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Probabilistic earthquake risk assessment of Newcastle and Lake Macquarie, Australia: Part 2 – Earthquake vulnerability and risk

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ABSTRACT: This earthquake risk assessment focuses on economic losses caused by building damage from ground shaking. The hazard model is presented in a companion paper. A comprehensive field survey in the study region was conducted to document the vulnerability characteristics of a sample of more than 6,000 buildings. Australian damage models based on the capacity spectrum method were prepared and a modified HAZUS economic loss model was used. Damage and economic loss was calculated in a stratified Monte Carlo simulation of 1,200 events. The results were then aggregated to produce a loss curve for the study region. Natural variability was incorporated by allowing parameter values to vary in the simulations. Simulations of the 1989 Newcastle earthquake were compared with observed data.

Results show that the annualised loss for the study region is of the order of 0.04%, or around $11 million per year. The majority of the earthquake risk is from events with return periods in the range 50 - 1,000 years. The 1989 Newcastle earthquake had an economic impact with a return period of the order of 1,500 years. Differences in regolith distribution and thickness cause strong local variations in the risk. Timber frame buildings contribute about three-quarters of the total risk and unreinforced masonry buildings contribute a further one-sixth. The risk of casualties is low.

1 INTRODUCTION

This earthquake risk assessment is one of two related papers prepared for the 2003 Pacific Conference on Earthquake Engineering. The companion paper present the results for the earthquake hazard model (Dhu et al. 2003). Together, the papers summarise the results of the report ‘Earthquake risk in Newcastle and Lake Macquarie’ (Dhu and Jones (Eds) 2002).

Geoscience Australia (GA) undertook the earthquake risk study of Newcastle and Lake Macquarie for several reasons. The ML 5.6 1989 Newcastle earthquake was one of the most catastrophic natural disasters in Australia’s history, causing the deaths of 13 people and more than AUD1 billion damage. At least four other moderate-magnitude (~ML 5 – 5.5) earthquakes have occurred in the Hunter region since European settlement in 1804 (McCue 1995) and it is reasonable to expect that more events will occur there in the future. Therefore, an understanding of the earthquake risk to the two cities is important for community leaders and decision makers.

Because the 1989 earthquake was by far the most catastrophic earthquake in Australia, it provides a valuable reference point against which GA can test its earthquake risk assessment models. Because the earthquake occurred relatively recently, much relevant information has survived, and the composition of the building stock has not changed radically since 1989.

2 RISK ASSESSMENT MODEL

2.1 Building damage model

GA's probabilistic earthquake risk model for Newcastle and Lake Macquarie is based upon a stratified Monte Carlo simulation (Fulford et al. 2002). The building damage (or vulnerability) model is used to determine how much a building is damaged given a specified amount of ground shaking, and the economic loss model produces corresponding estimates of the cost of replacement or repair (Figure 1).

