

CHAPTER 8: EARTHQUAKE RISKS

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The Earthquake Threat

Earthquakes occur when stresses in the Earth exceed the rock's strength to resist, thus causing the sudden rupture of rocks and displacement along a surface called a fault. The fault may already have existed or may be newly created by the earthquake rupture. Energy from the fault rupture is transmitted as seismic waves that cause nearly all damaging earthquake effects.

The size of an earthquake is often expressed in terms of Richter (or local) magnitude, denoted by ML. Richter magnitude is determined by measuring seismic wave amplitude instrumentally and was developed by Charles Richter for California in 1935. The energy released by earthquakes varies enormously and so the Richter scale is logarithmic. An increase in magnitude of one unit is equivalent to an increase in energy released of about 33 times. For example, an earthquake with Richter magnitude 6 releases about 33 times the energy of an earthquake with Richter magnitude 5, and about 1000 times the energy of an earthquake with Richter magnitude 4. The Richter magnitude scale has been adapted to Australian conditions and is a suitable measure of Australian earthquakes except for the very largest events. The largest earthquakes are measured by the Moment Magnitude scale (Mw), preferably, or the Surface Wave magnitude scale (Ms).

Descriptions of the severity of earthquake ground shaking at any place may be given using intensity scales such as the Modified Mercalli Intensity scale. The Modified Mercalli (MM) scale describes the strength of shaking by categorising the effects of an earthquake through damage to buildings, landsliding, liquefaction, soil cracking and other types of ground failure, and the reactions of people and animals. A full description of the Modified Mercalli Intensity scale is provided in Appendix H.

The Modified Mercalli Intensity scale is useful because it is easily applied and understood, and because it can be used to extend our knowledge of earthquakes from observational effects described by witnesses, in cases where the event may not have been recorded by instruments (e.g., 19th Century earthquakes). However, Modified Mercalli intensity is a coarse measure of ground shaking. It does not correlate well with instrumental recordings of strong earthquake ground shaking. There are other difficulties associated with MM intensity as well. Instrumental recordings of earthquake strong ground motion are much preferred to MMI description, but they usually have not been available for Australian earthquakes.

The Australian continent is distant from the boundary between the Australian and Pacific tectonic plates. This narrow band of earthquake activity passing through Papua New Guinea, the South-West Pacific countries and New Zealand. South-East Queensland is situated more than 1500 km from this plate boundary. Nonetheless, strong earthquakes have occurred in Australia, and more will occur.

The most damaging earthquakes in Australia during the period 1950-2000 are listed in Table 8.1.

Although damaging earthquakes are relatively rare in Australia, the high impact of individual events on the community makes them a costly natural hazard. Recent figures produced by the Bureau of Transport Economics (2001) put the historical cost of earthquakes in context. They estimated that the direct cost of natural disasters to the Australian community in the period 1967-1999 was about \$37.3 billion, or an average of \$1.13 billion per year. Of this total, floods contributed about 28%, severe storms about 25%, tropical cyclones about 24%, and earthquakes about 13%.

With increasing urbanisation and dependence on power, water, telecommunications and other lifelines, Australian communities are becoming increasingly vulnerable to earthquakes.

The epicentres of historic earthquakes in the South-East Queensland region are shown in Figure 8.1.

Table 8. 1 Most-damaging Australian earthquakes, 1950-2000

Date	Location	Magnitude	Damage	
			Contemporary	2000 ¹
03/01/1954	Adelaide SA	5.4	\$8.8 M	\$100 M
22/05/1961	Robertson/Bowral NSW	5.6	\$0.5 M	\$4.7 M
14/10/1968	Meckering WA	6.9	\$5 M	\$39 M
10/03/1973	Picton NSW	5.5	\$0.5 M	\$3.2 M
02/06/1979	Cadoux WA	6.2	\$3.7 M	\$11 M
22/01/1988	Tennant Creek NT (3 events)	6.2, 6.3, 6.5	\$1.1 M	\$1.7 M
28/12/1989	Newcastle NSW	5.6	13 killed, \$862 M insured damage, est. \$1500 M total damage	\$1994 M
06/08/1994	Ellalong NSW	5.4	\$34 M	\$39 M

¹ Source: ABS, 2001

The recorded history of earthquake activity in Queensland is brief in comparison to the time-scale of geological processes - too brief for us to obtain an accurate estimate of the true rate of earthquake activity in the area. According to Rynn (1987) the first earthquake report for Queensland was from Cape York Peninsula in 1866. Recent research, however, has brought to our attention apparently significant earthquakes in 1861 and 1862.

The following extracts are taken from the personal diaries of John and James Green, early pioneering settlers of the Nanango District of the South Burnett in South East Queensland who explored the Gympie-Cooloola/Fraser Island-Noosa-Mary Valley regions between 1850-1870 with the assistance of the native Kabi clans in the area. Edited versions of the text are found in de Grene (1996). We stress that these reports have not been authenticated or corroborated at the time of publication.

Tuesday 25th June 1861:

The sun is an hour from setting. The natives have settled after a period of panic when the earth growled, the ground jumped and shook violently from a quake force deep within the soil. Trees swayed and the seawaters were in array swishing back and forth in quick succession over the sands exposed by the low waters. It was a short frightening experience for I had never taken part in such an occurrence.

(Edited version in de Grene (1996, Vol. 3, pp. 60-61).) This account indicates moderate to strong earthquake shaking from a moderate magnitude earthquake, as indicated by the short duration of shaking.

Another, more vivid, account of earthquake activity is found in the diaries of the following year. On the afternoon of 3 September 1862 near the shores of Lake Cootharaba, north of Noosa:

There was an eerie quietness over the land. The birds had fled. There was no movement of the leaves - not a ripple on the water. David I noted was ill at ease. He said the earth spirits were angry. A great roar sounded beneath our feet and the lands shook violently. Trees heaved upwards and downwards - falling in many directions. I fell upon the ground and could not move so violent was the ground shaking and sliding - one way, then the next. I could not stand no matter my effort. The horses cried out in fear as they fell upon the each other trying to get upright and free all at the same time. It seemed an eternity before it ceased.

There was a hush as we quietened the horses and secured them further so that they could not

escape in their fear. I was fortunate to have placed the camp on high ground for the lake waters had risen considerably to a new shoreline on many feet and gained much depth of water....The great shaking came again and we were thrown to the ground as jolt after jolt came forth under the ground. Great waves rolled across the waters and crashed upon the new shores filling the waters with trash and debris. More shaking occurred soon after and again and again, until it was no more than rumbles in the ground.

The ground quake had indeed done its damage. I report that on seeking way to the ancient stone structures and its columns by new routes, I found that all had been changed. The point had gone - there was nothing but waters. The structures have seemingly collapsed, shattered upon the ground, only then to be covered by the new levels of the lake waters. It was as though all had been taken from my view in reasoning, not to be seen again by the naked eye though I knew of rough estimation where it had once been.

(Edited version included in de Grene (1996, pp. 40-42, Vol. 4).

The Green brothers' extraordinary account indicates strong earthquake ground shaking corresponding to a seismic intensity of at least MMVII (Appendix I). Their camp may have been close to the earthquake fault rupture if the change of the height of the lake relative to the shore is accurate. This change in water level would have resulted from some type of permanent ground displacement such as surface faulting, differential settlement, lateral movement or liquefaction. Other evidence that the camp was close to the earthquake fault rupture is the intensity of ground shaking from the aftershocks.

