A NEW PROBABILISTIC SEISMIC HAZARD MODEL FOR NEW ZEALAND

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SUMMARY

The Institute of Geological and Nuclear Sciences (GNS) has developed a new seismic hazard model for New Zealand that incorporates state-of-the art methods of multidisciplinary probabilistic seismic hazard analysis (PSHA). The new model incorporates paleoseismic data, historical seismicity data, and new attenuation relationships for New Zealand. Maps derived from the model show the levels of peak ground acceleration and 0.2 second response spectral acceleration expected at 10% probability in 50 years at "Class B" (stiff to intermediate soil) sites. The maps generally show much higher estimates of PSH than the estimates produced in earlier studies, largely because of the explicit inclusion of active faults as seismic sources, and are therefore expected to result in considerable modifications to the building code.

INTRODUCTION

In recent years, major advances have been made to the methodology of probabilistic seismic hazard analysis (PSHA), mainly due to the incorporation of geologic data into PSHA. Up until recently, national PSH maps were largely based on the historical record of earthquakes (e.g. Matuschka et al. 1985; Smith and Berryman, 1986), with some consideration of geological information on a regional basis. The combination of geological data (i.e. slip rate and paleoearthquake data derived from studies of active faults) and historical seismicity data in a PSHA generally produces higher hazard estimates than those that are based on the historical record of earthquakes alone. This is because, in general, the historical record is not long enough to have recorded large earthquakes on all the major sources that are preserved in the geological record. Integration of geological and historical seismicity data into a recent experimental PSHA of New Zealand (Stirling et al. 1998) resulted in considerably higher estimates of probabilistic seismic hazard in areas close to major active faults (e.g. Alpine Fault).

Our approach at the Institute of Geological and Nuclear Sciences (GNS) for revising the New Zealand PSH model is to build on the methodology developed by Stirling et al. (1998). That model has been refined through the incorporation of new fault data, more detailed modelling of distributed (historical) seismicity (McGinty, 1999), and new ground motion attenuation relationships. In this paper we provide an overview of the features of the new PSH model, and show some PSH maps developed from the model for the Canterbury region. The new model will provide the basic New Zealand seismic hazard input for a joint New Zealand-Australia Loadings Standard.

FEATURES OF THE NEW MODEL

General Methodology

The new PSH model is developed according to the standard methodology of PSHA (Cornell, 1968). This involves defining the location and recurrence behaviour of earthquake sources to estimate the hazard (peak ground acceleration and response spectral acceleations) that the sources are expected to produce at a gridwork of sites that cover the entire country. As part of these calculations we also adopt the standard practice of modern

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PSHA of taking into account the uncertainty in acceleration estimates from the attenuation model (McVerry et al., this conference). In calculating the ground motions expected in a certain time period, we generally assume a Poisson model of earthquake occurrence, in that we base our estimates of hazard on the average time-independent rate of earthquake occurrence on each fault.

Earthquake Sources

Faults

We have defined about 200 fault sources for the national PSH model. The dataset is based on the original fault data compilation of Stirling et al. (1998). This dataset has been reviewed and updated to include newly synthesised fault data for the Alpine Fault, Taupo Volcanic Zone, and lower Waitaki region of south Canterbury/north Otago. Data bearing on the geometry (fault coordinates, depth and dip), activity (slip rates, single event displacements, and return times), and sense of slip of the fault sources are used in the PSHA.

Our methods of estimating the likely maximum magnitude (Mmax) and return time of earthquakes produced by each fault source vary according to the quantity and quality of available data for each fault. Where possible, the magnitudes of large historical earthquakes (usually well constrained from instrumental records or from MM intensity data) and lengths of the associated surface ruptures are used to define the Mmax and length of particular fault sources. If historical observations are unavailable for a fault source, then the next most preferable method of defining Mmax is to calculate it from estimates of single event displacements and fault area. Lastly, if single event displacement data are unavailable, then an empirical regression of Wells & Coppersmith (1994) is used to estimate Mmax from fault rupture area. Return time (T) estimates either come directly from geological investigations, or are calculated from slip rate with the equation of Wesnousky (1986).

