

CHAPTER 4: EARTHQUAKE RISKS

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 1 000 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. The largest earthquakes are measured by the Moment Magnitude scale or the Surface Wave magnitude scale.

Descriptions of the severity of an earthquake 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, the disruption of ground conditions, and the reactions of people and animals. A full description of the Modified Mercalli Intensity scale is provided in [Appendix G](#).

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 not 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 which usually have not been available for Australian earthquakes, although they are much preferred. Furthermore, estimations of MM intensity can be seen as part of a circular argument that omits reference to the actual ground shaking. This is because the Modified Mercalli intensities on the scale have been defined in part by compiling observations of damage to different types of buildings. In turn, estimates of Modified Mercalli intensity are made by comparing field observations of building damage to the scale.

Updated versions of the MM intensity scale have been devised to extend its usefulness. New versions include that of Dowrick (1996) given in [Appendix G](#). New versions describe the expected effects of earthquakes on new types of building construction including buildings incorporating modern, earthquake-resistant design.

None-the-less, it remains difficult to use MM intensities to compare ground shaking from earthquakes occurring in different countries or for different historical times in the same country. The aim of such comparisons is to predict losses from future earthquakes. The damage patterns from particular earthquakes are often complex and depend upon the types of buildings present, their age and condition, geological conditions and the nature of the earthquake itself.

The Australian continent is distant from the narrow band of earthquake activity passing through Papua New Guinea, the South-West Pacific countries and New Zealand, which delineates the boundary between the Australian and Pacific plates. Cairns is situated more than 1 100 km from this plate boundary. Nonetheless, earthquakes have occurred in Australia, and more will occur.

The most damaging earthquakes in Australia in 1950-1999 are listed in [Table 4.1](#).

Table 4.1: Most-damaging Australian earthquakes, 1950-1999

Date	Location	Magnitude	Damage \$M	
			Contemporary	1995
03-01-1954	Adelaide SA	5.4	8.8	91
22-05-1961	Robertson/Bowral NSW	5.6	0.5	4.2
14-10-1968	Meckering WA	6.9	5	35
10-03-1973	Picton NSW	5.5	0.5	2.9
02-06-1979	Cadoux WA	6.2	3.7	10
22-01-1988	Tennant Creek NT (3 events)	6.2, 6.3, 6.5	1.1	1.5
28-12-1989	Newcastle NSW	5.6	13 killed, 862 insured damage, est. 1500 total damage	1800
06-08-1994	Ellalong NSW	5.4	34	35

Although damaging earthquakes are relatively rare in Australia, the high impact of individual events ranks them amongst the most costly of natural hazards to the community. According to Insurance Council of Australia (ICA) figures, of the \$7.068 billion insured losses from natural hazards in Australia in the 20 years 1967-1998, earthquakes and floods each caused about one-sixth of total insured damage, tropical cyclones caused nearly one-quarter, and hailstorms accounted for more than one-fifth (Blong, 1998). At the time of publication (May 1999), ICA estimates of the insured losses from the 1999 Sydney hailstorms of more than \$1 billion will alter these proportions significantly. With increasing urbanisation and reliance on power, water and telecommunications lifelines, Australian communities are becoming increasingly vulnerable to the impact of earthquakes.

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, some ten years before the establishment of Cairns. Recent research, however, has brought to our attention a significant earthquake (possibly around ML 6.0) felt in the Noosa area of south-east Queensland in 1862. This recent addition reinforces Rynn's observation that a significant proportion of the available earthquake data for Queensland has come from reports of felt earthquakes because of the paucity of seismograph stations. This is especially the case in the north and far north of the State where isolation, low population densities and poor instrumental coverage provide a more fragmented record of earthquakes than in other coastal areas of Queensland generally.

No permanent seismographs were installed in the north or far north of Queensland before the Charters Towers seismograph, operated by the University of Queensland, was installed in 1957. This seismograph is some 340 km south of Cairns and, although it will detect Cairns earthquakes with magnitudes larger than about Richter magnitude 3.0, such earthquakes cannot be located accurately using the Charters Towers seismograph data alone (R. Cuthbertson, QUAKES, personal communication, 1998). Three seismographs, optimally placed, are usually considered the minimum number required to locate earthquakes. Apart from the Charters Towers seismograph, other seismographs were installed to monitor the safety of dams along the Burdekin River around 1984, and near Tully around 1990.

[Table 4.2](#) lists the seismographs within about 500 km of Cairns and their dates of operation. Their locations are shown on [Figure 4.1](#) (the Burdekin network is off the map to the south-east of Townsville). Although the Burdekin and Tully seismographic networks have improved the capability to locate north-east Queensland earthquakes, their main purpose is to locate earthquakes immediately near the dam sites, and their clustered locations gives them a poor capability to locate earthquakes

further afield. Rynn (*op cit*) listed a seismograph operating at Kuranda from 1959 to 1964 and another operating at Townsville from 1956 to 1965 but the effectiveness of these instruments is not known. The Townsville instrument, however, was a long period horizontal seismograph, which would be unsuitable to detect local, moderate magnitude earthquake activity.

Given the instrumental coverage and low population densities of the region, many small and moderate earthquakes will almost certainly have gone undetected and consequently the earthquake catalogues for north-east Queensland are incomplete. Indeed, prior to the installation of the Charters Towers seismograph, potentially damaging earthquakes of Richter magnitude 5.0 or even slightly larger may have been overlooked and consequently omitted from the catalogue. Small to moderate earthquakes (e.g. with Richter magnitudes $3\frac{1}{2}$ to $4\frac{1}{2}$) occurring between the installation of the Charters Towers seismograph and the mid-1980s would have been detected by that seismograph but it may not have been possible to locate them all. Some of these pre-1980s events, however, have been documented from press and other historic records (see especially Rynn, 1987, and Rynn and others, 1987).

