6 EARTHQUAKE RISK (G. FULFORD, T. JONES, J. STEHLE, N. CORBY, D. ROBINSON, J. SCHNEIDER AND T. DHU)

The impact of earthquakes in Newcastle and Lake Macquarie and their associated risk in terms of the economic loss is analysed in this Chapter. An overview of the methodology used to calculate the building damage and the economic loss model is described in Section 6.1. Further technical details of the model can be obtained from the authors of this Chapter at Geoscience Australia. The Newcastle 1989 earthquake is then run as a scenario and compared with data from this event in Section 6.2. Finally, in Section 6.3, a probabilistic risk analysis of future earthquakes in Newcastle and Lake Macquarie, in terms of economic loss from building damage, is done.

6.1 Methodology for Vulnerability and Economic Loss

The probabilistic earthquake risk model, used in this study, is based upon a stratified Monte Carlo simulation. This involves random placement of earthquakes with random magnitudes. Building damage and economic loss modules are used to determine how much a building is damaged and the corresponding replacement costs, due to a given amount of ground shaking. A description of the ground shaking (or hazard) part of the simulation methodology has been given in Chapter 4. A building damage model which inputs to an economic loss model (see Figure 6.1) produces results that are used to analyse the risk of future earthquakes in Newcastle and Lake Macquarie.

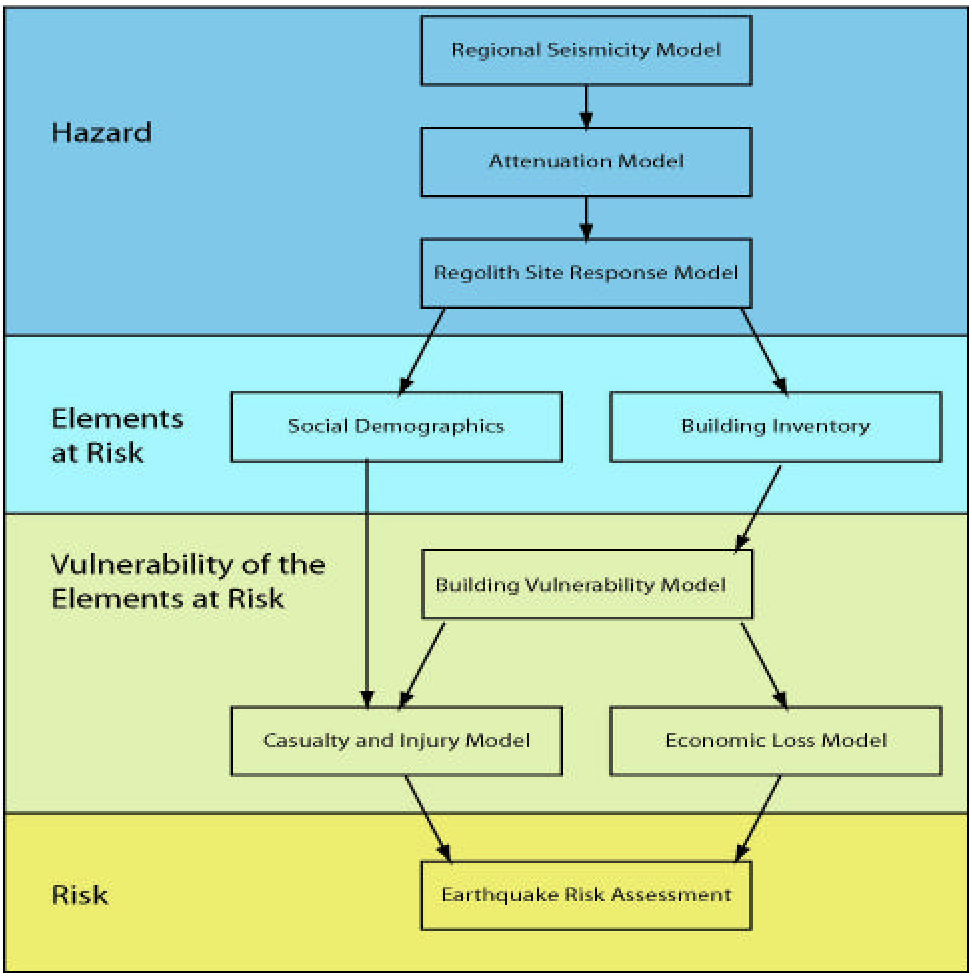

Figure 6.1: Flow-chart describing the earthquake risk assessment process as applied to Newcastle and Lake Macquarie

The overall simulation model includes the following sources of random variability: earthquake location, earthquake magnitude, attenuation, soil amplification, building capacity and building damage states.

The building damage was calculated according to the methodology known as the Capacity Spectrum Method. This methodology had also been used in the HAZUS program of FEMA in the United States (National Institute of Building Sciences, 1999). A good description is given in (Kircher et al., 1997) and in the HAZUS technical manual. The Capacity Spectrum Method determines the displacement and acceleration response of a building due to a given earthquake response spectrum.. It is based upon finding the intersection of the response spectrum (at a given building site) with a building capacity curve (commonly called a push over curve). Each building construction type has a different building capacity curve that depends on certain parameters (e.g. the building natural period, the ductility). The building capacity curve (see Figure 6.2) has a linear part, corresponding to elastic deformation, and a non-linear part corresponding to plastic deformation. The peak response displacement and acceleration for the building is determined by the location on the graph where the building capacity curve intersects the damped demand spectrum (from ground shaking) (see Figure 6.2). The original, 5% damped, elastic response spectrum (due to ground shaking) is further adjusted to account for the additional energy absorbed by the structure of the building through its increased elastic and hysteretic damping.

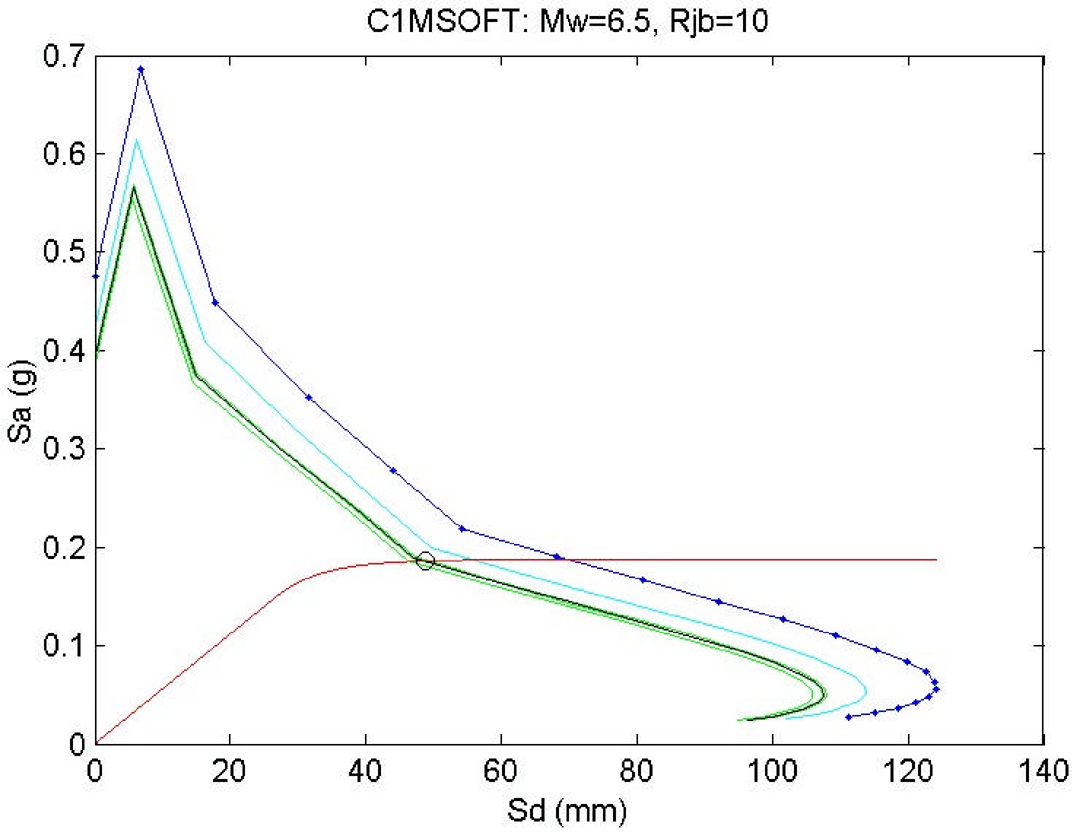

Figure 6.2: The Capacity Spectrum Method for a single earthquake event with moment magnitude 6.5 and Joyner-Boore distance of 10 km, on soft rock, for a reinforced concrete frame (soft storey) building. The building capacity curve (red) intersects with the final damped demand spectra (black) to give the peak displacement and peak acceleration of the building. The original spectral response curve (dark blue) is modified, first by elastic damping (light blue) then by hysteretic damping (green) in an iterative process that converges to the black curve

A key difference in our implementation of the Capacity Spectrum Method to that used by HAZUS is using the full response spectrum for intersecting with the building capacity curve rather than a design spectrum based on only a few building periods. For example, the HAZUS approach only uses periods of 0.3 and 1.0 seconds. Our approach has the advantage that the full shape of the response spectrum and all the available information for the soils amplification factors, at all periods, (see Chapter 4) is taken into account rather than at only two periods.