More research is needed to verify these accounts and to estimate the magnitudes of the earthquakes that the Green brothers described. A first check of Brisbane newspapers indicated no report of earthquake activity (Kevin McCue, AGSO, written communication, 2001).

Other notable Queensland earthquakes include the 1918 'Bundaberg' earthquake sequence and several earthquakes near Gayndah (Table 8.2). The Bundaberg mainshock had a magnitude of ML 6.3 and is the largest historic earthquake in eastern Australia. Its offshore location minimised the damage it caused, but damage was reported in Bundaberg, and in Rockhampton where

'chimney stacks fell down, cracks appeared in buildings, windows were broken ... the event was widely felt in most suburbs in Brisbane ...'

(Everingham and others, 1982).

Six moderate magnitude aftershocks, and presumably many more smaller aftershocks, occurred over the next four days. The earthquake was felt over a wide area in Queensland and northern NSW.

Several significant earthquakes have also occurred near Gayndah over the last 120 years or so. Moderate magnitude earthquakes occurred there in 1883, 1910 and 1935, the latter causing minor damage (Table 8.2). The 1935 earthquake was also felt over a wide area including South-East Queensland.

The earthquake hazard for South-East Queensland is, however, low by global standards (Giardini and others, 1999).

Earthquake risk assessment method

Earthquakes threaten communities most through building damage. Our earthquake risk assessment for the South-East Queensland community is based almost entirely on scenario analysis of damage to residential buildings in Queensland (houses and flats). These buildings comprise about 94% of all South-East Queensland buildings. Community risk is a function of the composition of the building

construction types in the region, the extent of damage to each type of building, the uses to which buildings are put, and the potential for community disruption and business interruption through building damage.

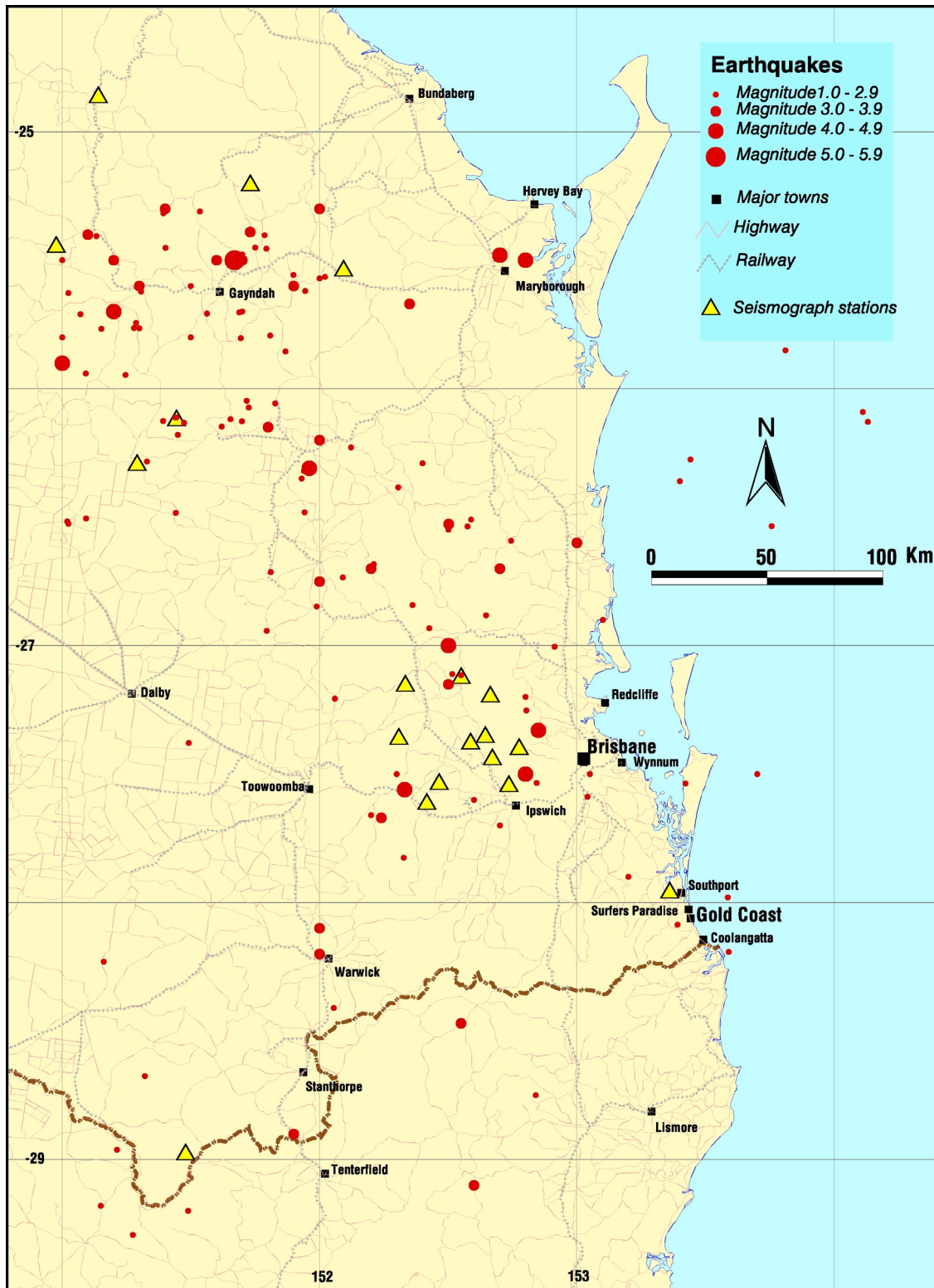


Figure 8. 1 Historic earthquakes in the South-East Queensland region

Table 8. 2 Significant historical earthquakes in the South-East Queensland region

