Probabilistic seismic hazard assessment in the wake of world disasters: Honing the debate and testing the models

Ross S. Stein (U.S. Geological Survey, Menlo Park, CA) *and*
Mark W. Stirling (GNS Science, Lower Hutt, New Zealand)

Devastating—and in at least some sense, unforeseen—earthquakes in Japan, New Zealand, Haiti and elsewhere have triggered a heated debate about the legitimacy and limitations of PSHA, probabilistic seismic hazard assessment (Frankel, 2013; Stein and Stein, 2014). PSHA attempts to capture the likelihood of exceeding a level of shaking over any time period of interest, explicitly incorporating data uncertainty and lack of knowledge. In response, four workshops at USGS John Wesley Powell Center for Analysis and Synthesis, Ft. Collins, Colorado brought together university, government, and insurance industry scientists from countries straddling plate boundaries and those in plate interiors to develop tests of what we have built, and to seek viable alternatives. There are three crucial aspects of the Powell Center process that made it work, and that any workshop could adopt:

First, we asked each invitee to take what we called the 'Powell Blood Oath': You are welcome to argue passionately for your views, but you must also present and acknowledge the weaknesses in your position. The oath kept everyone humble; no one grandstanded or dismissed others, because no one had all the answers. Those who could not abide by the oath turned our invitation down.

Second, we sat around the table, each with a laptop plugged into the projector, so that anyone could interject with figures or images from their computer by clicking a switch. No lectern, no uninterrupted talks, no fealty to the clock; everything was conversational, open, informed, and fluid. Further, the minutes were written into an Etherpad that all could access and modify on the fly, and so no single person shaped the record.

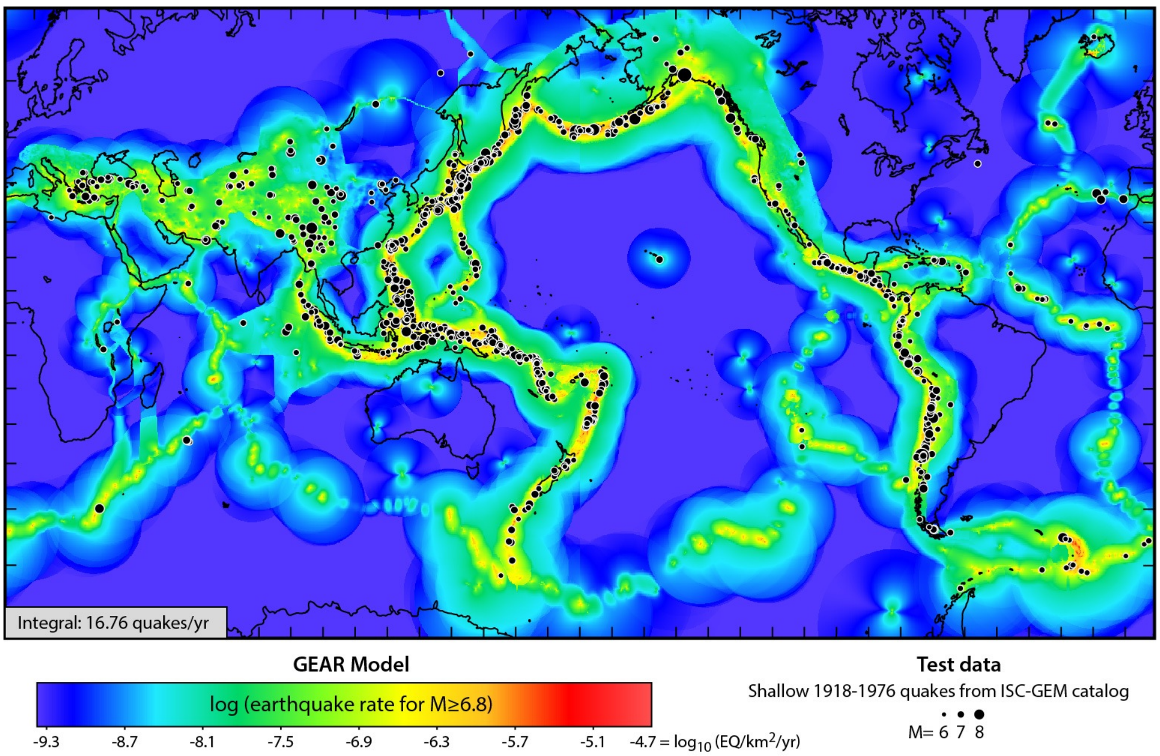
Third, we took a hike in the Rockies during the middle day of each workshop, during which the scientific conversations only deepened. Talking on a hike is less confrontational and more engrossing than around a table, and so delicate issues got discussed in depth. People who were quiet around the table found themselves in deep discussions on the trail, and so their views had greater impact.

