What Drives Seismic Risk in New Zealand? Insights from a next-generation loss model

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ABSTRACT: New Zealand's exposure to seismic hazard has been highlighted dramatically in recent years through the Canterbury Earthquake sequence (CES) from 2010 to present, and the near-misses for Wellington during the Cook Strait earthquakes in 2013. These events have generated unprecedented data and provided a number of lessons that have allowed modellers to develop next-generation loss models that are a step change on their predecessors. Improvements include developing new vulnerability functions based on a wealth of recorded near-source ground motions and damage and loss data on modern constructions, the ability to explicitly model secondary perils, such as liquefaction, and utilising state-of-the-art modelling software such as OpenQuake that is being developed by the Global Earthquake Model. This paper presents a next-generation loss model for New Zealand and highlight the main drivers of seismic risk in New Zealand from an economic perspective.

1 INTRODUCTION

Seismic risk assessments and loss forecasts are an important tool in mitigating the risk from earthquakes. These assessments provide the foundation for evidence-based decision making on risk mitigation options such as risk transfer through (re)insurance, building codes and seismic strengthening, as well as for emergency management purposes. The main output of a seismic risk assessment is a loss curve that describes the annual probability of exceeding a given level of loss. The loss curve can be used to identify the level of loss forecast for an annual probability of interest (or return period). Further, by integrating the area under the loss curve the average annual loss (AAL) can be estimated. These statistics are then used for decision-making, such as in the insurance industry where AAL can be linked to insurance premiums for customers, or for decisions on what level of reinsurance should be sought or how a portfolio of buildings should be managed. Alternatively such information can be used by Governments to understand the risk profile of the country or region, and on where to invest in seismic risk reduction activities. While the loss curve is a major output and decision making tool of any seismic risk assessment, the source of the risk is often overlooked or limited to deaggregation of likely earthquake sources. To effectively mitigate risk the key risk drivers must be understood.

Following the recent Canterbury Earthquake Sequence (CES) a number of research efforts have been undertaken to improve various components of seismic loss modelling in New Zealand. These include updating vulnerability functions to improve loss estimates on modern construction types, including time-varying seismicity in Canterbury to incorporate the enhanced aftershock seismicity, explicitly modelling secondary perils such as liquefaction, and improved seismic source and ground motion modelling using OpenQuake a state-of-the-art seismic hazard and risk modelling engine. These changes have been incorporated in the RiskScape[1] Seismic Risk Model (King and Bell, 2009), a multi-hazard risk modelling tool that models seismic losses to buildings, infrastructure and people and used to generate updated forecasts of seismic risk for New Zealand.

This paper presents the impact of these improvements on seismic risk forecasts for New Zealand, in terms of direct economic losses to buildings. Further, the New Zealand seismic risk model is interrogated to identify the main contributors of seismic risk. This study provides the first step in understanding New Zealand's seismic risk profile and the key drivers of seismic risk to assist in seismic risk reduction activities.

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[1] http://riskscape.co.nz

2 NZ RISK MODEL COMPONENTS

Various components of the New Zealand Seismic Risk Model (NZSRM) have been previously described by Cousins (2004) and King & Bell (2009) in detail. Here, the main components of the seismic risk model, namely the hazard, vulnerability and exposure models are briefly summarised to highlight updates since those previous studies.

2.1 Hazard Model

The NZSRM uses the seismic source model from the 2010 update of the National Seismic Hazard Model (Stirling et al. 2012). The latest source model has two main components, 1) a fault model of over 500 active faults sources (Figure 1, right), and 2) a background seismicity model that represents seismicity on unknown faults (Figure 1, left). The 2010 model also includes new time-dependent rates on a few active faults that have well constrained data on the timing of previous earthquakes.

