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# SEISMIC HAZARD ANALYSIS IN NEW ZEALAND

FU WANG[1], DONALD S. WINDELER, JR.[1], CHRISTIAN P. MORTGAT[1],
JANET BOLEY[1], RACHEL DAVIDSON[2]

[1]Risk Management Solutions, Inc., Menlo Park, CA, 94025, USA
[2]Civil Engineering Department, Stanford University, Stanford, CA, 94305, USA

## ABSTRACT

This study presents the results of two seismic hazard studies for the country of New Zealand. A probabilistic model was used to produce a seismic zonation map for the entire country. A deterministic analysis of an Ms 7.8 earthquake on the Wellington fault was combined with digital geologic information to produce a microzonation map for the Wellington region.

## KEYWORDS

maximum magnitudes, Mercalli intensity, New Zealand, probabilistic hazard assessment, seismic sources, soil effects, Wellington fault

## INTRODUCTION

New Zealand lies astride the juncture of two tectonic plates, the Pacific to the east and the Indian to the west. The convergence of these crustal masses raised New Zealand from the ocean with a force that continues to shape its landscape today. Active volcanos and frequent earthquakes furnish constant reminders of New Zealand's place in one of the Earth's more geologically volatile environments (Figure 1).

The confluence of the Pacific and Indian plates in the vicinity of New Zealand comprises several tectonic styles. Northeast of the North Island, the Pacific plate is being subducted beneath the Indian plate. Southwest of the South Island, the roles are reversed as the Indian plate subducts beneath the Pacific. These two subduction zones are joined by a zone of shallow faulting and deformation that accommodates the shifting plates and runs nearly the entire length of New Zealand. Between the North and South Islands, this transition zone is prone to large, shallow earthquakes on numerous faults, and is the area of highest hazard. On the South Island, movement is largely focused along a single structure, the Alpine Fault. Often compared to the San Andreas in California, this transform fault has displaced rocks 500 km along its length over the last 20-30 million years.

New Zealand's tectonic diversity results in numerous earthquakes, shallow and deep, onland and offshore. On the average, New Zealand experiences about one earthquake of magnitude 6 per year, one greater than magnitude 7 per decade, and one greater than magnitude 8 per century (Adams, 1974). As a consequence, the hazard from damaging earthquakes is substantial.

This study examines two aspects of seismic hazard in New Zealand: the overall level of hazard across the entire country, analyzed probabilistically, and the relative levels of hazard in the Wellington area, analyzed deterministically. The country-wide map was generated using standard probabilistic hazard analysis methods with a seismic source model described below. Probabilistic maps display a measure of the level of hazard due to the contribution of all seismic sources but provide little information on event-specific scenarios. Deterministic analyses can shed additional insight on localities at higher risk. Using digitized soil data and results from the hazard model, a "worst case" scenario map for Wellington is presented: a magnitude 7.8 earthquake along the Wellington-Hutt Valley segment of the Wellington fault.

