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DEVELOPMENT OF TESTS FOR PROBABILISTIC SEISMIC HAZARD MODELS FROM HISTORICAL AND PREHISTORICAL DATA

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SUMMARY

We compare predicted rates of seismic hazard (felt intensities or peak ground accelerations) from the national seismic hazard models for New Zealand and the USA against the historical rate of exceedance for specific felt intensity levels at towns and cities in the two countries. The comparisons reveal a tendency for the probabilistic seismic hazard (PSH) models to slightly overestimate the historical hazard at about 30 towns and cities in New Zealand, and to significantly underestimate the historical hazard at a similar number of centres in southern California, and across the continental USA. The discrepancies in the USA are most marked in the areas of lowest seismicity and seismic hazard, and where strong site response is likely to be observed during large earthquakes. The results of these comparisons are preliminary, and future work is expected to be geared towards determining the reasons for and statistical significance of the discrepancies observed in southern California/continental USA, the difference in result between southern California/continental USA and New Zealand, standardising the procedure for the three areas, and introducing constraints on ground motions provided by ancient precariously-balanced rocks to the overall analysis.

INTRODUCTION

A serious deficiency that has long faced probabilistic seismic hazard (PSH) methodology is that no methods are available to formally test or validate the resulting estimates of PSH. In the past year our Foundation for Research, Science and Technology (FRST), US Geological Survey (USGS) and Southern California Earthquake Centre (SCEC)-funded research has addressed this deficiency by developing site-specific tests for PSH models from the historical record of felt intensities (Modified Mercalli intensities, or MMI) in New Zealand, southern California and the continental USA, and then undertaking preliminary

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tests of the New Zealand and USGS/California Geological Survey (CGS) PSH models (Stirling, et al. [1]; Frankel [2]) at these same sites. Development of these tests is ultimately geared towards providing a formal test for these models, and for PSH methodology in general. While some substantial efforts have gone into testing the New Zealand PSH model (Rhoades et al. [3]; Dowrick & Cousins [4]), the present project is designed to develop a generic approach to testing PSH methodology and models from a geographically diverse collection of data and models. The choice of the two PSH models was based on the marked similarity of the datasets and methodology used in the models. In this short paper we provide a précis of our efforts to develop these historically-based tests, the work largely achieved during 2002 while the senior author was the inaugural USGS Senior Scientist in Residence, and in 2003 while working on SCEC-funded research at USGS Pasadena.

HISTORICAL ANALYSIS

Methodology

Our general method has been to use the historical record of felt intensities at a suite of towns and cities around New Zealand, southern California and the continental USA to develop historically-based hazard curves (annual rates of exceedance for a suite of MMI levels) and then compare these historically-based curves to the hazard curves calculated for the sites from the relevant PSH models. The basic premise has been that the felt intensity data can be used in this manner as these data and PSH models are essentially independent of one-another. Specifically, the felt intensity data have not been used directly in the PSH models, only indirectly through the use of the intensity data to estimate magnitudes for some early earthquakes.