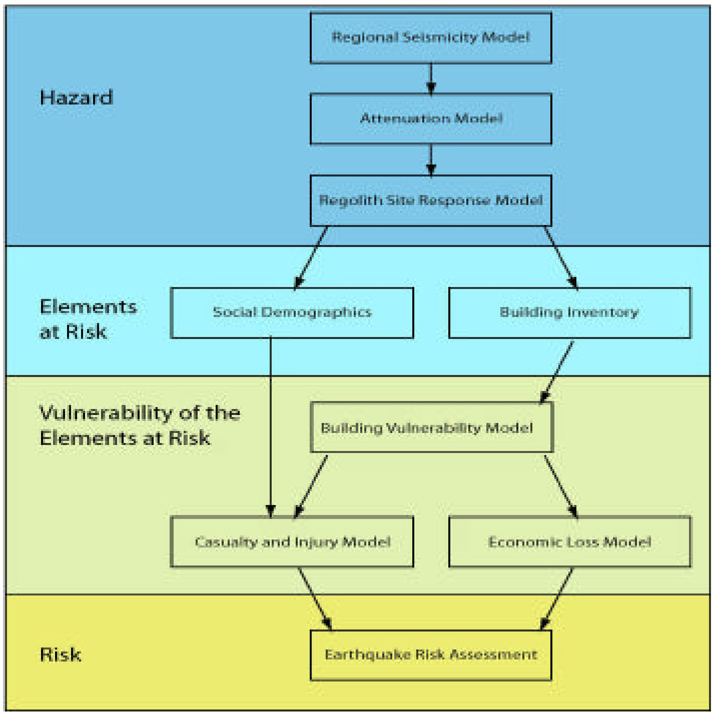

Figure 1: Flow-chart describing the earthquake risk assessment process applied to Newcastle and Lake Macquarie.

The building damage is calculated according to the Capacity Spectrum Method (e.g., Kircher et al. 1997). This methodology was also used in the US Federal Emergency Management Agency's program HAZUS (National Institute of Building Sciences 1999). It is based upon finding the intersection of the demand spectrum (at a given building site) with a building capacity curve (or pushover curve) to determine the displacement and acceleration response of the building. In the convergence process the original, 5% damped elastic response spectrum is adjusted to account for the additional energy absorbed by the structure through increased elastic and hysteretic damping (Fulford et al. 2002). Each of the 36 HAZUS building construction types has a different building capacity curve defined by a set of capacity parameters.

In February 2001, a workshop was held at the University of Melbourne to assess the suitability of the HAZUS capacity parameters for Australian construction types (Stehle et al. 2001). Subsequently, the capacity parameters for several HAZUS building types were adjusted, and some HAZUS types were subdivided to reflect differences in wall and roof materials (Table 1). In 2002, the University of Melbourne reviewed GA's building vulnerability methodology (Edwards et al. 2002). Based in their recommendations, new parameter values for the subtypes of timber frame and concrete frame categories are adopted in this study (Fulford et al. 2002). Although the revised parameter sets are thought to be more appropriate for Australian conditions than the US-based HAZUS parameters, they have not been broadly and rigorously reviewed. This review is an important priority in the efforts to improve the damage models.

Three types of damage are defined by the model: drift sensitive damage (structural and non-structural), and acceleration sensitive non-structural damage. For each type of damage, there are four possible damage states: slight, moderate, extensive and complete. The damage states are determined by thresholds defined for each construction type. The workshop participants recommended changes to the HAZUS drift ratio values for non-structural damage, and separate values for residential and non-residential buildings.

Table 1. Building construction types with Australian capacity parameters.

Construction type	Description
W1MEAN*	Timber frame
W1BVTILE	Timber frame, brick veneer wall, tiled roof
W1BVMETAL	Timber frame, brick veneer walls, metal roof
W1TIMBERTILE	Timber frame, timber walls, tiled roof
W1TIMBERMETAL	Timber frame, timber walls, metal roof
C1MEAN* **	Reinforced concrete frame
C1SOFT**	Reinforced concrete frame (soft storey)
C1NOSOFT**	Reinforced concrete frame (non soft storey)
URMMEAN* ***	Unreinforced masonry
URMTILE***	Unreinforced masonry, tiled roof
URMMETAL***	Unreinforced masonry, metal roof

* Not otherwise classified

** Three categories - Low, Medium and High Rise

*** Two categories - Low and Medium Rise

2.2 Field data collection for building inventory

The construction type, usage, floor area and other vulnerability attributes of more than 6,300 buildings were compiled by GA in a comprehensive field survey. The survey sampled approximately 5% of all buildings in Newcastle and Lake Macquarie. Sampling rates were highest in the Newcastle CBD. This building inventory was used in the simulations, with appropriate multipliers to generate risk results for all of the approximately 120,000 buildings in Newcastle and Lake Macquarie. Particular efforts were made to survey all essential service facilities such as hospitals, and ambulance and fire stations.

Construction types that are commonly found in Newcastle and Lake Macquarie are timber frame (including brick veneer, timber and fibro wall cladding), unreinforced masonry, light steel frame and reinforced and pre-stressed concrete buildings.