On 23 February 2001, a workshop was held at the University of Melbourne to assess the applicability of the HAZUS building capacity parameters to Australian building construction. A number of recommendations were made, including the subdivision of some of the HAZUS types into subtypes depending on wall and roof materials (See Table 6-1 for the definitions of the sub-types and Chapter 5 for a discussion of the main HAZUS construction types in Newcastle and Lake Macquarie). It was also recommended that the adjustment of the building parameters be undertaken to better suit buildings constructed according to Australian standards. Note that HAZUS gives parameter values for four different code design levels (High, Moderate, Low and Pre- code). We have assumed all buildings are Pre-code, due to lack of any other information.

Table 6-1 Sub classification of HAZUS building types, for types (W1, timber frame), C1L, C1M, C1H (low, mid and high-rise reinforced concrete frame) and URML, URMM (low and mid-rise unreinforced masonry) as recommended by the workshop (Stehle et al., 2001)

W1MEAN	Timber frame (not otherwise classified)
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
C1LMEAN	Low-rise reinforced concrete frame (not otherwise classified)
C1LSOFT	Low-rise reinforced concrete frame (soft story)
C1LNOSOFT	Low-rise reinforced concrete frame (non soft story)
C1MMEAN	Mid-rise reinforced concrete frame (not otherwise classified)
C1MSOFT	Mid-rise reinforced concrete frame (soft story)
C1MNOSOFT	Mid-rise reinforced concrete frame (non soft story)
C1HMEAN	High-rise reinforced concrete frame (not otherwise classified)
C1HSOFT	High-rise reinforced concrete frame (soft story)
C1HNOSOFT	High-rise reinforced concrete frame (non soft story)
URMLMEAN	Low-rise unreinforced masonry (not otherwise classified)
URMLTILE	Low-rise unreinforced masonry, Tiled roof
URMLMETAL	Low-rise unreinforced masonry, Metal roof
URMMMEAN	Mid-rise unreinforced masonry, (not otherwise classified)
URMMTILE	Mid- rise unreinforced masonry, Tiled roof
URMMMETAL	Mid- rise unreinforced masonry, Metal roof

Subsequently, Geoscience Australia contracted the University of Melbourne to further investigate the building capacity parameter values for some of the new construction sub-types, to report on their suitability and to provide new values where necessary (Edwards et al., 2002). These new and reviewed values are listed in Table 6-2. This table also shows the values for the URML and URMM types suggested in the workshop, which are different from the original HAZUS parameters. Whilst these parameters were felt to be more appropriate for Australia than the previous HAZUS parameters, they have not been broadly and rigorously reviewed, and this should be a priority for future research in the Australian engineering community.

Table 6-2 New and reviewed building parameters for subdivided HAZUS types. The W1 (timber frame) and C1 (reinforced concrete frame) building parameters have been provided or reviewed by the University of Melbourne (Edwards et al., 2002) whereas the URML, URMM types (unreinforced masonry) are from the workshop (see text). Note that the hysteretic damping coefficients are provided for short (S), medium (M) and long (L) duration earthquakes. Units are dimensionless, except where otherwise indicated.

Building type	Design Strength	Height (feet)	Period (seconds)	Weight fraction	Height fraction	Overstrength (yield)	Overstrength (ultimate)	ductility	Hysteretic damping (S)	Hysteretic damping (M)	Hysteretic damping (L)	Elastic damping
W1MEAN	0.077	13	0.275	0.9	0.7	1.75	2	7	0.001	0.001	0.001	0.08
W1BVTILE	0.063	13	0.32	0.9	0.7	1.75	2	7	0.001	0.001	0.001	0.08
W1BVMETAL	0.082	13	0.28	0.9	0.7	1.75	2	7	0.001	0.001	0.001	0.08
W1TIMBERTILE	0.069	13	0.3	0.9	0.7	1.75	2	7	0.001	0.001	0.001	0.08
W1TIMBERMETAL	0.094	13	0.26	0.9	0.7	1.75	2	7	0.001	0.001	0.001	0.08
C1LMEAN	0.2	20	0.45	0.975	0.795	1.5	1.38	3.75	0.12	0.09	0.09	0.07
C1LSOFT	0.2	20	0.45	1	0.79	1.5	1.25	3.5	0.12	0.09	0.09	0.07
C1LNOSOFT	0.2	20	0.45	0.95	0.8	1.5	1.5	4	0.12	0.09	0.09	0.07
C1MMEAN	0.1	50	0.85	0.95	0.6	1.5	1.38	2.5	0.105	0.08	0.08	0.07
C1MSOFT	0.1	50	0.85	1	0.55	1.5	1.25	2	0.105	0.08	0.08	0.07
C1MNOSOFT	0.1	50	0.85	0.9	0.65	1.5	1.5	3	0.105	0.08	0.08	0.07
C1HMEAN	0.05	120	1.6	0.925	0.55	1.5	1.38	2	0.095	0.07	0.07	0.07
C1HSOFT	0.05	120	1.6	1	0.5	1.5	1.25	1.5	0.095	0.07	0.07	0.07
C1HNOSOFT	0.05	120	1.6	0.85	0.6	1.5	1.5	2.5	0.095	0.07	0.07	0.07
URMLMEAN	0.15	15	0.15	0.75	0.75	1.5	2	2	0.001	0.001	0.001	0.05
URMLTILE	0.15	15	0.15	0.75	0.75	1.5	2	2	0.001	0.001	0.001	0.05
URMLMETAL	0.2	15	0.13	0.75	0.75	1.5	2	2	0.001	0.001	0.001	0.05
URMMMEAN	0.1	35	0.28	0.75	0.75	1.5	2	2	0.001	0.001	0.001	0.05
URMMTILE	0.1	35	0.28	0.75	0.75	1.5	2	2	0.001	0.001	0.001	0.05
URMMMETAL	0.15	35	0.23	0.75	0.75	1.5	2	2	0.001	0.001	0.001	0.05

An inventory of over 6,300 buildings was compiled (see Chapter 5) and used in the simulation. Residential type buildings were multiplied by a suitable survey factor to approximate the total number of residential buildings in Newcastle and Lake Macquarie.

The peak displacement and acceleration of a particular building was used to determine various damage states that the building falls into. There are different types of damage: structural damage, corresponding to damage to the building frame, foundations and walls; and non-structural damage, corresponding to damage to partitions, ceilings and cladding. Non-structural damage is divided into drift sensitive (displacement sensitive) and acceleration sensitive components. For each of these three types of damage, there are five possible damage states: None, Slight, Moderate, Extensive and Complete. These are defined in the HAZUS technical manual for each building construction type. The damage states are determined by thresholds, which are defined for each building construction type. For drift-sensitive damage the thresholds are obtained from drift ratios. The workshop also recommended that the values for drift ratios for non-structural damage were changed from the standard HAZUS ratios (see Table 6-3) and also that different values be used for residential and non-residential buildings.

Table 6-3: Drift ratios used to define median fragility curves for non-structural drift-sensitive damage. These values were recommended by the Engineers workshop held at the University of Melbourne

Damage state	Slight	Moderate	Extensive	Complete
non-residential	0.004	0.008	0.02	0.03
residential	0.001	0.008	0.015	0.025

6.1.1 Incorporating Variability in the Building Vulnerability Models

The HAZUS methodology uses fragility curves to determine the probability of a building being in a given damage state, given the peak displacement (or peak acceleration, in the case of acceleration sensitive damage). In HAZUS there are 12 fragility curves for each building construction type corresponding to the four damage states for each of the three types of damage (structural, non-structural drift sensitive and non-structural acceleration sensitive). The HAZUS approach only crudely takes account of the various uncertainties contributing to the ground shaking and is more suited to a scenario-based approach than the full probabilistic approach adopted in this report. We have adopted a modified approach where, in our Monte Carlo-like simulation, we generate a separate random ground motion for each earthquake. For each sampled building site a random building capacity curve is chosen from a lognormal distribution with given median curve (according to building construction type) and a variability parameter[21] of 0.3, as used by HAZUS.

The fragility curves include the variability for being in the given damage state independent of ground shaking or building type. These 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. This study has used the values recommended by HAZUS.

6.1.2 Economic Loss Model

An important indicator of the severity of an earthquake on a community is the economic cost. We have taken a simplistic approach by including only the direct costs of replacement or repair to buildings and their contents.

The method used to determine economic impact of direct damage is based on that used by HAZUS (National Institute of Building Science, 1999) which was based upon U.S. data (the Means Square Foot Cost 1994, for Residential, Commercial, Industrial and Institutional Buildings). Buildings are classified in usage types where the costs of replacement (per square metre) are specified, together with the value of the contents. In Table 6-4 a description of the HAZUS usage types is given.