Date	Time (UTC ²) hr min	Lat (°S)	Long (°E)	Place	ML ³	I _{max} ⁴	Comments
25/6/1861				Felt near Noosa	4?	V?	First reported Queensland earthquake
3/09/1862				Felt near Noosa	5.0?	VII?	Second reported Queensland earthquake
24/11/1875	11 00	28.1	152	Warwick	3.9	IV	Felt MMV Allora
26/02/1877	21 45	27.5	152.8	Ipswich	4.3	IV	Felt MMIV Ipswich
10/08/1880	19 00	28.9	151.9	Bald Mountain	3.6	IV	Felt MMIV Bald Mountain
28/08/1883	16 55	25.5	151.67	Gayndah	5.9	VII	Damage to Gayndah, Bundaberg and Maryborough. Felt from Brisbane to Rockhampton
28/08/1883	18 20	25.5	151.67	Gayndah	5	IV	Felt in Gayndah, Maryborough and Rockhampton
24/11/1910	22 52	25.7	151.2	Gayndah	4.7	IV	Felt in Bundaberg and Rockhampton
01/05/1913	16 20	27	152.5	70 km NW Brisbane	4.8	V	Felt MMV Kilcoy, Esk and Crows Nest
06/06/1918	18 14	23.5	152.5	Offshore Bundaberg	6.3	VII	Damage in Rockhampton and Bundaberg. Felt from Mackay to Grafton to Charleville. Widely felt in Brisbane
06/06/1918	18 15	23.5	152.5	Offshore Bundaberg	5.1	III-IV	
06/06/1918	18 23	23.5	152.5	Offshore Bundaberg	5.5	III-IV	Felt MMIV Esk, Killarney
07/06/1918	19 00	23.5	152.5	Offshore Bundaberg	5.1	III	
08/06/1918	19 20	23.5	152.5	Offshore Bundaberg	5.7	III-IV	
09/06/1918	19 45	23.5	152.5	Offshore Bundaberg	5.1	III	
10/06/1918	20 15	23.5	152.5	Offshore Bundaberg	5.1	III	
12/05/1935	01 32	25.5	151.67	Gayndah	5.5	VI	Felt MMVI Gayndah, MMIII Brisbane
11/06/1947	10 03	25.48	152.7	Maryborough	4.3	IV	Felt MMIII Nambour 'Minor damage'
30/12/1951	21 40	25.9	151	Mundubbera	3	IV	Felt MMIV around Mundubbera
24/06/1952	01 44	25.5	152.8	Maryborough	4.8	IV-V	Felt MMIII Brisbane to Bundaberg
10/05/1955	22 36	26.7	152.2	Mt. Stanley	3.2	IV	Felt MMIII-IV Brisbane
17/11/1960	05 00	27.33	152.85	Mt. Glorious	4.4	III-IV	Felt MMIII Brisbane, Ipswich, Caboolture
25/03/1964	06 14	25.3	151.4	Mundubbera	3.9	IV	Felt MMIV at Gayndah. Damage in Mundubbera area
30/10/1984	06 29	26.31	151.96	Murgon	4.2	VII	Felt MMV-VII at Murgon. Damage to school, houses
14/08/1988	23 23	27.56	152.33	Gatton	4	V	Felt MMIV Gatton, Forest Hill, Laidley
25/10/2000	05 24	27.36	154.95	Offshore Brisbane	3.9	III	Felt South-East Queensland MMII-III

² UTC = Universal Coordinated Time = Australian Eastern Standard Time minus 10 hrs; ³ ML = Richter (or local) magnitude; ⁴ I_{max} = maximum seismic intensity measured on the Modified Mercalli Scale

The earthquake building damage assessment comprises the following processes.

- An earthquake hazard model was prepared for South-East Queensland. This model takes into account the likelihood of earthquakes occurring in the South-East Queensland region. The model also accounts for local site effects that can amplify earthquake ground shaking. These site effects are largely due to near-surface geological conditions. Numerous ‘scenario’ earthquakes were sampled from the earthquake hazard model as input for the building damage models.
- A South-East Queensland property database was prepared, based on the data provided by the eight LGAs. This database categorises buildings according to both their age and their usage.
- The damage to South-East Queensland residential buildings (houses and flats) was estimated using the HAZOZ earthquake loss software developed by AGSO (Stehle and others, in preparation.). This software estimates building damage using the capacity spectrum method described in HAZUS[®] (FEMA, 1999).
- Probabilistic loss estimates were determined for a range of Annual Exceedence Probabilities (AEP). Losses are expressed as the equivalent number of residences totally damaged. The results are presented at the level of Census Collectors District (CCD) and for the entire region.

Each of these processes is described more fully in the following sections.

Earthquake hazard in South-East Queensland

South-East Queensland regional earthquake hazard:

Four estimates of earthquake hazard have been prepared for the South-East Queensland region.

The basic model that was used to generate scenario earthquakes is the Tasman Sea Margin Zone (TSMZ), a single, uniform earthquake hazard source zone that extends from northern Bass Strait into Queensland as far north as the southern extremity of the Great Barrier Reef. The western margin of the TSMZ corresponds approximately with the 150 m AHD topographic contour west of the Great Dividing Range, and its eastern margin is located along the 200 m isobath at the eastern Australian continental shelf margin. The TSMZ was proposed by a panel of geological and seismological experts in Sydney in 2000 (Stewart and Jones, in preparation). The TSMZ is associated with the opening of the Tasman Sea and the separation of the New Zealand and Australian land masses. A maximum magnitude of 6.5 ± 0.5 is assumed for the Tasman Sea Margin Zone.

A further three estimates of earthquake hazard are included to give the reader an indication of the uncertainty in earthquake hazard assessment for South-East Queensland. Each estimate relates to a 10% probability of exceedence in 50 years at ‘rock’ or ‘firm’ sites. This probability corresponds to an AEP of approximately 1/475, or an average recurrence interval (ARI) of 475 years. The first of these estimates of hazard is found in *AS1170.4-1993* and its replacement, the draft *ANZS DR 00902* (Standards Australia, 2001). An ‘acceleration coefficient’ of 0.06 for the South-East Queensland area was taken from Table 2.3 of the standard. This value is equivalent to a peak horizontal ground acceleration (PGA) of 0.06 g, where ‘g’ is the acceleration experienced at the earth’s surface under gravity. More than half the area of Australia in the earthquake hazard maps in *AS1170.4-1993* has an acceleration coefficient in the range 0.05 - 0.1 g. The coefficient values across Australia range from a minimum 0.03 (‘low’ globally) to highs of up to 0.22 (‘moderate’ globally) in ‘bullseye’ areas.

The second of these estimates originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.1 g on rock, in line with their estimates of PGA for Queensland two to three times higher than previous estimates.

The third of these estimates is found in the work of Gaull and others (1990). The earthquake hazard maps in *AS1170.4-1993* were derived from this work. Gaull and others estimated a PGA value of 0.025 g for Brisbane.

Urban earthquake hazard in South-East Queensland

In addition to the regional earthquake hazard represented by, for instance, the state-wide hazard maps in *AS1170.4-1993*, earthquake hazard can vary considerably across a region as large as South-East Queensland, primarily because of local differences in site geology. This effect has been responsible for the concentration of damage in many earthquakes, including the 1989 Newcastle earthquake, the 1989 Loma Prieta (California) earthquake and the 1995 Kobe (Japan) earthquake. (In Kobe the focussing of seismic waves at the edge of a geological basin may also have had a significant role in producing the strongest shaking.) Ground shaking recorded from these earthquakes, and others, indicates that the localised earthquake hazard can vary by a factor of two or more depending on ground conditions.

South-East Queensland has been divided into three site classes that determine the relative severity of earthquake shaking (Site Classes B - D in Table 8. 3). A site class was assigned to each CCD.

The relative strength of earthquake shaking on each of the Site Classes B, C and D is described by a response spectrum for each site class. Figure 8. 2 plots the response spectrum for the site classes in South-East Queensland.

Table 8. 3 Earthquake site classifications for South-East Queensland

Site Class	Description	South-East Queensland setting
B	Rock. Mean shear wave velocity in the top 30 m assumed to be more than 1500 m/s.	All rock outcrop in South-East Queensland. The site class includes all rock units older than Tertiary (age greater than about 65 million years).
C	Thin sediments overlying rock. Sediments with natural periods of vibration less than 0.5 s (sediment thicknesses in the range 3-23 m approx.)	All Quaternary sediments with thicknesses estimated in this range. In South-East Queensland these are found along stream beds, alluvial plains, in estuaries, coastal plains, tidal deltas and beach deposits. Landfill may overlie these units.
D	1. Thick sediments overlying rock. Sediments with natural periods ≥ 0.5 s (sediment thicknesses in the range 24-70 m approx.); OR 2. Weathered profile in residual soils and colluvium overlying Tertiary geological units.	1. All Quaternary sediments with thicknesses estimated in this range. In South-East Queensland these are found along stream beds, alluvial plains, in estuaries, coastal plains, tidal deltas and beach deposits. Landfill may overlie these units; OR 2. All mapped Tertiary rock units. Extensive areas of Tertiary sediments and basalts are found in South-East Queensland.

