Seismic Hazard Assessment for Hamilton Area Based on the Updated NSHM

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Abstract

Many land development projects have been planned recently in the Hamilton area of New Zealand. Hamilton is located in the West of the North Island and situated in a low to moderate seismic risk area. However, it lies adjacent to the more seismically active fault zones, Extensional Western North Island Faults and Extensional Havre Trough – Taupo Rift. In recent decades, there has been intense seismicity within the adjacent fault zones. In this study, a site-specific seismic hazard assessment for Hamilton area is performed to estimate the peak ground acceleration corresponding to 25-year, 500-year and 1000-year return period using an update of the national probabilistic seismic hazard model (NSHM) for New Zealand. De-aggregation analysis is also performed to estimate the magnitude and epicentral distance for the design earthquakes. The assessment results are compared with those specified in the current New Zealand Code and local guidelines for earthquake geotechnical engineering practice.

Keywords: PSHA; NSHM; Hamilton area of New Zealand.

1 Introduction

Hamilton is an inland city located in the North Island and is the fourth most populous city in New Zealand. Many land development projects have been planned recently in the Hamilton area. The city is contemporarily located in a low to moderate seismic risk area and at a large distance from any tectonic plate margin. However, as shown in Figure 1, it lies adjacent to the seismically more active region of Taupo Volcanic zone and Western North Island faults. It has become important for engineers to be able to assess the possible intensity of future earthquakes in the building and infrastructural design based on the latest improved and updated probabilistic seismic hazard models.

Following the earlier national seismic hazard model (NSHM) developed in 2000 (Stirling et al., 2002) which has been used as the hazard basis for the New Zealand Loadings Standard (Standard New Zealand, 2004), considerable effort has been made by a team of earthquake geologists, seismologists and engineering seismologists to produce an update of the national probabilistic seismic hazard model for New Zealand. The new NSHM incorporated a fault sources model that has been updated with over 200 new onshore and offshore fault sources. The seismic sources proposed in NSHM comprised distributed earthquake sources and fault sources. The distributed earthquake source model was developed based on the distribution of seismicity and tectonics across New Zealand. The earthquake recurrence parameters of a and b values were calculated on a 0.1° x 0.1°grid at five depth levels (10, 30, 50, 70 and 90km) and assigned to the grid cells. A total of 542 faults have been identified and adopted in the NSHM. The likely maximum magnitude (Mmax) and recurrence interval of Mmax were estimated for each fault source. Mmax was estimated from three regressions of moment magnitude on fault area and the recurrence interval was calculated based on the single-event fault displacement and slip rate. The seismic fault zones defined in Stirling et. al. (2012) as shown in Figure 1. It was assumed in the NSHM that earthquakes smaller in size than the Mmax are modelled from the distributed seismicity model.

Probabilistic seismic hazard maps produced from the new NSHM (Stirling et. al., 2012) showed a similar pattern of hazard to the earlier model at the national scale, but there are some significant reductions and increases in hazard at the regional scale. In this study, site-specific seismic hazard analysis study is conducted to investigate the seismic hazard level for Hamilton Area based on the updated NSHM. The assessment results are compared with those specified in the current New Zealand Code (NZS 1170.5:2004) and proposed in Model 1 guidelines for earthquake geotechnical engineering practice published by New Zealand Geotechnical Society.