$T = Mo/Morate$

Mo is the seismic moment corresponding to magnitude Mmax, and Morate is the rate of seismic moment release on the fault, equal to uAS, in which u is the rigidity modulus, 3×10^{11} dyne/cm^2, A is the fault area, and S is the fault slip rate.

The fault dataset also includes dipping sources along the Hikurangi and Fiordland subduction interfaces. These are defined from the results of studies that have used the spatial and depth distributions of seismicity to map the 3D geometry of the coupled subduction interface, the likely positions of segment boundaries, and the degree of coupling (ratio of seismic slip to total slip) on the subduction interface (e.g. Reyners, 1998).

Distributed Seismicity

In addition to defining the locations, magnitudes and frequencies of large to great earthquakes on the crustal faults and subduction zones, we also allow for the occurrence of moderate-to-large distributed “background” earthquakes (M5 up to a selected choice of "cutoff magnitude", which may vary around the country) both on and away from the major faults. Our reasons for considering background earthquakes in the PSH model are twofold. First, earthquakes of M<6.5 are not generally large enough to rupture to the surface (e.g., Wesnousky, 1986), so it is possible that some future earthquakes of these magnitudes will occur on fault sources that have no surface expression and have escaped mapping by geologists. Second, since some of the historic large New Zealand earthquakes have not been able to be assigned to specific faults, the possibility exists that some future large earthquakes may also occur on unknown faults.

Extending the methodology of Stirling et al. (1998), we use the spatial distribution of historical seismicity since 1840 (i.e. the maximum extent of the historical record) to predict the likely locations and recurrence rates of distributed earthquakes in the crust and subduction zones. We take account of varying completeness levels in different eras. The catalogue is first declustered with the method of Reasenberg (1985). We then define the distributed earthquakes across a 3D gridwork of point sources spaced at 0.1 degrees in latitude and longitude, and at depth intervals of 20km to a maximum depth of 100km. In contrast, Stirling et al. (1998) limited their attention to shallow crustal seismicity, and the instrumental record since 1964. Also, we have reworked the catalogue to give more reliable locations, magnitudes and depths for many events (McGinty, 1999).

A Gutenberg-Richter distribution logN=A-bM, in which N is the number of events with magnitude greater than or equal to M, and A and b are empirical constants (Gutenberg and Richter, 1944) is used to predict the recurrence rates of distributed earthquakes at each point source. The rates are based on the number of earthquakes occurring in the immediate vicinity of the point source, with regionally-dependent b-value and magnitude cutoffs (Mcutoff) for the maximum magnitudes included in the background seismicity. N, b and Mcutoff are then spatially smoothed with a Gaussian smoothing function that preserves the general patterns of seismicity in the crust and subduction zones, and avoids the excessive smoothing and "edge effects" that are produced with the traditional use of area sources in PSHA (e.g. Smith & Berryman, 1986).

Attenuation Relationships

The attenuation relationships used in the New Zealand PSH model have recently been developed for 5% damped acceleration response spectra (SA(T)) from a database of New Zealand earthquakes (McVerry et al., this conference). An important feature is that the models take account of the different tectonic types of earthquakes in New Zealand i.e. crustal, subduction interface and dipping slab. The attenuation expressions for crustal earthquakes have further subdivisions, through mechanism terms, for different types of fault rupture (strike-slip, normal, oblique/reverse and reverse). The site classes defined in the attenuation models are moderate to strong rock sites (class MA/SA), weak rock sites (class WA), stiff to intermediate soil sites (class B), and flexible or deep soil sites (class C).