2.3 Economic loss model

The HAZUS method to determine the economic impact of direct damage is used, wherein the cost of replacement (per square metre) is specified for buildings of particular usage types, together with estimates of the value of their contents. Eighteen HAZUS building usage types were identified in Newcastle and Lake Macquarie, spanning residential (five types), commercial (five types), industrial (three types), government (two types), educational (two types) and religious usage.

Estimates of the replacement costs for double brick, brick veneer and timber residential buildings are based on limited Australian insurance data. The replacement costs for other usage types are normalised by the replacement cost for residential brick veneer.

The total building replacement cost is sub-divided into costs for the structure, the drift sensitive non-structural components and the acceleration sensitive non-structural components. Some building usage types (e.g., hospitals) have contents that are more valuable than the building itself, whereas for residential types the contents comprise 50% of the value of the building.

For drift sensitive components it is assumed (following HAZUS) that complete damage corresponds to 100% of the total replacement value of that component of the building, extensive damage to 50%, moderate damage to 10% and slight damage to 2%. For acceleration sensitive components the corresponding ratios are 100%, 30%, 10% and 2%. For contents the ratios are 50%, 25%, 5% and 1%, based on the assumption that half the value of the contents can be salvaged after an earthquake. It is not clear whether this assumption is accurate. In general, significant efforts are needed to develop appropriate Australian economic loss models.

In any earthquake simulation event, the damage to a particular building will be distributed across the zero, slight, moderate, extensive and complete damage states, for drift sensitive and acceleration sensitive damage. The economic loss for that building, in a single earthquake simulation event, is the sum of the losses for each of the four damage states, for each type of damage.

To obtain the total aggregated loss across Newcastle and Lake Macquarie (for a single earthquake simulation) the loss for each building is multiplied by the appropriate survey factor and summed over all of the approximately 6,300 buildings in the inventory. A total of 1,200 earthquake scenarios were generated to compile the aggregated risk results for Newcastle and Lake Macquarie.

2.4 Incorporating variability in the damage model

Random ground motion is generated for each earthquake simulation. For each building in the inventory, a random building capacity curve is chosen from a lognormal distribution with given median curve (according to building construction type) and a variability parameter of 0.3. This parameter is the standard deviation of the natural logarithm of the random variable.

The fragility curves associated with the damage states are chosen from a cumulative lognormal distribution with variability parameters 0.4, 0.5 and 0.6 for structural damage, non-structural damage (drift sensitive) and non-structural damage (acceleration sensitive), respectively.

3 RESULTS

3.1 Simulation of the 1989 Newcastle earthquake

Computer simulations of the 1989 earthquake in Newcastle were generated from the epicentre of the 1989 earthquake, adopting a moment magnitude of 5.35, and allowing variability in the attenuation, soil amplification and building damage models.

In broad terms, our simulated results are consistent with the observed economic loss data from the earthquake. The median value of the losses estimated from 1,000 simulations is approximately AUD1.1 billion (in 1989 dollars), corresponding to a percentage loss of 7.2% for all buildings and their contents. This compares with the insured losses of AUD862 million (Insurance Disaster Response Organisation 2002) and a damage ratio of 9.1% that we calculated for residential buildings and contents insured with NRMA, a major insurer in 1989. However, the NRMA database only contained information on the buildings for which claims were submitted, and so the 9.1% figure should be regarded as a maximum.

3.2 Earthquake risk in Newcastle and Lake Macquarie

A risk curve for the region is shown in Figure 2. This curve describes the probability of the study region incurring various minimum levels of economic loss within a single year. Economic loss is expressed as a percentage of the total value of all buildings and their contents in the study region.

The simulated 1989 Newcastle event had a loss on the order of 7.2% of the total value of the building stock and associated contents. Locating this point on the risk curve suggests that the 1989 earthquake, in terms of impact, had a probability of about 0.0006 of being exceeded in any single year or, alternatively, a return period of around 1,500 years.

By integrating the area under the loss curve we obtain an estimate of the annualised economic damage loss for Newcastle and Lake Macquarie (Figure 3). The annualised loss becomes larger when increasingly rare events are included in the analysis.