We have developed historically-based tests at about 30 towns and cities distributed uniformly across New Zealand, and a similar number across southern California, and across the continental USA. The uniform coverage of the two areas therefore encompassed areas of very high to very low seismotectonic activity and seismic hazard (Fig. 1). For these sites we searched historical databases on the web and in the literature (primarily relying on the analysis of Dowrick & Cousins, [4] for New Zealand, and the USGS's NGDC website http://www.ngdc.noaa.gov:8800/seg/plsql/eqi.main for southern California). For New Zealand we used the Dowrick & Cousins [4] calculated rates of exceedance for given MMI levels directly for each site. For southern California and the continental USA we started from first principles with a search that resulted in the careful selection of MMI data and construction of three MMI "sub catalogues". The sub catalogues contained a complete record of the following, on the basis of discussions with knowledgeable USGS personnel: (1) MM7 and above from the incorporation (founding) year of each town/city to the end of 1930; (2) MM6 and above from 1931 to the end of 1985 (the main period covered by the NGDC database), and (3) MM6 and above from 1985 to the present day (data for the latter not available for all 27 sites, and mainly derived from the USGS's SHAKEmap; http://www.trinet.org/shake/). For southern California and continental USA the MMIs were then converted to the equivalent peak ground accelerations (PGA) by way of the equations of Wald et al [5] and Trufunac & Brady [6] to enable the comparison of the historical data directly to hazard curves derived from the PSH models. The Wald et al. [5] equations were considered to be most relevant to modern earthquake data and the Trifunac & Brady [6] equations most relevant to the older data due to differences in the response of newer versus older man-made structures to earthquake shaking. For the New Zealand sites the PGA hazard curves derived from the Stirling et al. [1] PSH model were converted to MMI by way of the equations of Wald et al [5] for comparison to the historical MMI data. Comparison of the historically-based rates of exceedance to PSH models was then accomplished simply by plotting both on the same graph (Fig. 1). The slightly different methods of MMI data compilation and comparison (in terms of PGA for southern California and continental USA, and in terms of MMI for New Zealand) is simply a function of the intermediate stage we have reached with this work in recent months.

While our tests are limited by the short historical record of New Zealand, southern California and the continental USA, they have a major advantage in being able to be simultaneously applied to a large number of sites from different tectonic environments. The shortcomings of the historical record are therefore compensated for by the ability to make comparisons at a large number and great diversity of sites.

