ResQ: An Earthquake Risk Prioritisation Tool

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ABSTRACT: Many New Zealand organisations with large portfolios of buildings occupied with staff are currently undertaking seismic evaluation and strengthening of their nation-wide premises under their health and safety programmes. The evaluation methodology involves the Initial Evaluation Procedure (IEP) prescribed by the New Zealand Society for Earthquake Engineering (NZSEE) and results in the evaluation of a building vulnerability class based on the percentage of New Building Standard (%NBS). This measure is used by various organisations to establish a policy to dictate acceptable timeframes within which high risk premises should either be strengthened or abandoned. However, various limiting factors such as funding limitations make meeting such deadlines very difficult, and consequently allocation of available resources to the most vulnerable sites with highest life risk becomes a priority.

This paper proposes a procedure to evaluate relative life risk of premises within a portfolio to better inform such prioritisation decisions. The proposed solution is the provision of a software risk evaluation model which will rank each property according to its risk to life. The core components of the model are: a) Building characteristics identified as part of the IEP, as input, b) the National Seismic Hazard Model (NSHM) from which ground shaking intensity for any given reference period is estimated and modified using a near-surface ground condition map, c) a suite of vulnerability functions (which provides the link between building type, ground motion and associated damage), and the GNS casualty models (which project injury and fatality rates from building damage), and d) a prioritised list of the resulting risks for all properties within the portfolio, as output.

1 INTRODUCTION

Changes to the New Zealand Building Act in 2004 have resulted in all local authorities being required to adopt a policy to identify earthquake-prone buildings. The evaluation methodology involves an initial screening programme which uses the Initial Evaluation Procedure (IEP) prescribed within the earthquake risk buildings recommendations (commonly known as the red book) published by the New Zealand Society for Earthquake Engineering (NZSEE) and endorsed by the former Department of Building and Housing (NZSEE 2006). The NZSEE introduced a system for grading buildings according to their assessed seismic performance compared to the current code requirements and is expressed as the Percentage of New Building Standard (%NBS). According to this grading, a building is considered to be low risk if it scores at least 67% or 2/3 of the current code consequently having less than 5 times relative risk (Grade A or B), moderate risk if scores below 2/3 but above 1/3 (Grade C), and high risk if it meets less than 1/3 of the current code requirements and therefore is deemed to have a relative risk of 10 times or more compared to a current code compliant building (Grade D or E). High risk buildings are required to either be strengthened or abandoned under the Building Act and moderate or low risk buildings are considered to be acceptable legally although improvement is encouraged.

The initial evaluation, as the name suggests, is a relatively quick assessment of building capacity to withstand earthquakes by visiting the building and in some cases reviewing building drawings to confirm site visit information. This means that not very long after commencement of the seismic evaluations, building portfolio managers will end up with a pile of moderate to high-risk building reports to act upon. However, these organisations often have limited resources to deal with all the earthquake-risk buildings at the same time. Therefore, there is a great need for a decision support tool to prioritise post-evaluation response to buildings with the highest risk in the portfolio. Simply using %NBS to rank earthquake risk buildings is not adequate because: a) the likelihood of major earthquakes in different areas is not the same, b) occupancies of buildings might be different and consequently the risk would be different should an earthquake occur, and c) there might be several buildings with more or less the same scores within the portfolio.

This paper aims to develop a protocol which would assist prioritising the response to earthquake-risk buildings by making an allowance for multiple affecting factors. The proposed solution is the provision of a software risk evaluation model, ResQ, which will rank each building according to its life risk because of earthquake. The tool uses the National Seismic Hazard Model (NSHM) to estimate maximum probable ground shaking intensity for any given reference period and a near-surface ground condition, identifies the associated building damage according to the building vulnerability class determined from the building characteristics, and finally projects associated injury and fatality rates from the building damage to produce a prioritised list of the resulting risks for all buildings within a portfolio. The core components of the model are further discussed in the following sections.