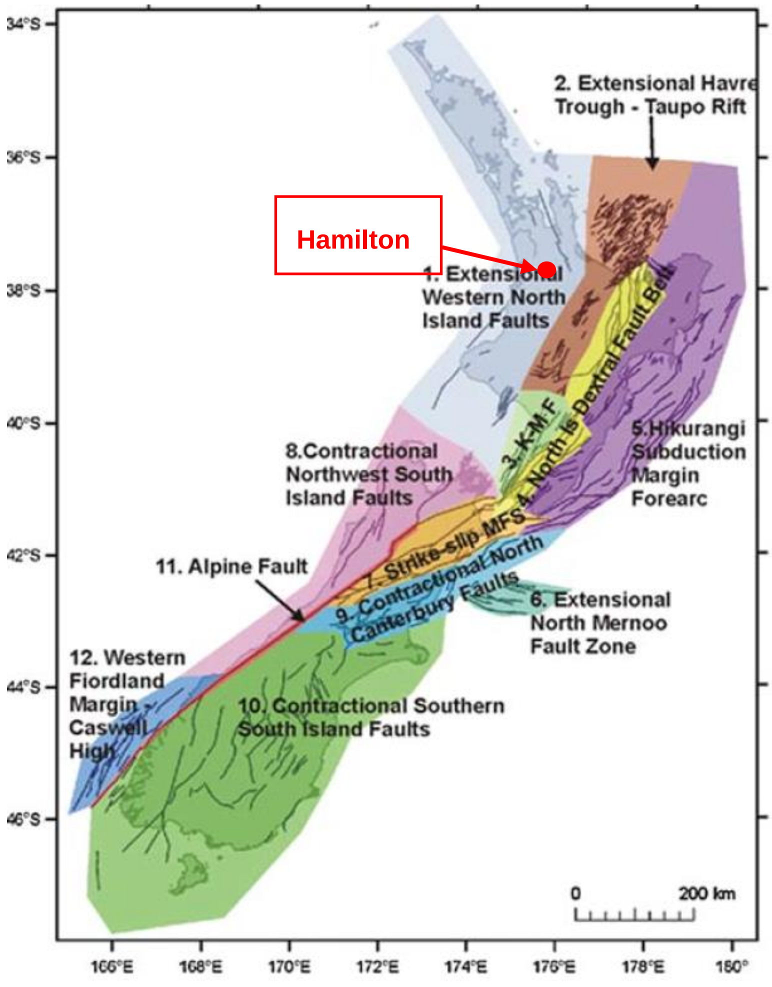

Figure 1 Fault Distribution Map (Stirling et. al., 2012)

2 PSHA Methodology

The methodology used to conduct probabilistic seismic hazard analysis (PSHA) was initially developed by Cornell (1968) and described in several publications, such as, Reiter (1991) and McGuire (2004). A Poisson probability model given in Equation 1 is used to represent the relationship between the probability of exceedance P of a ground motion level z in an exposure time or design time period t at a site and the annual frequency of ground motion exceedance γ_z at the site.

$$P(z) = 1 - \exp(-\gamma_z\ t) \tag{1}$$

PSHA is performed to obtain γ_z using Equation 2. P(z) can then be obtained through Equation 1. The return period for ground motion exceedance at a site is equal to the reciprocal of γ_z.

$$\gamma_z = \sum \alpha_i \int_{m_0}^{m_u} \int_{r=0}^{r=\infty} f_i(m)\, f_i(r) P(Z > z \mid m, r)\, dr\, dm \tag{2}$$

In Equation 2, α_i is the mean rate of occurrence of earthquakes between lower and upper bound magnitudes (m0 and mu) being considered in the ith source, fi(m) is the probability density distribution of magnitude (recurrence relationship) within source i, fi(r) is the probability density distribution of epicentral distance between the various locations within source i and the site for which the hazard is being estimated and P(Z>z|m,r) is the probability that a given earthquake of magnitude m and epicentral distance r will exceed ground motion level z.

The basic steps of PSHA can be seen in Figure 2. Step 1 is the definition of earthquake sources. Step 2 is the definition of seismic recurrence characteristics for each source zone. Estimation of the earthquake effect based on ground motion attenuation relationship is carried out in Step 3. Seismic hazard curves in terms of the peak ground acceleration at the specified periods for the project site can then be determined in Step 4.