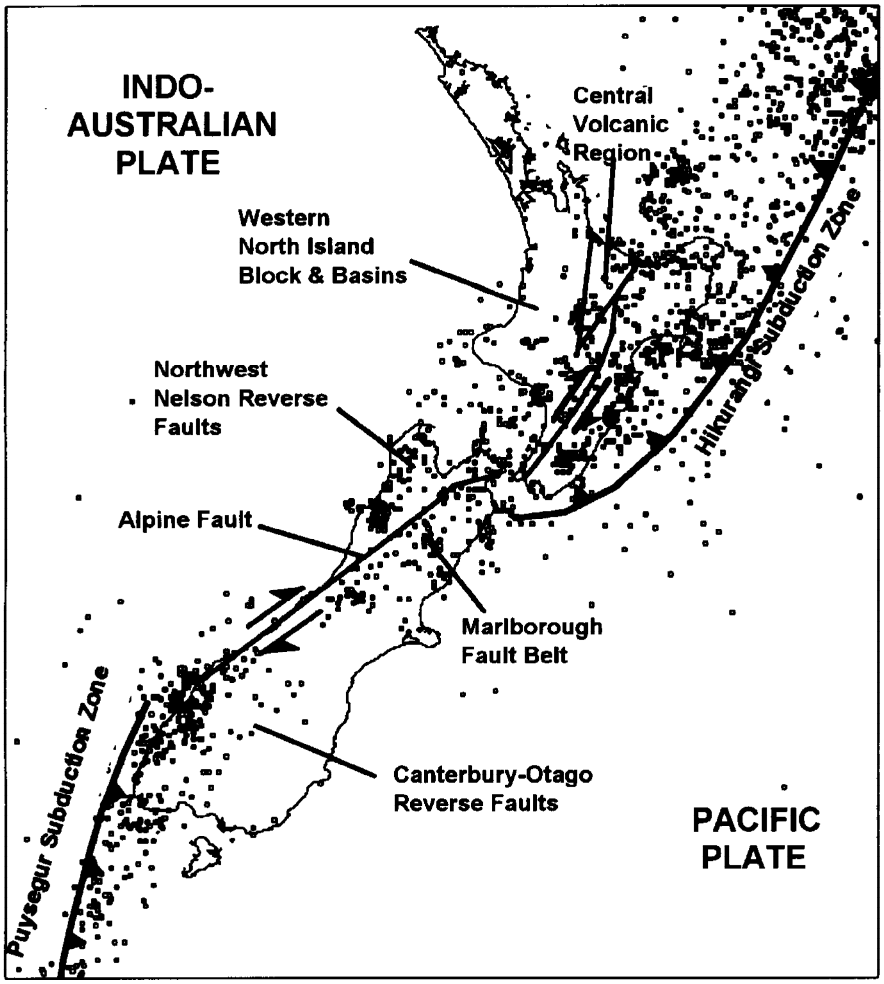

Fig. 1. Shallow seismicity (<50 km) and major tectonic structures of New Zealand. Tectonics modified from Berryman and Beanland (1991). Earthquakes Ms≥4.5 from 1940-1977, Ms≥3.0 from 1978-1990.

Four studies of probabilistic hazard analysis of New Zealand provided important data: Matuschka (1980), Peek (1980), and Smith and Berryman (1986, 1992). The source model described herein was designed in part considering the source geometry, maximum magnitudes, and recurrence parameters from each study. A fifth study, Berril *et al.* (1993), was consulted in defining sources around the Christchurch region.

A key reference for the deterministic analysis of the Wellington area was a 1993 report by the Wellington Earthquake Lifelines Group (WELG), published by the Wellington Regional Council. The WELG (1993) report examines the effects of two earthquake scenarios on the lifelines in the Wellington region, considering likely input ground motions, soil amplification and liquefaction effects.

## EARTHQUAKE HAZARD MODEL

### Seismic Source Zones and Recurrence Modeling

The seismicity of New Zealand is modeled by 18 source regions, 16 shallow and two deep (Figure 2). Following the framework of studies by Smith and Berryman (1986, 1992), Peek (1980) and Matuschka (1980), these have been delineated on the basis of geologic and tectonic boundaries. Their distribution has also been influenced by spatial inhomogeneities in the historical seismicity; for example, two segments of the Alpine fault system have been differentiated (7 and 10). Within a given source zones, the seismicity is assumed to be uniform and to have a consistent maximum magnitude. Maximum magnitudes for each source zone were assigned from consideration of published estimates, maximum historical events, and geological characteristics.

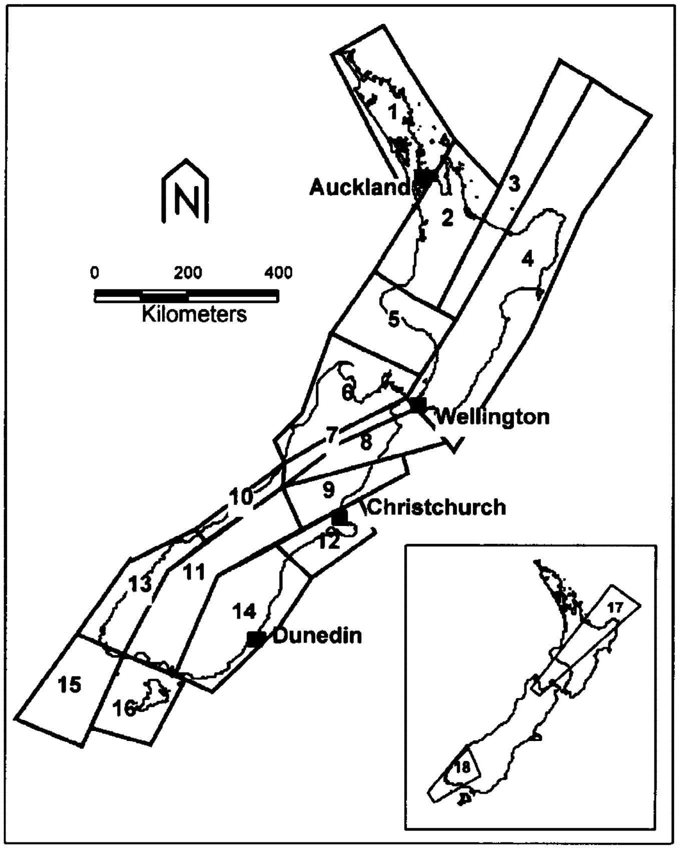

Fig. 2. Shallow and deep (inset) seismic sources used in the hazard model.