2 GROUND SHAKING INTENSITY

Embedded within ResQ is the NSHM from which ground shaking intensity for any given location and reference period is estimated. The reference period is chosen according to organisation-specific response timeframes and the importance level of buildings. The NSHM includes a database of the locations and characteristics of 550 known active faults in New Zealand (Stirling, McVerry et al. 2012). For each of the faults a characteristic magnitude, mechanism, and mean recurrence interval have been estimated. However, many significant active faults in New Zealand do not extend to the ground surface and hence not all active faults have been identified. Earthquakes on the presently unknown faults, especially buried ones, are accounted for with a distributed seismicity model. It consists of magnitude and occurrence rate parameters defined at a grid of about 40,000 points that cover the country and extend to 90 km depth, with the magnitude and occurrence rate parameters having been derived from historical earthquake data.

In a recent development, the annual probability of occurrence of earthquakes on well-studied faults in terms of the recent history, i.e. a probability that takes account of the elapsed time since the last earthquake, has been studied for the Wellington, Wairarapa, Ohariu (southern segment), all near Wellington, and some main Christchurch faults (Rhoades, Van Dissen et al. 2010). The model also includes short-term enhanced seismicity due to the aftershock activity in the Canterbury region following the 4th September Darfield earthquake (M 7.1) and its damaging Christchurch aftershocks (e.g. 22nd February 2011, M 6.2; 13th June 2011, M 6.0).

For casualty modelling purposes, the strength of earthquake shaking is usually quantified with the Modified Mercalli (MM) Intensity scale (NZSEE 1992; Dowrick 1996; Hancox, Perrin et al. 2002). The MM scale is a 12-point scale in which MM1 is barely perceptible shaking, MM6 is the level at which damage to fragile contents of buildings begins to occur, MM8 is the onset of structural damage, and MM10 corresponds to significant structural damage to normal well-designed buildings. Intensities MM11 and MM12 would in principle result in severe damage to most construction, but would require major deformation of the ground and have almost never been observed.

In order to estimate the expected intensity of ground motion at any given location, due to an earthquake elsewhere, a suitable attenuation model is needed. The 2005 model of Dowrick and Rhoades (Dowrick and Rhoades 2005), as modified by Smith (Smith 2002) is used in ResQ. The Dowrick & Rhoades model describes the attenuation of MM intensity for New Zealand earthquakes. It takes into account not only the magnitude of the earthquake and its location, but also its focal depth, mechanism and the orientation of the fault source.

An important point about the Dowrick and Rhoades model is that it predicts shaking intensities for average ground. Actual intensities on non-average ground, i.e. soft soil or rock, can be higher or lower than the average-ground case as a result of microzonation phenomena. Microzonation is the term used to describe how local ground effects modify the seismic shaking that is experienced at a specific site. Various phenomena can be involved, with those of most relevance to seismic risk studies being amplification of shaking by soft soils, liquefaction, landslide, and topographic enhancement of shaking. Amplification is important at low intensities of shaking, MM7 and below. The remaining three phenomena are important at high intensities, MM8 and above. The impacts of soft-soil amplification, liquefaction and landslide were accommodated by applying increments to the average MM value estimated at each asset site, with the size of the increment being determined by the MM and the susceptibility of the site to each of the phenomena. The maximum amounts of the increments were guided by such data as were available, but to a large degree were based on judgement (Figure 1). Table 1 shows approximate relationships between the microzonation susceptibility classes and building code ground classes. Topographic enhancements and tectonic movements may be significant for some areas. However, they have not been included in ResQ because we currently do not have proper models for such phenomena.