PSHA OF THE CANTERBURY REGION

In early 1999 we focused our development of the new PSH model on the central South Island. Specifically, we were commissioned by the Canterbury Regional Council to undertake a PSHA of the Canterbury region (Stirling et al. 1999). The locations, sizes, and recurrence rates of active faults defined by the Natural Hazards Research Centre of the University of Canterbury and GNS (Pettinga et al., 1998; Fig. 1a), and the historical earthquake record since 1840 (Fig 1b) were used to estimate the PSH (levels of peak ground acceleration and response spectral accelerations expected in various return times) across the region (Figure 2). In calculating the accelerations expected in a certain time period, we generally assumed a Poisson model of earthquake occurrence, in that we based our estimates of hazard on the average time-independent rate of earthquake occurrence on each fault. The only fault treated differently was the Alpine Fault. In this case we utilised the results of recent paleoseismic studies (Berryman et al. 1998; Yetton et al., 1998) to develop estimates of PSH that took into account the elapsed time since the last earthquake on the fault.

In Figure 2 we show maps of the levels of peak ground acceleration (Fig. 2a) and 5% damped response spectral acceleration (0.2 second period; Fig 2b) expected across the Canterbury region with a return period of 475 years (i.e. 10% probability of exceedance in 50 years). The maps assume "Class B" site conditions. In general, the highest peak ground accelerations tend to occur in the west to northeast of the region, where the greatest concentrations of active faults and historical seismicity are located. Peak ground accelerations of 0.7-0.9g, and 0.2 second spectral accelerations of over 2g are estimated for these areas for the 475 year return period. In general, the estimates of PSH for Canterbury generally exceed estimates from the earlier national model (Smith and Berryman, 1986) because of the explicit incorporation of active fault data into the PSHA, the new method for treatment of distributed seismicity, and the use of new attenuation relationships (McVerry et al., this conference). The estimates of PSH decrease to the south and southeast. Peak ground accelerations of about 0.4g, and 0.2second spectral accelerations of about 1g are estimated for the city of Christchurch, exceeding the recent estimates of Dowrick et al. (1998). This increased PSH for Christchurch can be attributed to the new fault data acquired after the Dowrick et al. study, and again to differences in treatment of distributed seismicity and attenuation relationships.

CONCLUSIONS

The New Zealand earthquake hazard model has been updated to incorporate new geological data, an improved historical earthquake catalogue, newly-developed methods for the treatment of historical catalogue data, and new attenuation relationships for peak ground acceleration and response spectral accelerations. Maps produced for the Canterbury region show higher estimates of PSH than those produced in the earlier PSHAs. The new PSH model is therefore expected to result in considerable modifications to the building code.

ACKNOWLEDGEMENTS

Numerous individuals at GNS and elsewhere have thus far contributed to the development of the national PSH model. In particular, Kelvin Berryman, Graeme McVerry, Pilar Villamor, Russ Van Dissen, David Dowrick, Jim Cousins, Peter McGinty, Jarg Pettinga and Mark Yetton have all been instrumental in the development of the earthquake source datasets, and have also provided assistance with developing the methodology for the new PSH model. Graeme McVerry and Judith Zachariasen provided useful comments on the manuscript. The support of the EQC Research Fund, the New Zealand Foundation for Research, Science and Technology, and the Canterbury Regional Council (in particular Peter Kingsbury) are gratefully acknowledged.

Institute of Geological and Nuclear Science contribution number 1754.