Since the mid-1980s, by contrast, moderate and large earthquakes occurring in north-east Queensland should have been located using the Australian national network of seismographs (operated by AGSO). Further, any large north-east Queensland earthquakes (~ magnitude 6 or larger) should have been located by the global network of seismographs for the past 90 years or more. The Cairns region earthquake catalogue should be complete for earthquakes of these minimum magnitudes from the onset of the times mentioned. Gaull and others (1990) stated that the catalogue was complete for their north-east Queensland Zone 30, which includes Cairns, from 1981 for earthquakes of Richter magnitude 2 to 3 and larger, and from 1945 for earthquakes of magnitudes 4 to 5 and larger. In light of the low population densities and very sparse seismographic coverage mentioned above, we consider it to be unlikely that the earthquake catalogue was complete from these dates for these magnitudes.

An indication of earthquake activity that may be missing from the catalogue for most years is given by the 140 or so very small earthquakes located in period 1990-1993 with the assistance of the Tully instruments, now decommissioned. About half of these were located about 40 km offshore from Innisfail in 1990 and 1991 following the nearby 1989 and 1990 Richter magnitude 4.0 events. Another 75 or so small events in 1990-1993 were located about 65 west-south-west of Innisfail. In total numbers, if not in importance, these small events comprise more than half the catalogue for the Cairns region. Most of this group of 140 events have one of only two epicentres, so that they do not appear numerous in [Figure 4.1](#). Their coincident epicentres give an example of the inability of the north-east Queensland seismographic network to locate earthquakes accurately.

The seismographic coverage of Cairns improved with the installation of two Cairns instruments in 1997 under the Joint Urban Monitoring Program (JUMP), an initiative of the Commonwealth and States following the disastrous 1989 Newcastle earthquake. One instrument is an accelerograph (installed at Tunnel Hill), which records strong earthquake ground shaking data for use in developing earthquake building code standards. The other instrument in Cairns is a combined seismograph and accelerograph and is installed at Henley Hill. Seismographs are far more sensitive than accelerographs, and are used primarily to locate earthquakes.

The significant recorded earthquakes within 200 km of Cairns are listed in [Table 4.3](#), and the complete listing of all recorded earthquakes in the Cairns region is listed in [Appendix F](#). This detailed list of approximately 260 events comprises information on approximately 220 earthquakes from the Australian Earthquake Database, maintained by AGSO, and an additional 40 or so small events from the database of the Queensland University Advanced Centre for Earthquake Studies (QUAKES) not contained in AGSO's database.

Most historic earthquakes in the Cairns region, including seven of the eight earthquakes of Richter magnitude 4.0 or greater listed in [Table 4.3](#), occurred within about 100 km of the coastline. There is, however, a considerable degree of uncertainty regarding the locations of all earthquakes that occurred

up to the time of installation of the Burdekin seismographic network - some epicentres may be several tens of kilometres from the true locations of the earthquakes.

Table 4.2: Seismographs within about 500 km of Cairns

Code	Site name	Operator ¹	Type ²	Latitude °S	Longitude °E	Opening date	Closing date
CTAO	Charters Towers	AGSO/QLD	DWWSSN	20.08	146.255	09-57	Open
CN1	Henley Hill	QLD	DSA	16.954	145.736	07-03-97	Open
CN2	Tunnel Hill	QLD	DA	16.911	145.710	05-03-97	Open
TV1	Townsville	QLD	DSA			1998	Open
TV2	Townsville	QLD	DA			1998	Open
BGR	Glenroy	QLD	S	20.549	147.105	16-02-81	Open
BLO	Burdekin Lookout	QLD	S	20.624	147.120		Open
BSL	Bruslee	QLD	S	20.867	146.564	02-03-84	Open
CVL	Collinsville	QLD	S	20.59	147.609	30-04-85	Open
DLB	Dalbeg	QLD	S	20.151	147.264		Open
DNG	Doongara	QLD	S	20.555	146.475		Open
MCP	Mt Cooper	QLD	S	20.552	146.806		Open
MHP	Mt Hope	QLD	S	21.396	146.802	10-04-84	Open
PFD	Peter Faust Dam	QLD	S	20.385	148.374	18-04-91	Open
UKA	Ukalunda	QLD	S	20.899	147.127	28-03-84	Open
BCS	Camp Site	QLD	S	20.619	147.131	11-01-81	15-01-81
BGC	Glendon Crossing	QLD	S	20.614	147.160	12-12-81	29-04-85
BMG	Mt. Graham	QLD	S	20.614	147.060	13-02-81	30-04-85
BNG	Bungobine	QLD	S	21.344	147.312	05-05-85	30-08-85
DBG	Dalbeg	QLD	S	20.275	147.299	05-03-84	02-04-84
GVA	Glen Eva	QLD	S	21.489	147.482	18-03-86	01-06-87
BLP	Blunder Park	QLD	DS	17.758	145.422	19-01-90	1995
CCQ	Carron Ck Quarry	QLD	DS	17.849	145.567	20-01-90	1995
DPT	Dingo Pocket	QLD	S	17.912	145.822	1994	1995
HRD	H Road	QLD	DS	17.76	145.65	23-01-90	1995
MNH	Munroe Hill	QLD	S	17.97	145.8	21-01-90	1994
RVH	Ravenshoe	QLD	S	17.633	145.484	16-01-90	1995
SCY	Sunday Creek Yard	QLD	DS	17.878	145.337	18-01-90	1995

NOTES:

¹ QLD = QUAKES (University of Queensland)

² Types are: DWWSSN = digital worldwide seismographic network station; DS = digital 3-component seismograph; DA = digital 3-component accelerograph; DSA = digital 6-component combined seismograph and accelerograph; S = vertical-component analogue (drum recorder) seismograph

The largest known earthquake in north-east Queensland, the Richter magnitude 5.7 Ravenswood earthquake of 18 December 1913, is listed in [Table 4.3](#) for reference, although its epicentre is more than 350 km south of Cairns. This event also appears to have occurred within 100 km of the coast. The proximity to the coast of historic earthquake activity is reflected in the earthquake hazard contours paralleling the coast in the Queensland earthquake hazard map published as Figure 2.3(g) in the Australian Building Code minimum design loads on structures for earthquakes, known as Australian Standard *AS1170.4-1993* (Standards Australia, 1993). These contours show the relative expected severity of earthquake ground motion across the state expressed as an ‘acceleration coefficient’.

Three estimates of regional earthquake hazard are known for Cairns. All three estimates relate to a 10% probability of exceedence in 50 years at 'rock' or 'firm' sites. The 10% probability of exceedence in 50 years corresponds to an annual exceedence probability (AEP) of approximately 1/475.

The first estimate is found in Gaull and others (1990). Their estimate is described in [Appendix H](#). The second estimate is found in *AS1170.4-1993*. An acceleration coefficient of 0.06 for the Cairns area was provided in Table 2.3 of *AS1170.4-1993*. This value approximates a peak horizontal ground acceleration, or PGA, of 0.06 g, where 'g' is the acceleration of a falling object under gravity. The third estimate of hazard originates from QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.2 g on rock, in line with their estimates of PGA for Queensland 2-3 times higher than previous estimates. A comparison of the three results is given in [Appendix H](#).

Considerable debate has surrounded the contrasting earthquake hazard estimates of Cuthbertson and Jaume (1996) and those in *AS1170.4-1993*. We prefer to use the acceleration coefficient in *AS1170.4-1993* until new estimates of earthquake hazard for Queensland are made under the current revision of *AS1170.4-1993*. The revised standard is expected to be published within several years.

The earthquake hazard for Cairns is moderate by Australian standards. More than half the area of Australia in the earthquake hazard maps in *AS1170.4-1993*, including Cairns, has an acceleration coefficient in the range 0.05 - 0.1. The coefficient values across Australia range from a minimum 0.03 to highs of up to 0.22 in 'bullseye' areas.

The magnitude of the Maximum Probable Earthquake has a moderate effect on earthquake hazard estimates. In light of the incomplete history Gaull and others (1990) estimated maximum magnitude to be half a magnitude unit higher than that observed. For the Cairns area, their estimate was magnitude 5.8. This value is too low and the estimate of Cuthbertson and Jaume (1996), magnitude 7, is more appropriate.

[Appendix H](#) presents the rock response spectrum of Somerville and others (1998) which may be used to complement, or augment, earthquake hazard estimates for Cairns in *AS1170.4-1993*.

The Cairns Earthquake Experience

Earthquakes so far have not caused significant damage in Cairns. The 1896 earthquake produced the highest known ground shaking intensities in Cairns, MM V, and caused cracking in concrete railway tunnels. At Mareeba, small objects were thrown off shelves. The 1913, 1950, 1958 and 1989 earthquakes were also felt in Cairns. The 1913 Ravenswood earthquake was felt over a large part of north-east Queensland, including Cairns, although apparently without causing damage (Rynn and others, 1987). The 1958 earthquake caused ground shaking intensities of MM IV in downtown Cairns and MM V in what are now the northern beach suburbs of Cairns. The QUAKES database notes 'minor damage' for this earthquake. A foreshock and several aftershocks, all within a period of eight hours, apparently were felt in Cairns. [Figure 4.2](#), [Figure 4.3](#), [Figure 4.4](#) and [Figure 4.5](#) show the seismic intensities recorded from the 1896, 1913, 1950, and 1958 earthquakes respectively.

We note some minor discrepancies in the catalogue for the 1950 and 1958 earthquakes. The magnitude of the 1950 earthquake is listed as ML 3.2 in the AGSO catalogue ([Appendix F](#)) and as ML 4.0 in [Figure 4.4](#). Different sources provided these two magnitude values. We consider the magnitude of ML 3.2 is more appropriate. [Figure 4.5](#) contains two further errors. The origin time of the 1958 earthquake listed in [Figure 4.5](#) is probably incorrect. We think the event occurred at 10 hr 35 min. 31 sec. and that one of the aftershocks occurred at 10 hr 38 min., although this has not been confirmed. [Figure 4.5](#) lists a magnitude of ML 4.4 for this event but a more recent estimate of the magnitude is ML 4.7.

The most recent earthquakes close to Cairns occurred at 1:55 am and 4:38 am local time on 25 November 1997 (see [Appendix F](#) and [Figure 4.1](#)). Although these two earthquakes were small (Richter magnitudes 2.5 and 2.1 respectively) and apparently were not felt in Cairns, they are a reminder that the area near Cairns is seismically active and that larger earthquakes are possible. These earthquakes would have been poorly located, if at all, without the JUMP instruments.