The NSHM is used as a basis for generating a synthetic earthquake catalogue representing one million years of seismicity. For each earthquake in the catalogue, ground motions are estimated at each asset location to create a suite of ground motion fields for each earthquake, which is then subsequently used for estimating losses for each event. For more detailed information on this method see Cousins (2004).
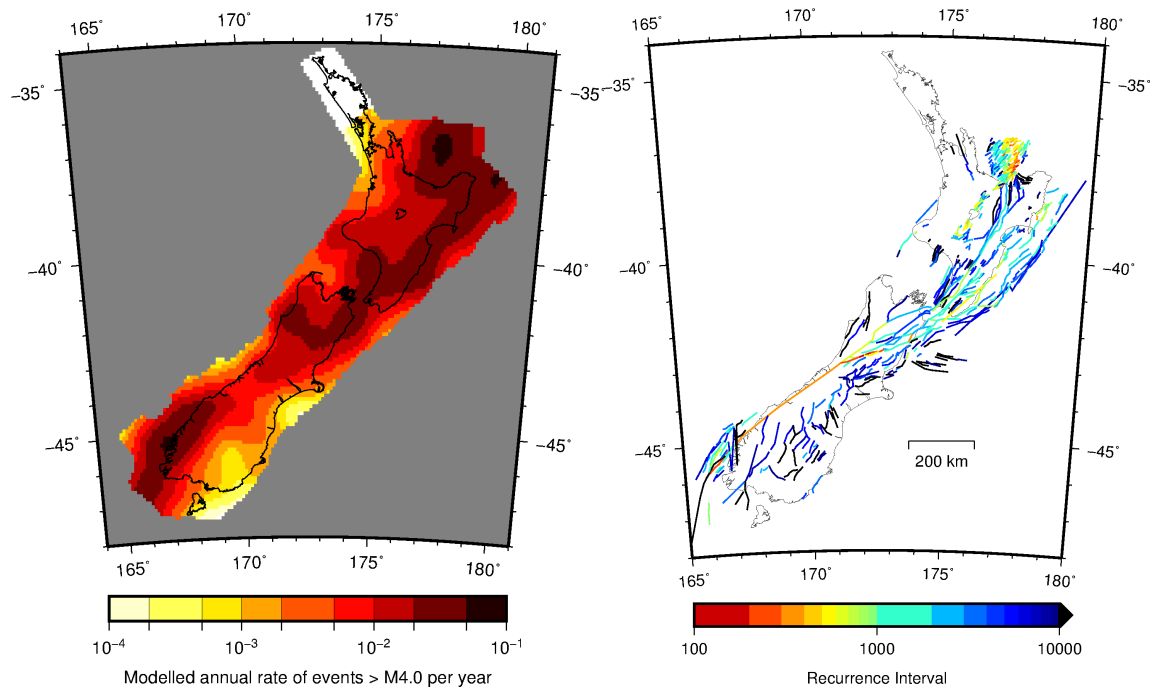

Figure 1. Seismic source models used in the NZ Seismic Risk Model. Left: background seismicity model showing the annual rate of M>4.0 earthquakes per year. Right: fault sources with their average recurrence interval in years (after Stirling, 2012).