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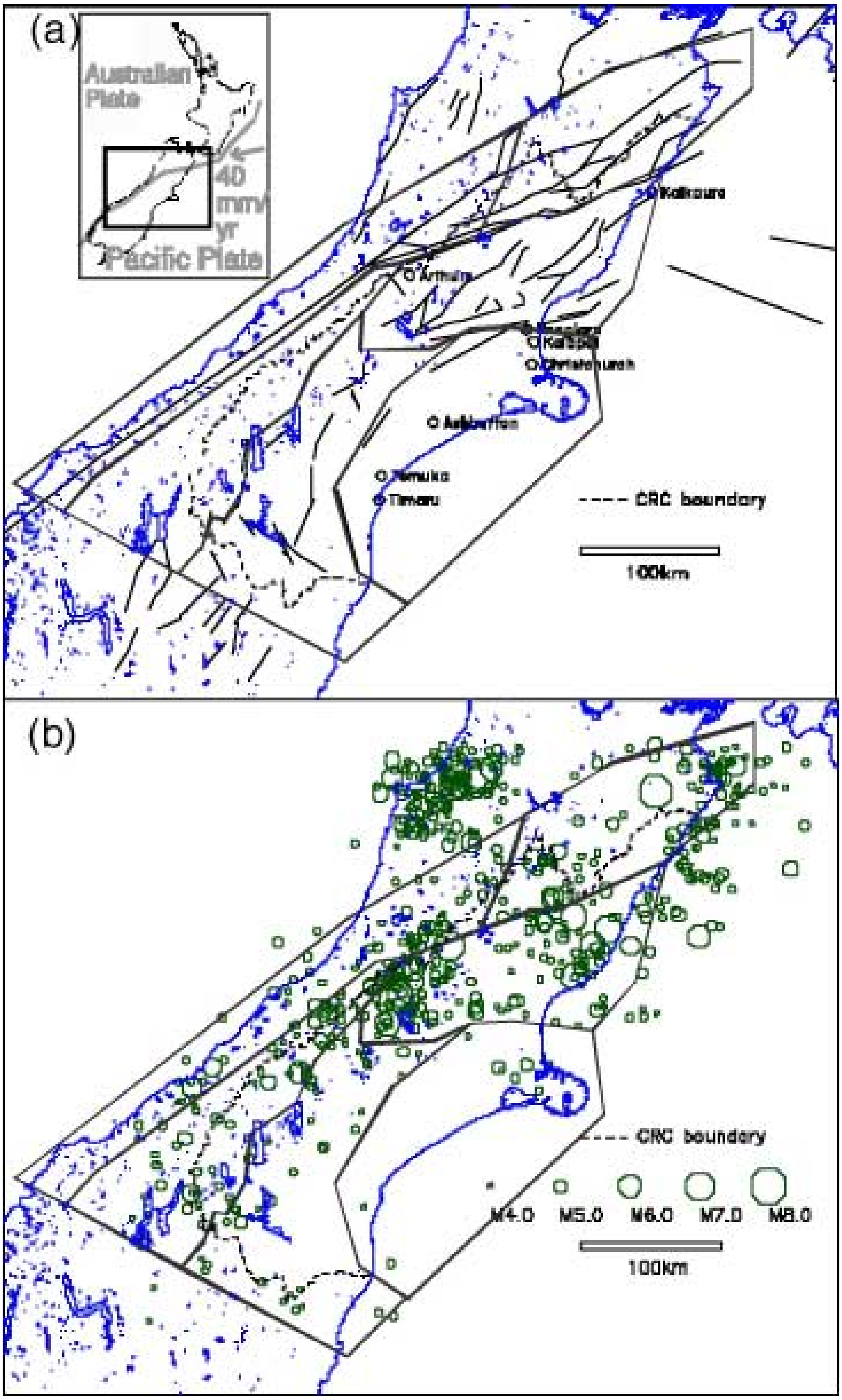

Figure 1. Input to the PSH model; (a) active faults (simplified traces shown) and structural domains (source = Pettinga et al. 1998), and (b) historical seismicity of the Canterbury region. The boundary of the Canterbury region ("CRC") and main towns and cities are also shown.