The depth of each source zone is determined by the distributions of the depth of historical earthquakes. Source zones 17 and 18 are used to model deep earthquakes in the Hikurangi and Puysegur subduction zones, respectively. Earthquakes at or greater than 82 km in depth were assigned to these sources. The deep sources use this depth as a maximum estimate of their potential hazard. All other sources (with the exception of source 1, see Table 1) are located at 12 km depth, which corresponds to the mode (peak) of the earthquake depth distribution. In this case the mode and the median are very close and provide a good estimate for the depth location of the seismic sources.

The earthquake occurrence in each source zone is described by the Gutenberg-Richter magnitude-frequency relation:

$$\ln N = \alpha + \beta M \tag{1}$$

where N is the annual number of earthquakes with magnitude greater than or equal to M, and $\alpha$ and $\beta$ are constants. The Poisson process model was used to describe earthquake occurrence in time.

The earthquake catalog described by Smith (1976) and supplied by NOAA (Rinehart *et al.*, 1985) was used to determine seismicity parameters. Although the date of occurrence of the first event in the catalog was 1460, the database used in the regression analysis covered the period from 1840 to 1977. The incompleteness of historical record with respect to magnitude was addressed by determining magnitude dependent time windows for which the record could be assumed reasonably complete. The windows used were 1940 to 1977 for events of magnitude 4.5 to 6.0 and 1840 to 1977 for events greater than 6.0. Seismicity parameters for each source are listed in Table 1.

Table 1. Maximum magnitudes (Ms) and return periods for maximum events

| **ID** | **Source Name** | **Depth (km)** | **Max Mag** | **Ret. per. (years)** |
|---|---|---|---|---|
| 1 | Auckland | 10 | 6.5 | 1,275 |
| 2 | Coromandel/Kawhia Harbor | 12 | 6.8 | 1,350 |
| 3 | Taupo Volcanic Zone | 12 | 7.0 | 225 |
| 4 | North East | 12 | 8.5 | 750 |
| 5 | Wanganui Basin | 12 | 7.8 | 2,300 |
| 6 | Nelson | 12 | 8.0 | 1,675 |
| 7 | North Alpine | 12 | 8.3 | 12,250 |
| 8 | Awatere-Hope | 12 | 8.3 | 5,575 |
| 9 | Torlesse | 12 | 8.3 | 9,000 |
| 10 | Central Alpine | 12 | 8.3 | 26,200 |
| 11 | Ostler | 12 | 8.0 | 7,400 |
| 12 | Christchurch | 12 | 7.8 | 76,600 |
| 13 | Fiordland | 12 | 8.5 | 6,050 |
| 14 | Otago | 12 | 7.5 | 11,600 |
| 15 | SW Subduction | 12 | 8.2 | 7,700 |
| 16 | Stewart Island | 12 | 7.5 | 6,950 |
| 17 | Northern Deep Subd. | 82 | 8.0 | 1,075 |
| 18 | Southern Deep Subd. | 82 | 7.5 | 550 |

## Ground Motion Attenuation

Several published intensity attenuations were evaluated for use in the model. The attenuation models by Dowrick (1992) discriminate between earthquake source mechanisms (normal, strike-slip, reverse). Most New Zealand source areas cannot be exclusively associated with one rupture type, so the two region-based attenuations of Matuschka (1980) were selected for the country-wide hazard analysis. These attenuations were chosen because they were considered to be a reasonable compromise between the reverse fault and strike-slip/normal fault attenuations of Dowrick (1992).

## RESULTS OF PROBABILISTIC MODELING

Based on the earthquake model described above, MM intensities have been calculated through standard seismic hazard analysis techniques. A country-wide seismic zonation map of intensities with a 10% probability of being exceeded in 50 years has been generated (Figure 3). These intensities are mapped by area unit (a New Zealand census division) and are compiled for average soil conditions and mean attenuation values.

Comparing this map with the results of Smith and Berryman (1986), it can be seen that the isoseismal shapes are in good agreement between the two maps. However, the intensity values presented in this study are generally lower by 1/2 to 3/4 units than those of Smith and Berryman (1986). This decrease can be attributed to two factors:

- the seismicity level of the earthquake model in this study is lower than that of Smith and Berryman (1986) in terms of both earthquake occurrence and maximum magnitudes
- the intensity attenuation model used in Smith and Berryman (1986) leads to higher intensities than the Matuschka (1980) relations used in this study.