2.2 Exposure Model

The RiskScape Building Exposure Model (King & Bell, 2009) is used as the basis of the building exposure in the New Zealand Seismic Risk Model. The RiskScape exposure data includes building level information for all of New Zealand, including construction characteristics, occupancy, and building values. The building level data was aggregated to a 1 km grid for the purpose of a national model to reduce computational demands. Figure 2 shows the distribution of the building stock and highlights the concentration of building value in the urban centres of Auckland, Christchurch and Wellington.
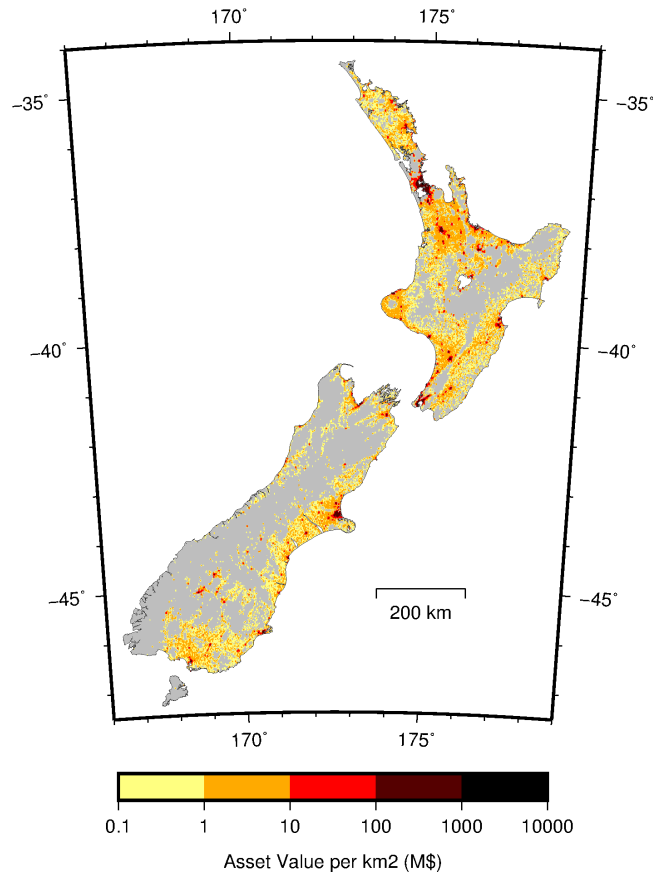
Figure 2. Building asset value distribution in New Zealand. Note the concentration in building value in the the urban centres of Auckland, Christchurch, Wellington, and the distributed nature in rural areas.

2.3 *Vulnerability Model*

Vulnerability models for New Zealand buildings are largely based on work by Dowrick (1991) and Dowrick & Rhoades (1993, 1995, 2002), who used insurance claim data for residential and commercial buildings from four New Zealand earthquakes to derive models to predict damage ratio (repair cost / replacement cost) as a function of Modified Mercalli Intensity (MMI). The most recent earthquake used in these studies was the 1987 Edgecumbe Earthquake in the Bay of Plenty. Following the Edgecumbe Earthquake, New Zealand did not have any significant damaging earthquakes and as a result many modern construction types were not represented in these earlier studies. Further, none of the earthquakes analysed by Dowrick & Rhoades (1993, 1995, 2002) impacted a major urban centre.

3 RECENT IMPROVEMENTS IN THE NZ RISK MODEL

3.1 *2014 Building Exposure Model*

The New Zealand RiskScape Exposure model utilises building valuation data developed by Core Logic (formerly Quotable Value). During 2014 an updated building valuation model was released by Core Logic, which included significant changes in Auckland due to rapid increases in housing values, as well as Christchurch, where the building stock is changing due to the rebuild underway. Furthermore, in Auckland, a new region specific building exposure model was created for a risk assessment commissioned by the Auckland Council. This new model included detailed information on non-residential buildings collected during Initial Seismic Assessments of buildings required under the "Earthquake Prone Building" policy and was included to update the Auckland RiskScape Exposure Model. The total value of the New Zealand building exposure database increased by 8% to NZ$781B.

3.2 *Time-Dependent Seismicity Model for Canterbury*

The updated NZ Seismic Risk Model includes a new seismicity model for the Canterbury region that captures the enhanced seismicity due to the on-going Canterbury earthquake sequence. Following the 4th September 2010 M_W 7.1 Darfield earthquake, the Canterbury region has experienced an ongoing sequence of earthquakes. The sequence started with the Darfield earthquake and has included other significant events such as the M_W 6.2 Christchurch Earthquake on 22nd February 2011, as well two M_W 6.0 events on 13th June 2011 and 23rd December 2011, in addition to thousands of earthquakes of lower magnitudes. This sequence is consequently increasing the seismic hazard and risk for the Canterbury region and should therefore be included in any seismic hazard or loss modelling.