The annualised loss curve suggest that, on average, the region will suffer an estimated economic loss of around 0.04% per year, or around AUD11 million per year. Events with return periods of less than 1,000 years contribute around 77% of the total annualised loss.

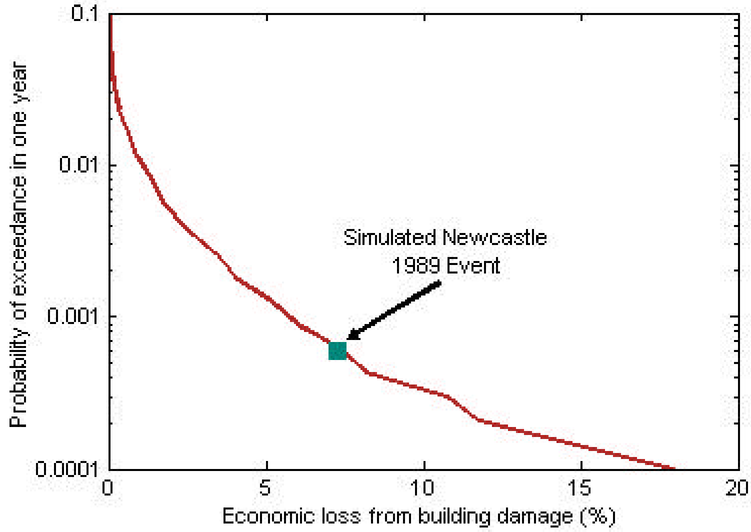

Figure 2: Loss curve for the Newcastle and Lake Macquarie region.

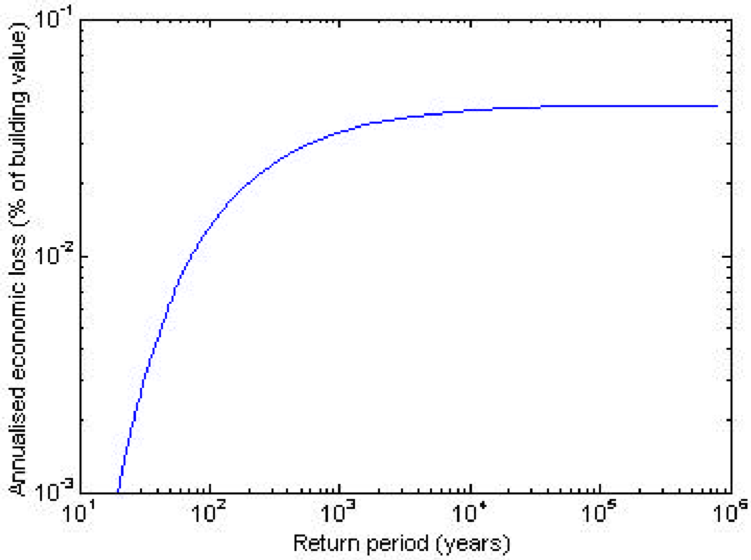

Figure 3: Annualised economic loss versus maximum return period considered for the study area.

Annualised loss varies considerably across Newcastle and Lake Macquarie. It depends strongly on the nature of the underlying regolith. In general, areas that are built on substantial thicknesses of geological sediments having noticeably higher annualised losses than other areas. The annual loss also depends on the building construction types, building usages and total floor areas in local areas. Figure 4 shows the annualised loss by suburb.

The predicted annualised loss varies with building construction type (Figure 5). Unreinforced masonry buildings have the highest average risks per building. The subclass of timber frame buildings with timber or fibro wall cladding (excluding brick veneer) is estimated to have annualised losses slightly less than half of the risks for unreinforced masonry structures, per building. However, there are many more timber frame buildings in the study area than unreinforced masonry buildings. Consequently, timber frame buildings make a greater contribution to the total risk in the study region than unreinforced masonry buildings. The reader should note that all of the building parameters need validating, and therefore the outcomes for particular building types could change with revised parameter sets.