Smith and Berryman (1992) provided updated parameters for their 1986 study. The overall intensity levels in this study are very close to those of Smith and Berryman (1992), with local variations in the isoseismal shapes.

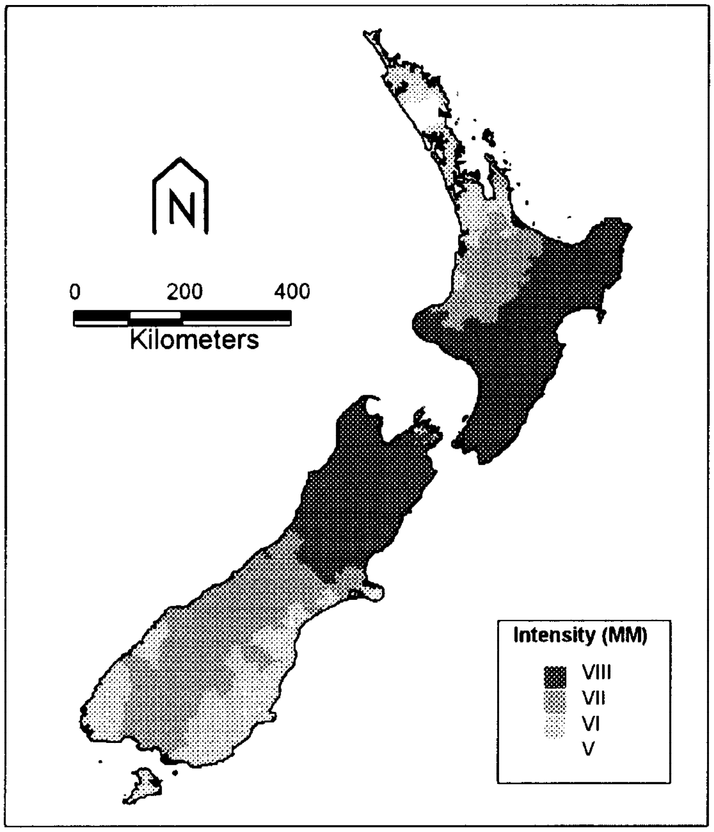

Fig. 3. Intensities with a 10% probability of exceedance in 50 years.

## EARTHQUAKE SCENARIO ANALYSIS IN WELLINGTON

Of particular interest to hazard planners in New Zealand is the Wellington urban area. This area lies in the midst of several active structures; the metropolitan region is bisected by the Wellington fault. At the local scale, site soil conditions are nearly as important as the distance to a fault -- often more. To address this issue, a deterministic "worst case" event incorporating local geology has been analyzed to supplement the probabilistic results. Collateral hazards such as liquefaction, landslide, and damage due to surface rupture are not included in this analysis. Neither are the effects of uncertainty in the attenuation model considered.

## Scenario Event and Ground Motion Attenuation

The scenario selected as the likely worst case event for the Wellington region is a Ms7.8 earthquake along the Wellington-Hutt Valley segment of the Wellington fault. The rupture stretches from the Cook Strait to Kaitoke in the Upper Hutt Valley. Fault rupture is likely to extend into the Cook Strait (Carter *et al.*, 1988) but for the purpose of hazard modeling in the Wellington region this does not have a significant impact. Depth of the event was set at 12 km. This scenario magnitude is slightly higher than the M7.5 event used in the WELG (1993) study. Berryman (1990) assigns a magnitude range of 7.1 - 7.8 for this segment of the Wellington fault, based on fault rupture length and single-event fault displacement. The WELG (1993) study also states their maximum magnitude as Ms 7.5 ±0.3, so the value of 7.8 in this study provides a conservative estimate.

The northern extent of the fault rupture terminates at a step in the Wellington fault near Kaitoke (Berryman, 1990). Berryman (1990) acknowledges, however, that this structural feature does not provide conclusive evidence of a segment boundary. If fault rupture continued to the north past Kaitoke there would be considerably greater damage than predicted in this study.

The Wellington fault is well-characterized as a predominantly strike-slip structure (Berryman and Beanland, 1991). In this case, the Dowrick (1992) strike-slip attenuation is an appropriate choice and produces results that are compatible with those described in other studies.

## Soil Data and Intensity Modifications

Given a scenario event and an attenuation relationship, it is relatively straightforward to calculate intensities for a grid of points. At any given site, however, the actual shaking intensity experienced is dependent on the local geologic conditions.