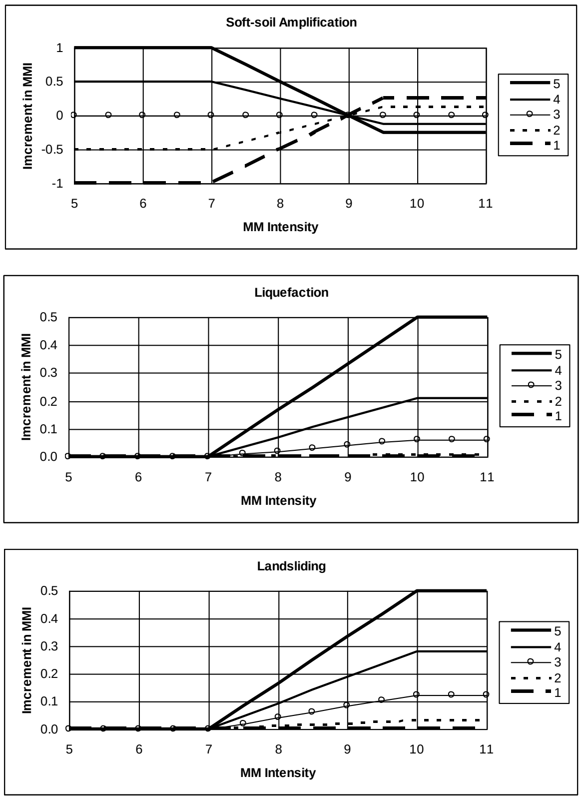

Figure 1.Adjustments to average MMI estimates to account for microzonation by susceptibility class (1 to 5) of the site of interest (King and Bell 2009).

Table 1.Approximate relationships between the microzonation susceptibility classes and code ground classes (King and Bell 2009).

NZS1170.5 Ground Class	Amplification susceptibility	Liquefaction susceptibility	Landslide susceptibility
Class A – Strong rock	1	1	4 – 5
Class B – Rock	2	1	4 – 5
Class C – Shallow soil sites	3	2	3 – 4
Class D – Deep or soft soil sites	4	2 – 4	2
Class E – Very soft soil sites	5	4 – 5	1

3 CASUALTY ESTIMATION

Depending on the intensity of shaking at a given building's location and its characteristics namely structural system, material, age (level of loadings designed to), height, and quality (e.g. %NBS), different building damage levels, ranging from no damage to collapse, and different resulting injury types, from none to death, could be experienced. Injury types can be divided into five main classes depending on the severity of injury viz. dead (Class 5), critical (person will die without expert medical attention), serious/severe (expert medical attention needed but life is not threatened), moderate (expert medical attention is not needed but the expertise of a doctor/nurse is required), and light to none (Class 1), and a direct relationship between the shaking intensity and the casualty rates can be established for different building vulnerability classes from a review of collated data from recent earthquakes (Spence, Pomonis et al. 1998; Cousins 2004; Cousins, Spence et al. 2008; King and Bell 2009):

$$C_r = A.10^{\frac{B}{MMI - C}} \tag{1}$$

where C_r (casualty rate) can be the death rate, critical injury rate, severe injury rate or moderate injury rate, *MMI* is the shaking intensity in MM, and *A*, *B*, and *C* are building casualty class constants which are different for the casualty classes defined. Figure 2 shows examples of the casualty curves for a post-1970 reinforced concrete building. The number of casualties for each casualty class is then obtained by multiplying the total number of building occupants by the calculated rate, and the number of uninjured and lightly injured people is obtained by subtracting the total number of casualties calculated for the four casualty classes above from the total number of occupants.