Recently, Gerstenberger et al. (2014) developed a new time-dependent seismic hazard model for the Canterbury region, which includes aftershock seismicity forecasts for the next 50 years. This model captures the current enhanced seismicity and forecasts a gradual decay of the seismicity over the next few decades. Including the enhanced Canterbury seismicity results in an increase in the AAL for New Zealand by 21% over the 2015 calendar year compared to using the pre-2010 seismicity rates (Figure 3). AAL, as a measure of risk, is quite sensitive to the rates of moderate sized earthquakes as it is calculated by integrating the loss exceedence curve. This is because the left side of the loss exceedence curve, which is defined by frequent-low loss events, contributes most to the AAL, and is where small to moderate sized earthquakes contribute most to the loss. The time-dependent seismicity model for Canterbury forecasts a large increase in the number of moderate sized earthquakes, which as a result drives up the losses from these events and therefore the AAL. This can be seen in Figure 3 where including aftershock forecasts for 2015 in the background seismicity model increases the forecast losses for return periods less than 500 years.
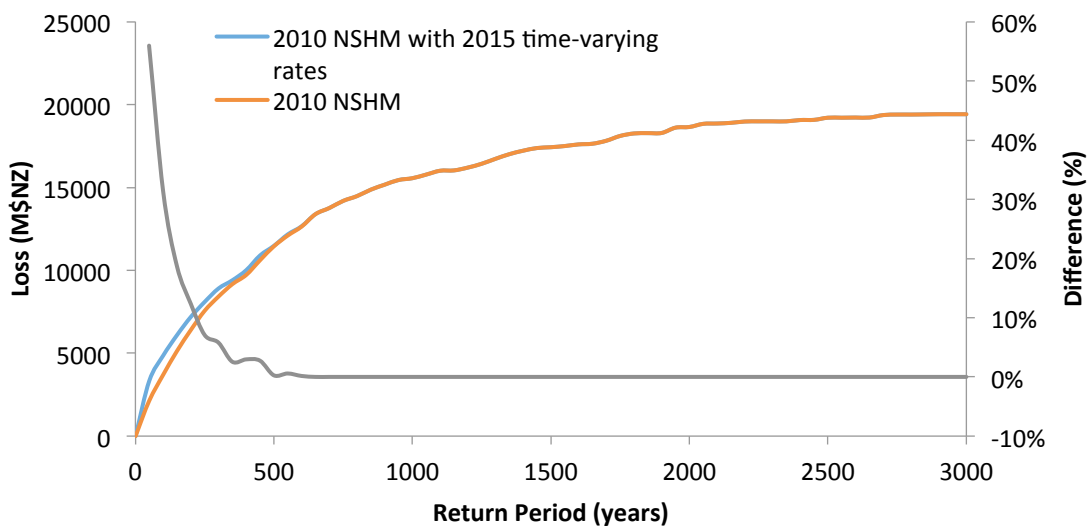

Figure 3. Loss exceedence curve (gross loss) for a NZ portfolio of buildings using the time-independent background seismicity rates from the 2010 NSHM (red line) and the 2010 NSHM that includes aftershock forecasts rates for the year 2015 in the Canterbury region (blue line).

3.3 *Updated Vulnerability Functions for Residential Buildings*

Following the CES a significant amount of work has been undertaken to create new or updated vulnerability and fragility models for New Zealand buildings. An unprecedented amount of data is now available on building damage and losses. Work by Lin et al. (2014) has used detailed engineering evaluations to derive new fragility curves for non-residential buildings, including many modern construction types for which no empirical damage data previously existed. However, data related to insured losses to the non-residential building stock has been difficult to obtain from private insurance companies and therefore no loss information is available. However, Horspool et al. (2015) used insurance claim data from the New Zealand Government residential insurance scheme run by the Earthquake Commission (EQC) to develop new vulnerability models for residential buildings. This

data has been made available to researchers and includes claim data to over 200,000 buildings across the Canterbury region. Both of these studies indicate that damage and losses are higher than predicted by earlier models.