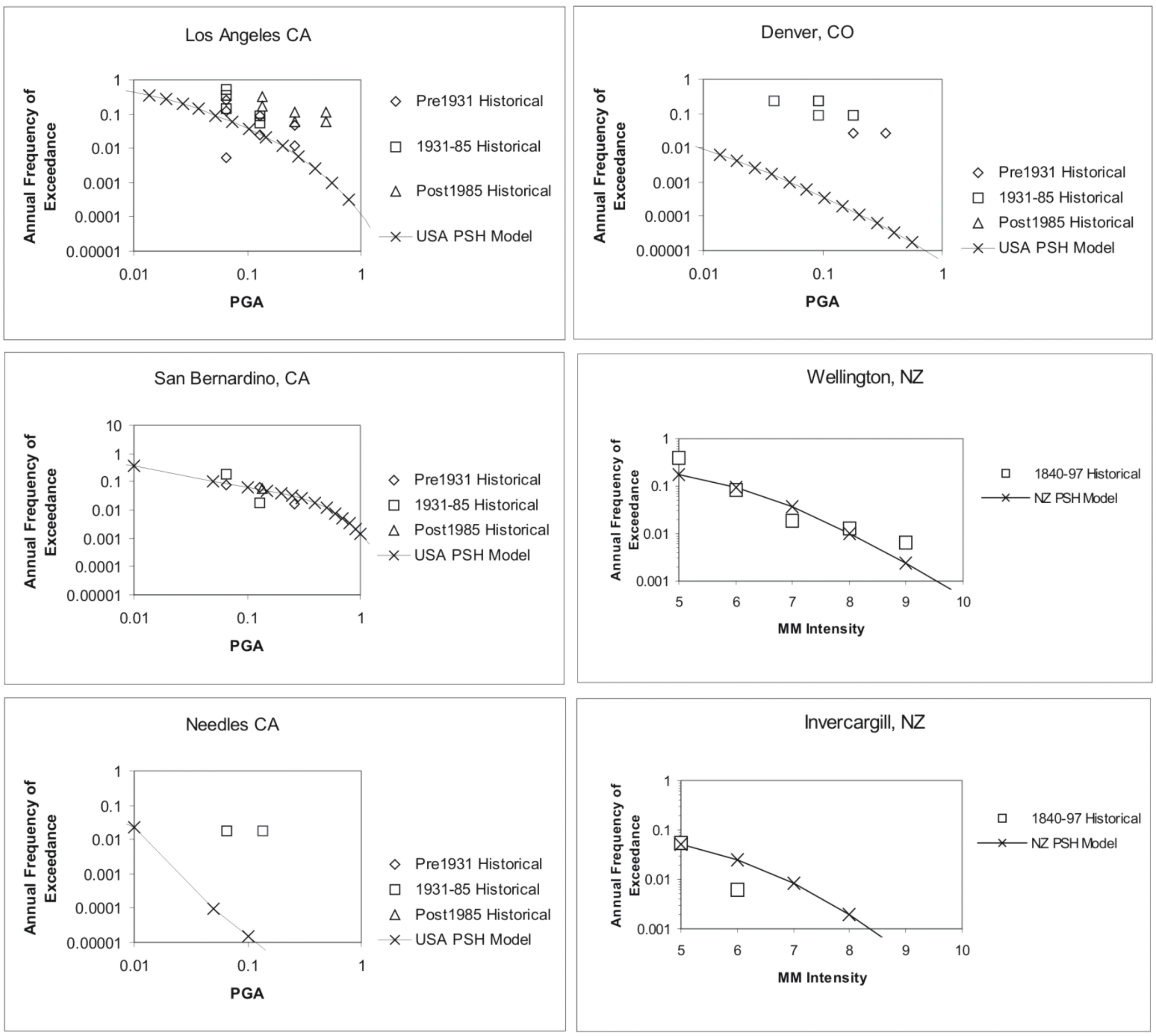

Figure 1. Examples of the comparisons of historical levels of hazard to the hazard predicted from national seismic hazard models of New Zealand and the USA.

Results

The six graphs in Figure 1 provide examples of the comparisons made at the New Zealand, southern California and continental USA sites. The graphs show the historical rates of exceedance for various levels of MMI for New Zealand, and PGA for southern California and continental USA (the latter converted from MM Intensity by way of Wald et al. [5] and Trifunac & Brady [6]) along with hazard curves derived from the New Zealand and USGS/CGS PSH models. The tendency is for the historical hazard to be equal, to slightly lower than that of the New Zealand PSH model, but higher than the hazard derived from the USGS/CGS model. The New Zealand result is in the same sense as the conclusions reached by Rhoades et al. [3] and Dowrick & Cousins [4]. The USA discrepancies are greatest in areas away from the plate boundary where earthquake rates are low and hazard is dominated by background earthquake sources ("Needles" in Fig. 1 is located in low-seismicity easternmost California), and least in the high-hazard areas dominated by fault sources ("San Bernardino" in Fig. 1 is located close to the junction of three major active faults in California).

The marked discrepancies between the USGS/CGS PSH model and the historical MMI data as compared to the New Zealand comparisons is surprising, given that the two PSH models share very similar datasets and methodology. The discrepancies in the USA appear to be in areas of low seismicity rates and away from active faults. They may be due to the standard procedure of spatially distributing or smoothing background seismicity rates in PSHA, the tendency being to "spread" or "dilute" the historical earthquakes near individual sites away from those sites. However, it is surprising that the same discrepancies are not observed in low-seismicity areas of New Zealand (e.g. Invercargill in Fig. 1). It may be the case that the seismicity rates of vast areas of the USA are much lower than those of New Zealand, and on average the distances from the USA sites to high-seismicity areas will be much greater than in New Zealand. The discrepancies may also be explained in some cases by the PSH models underestimating strong site response in areas of soft ground and deep basins (e.g. "Los Angeles" graph in Fig. 1). We have found that for most of the USA sites the discrepancies are so large that they cannot be accounted for by uncertainties in determination of MMI in the historical data and/or conversion from MMI to PGA.

PREHISTORICAL ANALYSIS

Collaborative efforts are also being focused on using the distribution of ancient precarious landform features (Fig.2) to provide upper-limits on the strength of ground shaking that has occurred at specific sites for time periods of thousands of years. Work over the last decade in southern California and Nevada (e.g. Brune [7]) has shown that PSH models may provide OVEREstimates of hazard for time periods of thousands of years. These results are contrary to the results of the historical comparisons described above. Preliminary efforts to investigate precarious rocks in New Zealand (Fig.2) are presently being made by way of a New Zealand Earthquake Commission Research Foundation (EQC)-funded pilot study.