Table 4.3: Significant historic earthquakes within 200 km of Cairns¹

Date	Time (UTC ²) hr min	Lat. (°S)	Long. (°E)	Place	ML ³	I _{max} ⁴	Comments
27-02-1896	10 58	17.0	145.7	15 km SW Cairns	4.3(I)	V	Cracking in five concrete railway tunnels and two culverts, Cairns
18-12-1913	13 54	20.0	147.0	Ravenswood	5.7(I)	V	Weakly felt Cairns
10-04-1942	03 00	16.2	145.7	Daintree	3.8(I)	IV	Not felt Cairns
19-06-1950	09 00	17.5	145.5	Atherton	3.2	IV	Weakly felt Cairns
01-12-1958	10 35	16.5	145.5	50 km NNW Cairns	4.7(I)	V	'Minor damage' Cairns
19-08-1961	02 26	15.8	144.7	170 km NW Cairns	4.1		
28-03-1963	04 29	17.6	146.2	Innisfail	3.2(I)	IV	Not felt Cairns
06-05-1974	16 55	17.5	146.0	Innisfail	4.0		
16-11-1989	10 43	17.39	146.30	Near Innisfail	4.0		Felt Cairns
13-05-1990	05 35	17.29	146.14	Near Innisfail	4.3		
04-09-1994	08 02	16.99	144.50	Chillagoe	4.0		

NOTES:

¹ Earthquakes ML ≥ 4 and earthquakes felt at or near Cairns. Sources: Australian Earthquake Database (AGSO); Queensland Railways Commissioner's Report, 1896; Everingham and others, 1982; Rynn and others, 1987

² UTC - Coordinated Universal Time = Australian Eastern Standard Time minus 10 hours

³ ML - Richter (or local) magnitude. The term (I) indicates a magnitude calculated from the radius of the felt effects of the earthquake

⁴ I_{max} - Maximum seismic intensity measured on the Modified Mercalli Scale (Dowrick, 1996; see [Appendix G](#))

Urban earthquake hazard in Cairns

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

We prepared urban earthquake hazard maps (or microzonation maps) for Cairns. Two examples are shown in [Figure 4.6](#) and [Figure 4.7](#). These maps indicate zones in Cairns where potential earthquake shaking is expected to be relatively weaker or stronger. They were prepared using existing 1:100 000 scale geological maps (Willmott and others, 1988), geotechnical data from borehole logs and test pits,

and microtremor data from recordings of low level ‘background’ ground vibrations (described below). **Appendix H** gives a detailed description of the methods used to prepare the urban hazard maps.

The Cairns geology has been grouped into four site classes for the urban earthquake hazard maps (**Table 4.4**). Our site classifications are based on those developed for the 1994 provisions of the US National Earthquake Hazard Reduction Program (NEHRP). The provisions were published in FEMA (1995) and we have referred to the version reproduced by Hwang and others (1997).

Sites requiring special consideration, including sites vulnerable to potential failure or collapse under seismic loading (liquefiable sediments, quick and highly sensitive clays, etc.), peats and/or highly organic clays, very high plasticity clays, and very thick ‘soft/medium stiff clays’, have not been identified in the zonation maps although they almost certainly exist in Cairns.

Table 4.4: Site classifications for earthquake hazard maps

Site class	Description	Cairns setting
A	Rock	Largely coastal ranges
B	Hard and/or stiff/very stiff soils; mostly gravels	Higher foothill slopewash gravels, sands and silts
C	Sands, silts and/or stiff/very stiff clays, some gravels	Lower foothill slopewash sands, silts and clays
D	Profile containing at least 3 m of soft/medium stiff clay	Coastal plain organic clays and sands

Figure 4.6 shows the first urban zonation map for Cairns. This map is designed for a particular period of vibration of earthquake ground shaking, period $T = 0.3$ seconds (i.e., the time taken to complete one cycle of vibration). Earthquake ground shaking with this period of vibration may affect low-rise buildings (1-3 storeys) and other structures with similar natural periods of vibration.

NOTE: Limitations of the earthquake hazard maps

The maps indicate the earthquake ground shaking hazard at a generalised local level. They should not be considered accurate at a site-specific level and should not be used to replace site investigations where required by building codes or local regulations.

The relative strength of shaking in the zones is described by a set of amplification factors linked to the site classes. Amplification factors in this map range from 1.0 (Site Class A), through 1.3 (Site Class B) and 1.5 (Site Class C) to 2.0 (Site Class D). The amplification factors were determined from recordings of Californian earthquakes (Borcherdt, 1994; Crouse and McGuire, 1996).

These amplification factors are similar to the Site Factors in *AS1170.4-1993*, and indicate a difference of a factor of two in hazard for different parts of Cairns. That is, the shaking of soft sediments on the low-lying coastal plains, found underlying suburbs such as Cairns North and City, would be twice as strong as that experienced on rock, found in parts of suburbs such as Bayview Heights, Kanimbla and Mooroolooloolo, during the same earthquake. (More correctly, this would be the case for a probabilistic earthquake scenario, independent of the location of the earthquake source. The outcome for any particular earthquake 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.)

The factor of two mentioned above, between the strength of ground shaking on rock and soft sediments, could, in fact, be higher in Cairns. Hard basement rock underlying sediments will increase the amplification factors and this may well be the case for Cairns. ‘Rock’ in Australia (*AS1170.4-1993*) is equivalent to ‘Hard rock’ in California (Hwang and others, 1997). *AS1170.4-1993* includes a Site Factor of $S = 0.67$ for ‘... rock strength Class L (low) or better’, resulting in amplification factors of three between hard rock and soft sediments. Crouse and McGuire (1996) had insufficient recordings of Californian earthquakes to distinguish between ‘Hard rock’ and ‘Rock’ response and they aggregated the recordings as ‘Rock’ (Site Class A for Cairns). We choose to use the empirical Californian data and we note that more research is needed to develop appropriate Australian amplification factors.