See Chapter 2 for an abbreviated description of the geology of South-East Queensland.

Earthquake motion described in terms of response spectra is useful to engineers. Spectral acceleration is the maximum acceleration of an idealised single degree of freedom 'structure' relative to its 'foundations'. The period T is the time taken to complete one cycle of vibration.

The spectrum for Site Class B was developed by Somerville and others (1998), and is used as the response spectrum for earthquake shaking on rock in Australia in *ANZS DR 00902* (Standards

Australia, 2001). The spectra for Site Class C and Site Class D were developed by multiplying the values of the Site Class B spectrum by amplification factors derived for Eastern United States (EUS) by Schneider and others. The EUS amplification factors are used in the absence of appropriate amplification factors developed for Australian conditions. The EUS factors were developed for site conditions similar to those in many parts of eastern Australia, where hard Palaeozoic basement rock underlies relatively thin, much softer, Cainozoic deposits. The amplification factors for Site Class C were developed for New Madrid Class L28 ('soft' sediments of thickness 3-23 m) with an input PGA value of 0.075 g. The amplification factors for Site Class D were developed for New Madrid Class M28 ('soft' sediments of thickness 24-54 m) with an input PGA value of 0.075 g.

Earthquake ground shaking will be stronger on Site Classes C and D than it will be on Site Class B, for periods of vibration that could cause damage to buildings (Figure 8. 2). For example, at a period of $T = 0.1$ s (corresponding approximately to the natural period of one-storey residences), the amplification of ground shaking on Site Class C is expected to be about $0.44 \text{ g} \div 0.19 \text{ g} = 2.3$ times stronger than the ground shaking on rock (Site Class B) at this period of vibration. Similarly, at the same period of vibration, the ground shaking on Site Class D is expected to be amplified by a factor of about 1.3 compared to the ground shaking on rock.

Low rise buildings with a natural period of vibration of around $T = 0.1$ s, including most residences, can readily take in energy from the earthquake ground shaking with this period of vibration. Generally then, low rise buildings on Site Classes C and D are likely to suffer more damage in earthquake scenarios than low rise buildings on Site Class B. The outcome for any particular earthquake, however, may differ because of the location of the earthquake in relation to the sediments, focussing of seismic waves, the possibility of surface faulting, the duration of earthquake shaking, etc.

In general, the amplification of ground shaking also changes with differing intensities of input ground motion. The chosen value of PGA on rock, 0.075 g, represents a compromise between PGA values for the weak earthquake shaking that could be expected for the frequently occurring events (i.e. relatively large AEPs), and the strong shaking that could be expected for very rare events (small AEPs).

Earthquake hazard scenarios for South-East Queensland

Earthquakes with four different magnitudes were used to generate hazard scenarios for South-East Queensland. The scenario earthquakes had magnitudes of 5, 5.5 (similar to the 1989 'Newcastle' earthquake), 6 and 6.5. Earthquakes in the range of magnitudes M5-6.5 dominate the source of earthquake hazard in Australia. Individual scenario 'earthquakes' were generated in each cell of a regular 10 km by 10 km square grid with sides of 300 km (i.e., a total of 900 scenario earthquakes for each magnitude). South-East Queensland is located at the approximate centre of the grid (Figure 8. 3). For each scenario earthquake, the PGA was calculated at the centroid of each CCD. The calculated value of PGA is a function of the distance between the scenario earthquake and the centroid of the CCD. We used the attenuation formula of Toro and others (1997) to calculate PGA at the CCD centroid. Scenario earthquakes of magnitude 5.5 or smaller were treated as point sources. Scenario earthquakes with larger magnitudes were considered to occur on faults of random azimuthal orientation, and the closest distance between the fault rupture and the CCD centroid was calculated in each case. The fault length varies with earthquake magnitude, and fault lengths were calculated using the relationships of Wells and Coppersmith (1994). The response spectra, scaled by the input value of PGA, were used as input into the building damage model.

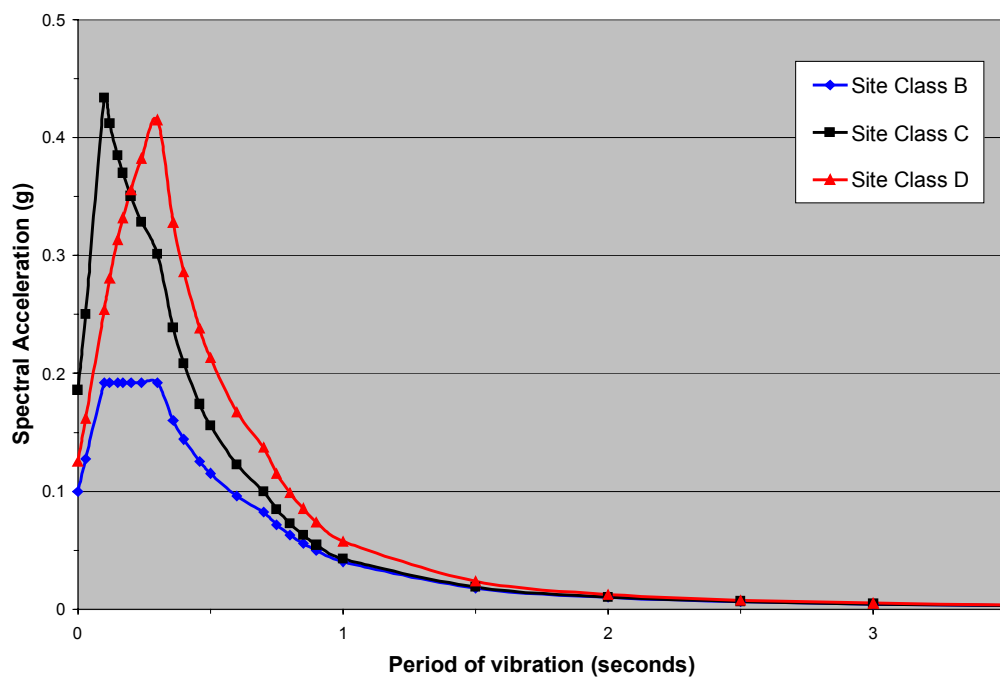


Figure 8. 2 Response spectra for South-East Queensland Site Classes B, C and D. Spectra are elastic and 5% critically damped. On this plot, spectra are tied to a Peak Ground Acceleration of 0.1 g on rock (Site Class B)

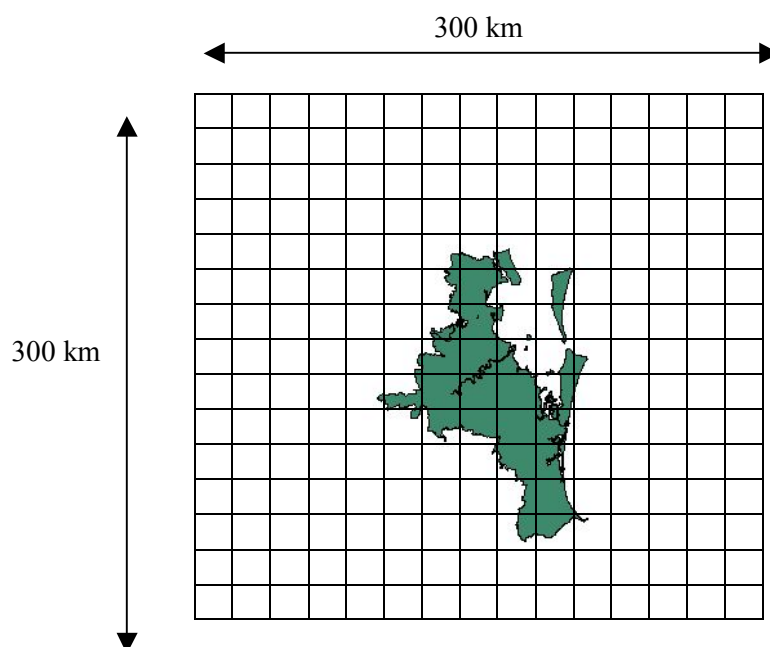


Figure 8. 3 Schematic of South-East Queensland study area and the regional grid used to generate scenario earthquakes.

