Annual Report, 1999

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SCEC Phase III Report - Accounting for Site Effects in Probabilistic Seismic Hazard Analysis

Background:

It has been known for over 100 years that neighboring sites can experience significantly different levels of earthquake shaking, often referred to as a site effect or site response. The most dramatic site effects are produced by sedimentary deposit, which influence ground motion in the form of impedance changes, resonant modes, focussing and defocussing effects, basin-edge induced surface waves, and nonlinear behavior. A fundamental question with respect to probabilistic seismic hazard analysis (PSHA) is how and if such site effects can be accounted for. Specifically, given the variety or earthquake locations considered in PSHA, are there any site attributes that systematically predispose a location to greater or lower levels of shaking?

This question is being addressed by a working group of the Southern California Earthquake Center (the so-called SCEC Phase III effort). In a collection of ten papers that will soon be published together in the *Bulletin of the Seismological Society of America*, we have addressed the problem from a variety of angles. These include both theoretical modeling and empirical data analysis. Based on the results, two new customized attenuation relationships have been developed for southern California to account for site effects (Steidl; and Lee & Anderson), and these are being evaluated with respect to implied seismic hazard (Field et al.)

Progress & Present Status:

Progress over the last year was substantially delayed because the person funded to do the hazard calculations bailed out of the project (after the results had been due). This left me to do the time-consuming calculations myself, which in retrospect was probably a good thing because the level of involvement ended up being beyond what the original person could have handled. The project was also delayed by major errors found in the SCEC strong-motion database, which required not only complete revisions of two papers, but also that the hazard calculations be redone. Such errors seem endemic to projects of this scope. The difference here is that we are (hopefully) catching them before publication.

At present, 5 of the 10 papers have been accepted for publication and 3 have been recommended for publication by reviewers (provided final comments are addressed). What remains is for the hazard calculations to be finalized and that paper written, and for the final overview paper to be written. We hope for final acceptance of these last two papers by April 1, 2000, and publication of the report by early summer.

I have organized a special session at the SSA-2000 meeting to present the Phase III papers; other related studies will also be included.

Tentative conclusions:

1) Detailed geological classifications (that is, beyond rock vs soil, or a Quaternary/Tertiary/Mesozoic distinction) are generally not significant with respect to site effects.

2) Sedimentary basin depth is a significant and important factor. For example, sites over the deepest parts of the LA basin have ground motion levels that are about 60% greater (on average) than sites near the edge. The physical explanation for this is not yet resolved; that is, the basin depth factor may be a proxy for something else (e.g., the model by Joyner implies that distance from the edge, which is correlated with depth, is more relevant).

3) The uncertainty of ground motion (i.e., sigma in the attenuation relationship) is not significantly reduced after making all possible site corrections. In other words, the intrinsic variability of response at a site remains high due to the sensitivity of basin effects and scattering in general with respect to different source locations. Thus, in terms of accounting for site effects, PSHA is reaching a point of diminishing returns. Obtaining more precise estimates of ground motion will require deterministic waveform modeling.

Issues that remain to be resolved in future studies include the exact influence of nonlinear sediment behavior (changes in amplification factors as a function of ground motion level), and ground motion during large (M>7) earthquakes, particularly in the near field. Existing data are very limited in terms of addressing these questions. As we await additional observations, theoretical investigations can provide valuable insights.

List of Papers:

A complete list of papers and abstracts, as well as a more detailed description of the project, can be viewed at: **http://www.scec.org/research/phase3**.

Java Applets:

One of the primary products of the Phase III effort are customized attenuation relationships for southern California (the Lee and Anderson model, and the Steidl model). I have written Java applets to allow potential users to contrast and compare these, and other attenuation relationships, by plugging in their own values from a web browser. Thus, we have dynamic versions of the results in addition to the static figures to appear in *BSSA*. These can be viewed by clicking " **Attenuation Relationship Java Applets**" at **http://www.scec.org/research/phase3**.

Working Group 2000 (Phase IV Effort)

Goals: To develop and test a range of viable earthquake-potential models for southern California (the probability per unit area, magnitude, and time of all M≥5 events).

To test these models against existing geophysical data (e.g., historical seismicity), and to design and document conclusive tests with respect to future observations.

To examine and compare the implications of each model with respect to probabilistic hazard (PSHA). This will not only reveal present uncertainties in seismic hazard, but also what research is needed to reduce these uncertainties.