CONCLUSIONS

Our preliminary tests of the New Zealand and USGS/CGS PSH models against the historical rate of exceedance for specific MMI levels at towns and cities around New Zealand, southern California and the continental USA show a tendency for the PSH model to slightly overestimate the historical hazard in the former area, and significantly underestimate the historical hazard in the latter two areas. The discrepancies are most marked in the areas of lowest seismicity and seismic hazard, and where strong site response is likely to be observed during large earthquakes. Future work will be geared towards determining the reasons for and statistical significance of the discrepancies observed in the USA analyses, the difference in result between the USA and New Zealand analyses, standardising the procedure for the three areas, and introducing the precarious rock data to the overall analysis as a potentially viable constraint on past (and therefore future) levels of seismic hazard.

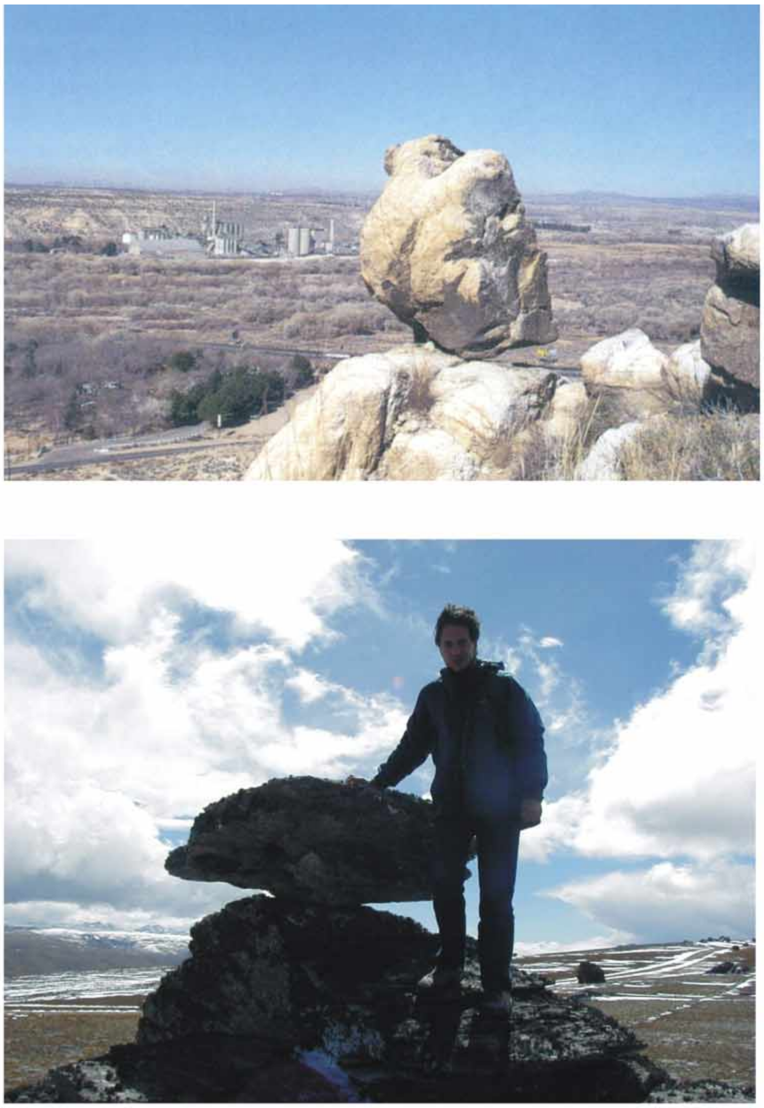

Figure 2. Precariously-balanced rocks in southern California (top; site is near the town Victorville in the Mojave Desert) and New Zealand (bottom; site is on the Old Man Range near Alexandra, central Otago, New Zealand)

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