The HAZUS methodology includes a Regional Cost Modifier, which is used to scale all of the cost estimates to account for the variation in construction costs in different locations. To adapt the methodology for Newcastle and Lake Macquarie, the value of the Regional Cost Modifier is determined by assuming the total replacement cost for a normal residential building is AUD 1,000 per square metre.

Table 6-5 lists the total building replacement costs per square metre (with, and without contents) for each of the HAZUS usage types, which have been used in Newcastle and Lake Macquarie. The Regional Cost Modifier has been included, and the values are for Australian dollars, in 2002. Total building replacement cost is also subdivided into costs for the structure, the drift sensitive non-structural components and the acceleration sensitive non-structural components. Note that some particular building usage types (e.g. universities, type EDU2; hospitals, type COM6) have contents that are more valuable than the building itself, whereas for residential types the contents comprise 50% of the value of the building. This value is quoted by HAZUS, and may be too high for Australian properties. Nevertheless, this is the only published value that the authors were aware of at the time of this study.

For structural and non-structural 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 with extensive

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[21] *For a random variable, with a lognormal distribution, the* variability parameter *is defined as the standard deviation of the natural logarithm of the random variable.*

damage to 50%, moderate damage to 10% and slight damage to 2%. For non-structural damage (acceleration sensitive) the ratios are 100% for complete damage, 30% for extensive damage, 10% for moderate damage and 2% for slight damage. For the replacement value for contents the ratios are 50% for complete damage, 25% for extensive damage, 5% for moderate damage and 1% for slight damage. These figures are based on the assumption that half the value of the contents can be salvaged after an earthquake. It is not clear whether this assumption, based on U.S. data, is accurate for Australia and it may be more appropriate to use a larger value (possibly 100%). Further study of existing data is necessary.

By multiplying the probabilities of being in the various damage state by the replacement costs for that damage state the economic cost for each of the four building components (structural, non-structural drift sensitive, non-structural acceleration sensitive, contents) is obtained. The total economic loss, for a single earthquake and a single building site, is the sum of these four quantities.

To obtain the total aggregated loss across Newcastle and Lake Macquarie (for a single earthquake) the loss for a single building site is multiplied by the appropriate survey factor (see Chapter 5) and summed over all the sites in the building inventory.

For very small levels of ground shaking (pga < 0.05 g) it is assumed that no measurable damage occurs, and hence the economic loss is set to $0. In addition to this, only earthquakes with moment magnitudes greater than 4.5 are considered capable of causing measurable damage.

Table 6-4: Description of HAZUS usage types used for economic loss calculations for buildings in Newcastle and Lake Macquarie

Usage Type	Description	Example
RES1	Single Family Dwelling	Detached House
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling	Apartment/Condominium
RES4	Temporary Lodging	Hotel/Motel
RES6	Nursing Home	
COM1	Retail Trade	Store
COM4	Professional/Technical	Offices
COM6	Hospital	
COM7	Medical Office/Clinic	Offices
COM8	Entertainment & Recreation	Restaurants/Bars
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/Drugs/Chemicals	Factory
REL	Church	
GOV1	General Services	Office
GOV2	Emergency Response	Police/Fire Station
ED1	Schools	
ED2	Colleges/Universities	Does not include group housing

*Table 6-5 Approximate replacement costs per square metre for building components for the subset of the HAZUS usage types in the Newcastle and Lake Macquarie building inventory. We have also added two further types (RES1tm, RES1db), corresponding to residential timber walled houses and residential double brick houses. The values are costs per square metre expressed in Australian dollars for the year 2002, they have been normalised relative to the RES1 building value of $1,000 m*$^{-2}$

Usage type	Ex-contents value (per square metre)	Structural	Non-structural (drift sensitive)	Non-structural (acceleration sensitive)	Contents value (%)	Total value of building (per square metre)
RES1	1,000	234	500	266	50	1,500
RES2	703	172	266	266	50	1,055
RES3	1,250	172	531	547	50	1,875
RES4	1,266	172	547	547	50	1,898
RES6	1,187	219	484	484	50	1,781
COM1	797	234	219	344	100	1,594
COM4	1,141	219	375	547	100	2,281
COM6	1,891	266	656	969	150	4,727
COM7	1,406	203	484	719	150	3,516
COM8	1,578	156	562	859	100	3,156
IND1	797	125	94	578	150	1,992
IND2	797	125	94	578	150	1,992
IND3	797	125	94	578	150	1,992
REL1	1,344	266	437	641	100	2,687
GOV1	1,047	187	344	516	100	2,094
GOV2	1,734	266	594	875	150	4,336
EDU1	1,156	219	562	375	100	2,312
EDU2	1,562	172	937	453	150	3,906
RES1(db)	1,100	258	550	292	50	1,650
RES1(tm)	850	199	425	226	50	1,275

6.1.3 Casualty Modelling

The casualty model estimates casualties caused directly from damage to buildings only. Excluded are those due to infrastructure collapse (e.g. bridges, as well as indirect casualties such as heart attacks, psychological effects or injuries suffered post earthquake (e.g. diseases or due to clean up activities).

Casualties are classified into four levels, according to severity. Severity level 4 corresponds to immediate deaths or mortal injuries. Level 3 corresponds to severe injuries that require hospitalisation and are life threatening. Level 2 corresponds to injuries requiring hospitalisation that are not life threatening whereas Level 1 corresponds to injuries requiring only basic medical aid and not hospitalisation.

The basic casualty model, adopted from HAZUS, is an event tree model that assigns a probability of a building in a given damage state causing an injury of a particular severity level. For buildings in the complete damage state there is also a different probability for a severity level, depending on whether the building structure has collapsed or not. Table 6-6 lists these probabilities for a typical building type in Newcastle and Lake Macquarie. The probabilities for other types of buildings are listed in the HAZUS technical manual. Most of these probabilities are similar, except for unreinforced masonry, for which the values are higher. The overall probability of a certain level of injury in a building, due to a single earthquake event, is then obtained by multiplying the probability of injury by the probability of being in that damage state, and then summing over the four structural damage states. Given the probability of a certain level of injury for a given building due to an earthquake event, the expected number of injuries of that level is obtained by multiplying this probability by the number of people in the building at that time. In the current simulation model this is estimated by distributing the overall population of the city over the buildings according to floor area.

Table 6-6: Probability of an injury occurring, given that the building is in a certain structural damage state. These values are for a W1BVTILE type (low rise, timber frame, brick veneer wall and tiled roof) of building

Damage State	Severity 1	Severity 2	Severity 3	Severity 4
Slight damage	0.05%	0.005%	0%	0%
Moderate damage	0.2%	0.02%	0%	0%
Extensive damage	1%	0.1%	0.001%	0.001%
Complete damage without collapse	5%	1%	0.01%	0.01%
Complete damage with collapse	50%	10%	2%	2%

6.2 The 1989 Newcastle Earthquake

To verify the earthquake risk assessment method and the models used, the 1989 Newcastle earthquake presents a good benchmark. Using information observed from this event, comparisons can be made with model predictions.

6.2.1 Available Data

The Newcastle City damage databases contain considerable detail of the impact of the 1989 Newcastle earthquake. However, in this report, the data have not been used to compare the simulations of damage in the 1989 earthquake with the observed data. One of the main problems with the data is that either no information was recorded on the building construction type or, if it was, it was recorded in a way that did not allow us to easily compare it with the construction types used in our simulation models. Only the damage rating given to each building, which indicates the structural safety of the structure, was recorded systematically. (See Chapter 3 for a map of the buildings classified into damage states). Since these do not match up with the HAZUS damage states, used in the simulation model, we made no attempt to compare these.

The Institution of Engineers report contained estimates of the economic impact caused by the 1989 earthquake (Melchers, 1990). Total economic loss estimates for the region were estimated to be of the order of $1 billion (1990 dollars), with this figure comprising mostly structural and non-structural building damage ($800 million) and contents and business disruption losses ($200 million). Many other estimates of economic loss exist, with figures even as high as $4 billion (BTE, 2001),which include losses due to business interruption.

The report by the Institution of Engineers estimated that the 1989 earthquake directly caused 12 deaths and 100 to 120 serious injuries (Melchers, 1990). Nine people died in the Newcastle Workers Club, and three died as a result of awning and parapet collapse in Beaumont Street, Hamilton. There was one further death caused by the earthquake due to cardiac arrest.

NRMA insurance records, obtained from the Newcastle City Council, are estimated to account for approximately 50% of the residential building claims in the study region. There were approximately 14,000 NRMA claims in total, some as far away as Canberra. The records included, for each claim, the suburb, the value insured, the pay-out and whether the claim was on a brick building, a timber building or on contents. The database was filtered to match the suburbs covered in the study region, reducing the number of claims to approximately 12,000 claims. There was a small number of entries with zero pay-outs. Presumably these corresponded to claims that were made but refused. For the whole study region the NRMA data gave total claims of approximately $97 million (1989 dollars) and total insured value (building plus contents) of $1,056 million (1989 dollars). This gives an estimate of approximately 9.1% of damage. However, this data is a biased sample of building damage loss as it does not include buildings for which claims were not made. The inclusion of buildings for which no claims were made would decrease this estimate of building damage. The percentage of sum paid out for claims, as compared to the total value insured, aggregated by suburb, is spatially displayed in Figure 6.3.