The hazard map indicates areas in Cairns that are likely to undergo the strongest shaking. These areas are inner city suburbs including Aeroglen, Cairns North, City, Parramatta Park, Portsmouth, Manunda and Westcourt, together with the northern beach suburbs of Holloways Beach, Machans Beach and Yorkeys Knob. Buildings in the proposed urban development in Trinity East would also experience the strongest shaking.

A second, similar earthquake hazard map for Cairns is shown in [Figure 4.7](#). This map shows zones of earthquake hazard for earthquake ground shaking with a period of vibration $T = 1.0$ second. It is pertinent to ground shaking that may affect some high rise buildings (10 storeys and higher) and other structures with similar natural periods of vibration. The reader will note that the zones in this map are identical to those in the previous map. However, the amplification factors are different and in this map they range from 1.0 through 1.7 and 2.0, to 2.9. Except for the unity rock value, these amplification factors are significantly higher (around 50%) than the Site Factors in *AS1170.4-1993*. The amplification factors are summarised in [Table 4.5](#).

The areas of Cairns expected to undergo the strongest shaking at this period of vibration include Cairns North and City where all of the city’s high-rise buildings are located.

The amplification factors in the two earthquake hazard maps ([Table 4.5](#)) are appropriate for moderate input levels of earthquake ground motion. The maps show an input level of Peak Horizontal Ground Acceleration (PGA) of 0.1 g. Our amplification factors are derived from empirical values recorded from Californian earthquakes (Crouse and McGuire, 1996).

With increasing levels of incoming peak ground acceleration, the amplification factors reduce to an extent. Also, as we have seen, the amplification factors differ for different periods of vibration of the ground. In general then, the amplification factors in the earthquake hazard maps depend on the strength of earthquake input ground motion and on the period of vibration of the ground motion under consideration.

Table 4.5: Amplification factors for Cairns hazard maps (input PGA ~ 0.05 g - 0.2 g)

Site class	Amplification factor ¹	
	$T = 0.3$ s	$T = 1.0$ s
A	1.0	1.0
B	1.3	1.7
C	1.5	2.0
D	2.0	2.9

NOTE: ¹Crouse and McGuire (1996)

A range of Cairns earthquake hazard maps, for periods of vibration of the ground in the range $T = 0.1$ seconds to $T = 3.0$ seconds, and for input shaking from $\text{PGA} = 0.1$ g to $\text{PGA} = 0.4$ g, can be produced. Their appearance is identical to [Figure 4.6](#) and [Figure 4.7](#) but the amplification factors will differ. We can model earthquake scenarios of varying severity and their effects on a range of building types by selecting the input parameters. [Appendix H](#) describes how to derive the range of Cairns earthquake hazard maps.

Multiplying the regional (input) earthquake hazard value by the relevant amplification factor in the zone produces absolute estimates of earthquake hazard in a particular zone. For example, a regional input PGA of 0.1 g is amplified by 2.0 on Site Class D at a period of $T = 0.3$ seconds, producing a value of $\text{PGA} = 0.2$ g on Site Class D at this period.

Map of natural resonant period of vibration of ground motion in Cairns

The alluvial sediments underlying the coastal plains of the corridors of the Barron River and the Mulgrave River (including the area north of the Mulgrave River extending into Cairns inner suburbs) are extraordinarily thick. A maximum thickness of at least 80 m of Quaternary alluvium has been recorded in the Mulgrave River corridor and more than 90 m has been recorded beneath the Barron River delta (Muller and Henry, 1982).

The earthquake response of these sediments may have a bearing on building behaviour in future earthquakes, especially that of high-rise buildings. In the simplest case, these sediments may resonate with characteristic periods of vibration when excited by seismic waves. Structures on top of the sediments and ‘in tune’ with them, (i.e. vibrating with a period close to the period of a mode of vibration of the ground) may receive significant seismic energy from the ground. This may lead to larger and larger displacements of the building with a consequently increased risk of damage. This phenomenon is thought to be responsible for the preferential damage to certain classes of buildings, in certain parts of Mexico City, in the September 1985 earthquake. The epicentre for this earthquake was more than 350 km away from Mexico City but site effects of a drained lake beneath parts of Mexico City resulted in extensive damage and 8 000 deaths. Resonance in the period range of 1-2 seconds is thought to have been responsible for the damage to buildings between 10 and 14 storeys high, which had resonant periods of between 1 and 2 seconds, where lower and taller buildings did not suffer structural damage (Bolt, 1988).

Cairns has had some experience of what could occur in a strong local or regional earthquake. On 19 March 1995, an earthquake of magnitude 7.1 in Irian Jaya caused movement in the 15-storey National Mutual Building in Cairns City. Although the earthquake was more than 1 900 km away from Cairns, blinds, pictures and doors were seen to move. The ‘slow’ swaying was described as ‘strong’ on Floors 14 and 15 and included ‘creaking and cracking’ sounds in a concrete column (C. Lynam, QUAKES, written communication, 1999).

The map of natural resonant period of ground vibration for Cairns ([Figure 4.8](#)) supplements the maps of amplification of ground shaking. It provides additional information on the fundamental period of vibration of the ground during earthquake shaking. It also provides additional information on the potential for increased damage to buildings due to the increased possibility of resonance between the ground and the buildings on it during earthquakes. The map was prepared by measuring the natural period of vibration of the ground by recording microtremors (very weak motion of the ground caused by ‘background’ noise from traffic, wind, surf, etc.) with portable seismographs in a joint AGSO-QUAKES survey in 1997 (Jaume and others, 1997). The point values of natural ground period taken at nominal 500 m intervals at more than 300 sites in Cairns were contoured to produce the map.