3.4 *Loss Modelling in OpenQuake*

One of the major changes in the NZSRM is the evaluation of the OpenQuake Engine (Silva et al. 2013). OpenQuake is a free and open-source, state-of-the-art seismic hazard and loss modelling engine developed by the Global Earthquake Model (GEM). OpenQuake has allowed improved modelling of seismic sources by representing background seismicity as more realistic finite faults instead of point sources used in previous version of the model. This allows ruptures to extend closer to the surface and capture shallow events, such as the February 22nd 2011 Christchurch Earthquake, that occurred on a blind fault a few kilometres beneath Christchurch city. OpenQuake also allows for modelling of ground motion fields that have spatially correlated residuals. Using this technique, ground motions fields for a given earthquake contain areas of high and low ground motions, representing the intra-event uncertainty in the ground motion prediction equations. Collectively, these two modelling improvements result in an increase in the forecasts losses for the New Zealand portfolio. At present OpenQuake is being evaluated for use in the NZSRM.

3.5 *Secondary Perils*

Other improvements, such as explicitly modelling liquefaction and landslide hazards have not been included in this paper as they are still in testing and validation phase of development. This new capability will be included in the NZSRM in the near future.

3.6 *Contribution of Improvements to Changes in NZ Seismic Risk Profile*

To understand how these new improvements will impact seismic risk forecasts for New Zealand a sensitivity study was undertaken by adding one change at a time to find the relative change in forecast losses from each component. It can be seen in Figure 4 that including these new improvements results in an increase in the AAL. Some of these changes, such as the time-dependent seismicity model for Canterbury will influence AAL more than metrics such as the loss at various return periods.
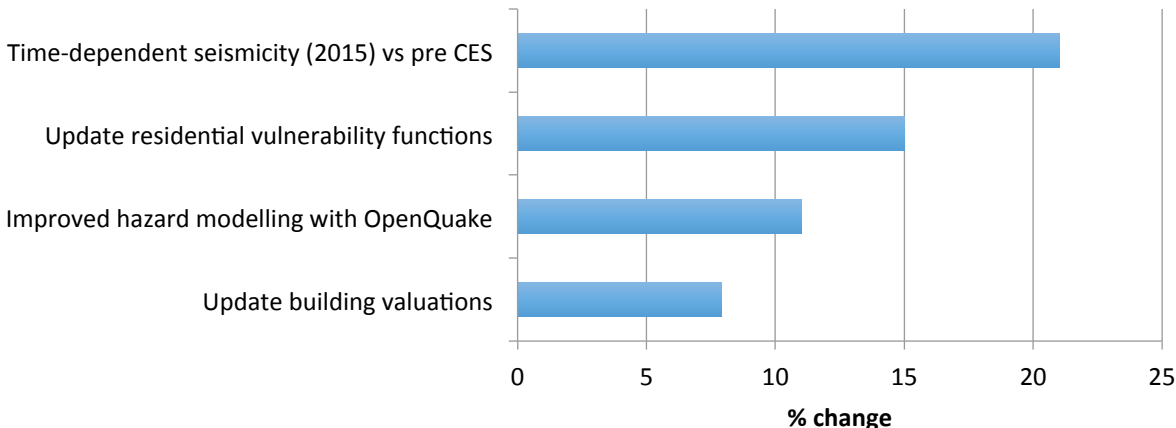

Figure 4. Percentage change in AAL (gross loss) for a New Zealand industry portfolio from improvements in the risk model.

4 DRIVERS OF SEISMIC RISK

The updated NZSRM is deaggregated to identify the major drivers of seismic risk. This is explored from a geographical, typological, and seismic perspective.