South-East Queensland building database

The property databases developed by AGSO from data provided by the eight South-East Queensland LGAs were used in our assessment. This database contains information on every developed property in South-East Queensland. The information typically includes the age of original development (by decade) and property usage. In addition, we have assigned a building usage category that relates to our method of assessing community geohazard risk (see Chapter 3).

We have also estimated the composition of the residential building stock with regards to the type of load-bearing frame or wall (Table 8. 4). Several common types of residential building construction are described below.

Light timber frame buildings: Most South-East Queensland buildings are of this type. These low rise buildings usually have timber wall cladding but may have brick, fibro or metal exterior cladding. Most are residential buildings, or ex-residential buildings used for other purposes such as businesses.

Buildings with light timber frames behave in a ductile manner in earthquakes and can undergo relatively large displacements because of their non-rigid construction.

The high-set buildings on stumps are of special interest because they are found in Queensland but not outside tropical and subtropical Australia. We do not know the number of older (pre-war) ‘Queenslander’ timber houses in Queensland. Their performance in strong earthquake shaking has not been tested. If they are in good condition they will have vertical joints connected, will be tied down from piers to roof, and may be less vulnerable to earthquakes than houses built in the 1960s and 1970s (John Ginger, James Cook University, verbal communication, 1999). Many old ‘Queenslanders’ are not in optimum condition, however, and their performance could be poor, particularly if they are not tied to the stumps or if the stumps are not cross-braced.

The wall type ‘brick’ could include both unreinforced masonry and brick veneer construction types. Brick veneer structures have a light timber frame. We made the assumption that nearly all ‘brick’ houses are brick veneer because residential buildings with brick walls are most common in suburbs that developed since the 1960s. Brick veneer became an accepted construction method in Queensland in the late 1950s and has been the predominant brick form since then.

Reinforced masonry buildings with reinforced concrete floors (concrete block buildings with concrete slab floor): Reinforced concrete block is the presumed third most common type of house construction in South-East Queensland. We consider that concrete block buildings complying with modern wind loading standards will probably perform well under moderate seismic loadings. However, older concrete block buildings not built to either a wind or earthquake loading standard will be less earthquake-resistant than equivalent modern buildings complying with the standards.

Reinforced concrete frame with unreinforced masonry infill panels: This type of construction has been popular for low and medium rise residences, and public works-related buildings such as hospitals and schools. Infill panels are often brick, and brick or other cladding may conceal the frame. Masonry infill panels provide lateral resistance, unintentionally in some cases. Upon cracking of the masonry, increased lateral loads are transferred to the concrete frame. Collapse can occur upon disintegration of the masonry infill or through shear failure of the frame. If masonry is absent from the lower storey or storeys of a building, a ‘soft storey’ can form under low levels of earthquake loading. This phenomenon was observed some 250 km from the epicentre of the recent Gujarat, India, earthquake (John Stehle, AGSO, written communication, 2001). In the 1989 Newcastle earthquake these buildings did not suffer structural collapse although there was significant damage to masonry infills and cladding (Institution of Engineers, Australia, 1990). At least one structure in Newcastle had to be demolished due to ‘soft storey’ damage. Only one pre-code concrete building has suffered collapse in any New Zealand earthquake, and this building had a ‘soft storey’. Dowrick and Rhoades (2000) attributed this excellent performance to structural walls of concrete, concrete blocks or brick infill.

Unreinforced masonry: These usually older buildings often have cavity brick construction with the inner leaf and outer leaf attached by ties. One leaf acts as the load bearing element. Interior walls may also be unreinforced masonry and load-bearing. Floors may be of any material but in the oldest buildings they are usually timber. Unreinforced masonry is brittle, and historically has performed poorly in many earthquakes around the world, although its strength may be improved by the presence of cross walls (John Wilson, University of Melbourne, verbal communication, 1999). Most unreinforced masonry buildings in South-East Queensland are probably used as commercial premises, though some public buildings, including some schools, also have this form of construction. Some of these older buildings (e.g., the former wool stores along the Brisbane River) are being re-developed as residential units.

Old unreinforced masonry buildings, both domestic and non-domestic, were the most extensively damaged buildings in the 1989 Newcastle earthquake (Institution of Engineers, Australia, 1990). Corroded wall ties and weak lime mortar were two major contributors to masonry damage in the Newcastle earthquake and they could contribute to building vulnerability in the South-East Queensland climate. In the Newcastle earthquake, extensive cracking, loss or tilting of exterior walls, and fallen parapets, awnings and gable ends were widespread and in some cases caused deaths.

Reinforced concrete shear walls: These structures have massive shear walls poured in situ. The walls are usually load bearing walls. In older buildings, the walls often are quite extensive and the wall stresses are low but reinforcing is light. In newer buildings, the shear walls often are limited in extent, generating concerns about boundary members and overturning forces. Poorly located shear walls may introduce torsion into the structure, hence increasing the likelihood of damage. Nevertheless, we expect these buildings to perform relatively well in the earthquake loading scenarios of this study.

Table 8. 4 Estimated percentages of South-East Queensland construction types of houses and flats

Construction type	Houses	Flats
Light timber frame low rise	97.5%	69%
Reinforced concrete frame low rise	0	8.5%
Reinforced concrete frame medium rise	0	7%
Concrete shear walls medium rise	0	4%
Concrete shear walls high rise	0	2%
Reinforced concrete frame with unreinforced masonry infill panels low rise	0	1%
Reinforced concrete frame with unreinforced masonry infill panels medium rise	0	3%
Unreinforced masonry low rise	2%	0.5%
Reinforced masonry buildings with reinforced concrete floors (concrete block buildings with concrete slab floor)	0.5%	5%

Building damage models for South-East Queensland

AGSO's HAZOZ methodology makes use of the capacity spectrum method and defines damage by the interstorey drift ratio. The drift ratio is the ratio of relative lateral displacement of a building floor to the height of a building storey. Different drift ratios determine the structural damage states (slight, moderate, extensive, complete). Different damage states are then used to determine the damage cost. The seismic capacity spectrum performance parameters of Australian residential buildings have been determined by a group of experts (Stehle and others, in prep.).

Damage cost is defined as a percentage of replacement value, as follows:

$$\text{Damage cost} = \text{cost of repair or replacement} / \text{total value (total replacement cost)}.$$

The cost of repair to non-structural damage to buildings is also assessed. Structural repairs relate to the load-bearing elements of the building. Non-structural elements can be sensitive to acceleration (e.g., ceilings, pipes and ducts) or to displacement (e.g., interior non-structural walls, exterior wall cladding, glass). Our calculations also include building contents damage, which are also modelled to be sensitive to acceleration.