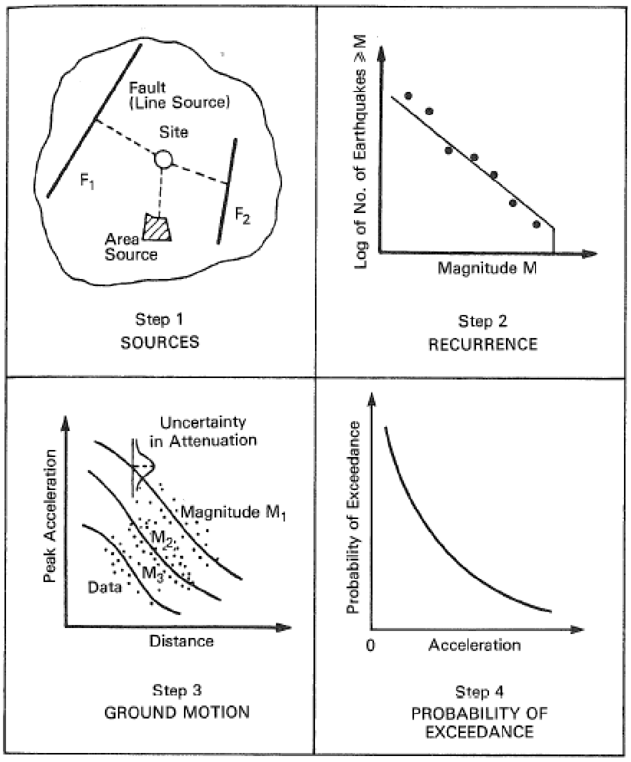

Figure 2 Basic steps of PSHA (Reiter,1991)

The distributed earthquake sources and fault sources defined in NSHM are adopted in PSHA. Based on the earthquake recurrence parameters of a and b values calculated at each point on a 0.1° x 0.1°grid, the annual frequencies of exceedance for the acceleration levels at the site due to each source is calculated. The final seismic hazard level, such as peak ground acceleration (PGA), is calculated by summing the results contributed from all the sources.

3 Ground Motion Attenuation Model

The selection of an appropriate ground motion attenuation relation for use in a probabilistic earthquake hazard evaluation is almost always critical to the results.

Based on all available data from the New Zealand strong-motion earthquake accelerograph network up to the end of 1995, McVerry et. al. (2006) developed ground motion attenuation equations for New Zealand. The ground motion attenuation equations have been developed for crustal and subduction zone earthquakes and been used in the study of Stirling et. al. (2012).

Stirling et. al. (2012) indicated that McVerry et. al. (2006) ground motion model is considered to be currently the only suite of ground motion attenuation relation for New Zealand, and therefore it is adopted in this assessment.

To consider the epistemic uncertainty, one NGA model (Chiou and Youngs, 2008) for crustal earthquake and Atkinson and Boore (2003) for subduction zone earthquakes are selected and adopted in the analysis. The models were developed from worldwide shallow crustal earthquakes and subduction sources.

The weights of 0.7 and 0.3 are assigned to McVerry crustal model and Chiou and Youngs (2008) crustal model, and the weights of 0.7 and 0.3 are assigned to McVerry subduction model and subduction model of Atkinson and Boore (2003).

4 PSHA Results

A probabilistic hazard analysis for the project site was carried out using the seismic source zone models proposed by Stirling et. al. (2012) with the proposed attenuation models. The results of the PSHA are presented in terms of ground motion as a function of annual exceedance probability.

The calculated rock site horizontal PGA corresponding to 25 years, 500 years and 1,000 years return period is presented in Table 1. The calculated horizontal PGA seismic hazard curve is shown in Figure 3. Based on the conversion factor proposed by Boore and Kishida (2017), the larger component/RotD50 is approximately 1.1 for frequency of less than 10Hz. Accordingly, a factor of 1.1 has been applied to the PGA of the NGA model.

The assessment results show that the calculated rock site PGA is comparable to that specified in NZS 1170.5:2004. The relatively larger PGA proposed in Module 1 (2021) is thought to be caused by the site effect. PGA proposed in Module 1 (2021) is applied for all site conditions. No site amplification factor has been provided in Module 1 (2021).

Table 1. Summary of Rock Site Horizontal PGA.