Critics of PSHA, and critics of the co-hosts, the USGS and the Global Earthquake Model (GEM Foundation), were invited and listened to. Those who lead the PSHA modeling for their nations saw how others are tackling similar problems with different approaches.

Together we identified what tests are most needed to assess the value of PSHA, and what tools are most needed to improve it. Two major efforts grew out of the Powell meetings:

Global Earthquake Activity Rate (GEAR) model

GEAR gives the rate of earthquakes of all sizes everywhere on earth. It was constructed through a log-linear blend of the GEM Strain Rate Model (reflecting the forces that drive fault slip), and the Global CMT catalog seismicity (the products of fault slip). It was built by a uniform, open, and reproducible process, and will soon be submitted to independent (CSEP) testing. GEAR can be applied uniformly over the globe, and so can serve as a reference model for regional efforts that use local fault and seismic data.



GEAR 1.0 model (colors) compared to the independent ISC-GEM Catalog earthquakes (black dots, Storchak et al, 2014). The model is based on a combination of 40% GEM Strain Rate Model (Kreemer et al, 2013) and 60% 1977-2004 Global CMT earthquakes, which yields the best forecast of 2005-2012 Global CMT quakes (Bird et al, in prep.).

Testing successive U.S. seismic hazard models against observed shaking

A second goal to emerge from the discussion is to demonstrate the utility of PSHA since it is provided to the public. So, another outgrowth is a retrospective test of the 1996 to 2014 US National Seismic Hazard Mapping Project (NSHMP) models. All of the strong motion or Did You Feel It? observations from California are pooled to create a single hazard curve, giving the probability of exceedance as a function of ground motion, which is compared to a pooled prediction curve from the models. The results are sensitive to how the data are binned and counted, but for high values of shaking (>0.1 g), each successive NSHMP model does a better job of matching the data (Mak and Schorlemmer, in prep.)

Unresolved problems of Probabilistic Seismic Hazard Assessment

Assignments of the maximum earthquake magnitude to faults are some of the least defensible elements in view of the Powell participants. We know only that the longer the observation period, the higher the observed maximum magnitude.

PSHA modeling typically seeks to strip out aftershocks, foreshocks and swarms to isolate mainshocks. This "declustering" is highly uncertain, leaving anywhere from 80% to 20% of the earthquakes as putative mainshocks. There should be standardized declustering algorthims and tests of whether the declustered catalog exhibits Poisson behavior (in other words, earthquake independence).

The intraplate regions of the world present some of the most difficult conditions for PSHA. Since little is typically known of the faults or their slip or strain rates, the historical record of quakes is often used, in which the distribution of small shocks is smoothed and scaled to estimate the rate and distribution of larg shocks. But do recent small shocks forecast large ones? Even if this strategy were justified, the appropriate amount of smoothing is unknown.

The Powell process generated new models, tests, and problems. But perhaps more important, it brought people together with opposing views, who worked together around a table and on a trail to find common ground.

References

Bird, P., D.D. Jackson, Y.Y. Kagan, C. Kreemer, and R.S. Stein, GEAR1: A Global Earthquake Activity Rate model constructed from geodetic strain rates and smoothed seismicity, in prep.

Frankel, A. (2013), Comment on "Why earthquake hazard maps often fail and what to do about it" by S. Stein, R. Geller, and M. Liu, *Tectonophysics, 592*, 200–206, http://dx.doi.org/10.1016/j.tecto.2012.11.032

Mak, S. and D. Schorlemmer (2015). Comparing the USGS national seismic hazard maps with observed ground motions from 2000 to 2013 (in prep.).

Stein, S., and J. Stein (2014), Playing Against Nature: Integrating Science and Economics to Mitigate Natural Hazards in an Uncertain World, 260 p., AGU/Wiley. Wash., D.C.

Storchak, D.A., D. Di Giacomo, E.R. Engdahl, J. Harris, I. Bondár, W.H.K. Lee, P. Bormann and A. Villaseñor (2014), The ISC-GEM global instrumental earthquake catalogue (1900-2009): Introduction, *Phys. Earth Planet. Int.,* in press, doi: 10.1016/j.pepi.2014.06.009.

Acknowledgements

We are grateful for support from the USGS Powell Center and the GEM Foundation, and for the outstanding efforts of the Powell Center's co-director and host, Jill Baron.

— ROSS S. STEIN, U.S. Geological Survey, Menlo Park, CA; email: rstein@usgs.gov; MARK W. STIRLING, GNS Science, Lower Hutt, New Zealand; email: M.Stirling@gns.cri.nz