The repair costs are apportioned as follows:

Structural damage	15/64 of building replacement value
Non-structural acceleration-sensitive damage	17/64 of building replacement value
Non-structural displacement-sensitive damage	32/64 of building replacement value
Contents	50% of building replacement value

These repair cost ratios are taken from HAZUS[®] (FEMA, 1999).

Method of calculating earthquake losses and uncertainties

The loss from each of the 900 scenario earthquakes, for each of the earthquake magnitudes (5, 5.5, 6 and 6.5), was calculated for each CCD. Loss is the equivalent repair or replacement cost, as mentioned above.

Each loss scenario was associated with a probability of occurrence from the hazard model. The level of damage in each CCD from individual scenarios ranges from negligible to high, depending on the location of the scenario event in relation to the CCD.

The damage level to houses and flats was calculated for each Census Collectors District (CCD), for each scenario event. Damage across the entire South-East Queensland region was also calculated for each scenario event. Cumulative loss curves for each CCD, and for the entire South-East Queensland region, were prepared by aggregating the probabilities of exceedence of various loss levels. A relationship describing the ARIs at which various levels of damage were exceeded was developed from the loss curve.

Statistical uncertainty/variation in the input ground motion, the building capacity curve and in the damage state thresholds are accounted for in the HAZOZ methodology. The result is that a group of buildings of the same building category and subject to the same ground motion will be in a range of damage states.

Results

A summary of the earthquake damage losses in the South-East Queensland region is given in Table 8.5 and plotted in Figure 8.4 and Figure 8.5. The losses are the minimum losses expected for the probability associated with that loss. For example, there is an annual probability of 0.2% that damage losses will be 0.31% of the total insured value, or higher than 0.31% (Table 8.5).

A probabilistic distribution of earthquake damage risk across the South-East Queensland region is shown in Figure 8.6. The annual risk to each CCD is shown. The risk is defined in terms of the percentage of the repair or replacement cost of a 'typical' residence including contents or, alternatively, the percentage loss of the repair or replacement cost of the residential building stock and contents (multiplied by an annual probability of one). The percentages in the legend of Figure 8.6 must be multiplied by 10^{-6} . All of the scenario earthquakes were used to prepare the map.

Table 8. 5 Estimated damage for South-East Queensland residential buildings

ARI (years)	AEP	Damage (repair or replacement cost of equivalent no. of buildings destroyed)	Damage (repair or replacement cost expressed as % of total replacement cost)
100	1.0%	60	0.01%
200	0.5%	450	0.07%
500	0.2%	2000	0.31%
1000	0.1%	3900	0.60%
2000	0.050%	7100	1.1%
5000	0.020%	13 000	2.0%

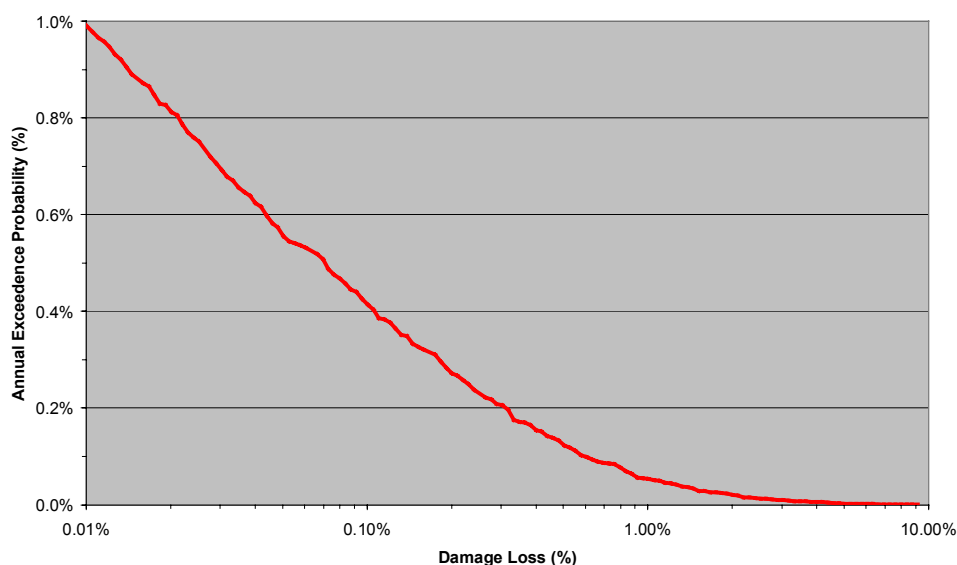


Figure 8. 4 Annual Exceedence Probabilities for residential building damage in South-East Queensland

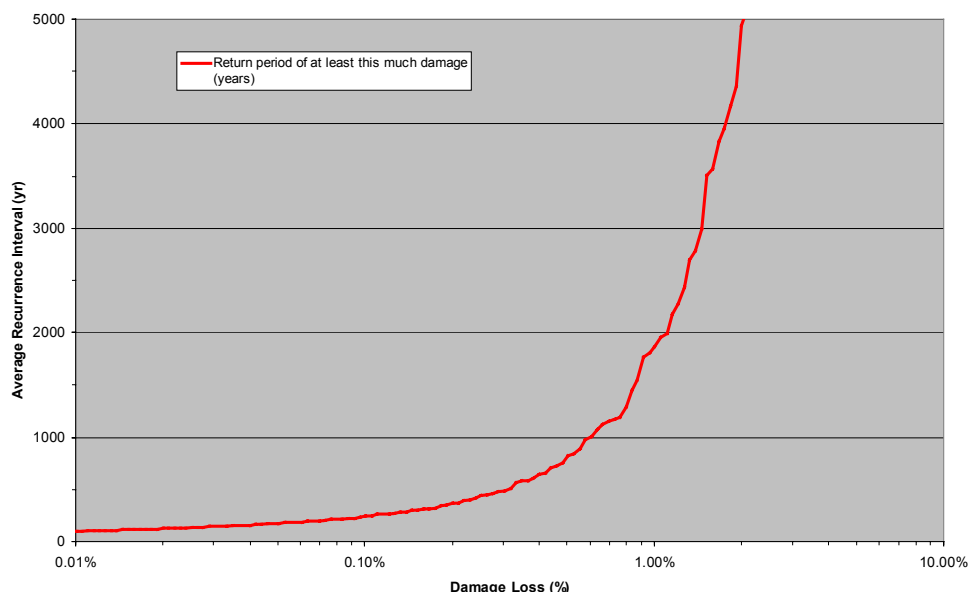


Figure 8.5 Average Recurrence Intervals for residential building damage in South-East Queensland

Discussion

The distribution of modelled earthquake damage reflects the locations of dwellings across the region. That is, modelled damage will tend to be concentrated in areas of high population density. Local site conditions will also have a significant influence on the distribution of damage (e.g., Figure 8.6) because residences situated on rock foundation will suffer less damage on average than residences on Site Class C or D (Table 8. 3).

Areas of South-East Queensland that contain significant numbers of flats are also estimated to suffer more damage than areas in which flats are not common. We have assumed that 0.5% of South-East Queensland flats are constructed of unreinforced masonry, 4% have a concrete frame with unreinforced masonry infill panels, and a further 17.5% have a concrete moment frame (Table 8.4). All of these types of building construction are expected to perform worse in earthquakes than buildings with timber frames, in particular the unreinforced masonry buildings. Only about 70% of flats are estimated to have a timber frame, whereas more than 95% of South-East Queensland houses are estimated to have a timber frame. The damage patterns would change with different sets of assumptions about the composition of the building stock.