Return Period	Rock Site Horizontal PGA (g)		
	NZS 1170.5:2004	Module 1 (2021)	This Study
25 years	0.04	0.06	0.03
500 years	0.16	0.25	0.14
1,000 years	0.21	0.32	0.19

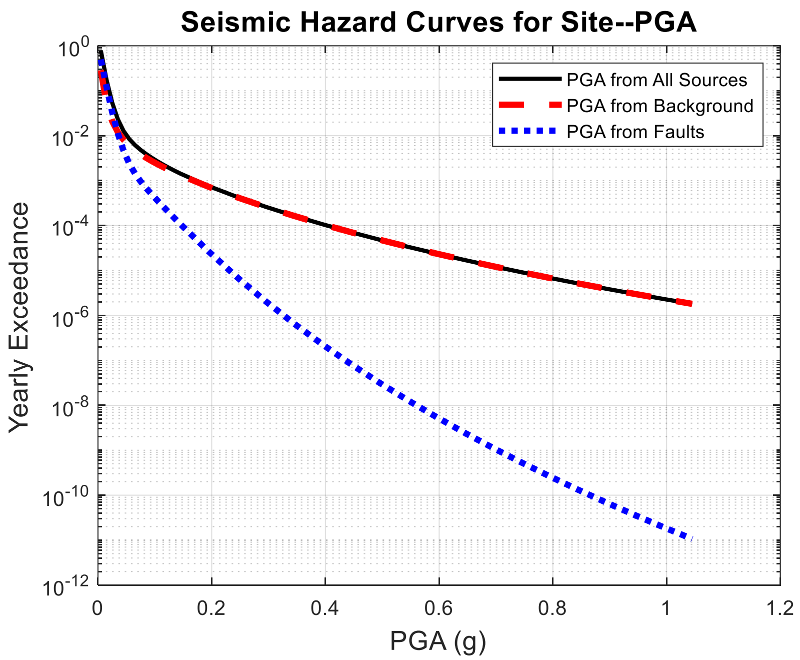

Figure 3 Seismic Hazard Curve

De-aggregation analysis has been performed to show the characteristics of contributing seismic events at a selected probability level.

The de-aggregation of the PSHA results indicate that the high-frequency hazard as reflected in PGA is dominated by moderate magnitude earthquakes close to the site for 500 and 1,000-year return period events, whereas significant contribution from moderate to large magnitude earthquakes at the adjacent faults sources (i.e. Kerepehi Central fault at approximately 45km, Kerepehi Sth fault at approximately 40km) is observed for 25-year return period events. The magnitude and distance contributions to the PGA Hazard for 25-year return period, 500-year return period and 1,000-year return period are shown in Figures 4 to 6.

The magnitude of the control earthquake for PGA for 25-year return period, 500-year return period and 1000-year return period are presented in Table 2. The selection of the control earthquake is mainly based on the assumption that the probability of exceedance of the design earthquake magnitude at the chosen return period (i.e. 25-year return period, 500-year return period and 1000-year return period) is less than 25%.

Based on the recorded data during the period of 1914 - 2022 collected by GeoNet Geological hazard information for New Zealand, there are about 5,273 earthquakes with magnitude larger than ML3 located within 200km of the project site. No earthquake with magnitude greater than M5.5 has occurred within 50km from the site.

Table 2. Summary of Design Earthquake Magnitude.

Return Period	Design Earthquake Magnitude		
	NZS 1170.5:2004	Module 1 (2021)	This Study
25 years	NA	M5.9	M6.5
500 years	NA	M5.9	M5.7
1,000 years	NA	M5.9	M5.7