It was difficult to compare the NRMA insurance data directly with the modelled economic losses. First, there was uncertainty as to what percentage of the buildings in the study region were insured by NRMA. It also wasn't simple to ascertain whether owners were underinsured, or if the insurance pay-out for an individual building is a true indication of the actual loss. The records also did not indicate what the excess fees were, but these were probably negligible.

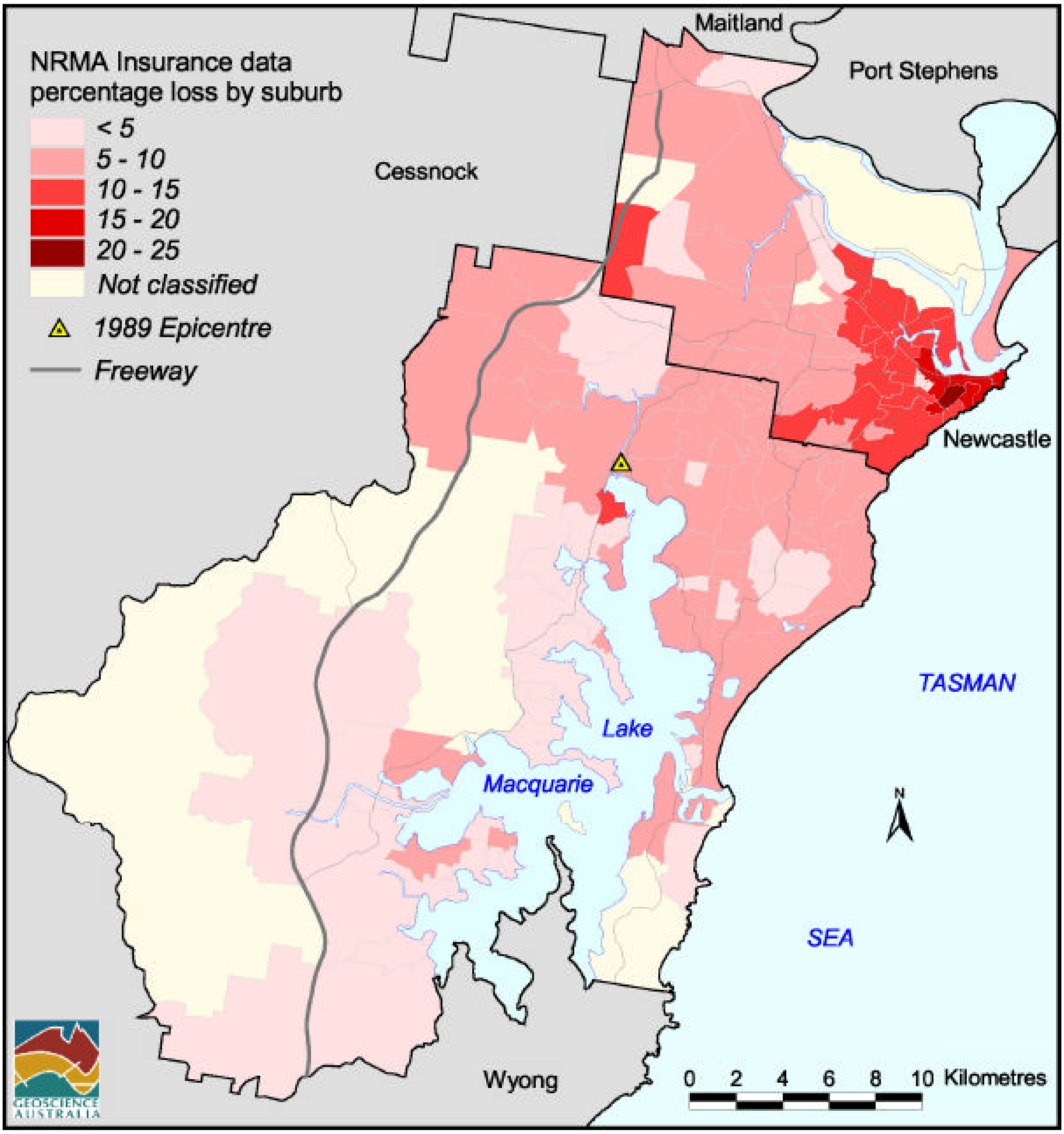

Figure 6.3: NRMA residential insurance pay-out (sum of claims for each suburb as a percentage of the amount insured) for the 1989 earthquake, according to suburb. This includes both building and contents claims

6.2.2 Results for the simulated 1989 Newcastle earthquake

The impact of the 1989 Newcastle earthquake has been modelled using the computer simulation code described earlier in this Chapter and in Chapter 4. A direct comparison of the results with recorded data however is difficult for many reasons. First, the elements at risk have changed due to population growth, and the development, demolition and renovation of buildings. The building inventory, which has been determined by a sampling process near the end of the year 2000, cannot be expected to exactly describe the nature of the inventory at the end of 1989. Buildings that are estimated to have been constructed after 1989 have been omitted from the calculation.

The spatial variability of modelled damage is a random phenomenon, so no two damage patterns can be expected to be exactly the same. The 1989 event could be viewed as a single realisation of a random process, however, we compared the 1989 event to median values in the simulation.

6.2.2.1 Economic losses

Running the simulation for the 1989 earthquake in Newcastle corresponds to fixing the location of the epicentre (or centroid of the rupture) to a position 32.95°S, 151.61°E, and the moment magnitude of the earthquake to 5.35 (based on a magnitude of 5.6 on the Richter scale and converted using the Johnston relationship described in Section 4.2). There is some uncertainty in the position of the epicentre (see Chapter 3) which hasn't been accounted for in this simulation. However, there is still variability in the attenuation, soil amplification and building damage so the result for the estimated overall economic loss for the earthquake is presented as a histogram of 1,000 simulations in Figure 6.4. The dollar estimates have been discounted from 2002 dollars to 1989 dollars.

The median value of the losses estimated from the 1,000 simulations is approximately $1.1 billion (in 1989 dollars), corresponding to a percentage loss of approximately 7.2% of total building value including contents (see Figure 6.4). Taking account of the random nature of attenuation, soil amplification and building damage produced a range of probable values of percent damage of 6.5-8%. As mentioned in Section 6.2.1, the damage data collected after the 1989 Newcastle earthquake has been used to provide estimates of the actual economic loss due to building damage from the earthquake. Melchers (1990) estimated an economic loss of approximately $0.9 billion (1989 dollars), which is slightly lower, but of the same order as our simulated loss of $1.1 billion. Using the NRMA database of claims we estimated an economic loss of 9.1% of total building value which is higher than our simulated result. Our simulated result is consistent with both of the estimates based on recorded data.

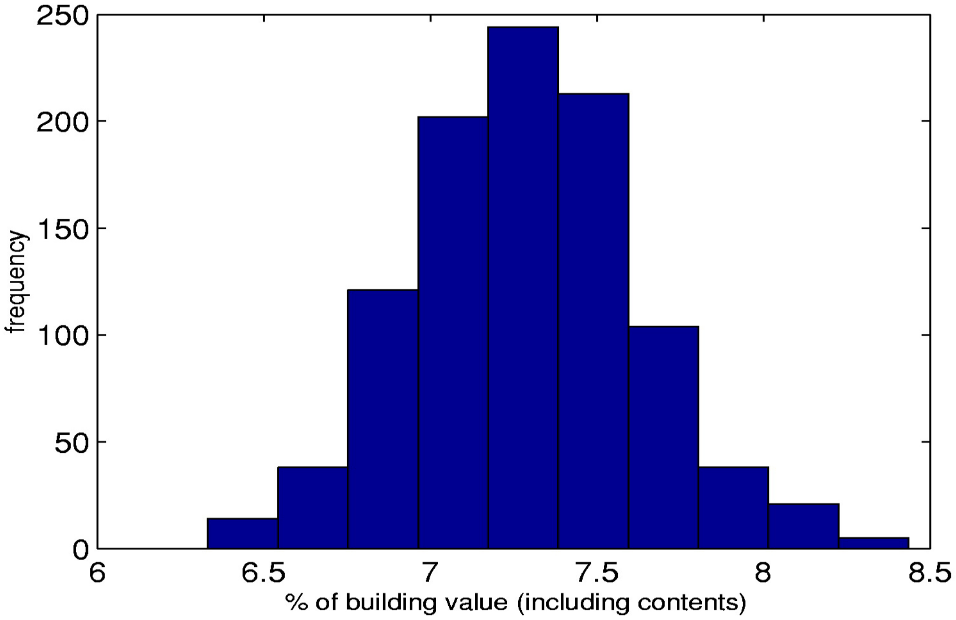

Figure 6.4: Histogram of estimated losses for 1,000 simulations of the 1989 earthquake. Aggregated losses are a percentage of total value of the building stock including contents

In Figure 6.5 a map is shown of the distribution of median values of the simulated economic loss by suburb. Here the total economic loss is calculated for all buildings in each suburb and a loss ratio is calculated by dividing the total economic loss in a suburb by the estimated total value of all buildings (including contents) for that suburb.