The estimates of losses can be converted very easily to expected direct dollar losses by inserting replacement costs appropriate to South-East Queensland. A surcharge for demolition, debris removal and administrative costs could be applied.

Potential earthquake damage to non-residential buildings

Our estimates of the distribution of earthquake damage in South-East Queensland are biased because we have only modelled damage to residential buildings. Significant other costs could be incurred through repairing or replacing damaged non-residential buildings, and because of business interruption. Significant social and cultural costs to the community could also occur (many of them caused by building damage), but these are more difficult to quantify.

AGSO has not made estimates of earthquake damage to non-residential buildings in this study. Estimates of damage to structures used for public safety, utilities, essential services, medical purposes, logistics, government, and business and industry give a broader description of the community's capacity to respond and recover from a significant earthquake than an assessment of damage to

residential buildings only. However, at the moment, we do not have specific information on construction types from which to estimate damage to these buildings.

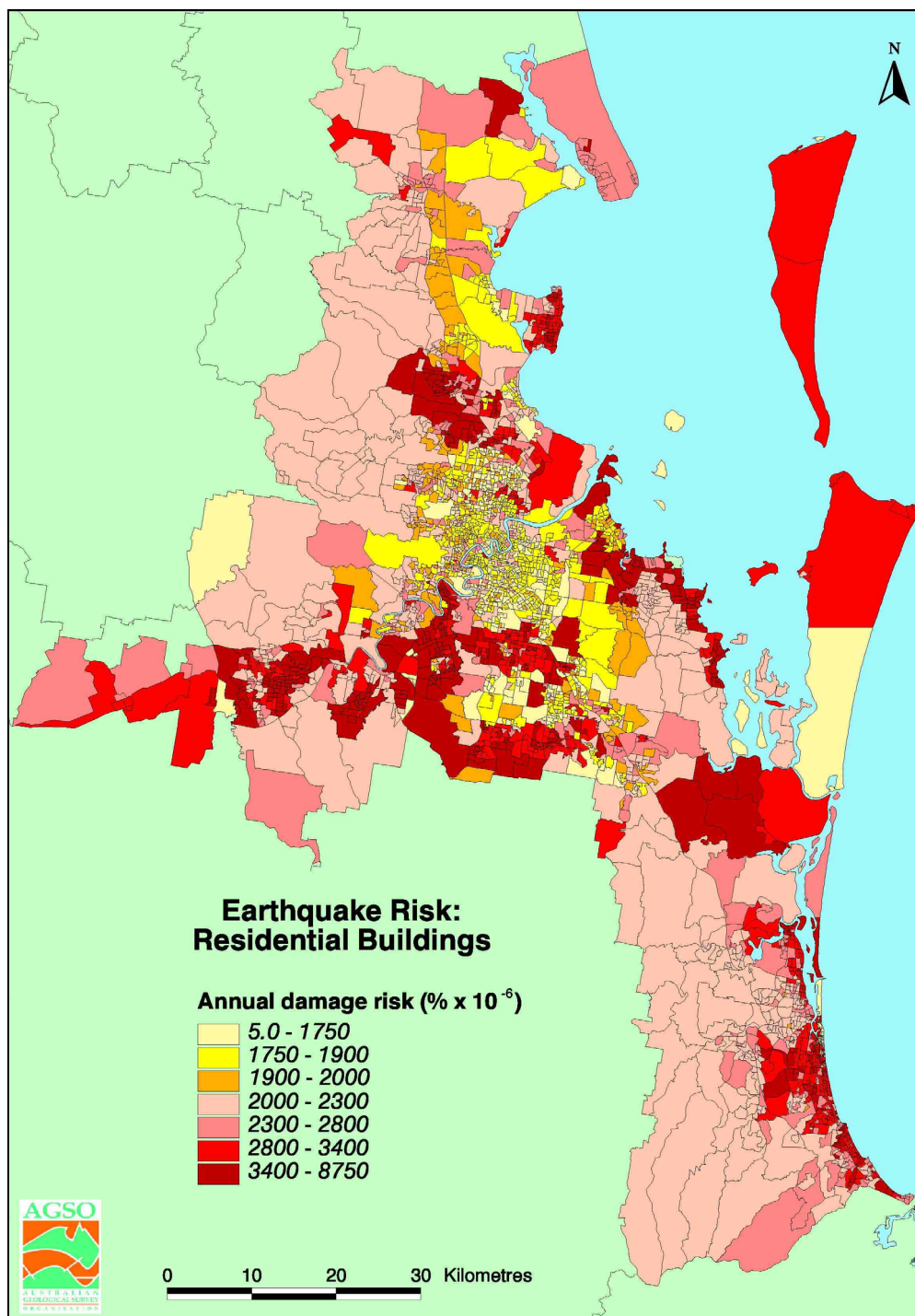


Figure 8.6 Annual earthquake risk to residential buildings. Units of annual risk are replacement value of a 'typical' residence including contents multiplied by 10^{-6} (see text)

Probability of casualties

The probability of death is low from any of the scenarios we considered. Dowrick (1998) published data on damage and casualties from New Zealand earthquakes. He estimated that the probability of

death in, or beside unreinforced masonry or soft storey reinforced concrete buildings was about 3 in 10,000 for earthquake shaking of MM VIII. He also found that nearly all building-related deaths from New Zealand earthquakes occurred in, or near unreinforced masonry buildings, and that more than 90% of all earthquake related deaths in New Zealand occurred at a very high intensity of ground shaking (MM IX).

The probability of injury that is immediately life-threatening if treatment is not available may be about the same as the probability of death. The probability of non life-threatening injury is about 100 to 1000 times more likely, depending on the damage state of the building (FEMA, 1999).

We cannot exclude the possibility of casualties or deaths in South-East Queensland from earthquakes. The 1989 Newcastle earthquake caused deaths through collapse of non-structural elements such as awnings and through partial structural collapse. If all buildings were in conformance with current building standards, few deaths could be expected from a 'Newcastle' type earthquake.

What is the earthquake risk to South-East Queensland?

In summary, South-East Queensland faces a moderately low risk to its residential buildings from earthquakes. The level of earthquake risk in South-East Queensland is certainly significant when considered on a regional basis, and earthquakes should be considered in risk management strategies for the region.

The earthquake hazard in the South-East Queensland region is low by global standards (Giardini and others, 1999). The relatively minor historical seismicity, and its correspondingly minor impact on human activity in the South-East Queensland region, are testimony to this. However, we need to be aware of the short historical record and the consequences of a rare, damaging earthquake.

Although overall hazard is low, it is higher in the many parts of South-East Queensland that are built on unconsolidated sediments or on Tertiary geological units. These ground conditions are expected to amplify the ground shaking from future earthquakes.

We rate the vulnerability of South-East Queensland residential buildings to earthquake as low. The great majority of residential buildings in South-East Queensland (an estimated 95%) are of light timber frame construction. Timber frame buildings perform well in earthquake and this is a positive factor in the earthquake risk that South-East Queensland faces.

Suggested options for earthquake mitigation

Although the earthquake risk to South-East Queensland is not high, Local Governments and Queensland Government authorities could consider taking the following simple steps to mitigate earthquake risk.

