Probabilistic Seismic Hazard Modelling: A Review in Light of Recent Events

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ABSTRACT: It has been recently suggested in high-profile literature that probabilistic seismic hazard (PSH) methodology may be flawed and in need of update. The main criticism is that PSH models have been inadequate for forecasting recent devastating earthquakes. It is important to evaluate criticisms, given the fundamental importance of PSH modelling for end-users.

The issues associated with the performance of PSH models do not arise from the logical late-1960s Cornell methodology. The issues instead result from deficiencies in the inputs and misuse of the models. PSH inputs should ideally be comprehensive enough to encompass all plausible hazardous events, as the output is only as good as the input. In terms of misuse, criticism of a PSH model "missing" a major earthquake is unjustified if the model has not been developed for short-term forecasting (the case for almost all PSH models), or if an inappropriate PSH return period is used as the basis for comparison.

To replace PSH methodology requires the development of reliable and versatile short-term-to-long-term forecasting methods. Promising efforts have been happening in New Zealand and elsewhere, but it is still unlikely that a replacement for PSH methodology will be found in the near future.

1 INTRODUCTION

The occurrence of recent, damaging earthquakes and tsunamis around the world have caused some scientists (e.g. Stein et al., 2011) to criticise the methodology of probabilistic seismic hazard analysis (PSHA). In particular, the devastating Tohoku, Haiti and Christchurch earthquakes have been cited as examples of PSHA failures, in that the earthquakes were either larger than the maximum earthquake size assumed in the PSHA, or they occurred in areas of low estimated hazard. The purpose of this paper is to discuss these observations from the perspective of a hazard modeller who's daily job is to provide practical hazard information to end-users.

2 PSHA: INTENDED USAGE

The PSH models referred to by Stein et al. (2011) are not short-term forecasting tools. They are tools developed to provide estimates of hazard for long return periods (e.g., hundreds to thousands of years) for engineering design and planning purposes. They are not developed to provide short-term (e.g., months to years) probabilities for impending earthquakes. Examples of appropriate PSH model applications are in building construction (typically 500 to 2,500 year return periods) and in nuclear facility and hydro-dam developments (typically $\geq$10,000 year return periods). Hazard maps for these return periods typically show large differences in hazard across regions like the western United States and New Zealand, reflecting differences in the expected future activity of earthquake sources across the regions. The differences seem logical, given that one would expect sites close to major plate boundary faults to experience more earthquakes in the long term than sites further away. This is useful information for engineering and planning, including the development of loadings standards (e.g. NZS1170.5; Standards New Zealand, 2004)). The PSH-derived hazard estimates can also be disaggregated to identify the most likely (or most unlikely) earthquake scenarios for the site or region in question, and these scenarios are often used by regional authorities and others to plan for future earthquake hazards. However, to give these PSH models the ability to provide actual short-term earthquake forecasts would require the integration of relevant forecasting models into the PSH model framework. World-leading, relevant efforts have been happening in the Canterbury region, and at GNS Science we are tasked with coming up with ways of applying these developing methodologies to the rest of the country.

Stein et al. (2011) do raise some perfectly valid issues with regard to the performance of the relevant PSH models. While the models are not intended to be used as forecasting tools, it is true that model parameters like maximum magnitude and expected ground motions should adequately encompass any event observed in the particular region. In this respect the Japanese PSH models underestimated the magnitude of the M_w 9, 11 March 2011 Tohoku earthquake. In New Zealand, the M_w 7.1, 4 September 2010 Darfield, Canterbury earthquake occurred on a previously unknown fault, reflecting a partial lack of knowledge about that part of New Zealand. However, the earthquake was to an extent accounted for in the distributed or background seismicity model, which has a maximum magnitude set at M_w 7.2 in the area of the earthquake. The main purpose of a distributed seismicity model is to allow for the occurrence of earthquakes on unknown sources, which is exactly what happened in Canterbury. Some modern PSH models have gone the extra step of incorporating comprehensive epistemic uncertainties into every component of the model to account for all possible surprise events. The Californian UCERF3 model (wgcep.org), for instance, allows virtually every possible combination of rupture geometry on the fault sources and uses seismological and geodetic data to define a range of distributed seismicity rates. In essence it is the input to the PSH model that is often deficient, rather than the PSH methodology being flawed. PSHA is, after all, a logical function of the inputs: the location, size, rate of occurrence, and predicted ground motions of surrounding earthquakes (Cornell, 1968).

3 PSHA NOW AND INTO THE FUTURE

The bottom line on PSHA is that it is the only practical method available for developing hazard estimates for end-users at the present time. Until it is replaced with a greatly-improved and ground-truthed methodology it will remain our only toolkit for providing timely solutions to end-users. PSHA is simple and logical, and can incorporate as much as the science can provide. Conversely, PSHA is only as good as: (1) the science that has been provided, and; (2) the person driving the PSH model. Inadequate input and overuse (e.g. using standard PSHA to do short-term forecasts) are big issues that lead to poor performance of the PSH models.

Some high priority areas of work that are showing promising progress towards improving PSH models are: the increasing detail and diversity of source models (e.g. Californian UCERF3 source model; wgcep.org); the development of testing methodologies (e.g. Collaboratory for the Study of Earthquake Predictability, cseptesting.org; Stirling and Petersen 2006; Stirling and Gerstenberger, 2010), time-dependent hazard modelling, and physics-based approaches. However, the largest barrier to making PSHA effective in short term forecasting is the inability to identify where/when major earthquakes are going to occur in areas/time periods of seismic quiescence. This is not a failing of PSHA methodology, but is one of the fundamental unknowns of seismology at the present time.

4 REFERENCES

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