4.1 *Regional Drivers*

The AAL for New Zealand was deaggregated by Administrative Regions to identify what areas contribute most to the seismic risk. Figure 5 highlights that about 40% of the risk is from the Wellington region, followed by Canterbury and Manawatu-Wanganui at around 12% each. Regions along the seismically active east coast of the North Island contribute between 2-10%. Auckland, although located in an area of low seismicity still contributes around 4% to the risk due to ~30% of the New Zealand building value being located in that region.

In addition to identifying the regions that contribute to the risk, analysis was undertaken to estimate the probability of experiencing shaking that is likely to cause minor damage requiring repairs to some residential properties over the next 30 years (Table 2). This time period represents the typical length of a mortgage in New Zealand so is useful for putting the risk in context to homeowners. Cities located in the main seismic belt of New Zealand have a >99% probability of experiencing this level of shaking over the next 30 years. While areas in low seismic hazard zones such as Auckland have around a 3% probability.
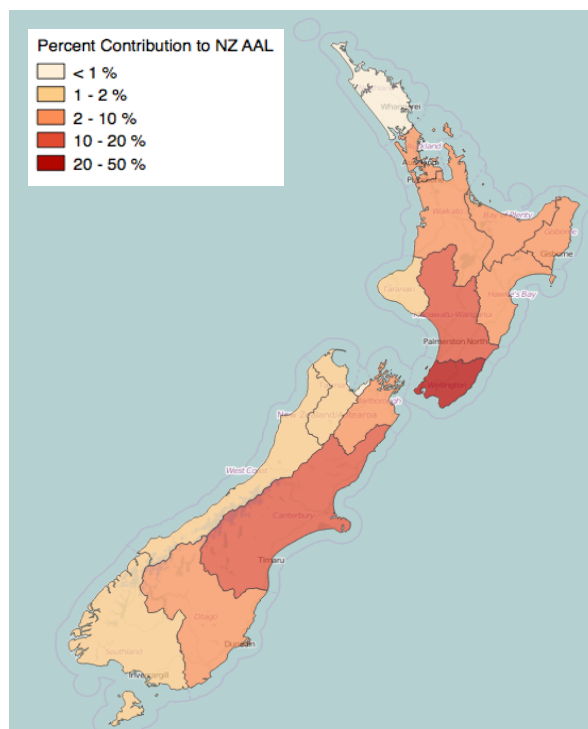

Figure 5. Contribution to the NZ Average Annual Loss (AAL) (gross loss) from different regions.

Table 2. Probability of experiencing a level of shaking that will likely cause damage to residential timber frame buildings in 30 years, the typical period of a mortgage for New Zealand home owners.

City	Probability of Experiencing a Damaging Level of Shaking (MMI7) in 30 years
Wellington	>99%
Palmerston North	>99%
Napier	>99%
Westport	>99%
Kaikoura	>99%
Gisborne	>99%
Greymouth	90%
Taupo	65%
Queenstown	62%
Nelson	55%

Christchurch	45%
Tauranga	39%
Rotorua	37%
Timaru	19%
Invercargill	14%
New Plymouth	13%
Hamilton	12%
Dunedin	9%
Auckland	3%
Whangarei	1%

4.2 *Building Typology Drivers*

It is important to understand what building types contribute to the risk as it is quite common to target seismic risk reduction activities at specific building typologies. Building typologies were broken into five classes as shown in Figure 6. This includes timber frame (mostly residential dwellings), concrete (most common commercial construction material), light industrial construction, unreinforced masonry (URM) and 'other' minor types including steel, concrete masonry and advanced designs.
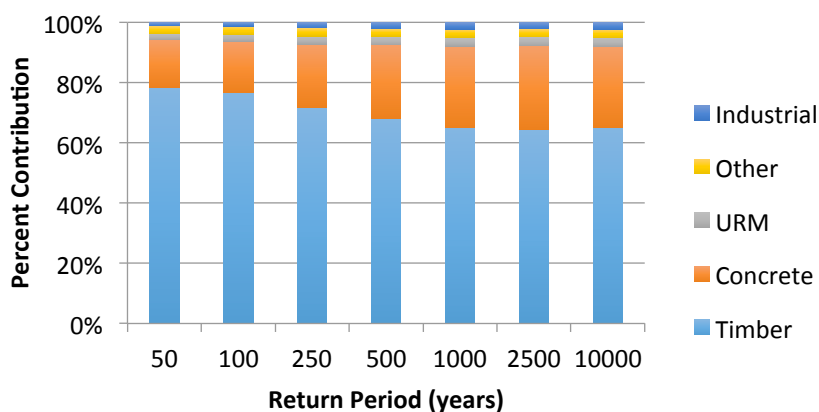