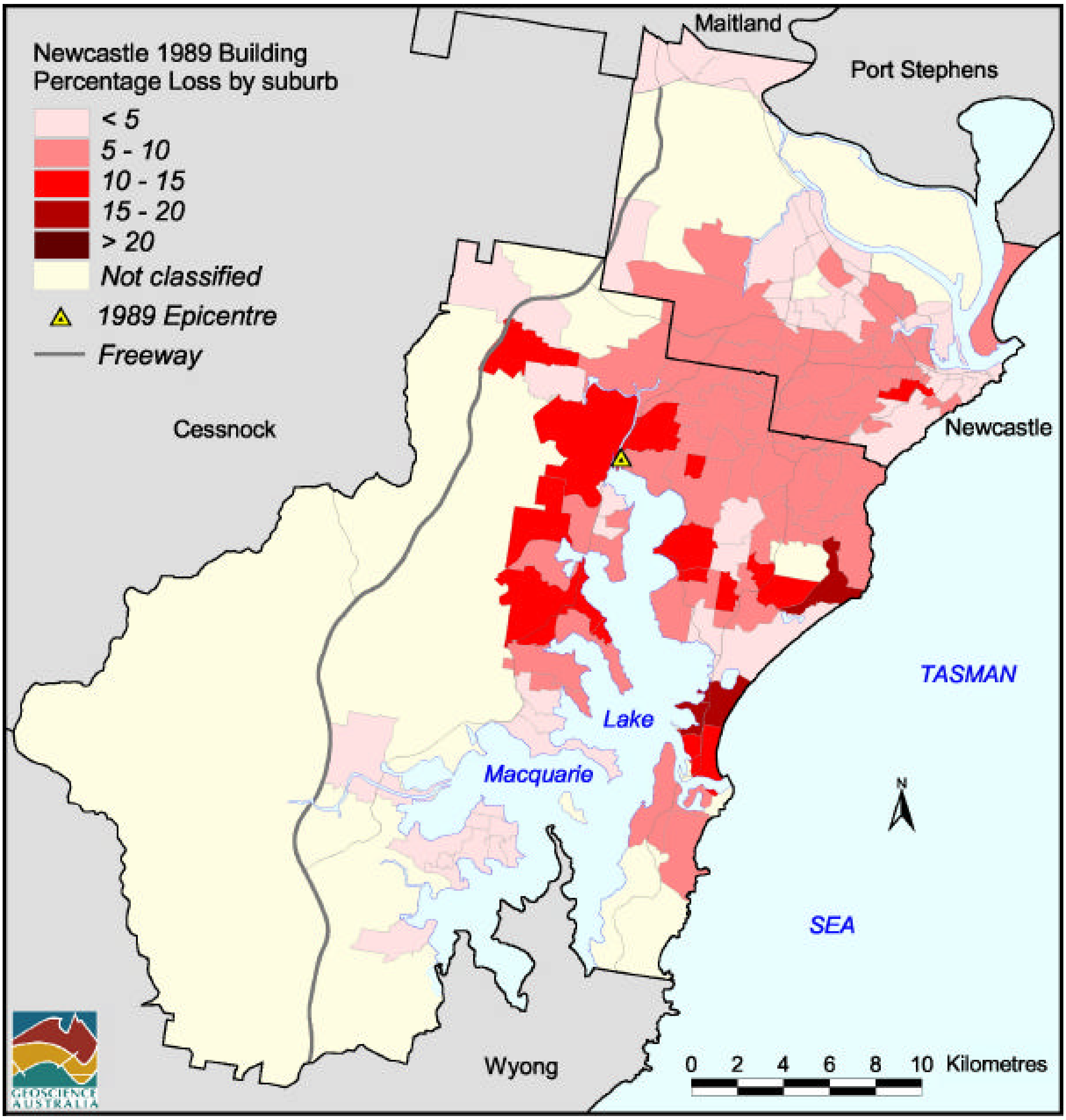

Figure 6.5: Distribution of simulated median losses (as a percentage of total building value plus contents), aggregated by suburb, for the 1989 earthquake

A comparison with the NRMA insurance data (Figure 6.3) indicates the losses are of a similar magnitude, with the main exception of the Newcastle CBD. Our simulated losses tend to have more damage near the earthquake epicentre than was actually recorded. The simulation underestimated the damage in the Newcastle CBD (approximately 20% losses indicated by the NRMA data compared to about 3% for the median result from the simulation). Given that the majority of buildings in the CBD are unreinforced masonry, one possible explanation for the discrepancy could be that the building parameters in the models require further refinement. Many of the buildings in this area are quite old. There is, currently, no provision in the building parameters for increased damage resulting from degradation of building materials over time.

It should be emphasised that the simulation represents a stochastic process and that the 1989 earthquake should be viewed as just one realisation of that process. In Figure 6.6 a map is given for a single realisation of the stochastic simulation. The spatial distribution of losses varies from the median case (by a few percent) although the overall trend is similar.

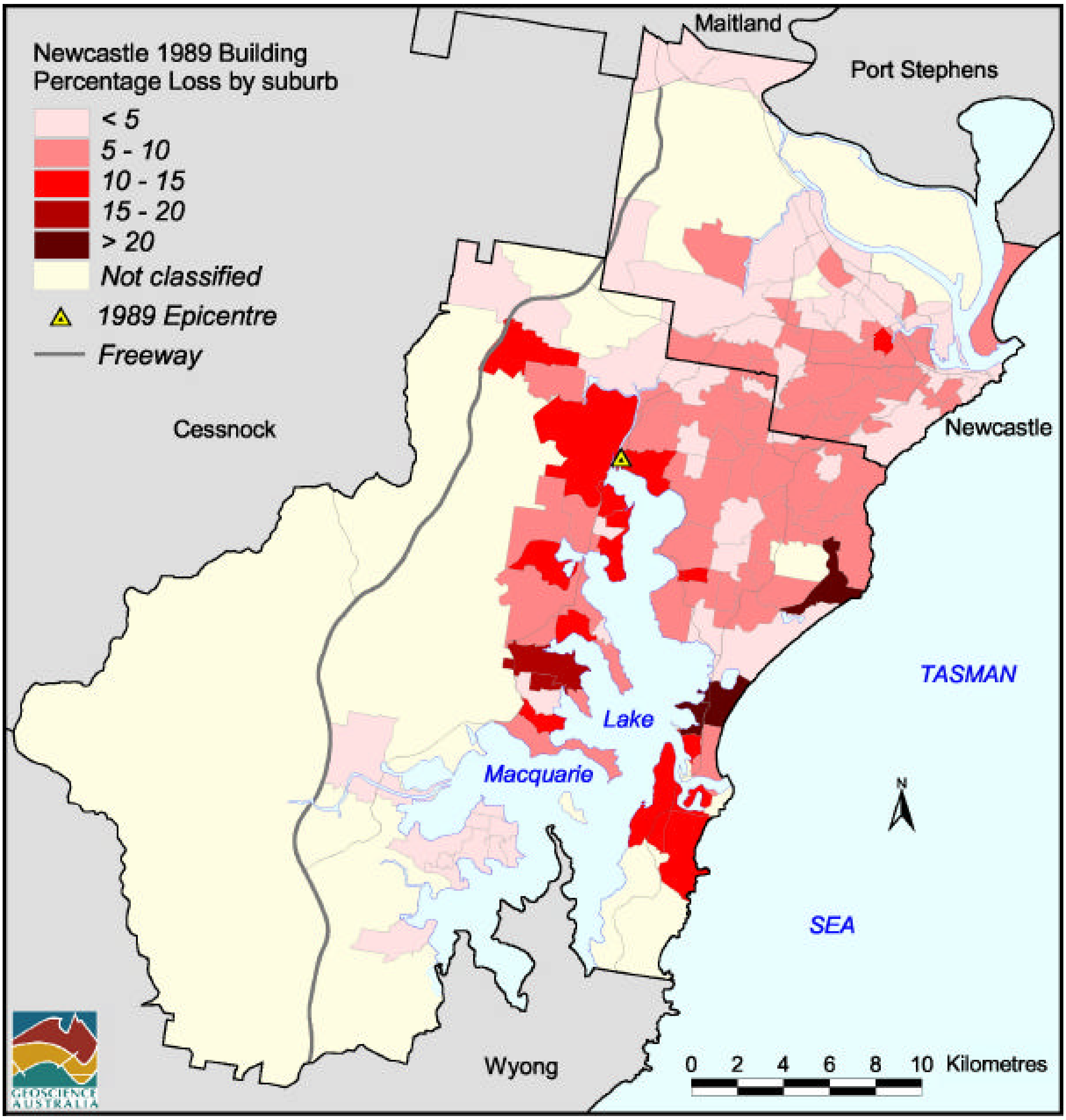

Figure 6.6: Results of a single simulation of the 1989 Newcastle earthquake. Damage ratios are a percentage of total building value plus contents aggregated across each suburb

6.2.2.2 Injuries and casualties

The total number of casualties simulated for the 1989 event can be compared to records of deaths and cases of hospitalisation. It was assumed the population in 1989, for the study region, was approximately 300,000. It was also assumed that the population was evenly distributed according to building floor area, and that 30% of people were outdoors at the time of the earthquake (it occurred mid-morning on a sunny day on 28 December). The simulation model predicted median values of approximately 44 deaths (severity level 4 casualties) and 550 less severe injuries requiring hospitalisation (severity level 2). These values are high compared with the 12 recorded deaths and 100-120 estimated severe injuries (Melchers, 1990). However, given the high levels of uncertainty involved in the assumptions of the population distribution at the time of the earthquake, these values are, at least, within an order of magnitude of the observed casualty figures.