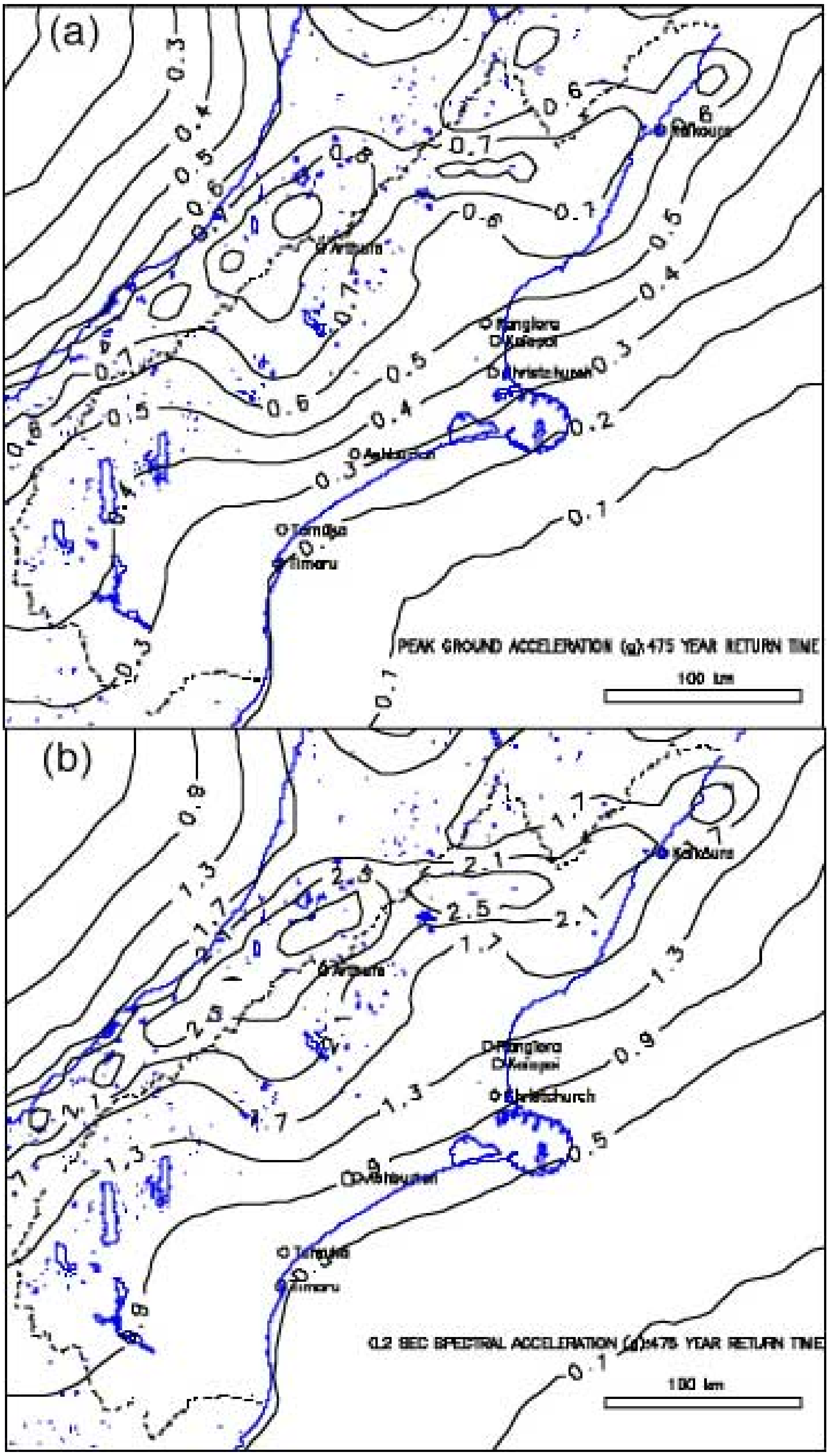

Figure 2. Maps of the Canterbury region, showing; (a) Peak ground accelerations, and (b) 0.2 second spectral accelerations (in g) expected at 10% probability in 50 years, assuming "class B" site conditions.