (PGA) shaking map for a magnitude 7.5 Puente Hills earthquake beneath Los Angeles (computed using the an OpenSHA application available to anyone). Also shown is the regional building exposure (middle) and earthquake losses (bottom) computed for this event using FEMA's HAZUS loss estimation software. With these tools one can now perform such loss estimates for virtually any earthquake using a variety of ground-motion models and site effect treatments. These plots are from a comprehensive, probabilistic loss analysis that has been submitted for publication (Field et al., 2004, *Earthquake Spectra*)



Box 3. Full probabilistic PGA hazard maps, including site effects, computed for the LA region using the ERF applied in our national hazard maps (Frankel et al., 2002). The map on the left was produced using the Abrahamson and Silva (1997) IMR (attenuation relationship), and that on the right was made with the Boore et al. (1997) relationship. Note that one implies the hazard in the San Gabriel mountains is relatively high compared to the adjacent LA basin, whereas the other implies the opposite; this is a manifestation of assumptions related to nonlinear sediment amplification. The application that generates these data utilizes GRID computing, where the computational load is distributed over any idle UNIX computers in USC's Condor pool. This reduces computation time by more than an order of magnitude.