Participants:

Confirmed: Edward **(**Ned) Field, David D. Jackson, William Foxall, Mark Petersen, Lucile Jones, James Dolan, Steven Ward, Egill Hauksson, Julie Nazareth, Kate Hutton, Zheng-kang Shen, Yan Y. Kagan, John Anderson, and Stefan Wiemer;

Tentative: Mark Stirling, Greg Anderson, Jeanne Hardebeck, Ross Stein, Ruth Harris, Tom Parsons, Ken Campbell, Frank Scherbaum, and Art Frankel; *others are welcome***.**

Overview:

SCEC's Phase II report (WGCEP, 1995, *BSSA*) represented the first effort to integrate seismic, geodetic, and geologic constraints into a complete seismic-hazard source model using the concept of seismic moment budgeting. However, the model predicted that magnitude 6 to 7 earthquakes will occur about twice as often as they have historically, which led to a widely publicized debate on whether the apparent deficit was real, an artifact of the limiting magnitude implied by fault size, or simply a reflection of uncertainties (Jackson, 1996, *SRL*; Hough, 1996, *SRL*; Schwartz, 1996, *SRL*; Stirling and Wesnousky, 1997, *BSSA*; Stein and Hanks, 1998, *BSSA*). Similarly, the model developed for the USGS/CDMG statewide hazard maps also exhibits a factor of two discrepancy near magnitude 6.5 (Petersen et al., 1996, *CDMG/USGS Report*). Field et al. (1999, *BSSA*) have since presented an alternative, mutually-consistent source model (based on active fault data and in agreement with historical seismicity). They also summarized several factors that produced the discrepancy in previous models.

Although neither $M \geq 8$ earthquakes nor an accelerated earthquake rate are *required* to satisfy available data, neither phenomenon is precluded either. For example, time-dependent recurrence models generally predict a rate acceleration because most faults are deemed overdue. In addition, some models allow a finite probability of M ~8.5 earthquakes (Kagan, 1999, *Pure & App. Geophys.*). Because these models cannot be excluded, it behooves us to evaluate their implications for seismic hazard. This will define the range of hazard levels implied by our current understanding and identify important issues for future research.

Our approach is different from previous "working group" reports in that we are evaluating several viable models rather than constructing one consensus model. This approach is appropriate for several reasons: 1) Our immediate goal is a scientific study, rather than a policy document or engineering study; 2) we won't force a consensus when none exists; 3) participants will not be asked to compromise their best judgement; 4) a comparison of results will reveal which factors are most significant, thereby establishing a basis for setting future research priorities; 5) our approach will provide the background research needed by those who produce official source models (in terms of exploring possible logic-tree branches); and 6) we won't confuse the user community with yet another "consensus" hazard map, or interfere with those whose mandate it is to generate such maps.

An important part of the effort will involve updating and documenting the geological fault database, the earthquake catalog, and the geodetic strain-rate map. We envision publishing our results as a collection of papers in a peer-reviewed journal such as the *BSSA*. Specifically, there will be separate papers on each model, or class of models, and on the updated data constraints. There will also be a paper comparing the hazard implications of each model, a paper outlining a formalism for testing the models against observed and/or synthetic earthquake catalogs, and an overview paper.

Models to be Tested:

We welcome any models that are well developed, well documented, and scientifically defensible (i.e., publishable in the next year). Those currently slated for analysis are:

(1) The standard CDMG/USGS (1996) model.

(2) The following by *Field, Jackson, & Petersen* (not necessarily in that order):

a) A characteristic earthquake model similar to WG-1988, with strict segmentation (no cascades), with and without time dependence.

b) A geologically based characteristic earthquake model with strong cascade interactions (with and without time dependence).

c) A geologically based model that abandons segmentation.

(3) A model based on smoothed historical seismicity that uses a modified Gutenberg-Richter distribution and allows magnitudes up to 8.5. *Jackson & Kagan*

(4) A model with seismicity proportional to the maximum shear strain rate. *Shen*

(5) Models with alternative LA Basin fault geometries (known sources versus known and speculative sources). *Foxall & Dolan.*

(6) A “Standard Physical Model” that includes stress interaction between earthquakes. *Ward*.

(7) A model that includes spatial and temporal foreshock/aftershock statistics. *Jones, Wiemer, & Hauksson.*

(8) Models based on stress evolution and rate and state friction, or at least a thorough evaluation and overview of such models. *G. Anderson & J. Hardebeck* ? and/or *R. Stein, R. Harris, and T. Parsons*?

Other Contributions (anticipated publications):

Official SCEC/USGS So. California Earthquake Catalog. *Kagan, Jones, Jackson, and Hutton.*

Updated Fault-Parameter Database. *Foxall, Dolan, Petersen, and Nazareth*.