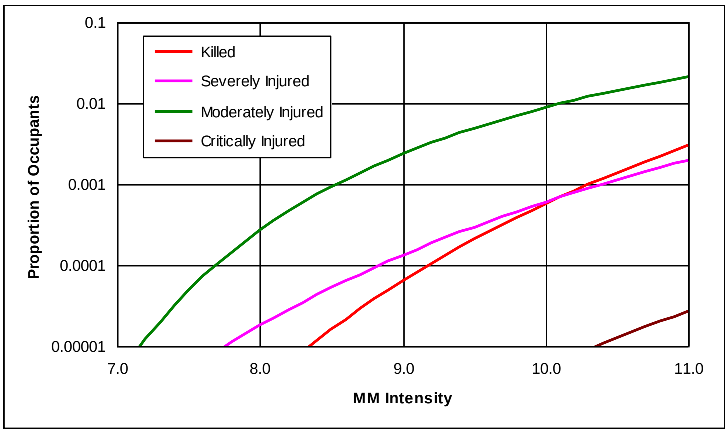

Figure 2.Derived relationship between MM Intensity and casualty rates in reinforced concrete buildings of 1970+ construction era (King and Bell 2009).

A few IEP attributes of each building are used to assign the building to one of 36 building casualty classes defined (King and Bell 2009). These attributes are the lateral load resisting system, material, age, and height of the building. The building casualty classes represent the average expected casualties in sound buildings of each class and do not include variations in the seismic strength of buildings designed for areas with different levels of seismic hazard. Therefore, an allowance is made for such variations by scaling the average casualty curves by a factor determined by the ratio of the code maximum Z factor (0.6) over the building location Z factor for post-1965 buildings. For Pre-1965 buildings, which were designed prior to the introduction of seismic zoning in New Zealand, the minimum Z factor (0.13) is assumed to be the design Z factor.

Once the building class is determined and the corresponding average casualty curves are adjusted for the building seismic zone, %NBS is used as a quality measure to determine the expected casualties of the building compared to those of a sound building of the same class and seismic zone. This is done according to the NZSEE recommendations for relative risk of non-code-compliant buildings as in Figure 3.

The above modelling procedure is summarised in Figure 4. The process relates to casualties due to building damage caused primarily by earthquake shaking. Casualties due to fault rupture, post-earthquake fire, landslides, liquefaction, tsunami, collapse of bridges or tunnels, burst of dams, etc are not included.

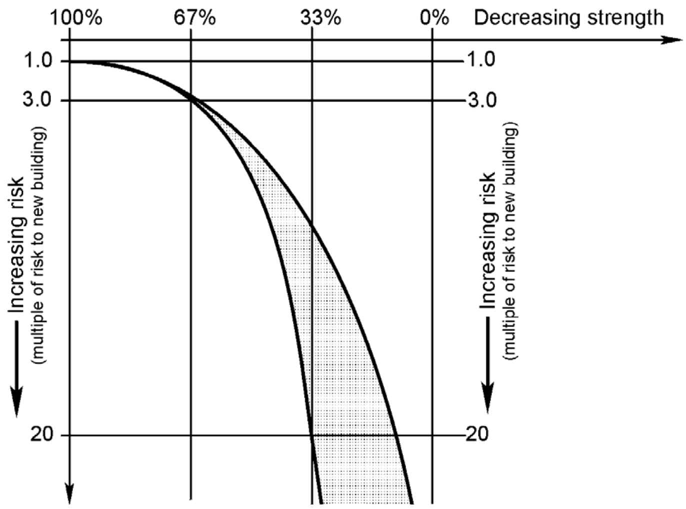

Figure 3.Relative risk vs. %NBS (NZSEE 2006)