Source data for the Wellington scenario event were acquired at two scales. The 1:250,000 scale map by Kingma (1967) was used for the regional isoseismal map, while the 1:20,000 hazard map by Kingsbury and Hastie (1992) was used for local microzoning. Geologic map units have been assigned to one of four classes based on their expected amplification of ground shaking, following the results of studies such as Borcherdt (1994). Other considerations such as geologic age and observed amplification effects in past events are also factored in when classifying units. An intensity shift is determined for each of the four classes, based on published data and comparison of historic events with modeling results. The intensity shifts in this study (Table 2) were adapted from those described in the WELG (1993) report and verified against the observed isoseismal maps of the 1987 Edgecumbe earthquake (Lowry *et al.*, 1989).

Table 2. Intensity shifts for local soil conditions

| **Soil class** | **Intensity shift** |
|---|---|
| Hard rock | -1.0 |
| Soft rock / gravel | 0.0 |
| Sand / silt / stiff clay | +0.5 |
| Soft clay | +1.0 |

Scenario Results

A "worst case" scenario map for Wellington is presented in Figure 4. Maximum intensities of X to XI occur on unconsolidated sediments along the fault zone, while local instances of intensity IX to X may occur up to 50 km distant.

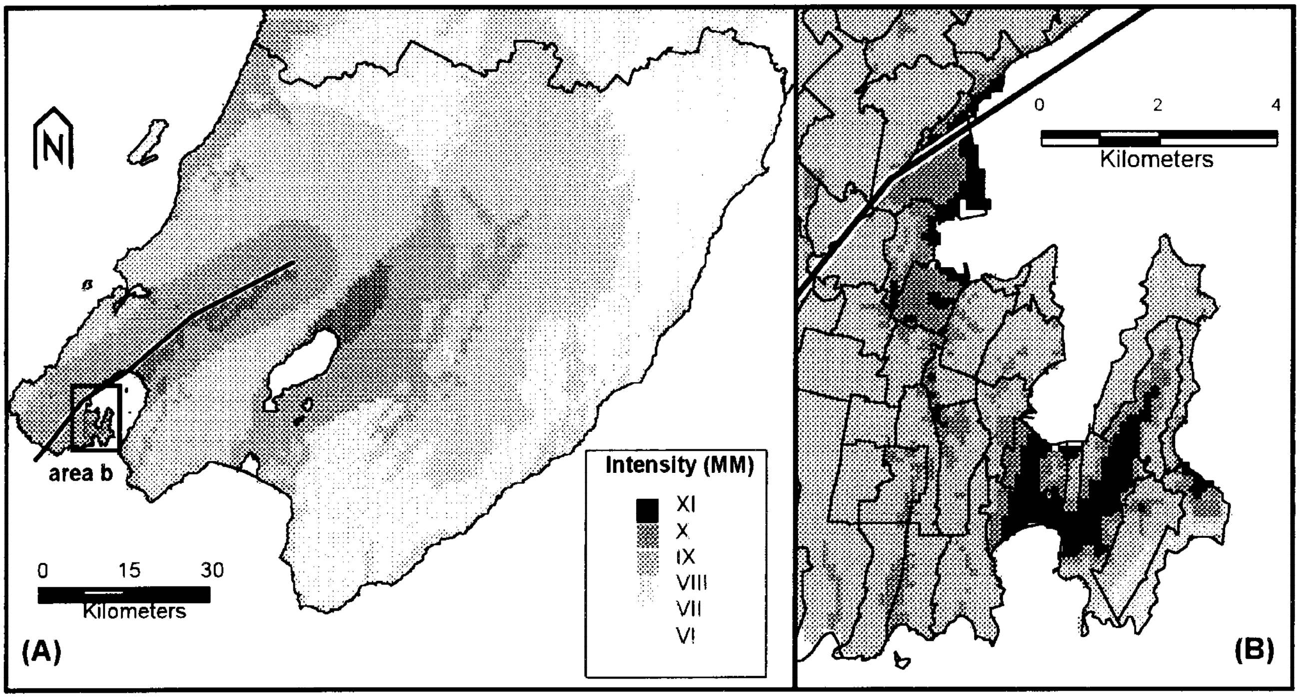

Fig. 4. Intensity distribution for a Ms7.8 event on the Wellington Fault for (A) the Wellington region, and (B) the city of Wellington.

## CONCLUSIONS

The primary goal of this study was to develop a model for use in seismic risk assessment. This model describes hazard from the primary seismogenic structures affecting the country of New Zealand. When used in conjunction with building damage curves, inventory and soil hazard data specific to the country, it provides a tool for financial institutions and local planners to quantify their potential loss to seismic hazards.

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