A new magnitude vs fault-dimension relationship (update of Wells and Coppersmith, 1994, *BSSA*), especially in light of recent m≥7 earthquakes. *Both Bill Ellsworth and Mark Stirling are working on this (independently).*

Evaluation of models with respect to PSHA. *Field, Petersen, Stirling, and others?*.

Evaluation of models against geophysical constraints (e.g., historical seismicity rates), and the development of conclusive tests with future data. *Jackson and Kagan*.

An overview and summary of the entire WG2K project. *All Participants.*

A new Java-based PSHA code. For various reasons, we had problems gaining access to such code in Phase III. I'd like to solve this by creating a publicly available "SCEC"

PSHA code. By writing it in Java, users could run it from any web browser (as with the Java Applets I wrote for Phase III: **www.scec.org/research/phase3**. *Ned Field*.

Other topics of interest include: seismogenic thicknesses; percentage of aseismic slip; the amount of seismic moment accommodated by compression; through-going rupture along the San Bernardino Mt. segment of the San Andreas; and whether previously defined segment boundaries are meaningful. We welcome paper submissions on these or other related topics.

Present status and schedule:

The effort has been delayed due to the recent spate $M \geq 7$ earthquakes, and due to continuing problems with the Phase III report. We held a very productive workshop in September 1999, where the overall goals and individual tasks were refined. I have since written a web page for the project (**http://www.scec.org/research/WG2K**). I have also written some tutorials/notes on PSHA, and on previous seismic-hazard source models for southern California. These, which can be viewed by clicking "**Tutorial Materials**" at the web page, are intended to bring WG2K participants up to speed without having to read the lengthy original documents. These materials could also be linked to SCEC's education and outreach page if so desired.

Our future goals are as follows:

March 1, 2000:

The exact information that will be required from each model (for PSHA calculations and testing against existing and future data) will be specified.

May 1, 2000:

SCEC/USGS southern California earthquake catalog finalized (& on line).

Updated fault database (including digital fault traces) finalized (& on line).

Alternative rupture scenarios for LA basin faults defined.

New magnitude vs fault dimension relationship available.

September 1, 2000

All models and papers submitted for publication in a peer-reviewed journal.

The hazard calculations will begin as soon as possible. We anticipate publication of the report in 2001. This schedule does not include seminars and workshops that will be conducted.

SCEC Master Model

(A straw man for the Legacy Document & future proposals)

comments are welcome

Notable quotes from the original SCEC proposal:

> "… the goal of SCEC is to integrate research findings from various disciplines in earthquake-related science to develop a prototype **probabilistic seismic hazard model (master model)** for southern California" … "In essence, it will be the solid earth dynamics equivalent of global atmospheric and ocean circulation models …"

I'd like to broaden the master-model definition in the context of common goals between earthquake science and seismic hazard analysis, emphasizing current trends in each discipline and the health benefits of maintaining intellectual autonomy in the integration process.

Master Model (refined definition):

A paradigm for earthquake research & its application to seismic hazard analysis

Ultimate Goal:

> To understand deformation (in southern California) over time and space, particularly during large earthquakes. In other words, the temporal and spatial distribution of the strain tensor, especially during dynamic fault rupture and wave propagation.

Practical Approach:

> To gather observations; to develop and test a variety of physically based models of earthquake phenomena; and to evaluate these with respect to implied seismic hazard.
>
> These "ingredients" are then communicated to the user community and to those whose mandate it is to construct official, consensus hazard evaluations.
>
> Remaining issues then guide future research in the next iteration toward reaching the ultimate goal.

My attempt at representing this graphically is in the attached figure.

Comments:

This differs from the original definition in the following ways:

> That the ultimate goal is a complete model for the spatial and temporal distribution of deformation (strain-tensor). This is obviously a "holy grail" or utopian vision (i.e., a worthy pursuit, but one that necessitates a practical approach).
>
> The practical approach emphasizes the fundamental science (in terms of developing and testing physically based models).
>
> The definition de-emphasizes the construction of "consensus" models, which is not our mandate, nor is it a healthy approach to advancing scientific knowledge. Note that the figure includes "orphan" models (out-of-box thinking) as suggested by Hiroo Kanamori.
>
> In terms of hazard analysis, it includes earthquake scenario simulations (in addition to the probabilistic approach identified in the original definition). As discussed more below, such deterministic simulations constitute an exciting future trend.

The figure is my attempt at being thorough while avoiding visual confusion (e.g., I've left out operational elements & looping arrows). There is obviously some overlap among the categories; my aim was to make them representative and all inclusive. I wanted the figure to include some of the more exciting questions and issues, separating them into those solved under SCEC and those that remain, but I couldn't figure out how to do this without adding clutter.