The contoured natural period is remarkably high in many parts of Cairns (more than one second). The contours are subparallel to the margins of the ranges in many parts, indicating a thickening of sediments toward the centres and mouths of the Barron and Mulgrave river corridors. Remarkably, areas of Edmonton and Gordonvale also have high natural periods, indicating thick sediments near the margins of the river corridors in these areas. No measurements were taken between these two suburbs and fill-in data in this area would be useful. There is a noticeable agreement between the areas of highest natural period and the areas of Site Class D in the earthquake hazard maps, indicating both thick sediments at depth in these areas and also slow seismic wave velocities in the near surface sediments. The latter are responsible for the Site Class D rating of these areas. In areas where no measurements were taken, natural period was estimated using information on thickness and the types of sediments present.

In the simplest case, where the fundamental mode of vibration of the sediments dominates and the fundamental mode of vibration of buildings with a high degree of symmetry is excited by earthquake shaking, the map of natural period provides a guide to areas which may be potentially hazardous for buildings of particular natural period. *AS1170.4-1993* stated that:

the structure period (T), in seconds, may be determined by a rigorous structural analysis. Alternatively, the fundamental period of the structure, and where the structure has different properties in two orthogonal directions, the period for the orthogonal direction for structures of uniform vertical distribution of mass and stiffness may be approximated by the following equations:

$$\text{Fundamental period:} \quad T = h_n / 46 \quad \dots 6.2.4(1)$$

$$\text{Period for the orthogonal direction:} \quad T = h_n / 58 \quad \dots 6.2.4(2)$$

where h_n = total height of the structure above the structural base (in metres). The fundamental period shall be associated with the more flexible structure direction and the period for the orthogonal direction shall be associated with the most rigid structure direction.

From these formulae, a typical 10 storey building in Cairns, with reasonably symmetric distribution of mass and stiffness around horizontal and vertical axes, may have a fundamental period of around 0.9 seconds, and a 15 storey building a fundamental period of around 1.4 seconds. Similarly, a three-storey building may have a fundamental period of around 0.25 seconds.

Numbers of buildings at risk and vulnerability of building stock

The total number of buildings, by suburb for Cairns, built on each Site Class (A to D), is shown in **Figure 4.9**. The suburbs are ranked, from left to right in the figure, according to the number of buildings on Site Class D, Site Class C, and so on. This comparison gives a first impression of suburb-by-suburb risk from direct damage to buildings. For example, Westcourt is entirely situated on Site Class D, the most hazardous site class, and also has the second largest number of buildings of any suburb. By contrast, we may expect that Caravonica is much less at risk from earthquake because it has a relatively small number of buildings, and over half of these buildings are situated on the two least hazardous site classes.

However, these data are not sufficient to assess suburban risk posed by building performance during earthquakes. The performance depends on building characteristics such as type of construction, age, height, condition, symmetries in the distribution of mass and stiffness and so on. The risk is a function of the damage states of the buildings, building usage indicating the numbers of people likely to be occupants, the degree of business interruption and the likelihood of secondary hazards such as fire and hazardous chemical spills.

We prepared detailed building inventories for each suburb, classifying by building type and also by site class, to calculate the number of elements at risk. The Cairns building database was used. This database was compiled from field observations of the exterior of buildings and, consequently, provides only details of wall cladding material rather than construction type. To assess building vulnerability to earthquakes, however, information on the type of structural frame or load-bearing walls is needed.

The importance of identifying the types of load bearing elements of a building, rather than simply the wall cladding, and the difference it can make to estimates of direct damage to buildings, is seen in the following example. In the 1989 Newcastle earthquake, solid brick houses performed about twice as poorly as brick veneer, in terms of percentage losses of the total insured value of the building stock. Houses with timber frames (brick veneer, fibro and timber cladding) all performed similarly (Blong, 1998). There is, none-the-less, a reasonably good degree of correlation between the type of wall cladding and construction type.