6.2.3 Uncertainties in the Model

The considerable uncertainty in the modelling methods has not yet been fully addressed in attempting a verification of the effects of the 1989 Newcastle earthquake. Neither has the considerable uncertainty in the recorded effects of the 1989 Newcastle earthquake. For example, the effect on simulated economic losses due to the uncertainty in the hypocentral location of the 1989 earthquake could be examined by varying the epicentral location. The full range of economic losses, particularly with regard to lifelines and key facilities, has not been addressed.

The results for economic damage are sensitive to the building parameters used. It is important that further research is undertaken to develop reliable numbers for these parameters for Australian buildings, and compare damage predictions with existing data. In particular, we have less confidence in the parameters for unreinforced masonry buildings, especially old buildings of this type where the mortar will have degraded with age or where poorer quality mortar may have used.

The method for distributing the population according to total floor area of buildings could be improved. One approach would be to have a randomly varying population on a building by building basis which would better account for the high level of variability expected in modelling casualties.

The 1989 Newcastle earthquake presented a unique opportunity to learn about the effects of earthquakes and how Australian communities could be made safer. With regard to this study, it represented an opportunity to verify the modelling techniques adopted. For the impacts quantitatively considered (building damage, economic loss and casualties), this has been performed with as good a match as one could reasonably expect from such a highly uncertain and random process.

The difficulties involved in achieving a close match have been illustrated. A major problem that clouds the ability to verify the results is the lack of systematically and accurately recorded details of earthquake impact. This includes poor constraint on the earthquake source location, inconsistent and incomplete damage surveys and a lack of details regarding economic losses. Hence, it is recommended that future post-disaster data collation efforts be conducted in a more systematic way, with a high degree of detail and accuracy.

Despite some concerns, the models used in this study are able to broadly predict the overall impact of the 1989 Newcastle earthquake. This supports the notion that the adopted models are appropriate for use in this earthquake risk assessment. The results are thought to be more reliable at a scale which encompasses the entire study region, rather than the scale of individual buildings or even suburbs.

6.3 Economic Risk in Newcastle and Lake Macquarie

6.3.1 Overall Impact

In this section we present results of running the simulation with earthquakes distributed randomly in seismic zones with magnitudes determined from a Gutenberg-Richter distribution**,** as discussed in Chapter 4. The possible implications of these results are discussed in detail in Chapter 7.

For each earthquake scenario, the economic damage loss values have been determined for every surveyed building site in the study region. Approximately 1,200 earthquake scenario events were used. Each scenario earthquake had a magnitude, a location and a probability of exceedance. The hazard map calculations in Chapter 4 used 10 times more scenario earthquakes in order to get consistent statistics. For economic loss results that are aggregated across sampled sites (more than 6,000) such a large number of events is not required. A detailed analysis of the minimum required number of earthquakes needed was not conducted here, however, 1,200 events was found to be sufficient.

By considering the impact of all earthquake events on any one or group of buildings sites, an annual probability of exceedance – loss curve can be generated. The probability of a loss level being exceeded and the annualised loss are of particular interest for risk management decision making. These results have been evaluated for the study region as a whole and on a survey site basis, in terms of economic and casualty losses.

A curve showing the estimated economic loss due to building damage for the entire study region is given in Figure 6.7. 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.

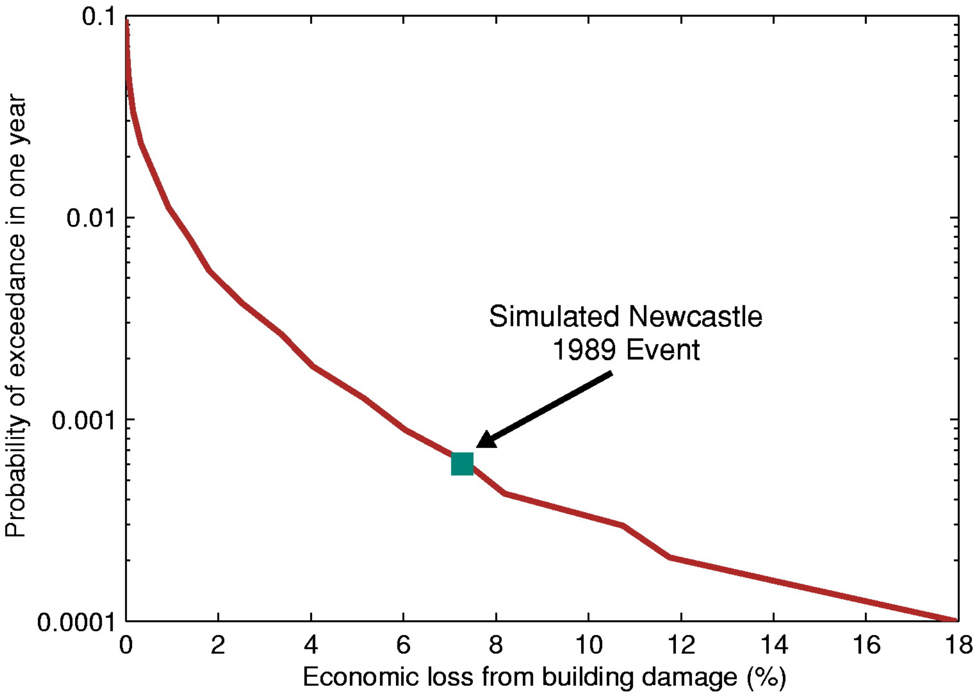

Figure 6.7: Probable maximum loss curve for the Newcastle and Lake Macquarie region

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 (see previous Section). Locating this point on the risk curve suggests that this level of loss has a probability of about 0.0006 of being exceeded in any single year. This annual probability corresponds to a return period of around 1,500 years for the 1989 Newcastle earthquake, and for other events that would have a similar impact on Newcastle and Lake Macquarie.

The integration of the area under the annual probability of exceedance-economic damage loss curve gives the annual expected economic damage loss (or annualised economic loss). This is a useful measure of risk for planning purposes. For example, how much should be spent annually on mitigation efforts such as building improvement, emergency response facilities, insurance premiums, etc. Annualised economic loss can be determined for any one or group of building sites, depending on the interests of the stakeholder. For example, federal and state governments may be interested in the whole study area, local governments in their own local area, and emergency management agencies in their own districts. Also, insurance companies may be interested in their portfolio of sites distributed over the region, and residents might be interested in their own properties. (However, comprehensive risk assessments for individual buildings are best conducted by experienced professionals). Annualised economic loss values are also useful for making comparisons to other hazards, particularly if rankings of impact intensity are dependent on the return period selected. The annualised economic loss for the whole study region, varying according to the maximum return period of events considered, is shown in Figure 6.8.