This figure could form the front page of the SCEC on-line legacy document (with education & outreach components added). Each element could then be a link to a fuller description and to additional links (and cross-links). This would be relatively simple to implement, as each member of SCEC could contribute whatever web pages they deem appropriate.

Thoughts on SCEC's Next Incarnation:

A first-order question is whether SCEC should bill its next incarnation as addressing seismic-hazard-analysis (in addition to earthquake physics), or whether it should focus solely on scientific issues. The original justification for a center mode of operation was unequivocal: to facilitate the interaction needed for constructing a "master" probabilistic hazard model, and to communicate the results to potential users.

I think we can have it both ways. There are plenty of very interesting scientific questions that bear directly on important seismic-hazard issues. Under the master-model paradigm, you want some members working on data collection, some working on scientific issues and model development, some thinking outside of the box, some incorporating the latest findings into the next generation of hazard models, and some communicating this information to the user community. This is exactly what SCEC's modus operandi has been.

So how do we reinvent and justify ourselves in terms of a new center? As the figure indicates, there are two complementary approaches to seismic-hazard analysis. One is the probabilistic approach (PSHA) which accounts for all potential earthquakes and all sources of uncertainty, but is limited to overly simplistic representations of ground motion. The other approach is deterministic ground-motion simulation, which provides the entire time history but considers only one earthquake at a time (which may not be the next event to occur). The approaches are complementary in the sense that the complete, probabilistic hazard map can be de-aggregated to reveal the most menacing scenarios for a particular location, and then complete synthetics can be generated for those events (thus, the clickable hazard map concept). Although the engineering community has recognized the need to use full seismograms (to conduct "performance based design"), it has remained entrenched in the traditional approach in all but very special projects. The reason is that simulation methodologies have not been adequately developed and tested for routine application. The situation is like the chicken-and-egg paradox, the user community is waiting for routine simulation methodologies to become available before moving toward performance based design, while the applied scientists are waiting for the demand before developing the methodologies.

This is where we have a clear opportunity. By the end of SCEC, we'll have thoroughly addressed PSHA (via the Phase X projects). Yes, some important questions will remain with respect to PSHA (e.g., near-fault/large-quake ground motions), but these will be answered by either obtaining more observations, or by conducting reliable ground motion simulations. In other words, PSHA will have been developed to a point of diminishing returns.

I think the new center should bill itself as developing and testing ground-motion simulation methodologies. Such an effort could literally drive a revolution in seismic hazard analysis (in terms of pushing the move toward performance based design). This is appealing because reliable simulations will depend on a better understanding of the physics, which in turn will require conducting fundamental science. I think we'd be very persuasive in justifying a center because a concerted effort is what's needed to develop reliable/routine methodologies, and to break us out of the chicken-and-egg dilemma. There are also huge financial incentives (e.g., going from a design PGA of 0.6 to 1.0 g at the Yucca Mt Repository translated into a 1-billion dollar difference in the cost).

The new center would build on SCEC's having accomplished the stated goal of developing probabilistic hazard analysis, and would lead the charge in a new direction. It would maintain the momentum built by SCEC, and would benefit from the many lessons learned (we now know how to do it right). It would include and depend on our entire community (those interested in fundamental science as well as those interested in applications). Again, we would approach the problem by developing and testing a range of models rather than providing one "consensus" methodology.

Field Publications

Field, E.H., D.D. Jackson, and J.F. Dolan (1999). A Mutually Consistent Seismic-Hazard Source Model for Southern California, *Bull. Seism. Soc. Am.* **89**, 559-578.

Field, E.H. (1996) Understanding Earthquake Ground Motion and Seismic Hazard Assessment: Developing the State of the Art in Southern California; *to be produced and published by the Earthquake Engineering Research Institute.*

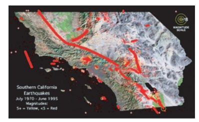
E.H. Field & the Phase III Working Group (1999). Accounting for Site Effects in Probabilistic Seismic Hazard Analysis: Overview of the SCEC Phase III Report, *to appear in a special issue of the Bull. Seism. Soc. Am.*, In Preparation.

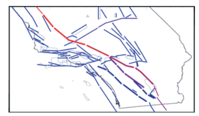
E.H. Field & others (1999). Probabilistic Seismic Hazard Calculations: Test of Various Possible Site Response Parameterizations, *to appear in a special issue of the Bull. Seism. Soc. Am.*, In Preparation.

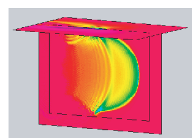
Observations & Data

Observations & Data

Geophysical Models







Geophysical Models

Seismic Hazard Models

Seismic Hazard Models