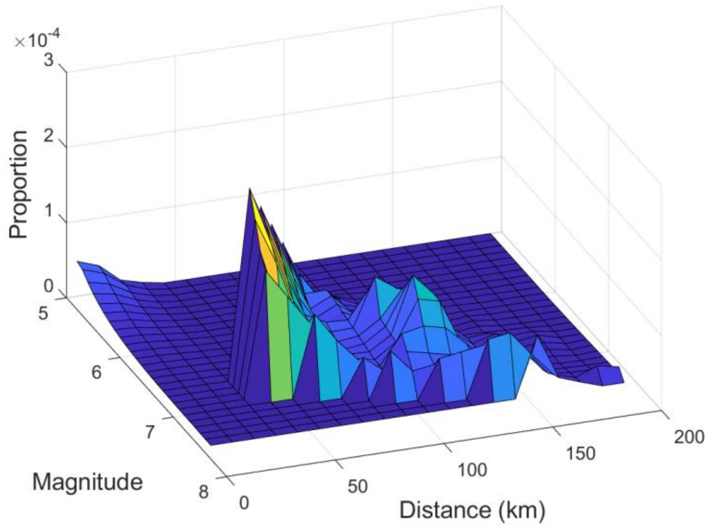

Figure 4 Magnitude and Distance Contribution to PGA for 25-year Return Period

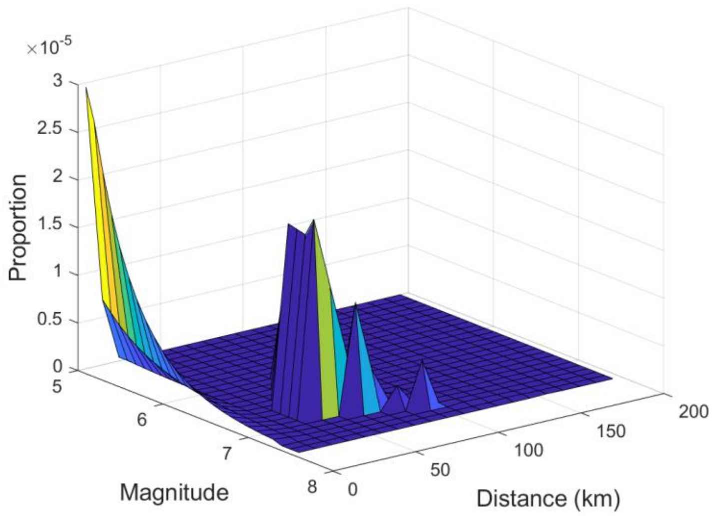

Figure 5 Magnitude and Distance Contribution to PGA for 500-year Return Period

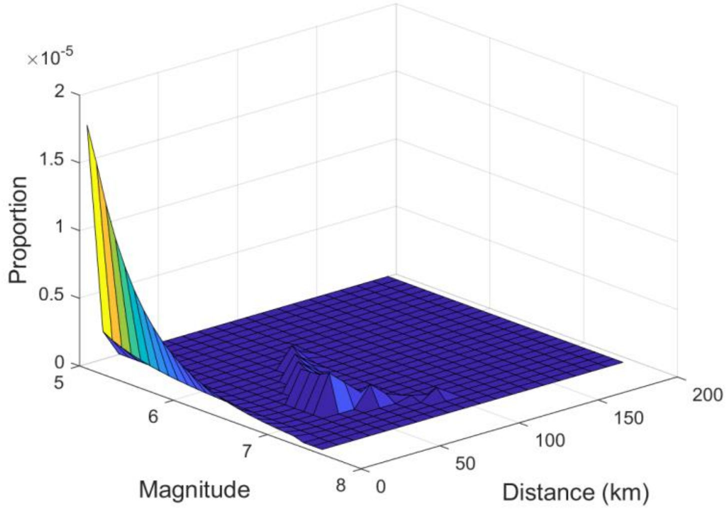

Figure 6 Magnitude and Distance Contribution to PGA for 1000-year Return Period

5 Conclusion

A probabilistic seismic hazard analyses (PSHA) for the project site were carried out in this study. Based on these analyses, our results are as follows:

- The PSHA results: the rock site PGA corresponding to 25, 500 and 1,000-year return period are estimated to be approximately 0.03g, 0.14g and 0.19g, respectively. This is comparable to that specified in NZS 1170.5:2004. PGA proposed in Module 1 (2021) is greater than that of the PSHA results as it is applied for all site conditions.
- Based on the de-aggregation of the PSHA results, design earthquake event of M6.5 is recommended for 25-year return period, and M 5.7 for 500 and 1,000-year return period.

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