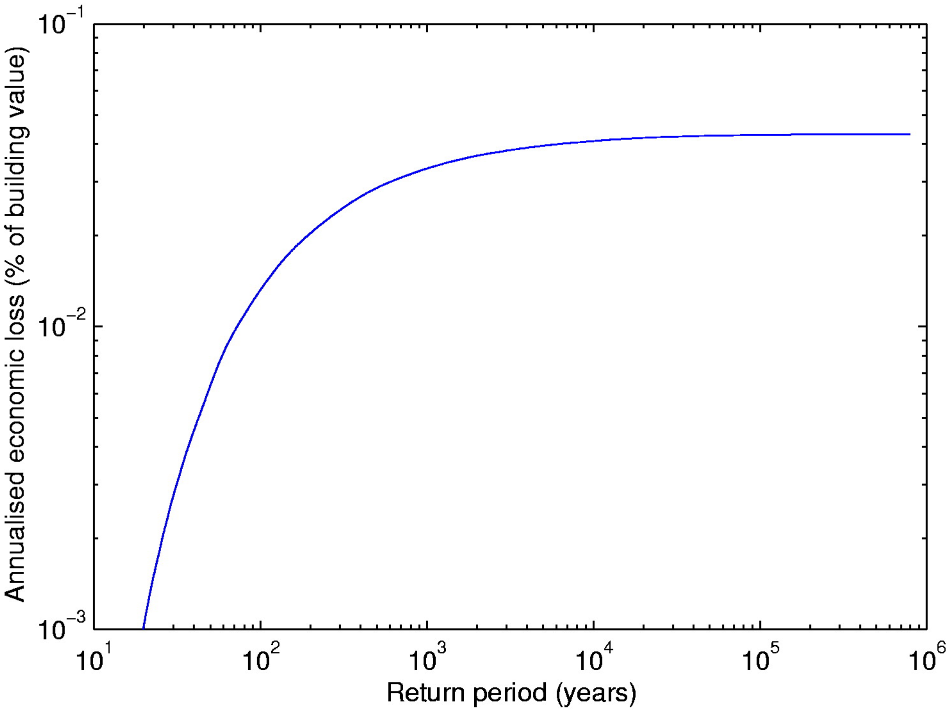

Figure 6.8: Annualised economic loss versus maximum return period considered, for the whole study area

The results of this study suggest that, on average, the Newcastle and Lake Macquarie region will suffer an estimated economic loss of around 0.04% per year. This corresponds to an annualised loss of the order of $11 million per year. This value has been calculated on the basis of the total value of buildings in the study region which is estimated by our models to be approximately $26.5 billion.

The majority of the earthquake risk in the study region is from events that have probabilities of occurrence in the range of 0.02 to 0.001 (return periods of 50-1,000 years). This suggests that the risk to the region is primarily from relatively infrequent events with low or moderate impacts. In contrast, very frequent events will have low impacts, and consequently they pose little risk to Newcastle and Lake Macquarie. Very high impact events could also occur in the region. These events are extremely rare and hence contribute little to the annualised risk, however, should they occur the impact could be catastrophic.

Events with return periods of 500 years or less contribute approximately two thirds of the total annualised losses. A return period of 500 years is similar to a 10% probability of occurrence in 50 years (return period of approximately 475 years) that is described in AS1170.4-1993. The 1989 Newcastle earthquake was estimated to have an impact with a return period of approximately 1,500 years. Events which are less severe than the 1989 earthquake contribute an annualised economic loss of approximately 0.035%, representing around 82% of the total annualised risk. Thus, events like the 1989 earthquake, or even more catastrophic events, make only a small contribution to the earthquake risk in the region.

It is possible to determine the relative contributions to annualised risk from earthquakes of varying magnitudes and distances from each sampled building site. The distance here is the Joyner-Boore distance, which is the closest horizontal distance from the site to the rupture plane of the earthquake (see Chapter 4). In Figure 6.9 a histogram is given for the contribution of overall annual risk for a number of moment magnitude and distance combinations.

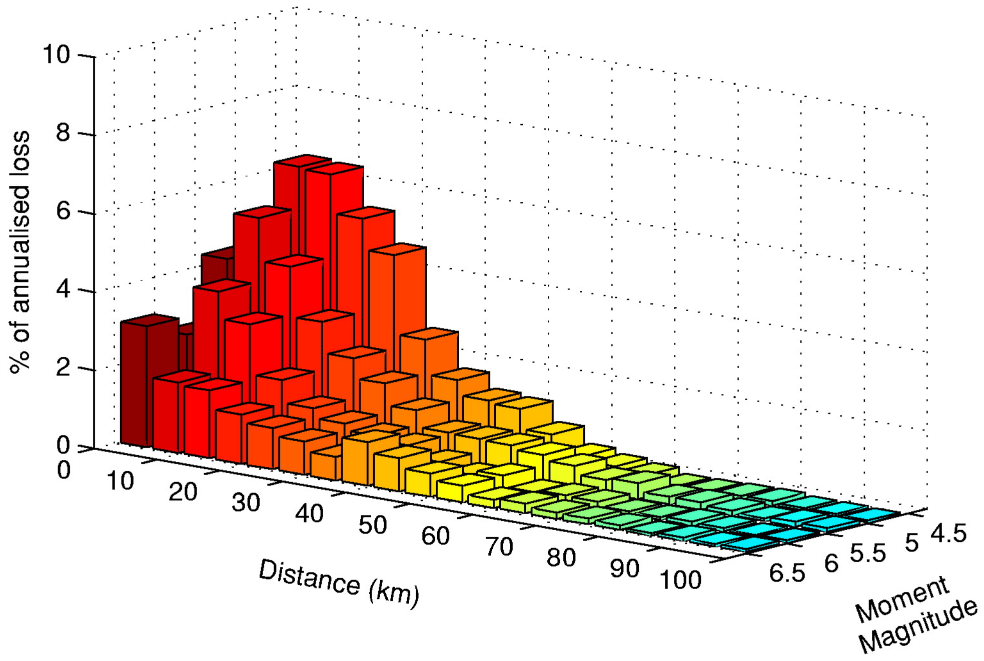

Figure 6.9: Contributions to the earthquake risk in Newcastle and Lake Macquarie from earthquakes of different magnitudes at varying distances to the building stock

Over half the earthquake risk in the study region is due to earthquakes with moment magnitudes around 5 at distances of less than 30 km. This result further suggests that the majority of the risk in the region can be attributed to moderate-impact, relatively infrequent events rather than high-impact, but extremely rare, events.

Most of the annualised risk for building usage type (see Table 6-4 for a description of usage types) is for the residential types (91%) with the next most common being commercial (4%). This is mainly because residential buildings make up the overwhelming majority of buildings in the study area, and comprise the majority of the total estimated value of all buildings in the study area. However, any problems with the data inventory, such as incomplete or incorrect classification of buildings, are expected to affect these relative contributions to risk.

It should be noted that the annualised loss varies quite significantly from building type to building type. For example, buildings constructed from unreinforced masonry (cavity brick construction) tend to have a higher annualised loss than any other building type in the study region (Figure 6.10). This is based on a per-building basis (i.e. by calculating the annualised loss for all buildings of that type, as a percentage of the total value of all buildings of that type). 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.

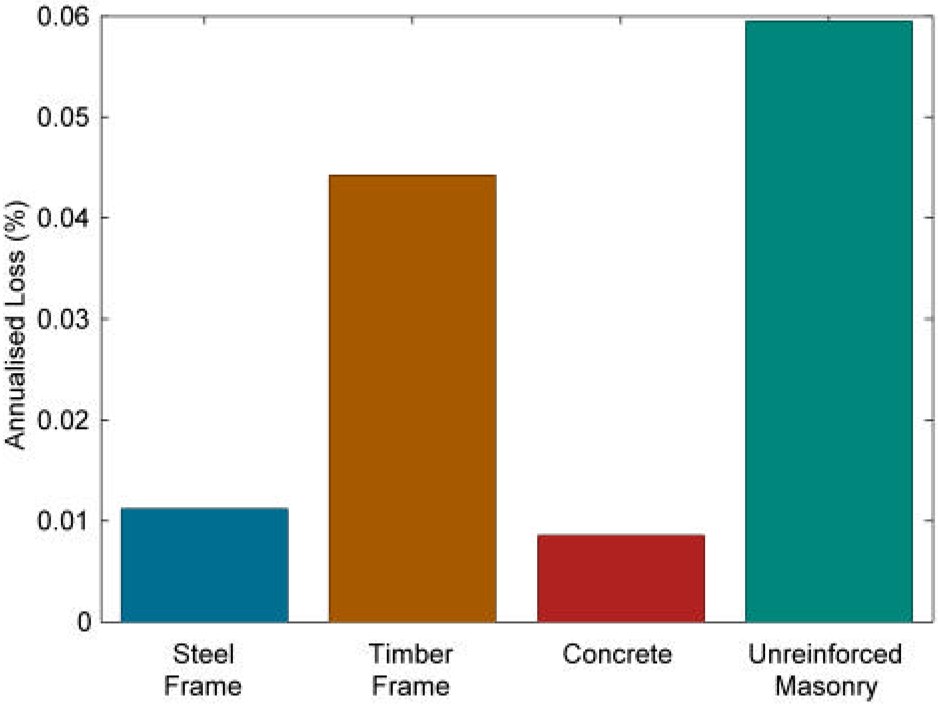

Figure 6.10: Annualised risk for a selection of building types in the study region. The annualised loss for a specific building type is described as a percentage of the total value of that building type in the study region

In Table 6-7 results for annualised risk are given for the sub-divided building construction types for the two most common classes of buildings in Newcastle and Lake Macquarie; timber frame and unreinforced masonry (see Table 6-1 for definitions of the subtypes). Timber frame, with brick wall and tiled roof, contributes nearly half of the total annualised risk for Newcastle and Lake Macquarie although this type of building makes up only about one third of the building stock in Newcastle and Lake Macquarie. On the other hand, timber frame with timber walls (tiled and metal roof) contribute more than a third of the number of buildings yet less than 12% of the total risk. If the vulnerability parameters were modified then the relative proportion of risk would vary. For example, if the model for unreinforced masonry was modified to account for older or degraded structures, the relative risk from unreinforced masonry buildings may well increase.