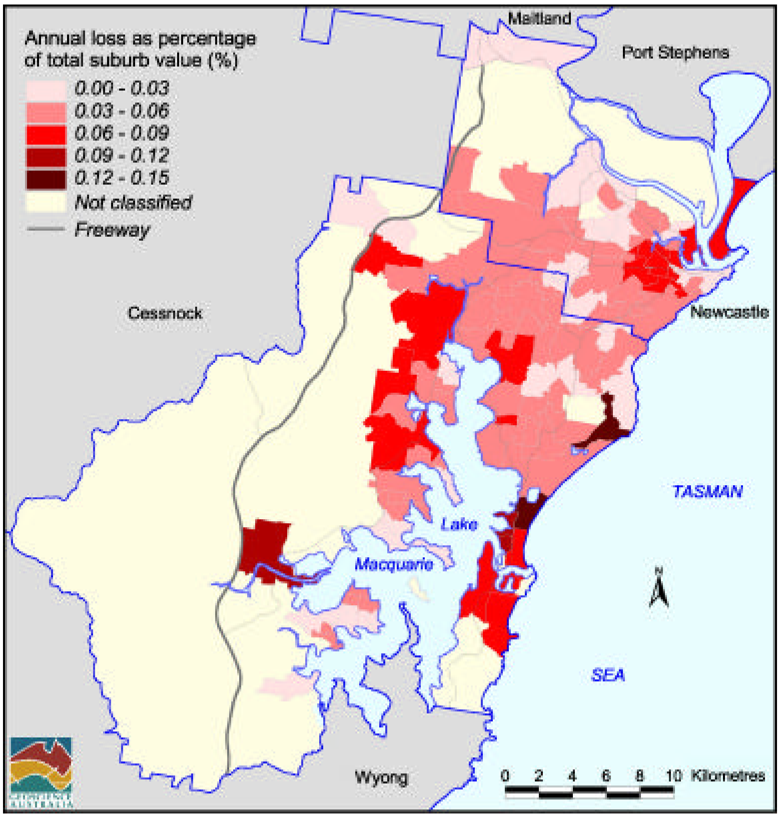

Figure 4: Annualised loss by suburb, calculated as a percentage of the total value of all the buildings and contents in the suburb.

4 CONCLUSIONS

The Newcastle and Lake Macquarie study has provided a comprehensive assessment of the earthquake risk to the two communities based on potential building damage. However, further development of the risk assessment framework, changes to the model parameters, or the addition of new data, could affect the results and our conclusions.

Some key conclusions produced by this study are:

- The annualised loss for the study region is of the order of 0.04% or $11 million per year;
- The majority of the annualised earthquake loss in the study region is from events that have annual probabilities of occurrence in the range of 0.02 to 0.001 (return periods of 50 - 1,000 years);
- Brick veneer buildings contribute about half of the total risk. This is partly because they comprise a large proportion of buildings in Newcastle and Lake Macquarie. Timber frame buildings with timber, fibro and other light wall claddings contribute approximately one-quarter of the risk. A further one-sixth of the risk is contributed by unreinforced masonry buildings;

- Damage to residential buildings contributes the vast majority of the risk. This is largely because residential buildings comprise the vast majority of all buildings in Newcastle and Lake Macquarie;
- The 1989 Newcastle earthquake had an economic impact with a return period of the order of 1,500 years. According to our models, approximately 82% of all annualised loss in Newcastle and Lake Macquarie is due to events with lesser economic impacts than the 1989 earthquake;
- Annualised loss varies considerably across Newcastle and Lake Macquarie. It depends on the nature of the underlying regolith, the composition of the building stock and building usage in particular areas;
- In general, the risk of casualties from earthquakes is low. However, we do not rule out the possibility that casualties in future events could be caused by damage to a single building, or a small number of buildings. It is extremely unlikely that any event capable of causing widespread casualties will occur in the study region;