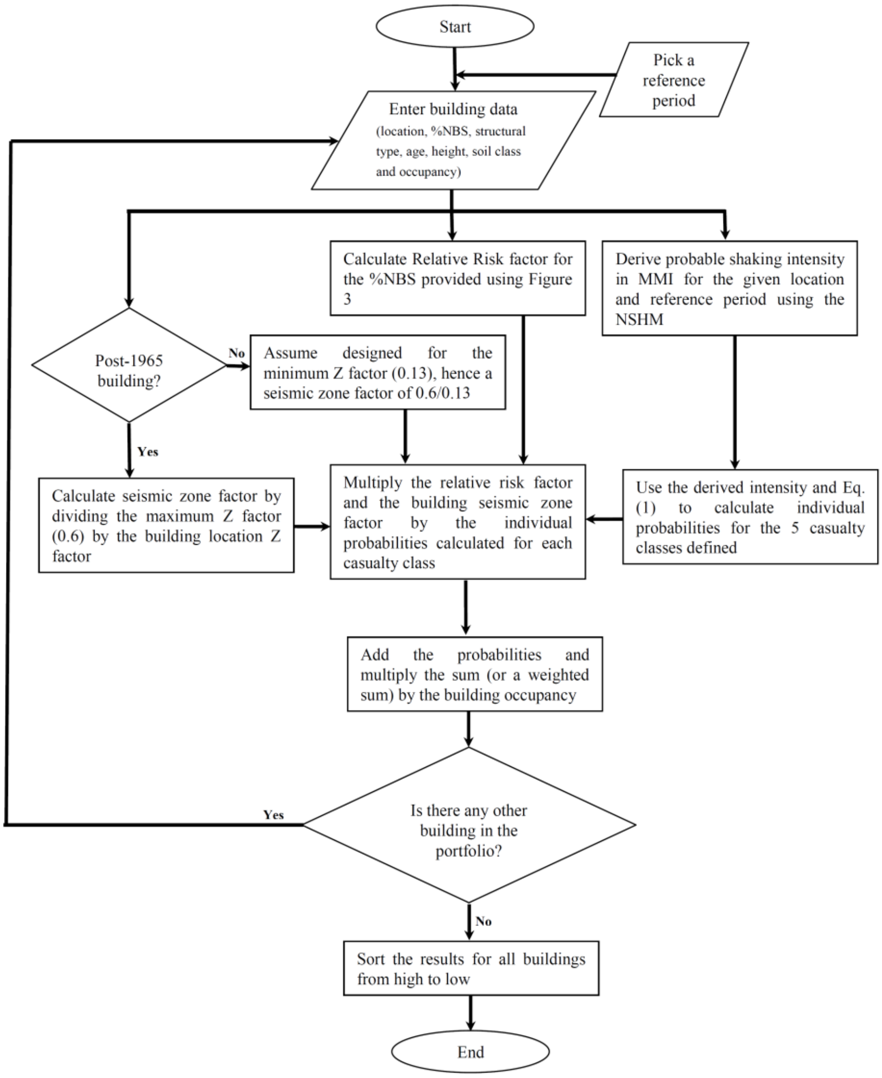

Figure 4.The life risk prioritisation procedure implemented in ResQ

4 RESQ

The procedure explained above was implemented in ResQ. Microsoft Excel was chosen as a popular and user-friendly platform for developing different modules of the model as built-in macros. Figure 5 shows the user interface designed for ResQ. From the top, a property name can be selected from a list of pre-compiled site data that might be available as part of an organisation's property management database. This can be customised for any other unique identifier that may be used by the organisation. The 'show site info' button, retrieves associated information to the selected site and displays it in the blue shaded cells and allows the user to enter (using 'save site data') or re-enter (using 'update previous records') site physical properties by typing them into the white cells. Once all the required site information is entered, the 'rank sites and create report' button generates a prioritised list of the resulting risks for all the properties entered.