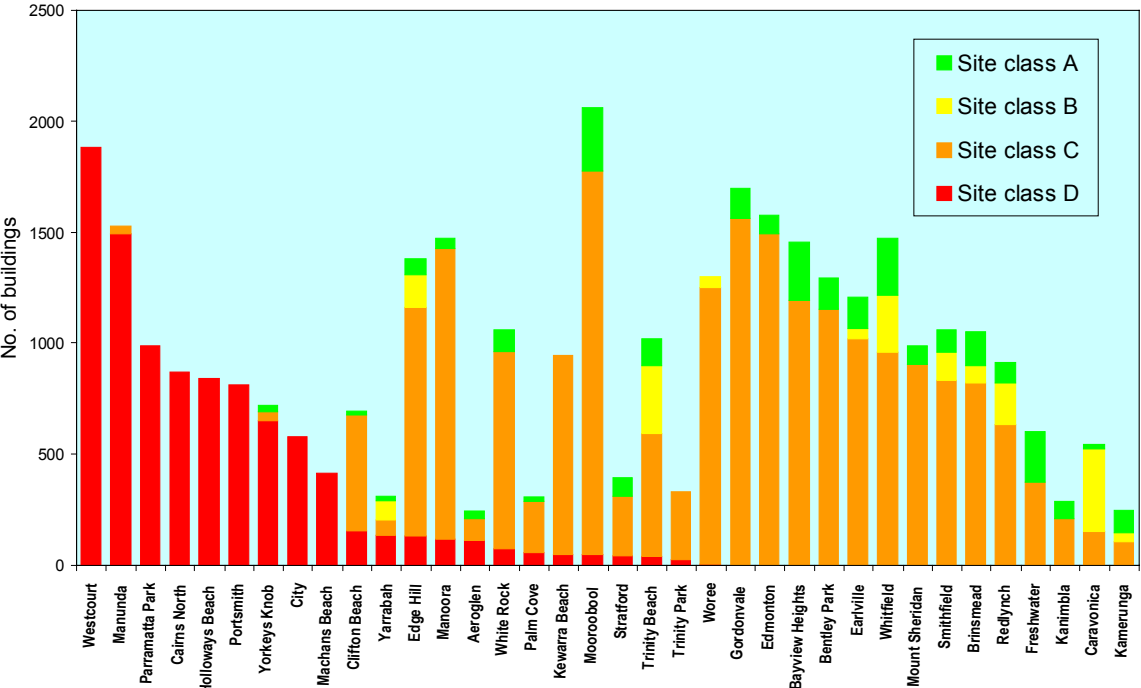


Figure 4.9: Number of buildings on Site Classes A-D for Cairns suburbs

Reinforced concrete block is the most common type of construction type in Cairns (Photo 4-1), outnumbering buildings with timber frames by a factor of about two. The overwhelming majority of these concrete block buildings are residential, and new housing increases the trend towards concrete block construction. We consider that concrete block buildings complying with modern wind loading standards will probably perform well under the moderate seismic loadings expected in Australia. However, the earthquake vulnerability of concrete block buildings may vary with age. Older concrete block buildings not built to either a wind or earthquake loading standard may be less earthquake-resistant than equivalent modern buildings complying with the codes. We have separated the concrete block buildings into several groups to reflect this expected difference in vulnerability according to their age (age data are available for residential buildings and we have estimated ages of non residential buildings). In 1975, as a consequence of Cyclone *Tracy*, wind loadings provisions were included in the Queensland Building Act. We consider that concrete block buildings constructed prior to 1975 are more vulnerable to earthquakes than those constructed after this date. However, domestic buildings were not included in the wind loading provisions until 1982. We consider that concrete block

residences built before 1983 retain the earthquake vulnerability of the non domestic concrete block buildings built prior to 1975.

The wall type 'brick' in the Cairns building database includes both solid brick and brick veneer construction types. We separated brick veneer construction from solid brick by making the assumption that all 'brick' houses and low-rise flats built up to 1960 in Cairns are solid brick (unreinforced masonry), and all 'brick' houses and low-rise flats built after 1960 have timber frames with brick veneer (**Photo 4-2**). Unreinforced masonry has a poor history of performance in earthquakes worldwide although its strength may be improved by the presence of cross walls (J. Wilson, verbal communication, 1999).

Buildings with light timber frames behave in a ductile manner in earthquakes. In Cairns they comprise buildings with walls of timber (**Photo 4-3**), fibro, brick veneer, and metal (used in residential buildings). No attempt has been made to subdivide these buildings by their second-order vulnerability to earthquakes, although the building database contains information that could be used for this purpose. For example, floor height vertical asymmetry displayed by the stump-mounted 'Queenslander' design, tile or steel roofing material, and size of window openings are all factors described in the database that have the potential to affect building performance of timber frame buildings in earthquakes.

The cyclone resistance of some classes of new buildings was significantly upgraded in 1982 with the introduction of Appendix 4 of the Queensland Building Act on 1 July. Improvements were made to the cyclone resistance of non-domestic buildings with light timber frames (George Walker, verbal communication, 1999). Importantly, for the first time, domestic buildings were described by the act. We consider that all domestic buildings in Cairns designed since that date also have significant earthquake resistance through their conformity to that code. In developing the building inventory for Cairns we have aggregated all domestic buildings constructed after 1982 into a group with common earthquake vulnerability.

'Engineered' (generally multi-storey) buildings were generally designed for resistance to strong winds much before that. The SAA Interim 350 Standard of 1952 provided stringent design standards for these buildings, and we consider that older, multi storey buildings in Cairns may have intrinsic earthquake resistance through the application of this standard.

Metal wall cladding is found on timber frame houses, both new and old, and also covering light steel frames on low-rise factories, small businesses, warehouses, etc. We separated the buildings with metal wall cladding into these two frame types, largely through assessing the building usage *Type* field in the Cairns building database (house or business/commercial/logistic, etc.).

Medium rise and high rise buildings in Cairns, apart from medium-rise concrete block buildings, have reinforced concrete frames and masonry infill (C. Baker, Cairns City Council, verbal communication, 1998), with a variety of wall claddings. Newer buildings have reinforced masonry (concrete block) infill and concrete slab floors. Some multi-storey buildings of pre-1975 vintage, have concrete shear walls poured in situ. Other older buildings, such as Calvary Hospital and the main (older) block of Cairns Hospital have unreinforced masonry (brick) infill. Buildings with concrete frame and unreinforced masonry infill panels are more vulnerable to earthquake shaking than those with reinforced masonry infills. One reason is that the unreinforced masonry infill is more prone to cracking. Upon cracking of the infill, the performance of the structure becomes largely dependent on the strength of the concrete frame.

We note that our count of only five buildings in Cairns with concrete tilt-up walls underestimates the future extent of this increasingly popular method of construction for low-rise business, commercial and industrial premises.

The older (pre-war) ‘Queenslander’ timber houses ([Photo 4-4](#)) on stumps are of special interest because they are found in tropical Australia but not elsewhere in Australia or in many other countries. Most of these are in older, inner Cairns suburbs such as Parramatta Park. Their performance in strong earthquake shaking is not known. 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). It has been argued that these houses have demonstrated their resistance to cyclones if not earthquakes through having survived many events. Many old ‘Queenslanders’ are not in optimum condition, however, and their performance could be poorer, particularly if the stumps are not cross-braced.