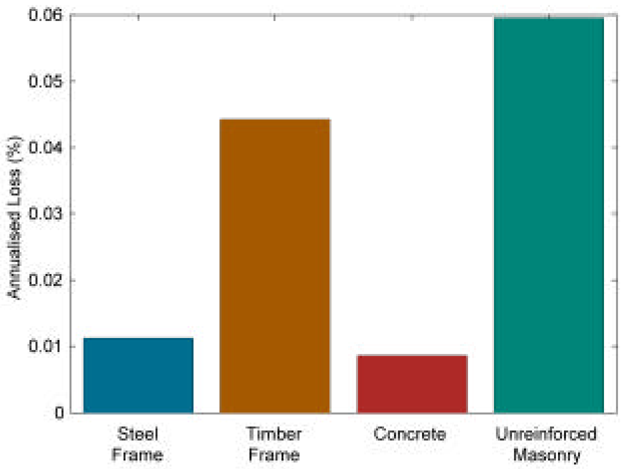

Figure 5: Annualised loss for a selection of building types, defined as a percentage of the total value of that building type in the study region. Timber frame includes brick veneer, timber and fibro wall cladding types.

- The results also have implications for the earthquake risk facing larger Australian cities such as Sydney, Melbourne and Adelaide. This is due to a number of factors, including similarities between the earthquake hazard in Newcastle and Lake Macquarie and other parts of Australia, and similarities between the urban environments, particularly the composition of the building stock;
- The earthquake risk to Newcastle and Lake Macquarie may be reduced gradually over time by improved building construction practices, attrition of vulnerable building stock such as unreinforced masonry, and by reducing vulnerability of existing buildings through renovations constructed to modern code standards;
- Good building practice may be the single, most important, long-term factor in reducing economic losses and casualties from earthquakes in Newcastle and Lake Macquarie.

5 FUTURE DIRECTIONS FOR EARTHQUAKE RISK ASSESSMENT

Many improvements and additions can be made to improve the techniques used in GA's study. Some important measures to improve earthquake risk assessment in Newcastle and Lake Macquarie are suggested below. The list is not comprehensive.

In the study, GA assessed direct economic losses due to building damage. The study has not addressed the direct losses from business interruption or the indirect losses to other communities resulting from earthquakes in Newcastle and Lake Macquarie. An assessment of these losses would give a more complete estimate of the total risk due to earthquakes in Newcastle and Lake Macquarie.

The importance of the impacts of earthquakes on 'lifelines' such as electric power and water supply needs to be investigated.

The socio-economic implications of earthquake impacts on Newcastle and Lake Macquarie also need to be assessed.

GA's damage and economic loss models will benefit from validation against other models, and these comparisons require the support and cooperation of others.

The engineering vulnerability models need to be checked, modified and produced as necessary to make them appropriate for Australian building stock. This requires a long-term, engineering research effort. The efforts to improve the models should concentrate on the construction types that are the most important contributors to risk, as they have done so far. For Newcastle and Lake Macquarie, these are timber frame structures (especially brick veneer structures) and unreinforced masonry structures. The results of the study also suggested that a damage model for masonry degraded by age, marine corrosion or substandard materials would have provided a better match with observations of the 1989 earthquake damage, and hence would improve the overall risk assessment. Details such as tile or steel roof, masonry gable ends, parapets and chimneys, number of storeys in low rise buildings, soft storey, are important components of the vulnerability models.

The degree of damage and economic loss predicted by the models can be used to assess the appropriateness of earthquake loading standard specifications. For example, is the economic loss predicted by ground shaking with a 10% probability of occurrence in 50 years acceptable to the loading committee, the insurance and construction industries, and to government?

Sensitivity tests are being run GA by varying parameter values in the models to give alternative estimates of risk. The results may point to areas where efforts should be made to improve the models or collect new data. Reduced variability in the models will lead to more accurate and reliable estimates of risk.

Assessments of future risk based on projections of changes in building stock and demographics would be valuable to assist decisions on the development of Newcastle and Lake Macquarie. A cost/benefit analysis of the effectiveness of introducing various mitigation measures would also assist the rational development of the cities.

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