Figure 6. Contribution to losses at various return periods from the major building typology classes.

The large number of residential buildings (89% of the building stock) contributes to between 65-79% of the seismic risk. Where as concrete and URM buildings represent 12% and 2% of the building stock respectively, but contribute to 22% and 3% of the risk. This indicates that concrete and URM buildings have a higher relative contribution to the seismic risk profile for New Zealand than timber buildings. It can also be seen in Figure 6 that there is general decrease in the contribution from timber frames and an increase in contribution from concrete buildings for longer return periods loss events.

4.3 *Seismic Source Drivers*

Seismic source deaggregation is common in seismic hazard assessments but less so in seismic risk assessments. Here, the key seismic sources are identified for various return periods (or loss levels). It can be seen in Figure 7 that at short return periods the dominant sources are the Wellington-Hutt Valley Fault (WHVF), Wairarapa Fault (WF), Hikurangi Subduction Zone (HSZ), other faults and background seismicity (BS) reflecting unknown faults. As the return period (and loss level) increases the WHVF and WF increase in contribution to the risk, while the HSZ, other faults and BS decrease in contribution. This is likely due to the WHVF and WF having high activity rates and being located very close to Wellington, a large urban centre. It is interesting to note that the HSZ does not contribute more at longer return periods, and this warrants further investigation.
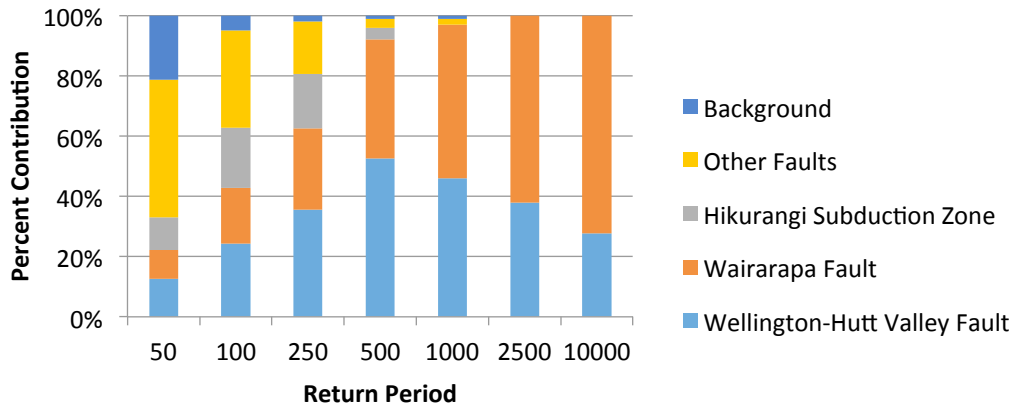
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Figure 7. Contribution to losses at various return periods from major seismic sources

5 CONCULSIONS

Seismic risk assessments are dynamic models that require constant updating as new information is gathered. This often occurs in the years following significant earthquakes, as is the case that is currently occurring in New Zealand following the Canterbury Earthquake Sequence. This paper has presented the key changes to the RiskScape NZ Seismic Risk Model and highlighted how the model can be used to identify key drivers of seismic risk in New Zealand.

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