Ensure the use of earthquake and wind loading provisions provided by relevant Australian Standards and the Queensland *Building Act*

We believe that wind loading standards and earthquake loading standards are highly effective mitigation tools.

Enforce appropriate ground amplification factors for domestic buildings

An appropriate amplification factor for low rise, new domestic buildings on Quaternary sediments in South-East Queensland is 2.3 (.Site Class C). An appropriate amplification factor for low rise, new domestic buildings on Tertiary sediments in South-East Queensland is 1.3 (.Site Class D).

In Table 2.4 (b) of *AS1170.4-1993*, the Site Factor for residential buildings is either unity ('normal soil') or 2.0 ('soft soil'). However, *AS1170.4-1993*, p.24, stated that (our bold emphasis):

*'6. In locations **where the soil profiles are not known, a site factor (S) equal to 1.5 should be used for general structures and 1.0 for domestic structures.***

A site factor of 1.0 is not appropriate for domestic structures in sediment areas in South-East Queensland.

As a guide, the geology map for South-East Queensland could be used to classify site conditions for development (see Chapter 2 for a geology map and see Table 8. 3 for the site classifications). In the simplest case, all areas of South-East Queensland underlain by Quaternary sediments could be considered Site Class C, and all areas underlain by Tertiary geological units could be considered Site Class D. All other areas of South-East Queensland could be considered Site Class B (rock).

The amplification factors in *ANZS DR 00902* (Standards Australia, 2001) are more appropriate than those in *AS1170.4-1993*, and their 'Shallow soil' sites have approximately the same amplification factors as those suggested here for Site Class C. *ANZS DR 00902* describes an amplification factor of 2.25 at a period of $T = 0.1$ seconds for 'Shallow Soil sites' with natural period less than $T = 0.6$ seconds.

Adopt the South-East Queensland maps of natural period as an aid to urban planning

South-East Queensland Local governments could adopt the South-East Queensland maps of natural period of ground vibration as an aid to engineering design of new structures. These maps were developed on an LGA basis and were included in the individual reports to eight Local Governments. The natural periods of vibration, of the sediments and the weathered profile of the Tertiary geological units, are described by these maps. Designers of new buildings with important functions could take these conditions into account in designing buildings to be non-resonant with their foundations.

LGAs could, for example, refer structural engineers to the maps of natural period in relation to building applications for General Structures of Importance II or III (*AS1170.4-1993*, Appendix A1).

Limitations and Uncertainty

We have made an earthquake risk assessment based on building damage and the study reflects the state of our methodology at present. Other aspects of risk assessment not covered in this study include assessments of:

- direct dollar losses such as the cost of repairing damage and the cost of business interruptions;
- direct social losses such as the cost of recovery from physical injuries and trauma, and the costs of relocating displaced persons;
- indirect economic and social losses which impact on the external community through damage in South-East Queensland; and
- the impact of secondary hazards including fire, hazardous material spills and debris.

Uncertainties and limitations in our results include the following:

Uncertainties in estimates of regional earthquake hazard

There is a fundamental problem with estimating hazard for ARIs longer than the complete historic record. The specific sources contributing to uncertainties in estimates of the hazard are many. Probably the most important are uncertainties in:

- the attenuation of ground shaking from earthquakes in the region - that is, the way in which the strength of earthquake shaking decays with distance from the earthquake. Uncertainty is present due to our incomplete knowledge of the attenuation process, and also due to the intrinsic variability of localised ground shaking;
- the definition of the Tasman Sea Margin earthquake source zone; and
- the level of earthquake activity within this source zone.

These uncertainties are manifest in the differences of the hazard estimates made by various authors.

Uncertainties and limitations in estimates of urban earthquake site amplification:

- The use of Eastern United States site classes and amplification factors for South-East Queensland is bound to be inappropriate to some extent. The degree of appropriateness or inappropriateness is not fully known, and locally developed site classes and amplification factors need to be developed to remove this source of uncertainty.
- The urban local site conditions were estimated using a medium-level process which included the use of limited geotechnical and geophysical data but not computer waveform modelling or the evaluation of local recordings of earthquakes. Locally recorded earthquake strong motion data were not available. The improved definition of site classes and their amplification factors using these techniques is an important step that would add considerable confidence to the damage assessments, and would also significantly reduce the uncertainties in the estimates of damage.
- Site class is assigned by CCD. The site classification does not have the resolution to be applied at an individual parcel level. Earthquake site classes were prepared for a very large South-East Queensland area with limited data. The geological mapping has largely the resolution of the regional map product from the Queensland Department of Natural Resources and Mines, and would contain inaccuracies at local levels. These data frequently do not contain a breakdown of Quaternary geology types, essential for good quality site class maps. For example, there may be no distinction made between sands and clays, or Holocene, Quaternary and in some cases Tertiary units. The available geotechnical data, although mostly of very good quality, were very localised and clustered, or located along transport routes. The microtremor data used to prepare the natural period maps were generally of good quality and cover extensive urbanised, sedimentary areas.

Uncertainties in the assessment of building performance:

- Estimates of the performance of different construction types of Australian residential buildings in earthquakes have benefited greatly from the input of a panel of expert structural engineers (Stehle and others, in preparation). However, the performance of Australian building construction types in earthquakes needs considerable further investigation. This work has national significance.
- In the methodology we used, buildings are aggregated into categories, based on construction type and usage, and the seismic performance of these categories is described probabilistically. Associated uncertainties in building performance are taken into account in the building damage state calculations.
- We have estimated the composition of the South-East Queensland residential building inventory (**Table 8. 4**) and errors in our assumptions will perturb the estimates of building damage. The estimates of damage are particularly sensitive to the numbers of unreinforced masonry and concrete frame buildings with unreinforced masonry infill panels in South-East Queensland.
- There are uncertainties in how building condition will affect seismic performance. We have not taken into account building condition in our modelling. Building condition could play a major role in damage scenarios. This effect was indicated by heavy nonstructural damage to buildings in Newcastle from shaking in the 1989 earthquake (Institution of Engineers, Australia, 1990). The marine climate of Newcastle was a contributing factor to the poor condition of many of its buildings. However, South-East Queensland does not have anywhere

near the percentage of unreinforced masonry or brick veneer buildings that Newcastle does, so this may not be as important a factor for South-East Queensland as it was for Newcastle.

Community Awareness

The broad community probably has little perception that earthquakes pose a significant threat to South-East Queensland. This is understandable because the rate of earthquake activity is low and the historical impact of earthquakes in southern Queensland is low. Moderate to strong earthquakes such as the 1918 'Bundaberg' earthquake and the 1935 Gayndah earthquake are not known to most residents.

The risk from earthquakes in South-East Queensland is largely from low probability, high consequence events, and these events are unlikely to occur in any individual's lifetime. Therefore these events may hold little fear for individuals, even if they are aware of the risks involved.

However, strong earthquakes have the potential to impact across large communities. Should they occur, losses can be very high when aggregated across the community. Effective management of this type of risk may be based appropriately at community or corporate levels, and there may be little that individuals should do about this type of risk beyond ensuring they have adequate insurance.

At the community level or beyond, mitigation measures such as building and planning codes, protection of essential facilities and services, and insurance probably rate highly in terms of effectively and economically treating risk.

Further Information

More detailed information on the levels of exposure of individual neighborhoods or properties to the various earthquake risks outlined here should be referred to the respective local government council.