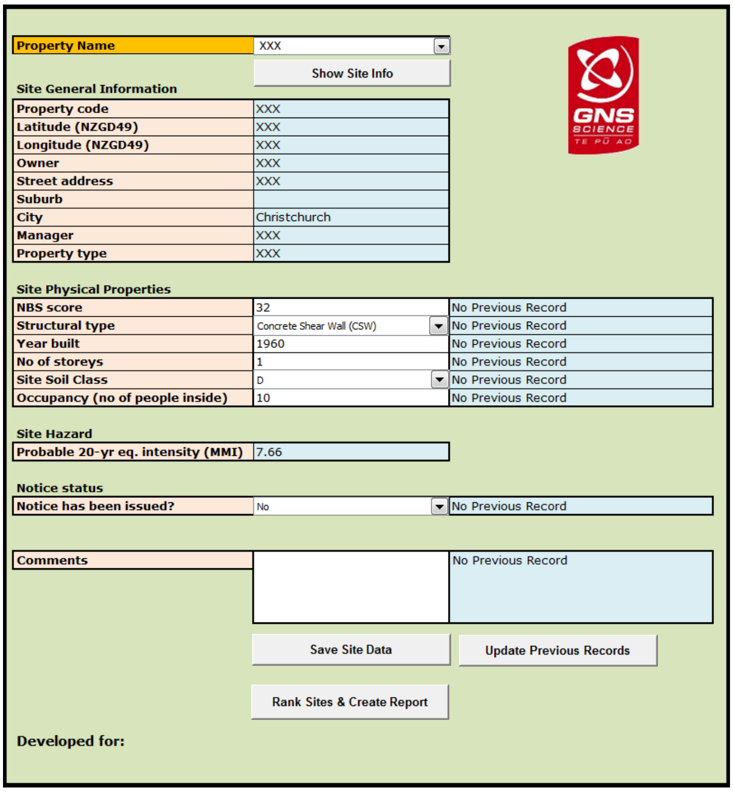

Figure 5.User interface of ResQ

5 RESULTS AND DISCUSSION

Table 2 shows results of the tool for a sample portfolio of 7 commercial buildings in order of their life-safety risk. The reference period for calculating the shaking intensities shown is 20 years or 5% annual probability of occurrence. The results presented show:

- Building A has a higher risk than Building B although it has a much higher NBS score (72 vs. 21). This is due to the fact that the expected shaking intensity is higher for Christchurch compared to Westport due to the enhanced seismicity in the Canterbury region following the Darfield earthquake.
- Building A and Building C both have same occupancy rates, probable shaking intensities, and NBS scores. However, Building A is deemed to impose higher risk to its occupants because of its construction type and age, and finally,

- Building F appears above Building G on the prioritised list although it is more modern. This is because of its much higher occupancy rate compared to the other building.

These points clearly show that %NBS alone is not sufficient to rank earthquake risk buildings and other contributing factors such as likelihood of major shaking intensities and occupancy rates should also be considered in the prioritisation for better informed decisions in dealing with the issue of earthquake risk buildings.

Table 2.Results from the tool for a sample portfolio of 7 commercial buildings for a 20-year reference period or 5% annual probability of occurrence (CSW: concrete shear wall, MRCF: moment resisting concrete frame, and MSW: masonry shear wall).

Risk Rank	Prop. Name	City	NBS	Construction Type	Year Built	Storeys	Soil Class	Occupants	MMI
1	A	Christchurch	72	CSW	1960	1	D	10	8
2	B	Westport	21	CSW	1929	1	D	10	7.3
3	C	Christchurch	72	Portal Frame	2006	1	D	10	8
4	D	Kawerau	27	Portal Frame	1950	1	D	10	7.1
5	E	Thames	25	MRCF	1937	2	D	10	5.8
6	F	Auckland	25	MSW	1957	1	A	50	3.6
7	G	Auckland	25	MSW	1910	2	A	10	3.6

6 CONCLUSION

A seismic risk prioritisation tool was presented. The tool takes a few building properties collected as part of the initial evaluation procedure and applies ground shaking intensities derived from the National Seismic Hazard Model and a database of near surface ground conditions to project likely casualties. This information provides a basis for prioritising evacuation, strengthening, or other necessary precautionary actions to the most vulnerable buildings for minimum consequent casualties should an earthquake occur. Therefore, the tool developed is particularly useful to risk/insurance or health and safety managers to make informed decisions in dealing with moderate to high risk buildings where limited resources are available to tackle the whole problem simultaneously.

7 ACKNOWLEDGEMENT

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