The annualised risk of a given building type expressed as a percentage of the total value of all buildings (including contents) of that type, gives a measure of risk that allows different construction types to be compared without the influence of the relative numbers of buildings. Table 6-7 shows that the buildings with the highest risk are generally unreinforced masonry (URML and URMM) which have values ranging from 0.038 to 0.067. The timber framed buildings (W1) are generally lower, with the exception of timber frame buildings with brick walls which have values of around 0.06. This suggests that the presence of brick walls on timber framed houses may cause these buildings to have similar risks to unreinforced masonry buildings.

The implications of these results and recommendations for future work that could improve the models that are the basis of these results are discussed in Section 7.4.

Table 6-7: Annualised risk for building construction types

Building construction Type	Estimated number of building (% of total)	Estimated total value of buildings of that type (% of total)	Annualised risk (% of total annualised risk)	Annualised risk (% of building value)
W1MEAN	18.36	17.12	12.4	0.031
W1BVTILE	30.34	35.17	48.8	0.060
W1BVMETAL	1.82	5.37	7.6	0.061
W1TIMBERTILE	22.94	12.61	6.0	0.020
W1TIMBERMETAL	15.76	7.64	5.0	0.028
URMLMEAN	0.28	1.05	1.6	0.067
URMLTILE	7.23	7.92	10.9	0.059
URMLMETAL	2.29	2.74	4.2	0.066
URMMMEAN	0.08	0.80	0.8	0.046
URMMTILE	0.03	0.35	0.3	0.038
URMMMETAL	0.03	0.59	0.7	0.048

6.3.2 Localised Impact and Risk

Of key interest to this study is the spatial variation of risk and a determination of which suburbs are most at risk, for whatever reasons. By calculating the annualised risk for each suburb in the study region as a percentage of the total annualised risk for the entire study region it appears that some locations are more at risk (on average) than others. For example, the suburbs Charlestown, Mayfield, Belmont South and New Lambton each contribute 4% or more to the total annualised risk, whereas many other suburbs contribute less than 1%. However, this higher contribution to the risk can be partly attributed to the fact that these suburbs contain a greater number of buildings than other suburbs and consequently contribute a greater amount of risk to the total annualised risk.

Perhaps a better measure of the economic vulnerability of a suburb is the annualised loss for the suburb, expressed as a percentage of the estimated total value of buildings in that suburb. For this measure of risk, the four suburbs with the highest percentage values are Estelville, Belmont South, and Redhead (greater than 0.12%), however, the percentage values are less heterogeneous across the region than for the percentages of total annualised risk. It should also be noted that the suburbs Estelville and Redhead had only a small number of sampled buildings, so the results may be significantly different for these suburbs, and other suburbs (mostly in Lake Macquarie) that were only sparsely sampled. A map of the annualised economic loss due to building damage has been determined on a suburb by suburb basis in Figure 6.11.

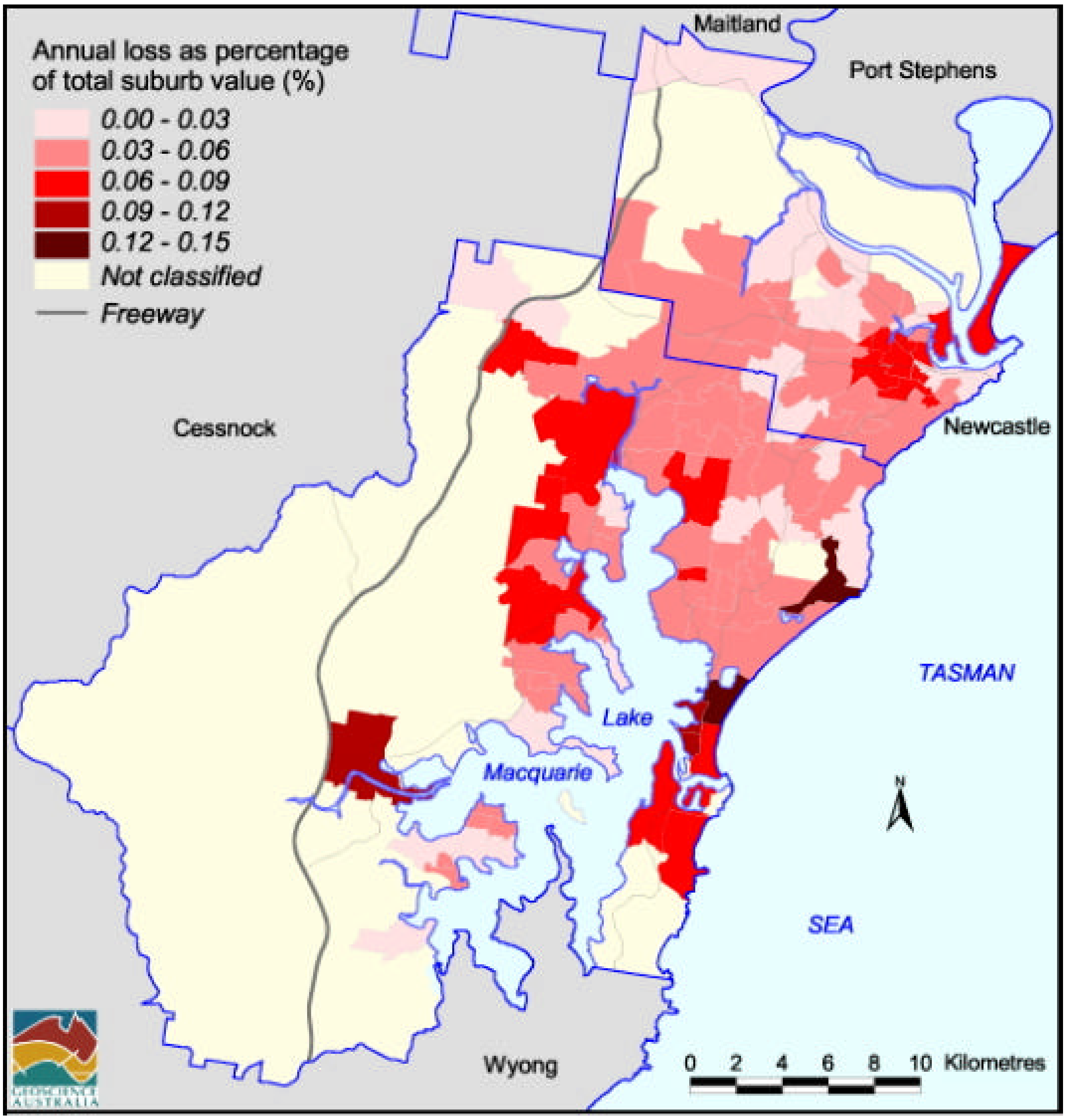

Figure 6.11: Annualised risk by suburb. The annualised risk in each suburb has been calculated as a percentage of the total value of all the buildings within the suburb. Note that some suburbs have not been classified due to the relatively low number of buildings surveyed

This figure clearly demonstrates that risk varies spatially across the study region. The variation in annualised risk can be partially attributed to differences in building stock across the study region. However, the underlying regolith also affects the annualised losses, and areas that are built on substantial thicknesses of regolith, such as parts of the Newcastle municipality, have a noticeably higher annualised risk. The map of observed building damage from the 1989 earthquake, from the Newcastle City Council, from Chapter**3**, also shows a strong correlation of high building damage with regolith thickness. Changes to the building parameters used, as well as improvements to the building inventory, as discussed in Section 7.4, could change this spatial distribution. For example, changes to unreinforced masonry parameters to account for degradation and age may well increase the annualised risk in suburbs containing older buildings, such as the Newcastle CBD. Also, the sampling rate in many Lake Macquarie suburbs was low, and consequently may have been biased towards a specific regolith class. Improvements to the sampling procedure and the building inventory in Lake Macquarie would alter the spatial distribution of annualised risk.

6.3.3 Uncertainties in the Modelling

The simulation model takes account of natural uncertainties by using random variables with assumed probability distributions. These include uncertainties in the earthquake location and magnitude, variation due to the degree of ground shaking observed between two adjacent sites, and natural variation between buildings of identical type at the same location. However, there are also further uncertainties associated with the choice of those distributions, along with the choices of models used. For example, the attenuation model used, and the choice of the building capacity method used, also contribute to overall variability. Taking account of these may tend to increase the risk. Conversely, further research that can improve the models can reduce the risk.

Results for casualty risk are not presented. The results for casualties from the 1989 earthquake simulation indicate that the casualty model needs further refinement. However, it is expected that a major casualty loss is unlikely.

As discussed in the next Chapter, the results of this risk assessment are useful to assess overall trends. They can be used to influence future planning decisions from the point of view of determining the most effective measures that can be taken to minimise the likely economic losses should another earthquake occur. However, there is a need to perform a detailed sensitivity analysis on the model, to determine whether changes in inputs such as earthquake magnitude and frequency parameters, attenuation parameters or building damage parameters cause significant changes in economic loss estimates.