None-the-less, old ‘Queenslanders’ may not pose an enhanced risk in terms of direct losses or casualties compared to other residential building types. Although we may expect that old ‘Queenslander’ houses will have larger horizontal displacements in earthquakes than newer timber frame houses on concrete slabs because of the ‘inverted pendulum’ effect of their elevated floors and walls, we would not expect this to lead to greatly increased casualties. These houses are not massive and occupants will not be vulnerable to the collapse of masonry walls and gables, or tile roofs.

These buildings are also the properties in Cairns that are most at risk from fire following a severe earthquake, because of the potential for breakage of electric and gas supply mains to them, and overturning of containers of flammable material. They may also be the most likely to spread fires due to their close proximity to one another in some areas ([Photo 4-5](#)), although the risk of fire is probably very low.

The revised building database ([Table 4.6](#)) shows that the most common construction types of buildings in Cairns are overwhelmingly:

- concrete block masonry (56% of total number of buildings constructed after 1974 and another 7.6% prior to 1975);
- timber frame domestic buildings (33%);
- light steel frame buildings used for small business and factories, etc. (1.6%); and
- unreinforced masonry (1.0%).

The remainder, which comprises only about 0.02% of the total Cairns building stock, is:

- medium and high rise concrete frame buildings with either unreinforced or reinforced masonry infill; and
- low rise concrete tilt-up buildings.

Table 4.6: Cairns building inventory by Site Class

Construction type	Site Class				Total
	A	B	C	D	
Domestic after 1982, light timber non domestic after 1982, reinforced masonry non domestic after 1974	2228	1213	14799	2735	20975
Light steel frame	0	2	69	472	543
Light timber frame before 1983	267	244	2839	3658	7008
Concrete frame & reinforced masonry infill	0	0	2	41	44
Reinforced masonry domestic before 1983, reinforced masonry non domestic before 1975	206	254	2565	2227	5252
Concrete frame & unreinforced masonry infill	1	0	13	13	27
Unreinforced masonry	9	13	82	213	317
Other	0	0	5	5	10

NOTE: See [Table 4.4](#) for an explanation of the site classes

We consider that: buildings with timber frames; concrete block buildings complying with wind loadings codes; buildings with reinforced concrete frames and reinforced masonry infills; and buildings with light steel frames, are less vulnerable to earthquake. Older concrete block buildings not complying with wind codes; buildings with reinforced concrete frames and unreinforced masonry infills; and, (especially) unreinforced masonry buildings, are most vulnerable.

The more vulnerable buildings, which are typically older, are concentrated in the older suburbs that are situated on the most hazardous ground conditions, especially Site Classes C and D.

An indication of the earthquake risk from direct damage to buildings in each suburb may be obtained from the plots by:

- the total number of buildings in the suburb; and
- the types of buildings on each Site Class and their numbers.

To use our previous example, Westcourt has a large number of buildings, all of which are located on Site Class D, and it also has a significant proportion of older concrete block and unreinforced masonry buildings, making it among the suburbs with the greatest exposure to earthquake damage. Caravonica, by contrast, has fewer buildings, all of timber frame or modern concrete block construction, and more than half its buildings are on Site Class A or B. It has a relatively low exposure to earthquake damage.

In order to produce a ranking of Cairns suburbs for earthquake risk from direct damage to buildings we have introduced a vulnerability ranking of building types, given in [Table 4.7](#). The ranking is not a measure of building vulnerability.

Table 4.7: Vulnerability ranking for Cairns building types

Building type	Vulnerability ranking
All domestic buildings built after 1982	1
Light timber frame non domestic buildings built after 1982	1
Non domestic reinforced masonry (concrete block) built after 1974	1
Reinforced concrete frame with reinforced masonry infill	1
Light steel frame	1
Light timber frame built before 1983	2
Domestic reinforced masonry (concrete block) built before 1983	3
Non domestic reinforced masonry (concrete block) built before 1975	3
Reinforced concrete frame with unreinforced masonry infill	3
Unreinforced masonry	4

Earthquake risk assessments

Suburb-by-suburb ranking of building damage: We used the earthquake hazard map for Cairns ([Figure 4.6](#)), the revised Cairns building database and the building vulnerability index ([Table 4.7](#)) in the formula:

$$Risk\ coefficient = \Sigma[(amplification\ factor) \times (number\ of\ buildings\ at\ risk) \times (vulnerability\ ranking)]$$

to produce an earthquake risk ranking for Cairns suburbs. An example of the calculation follows. Unreinforced masonry has a vulnerability ranking of 4. Suppose there are 10 unreinforced masonry

Table 4.8: Earthquake risk ranking for Cairns suburbs

Suburb	Risk coefficient	Risk rank	Suburb	Risk coefficient	Risk rank
Westcourt	6994	1	Bentley Park	1864	19
Manunda	5660	2	Machans Beach	1722	20
Mooroobool	4275	3	White Rock	1631	21
Parramatta Park	4110	4	Clifton Beach	1596	22
Edge Hill	3977	5	Kewarra Beach	1484	23
Bayview Heights	3907	6	Smithfield	1468	24
Whitfield	3778	7	Brinsmead	1465	25
Cairns North	3588	8	Mount Sheridan	1457	26
Earlville	3382	9	Redlynch	1401	27
Woree	3382	10	Stratford	1242	28
Manoora	3263	11	Freshwater	1181	29
Holloways Beach	3076	12	Trinity Park	879	30
Yorkeys Knob	2850	13	Palm Cove	875.5	31
City	2620	14	Yarrabah	756.5	32
Portsmith	2594	15	Caravonica	733.6	33
Gordonvale	2534	16	Aeroglen	690	34
Trinity Beach	2355	17	Kamerunga	419.2	35
Edmonton	2319	18	Kanimbla	395	36

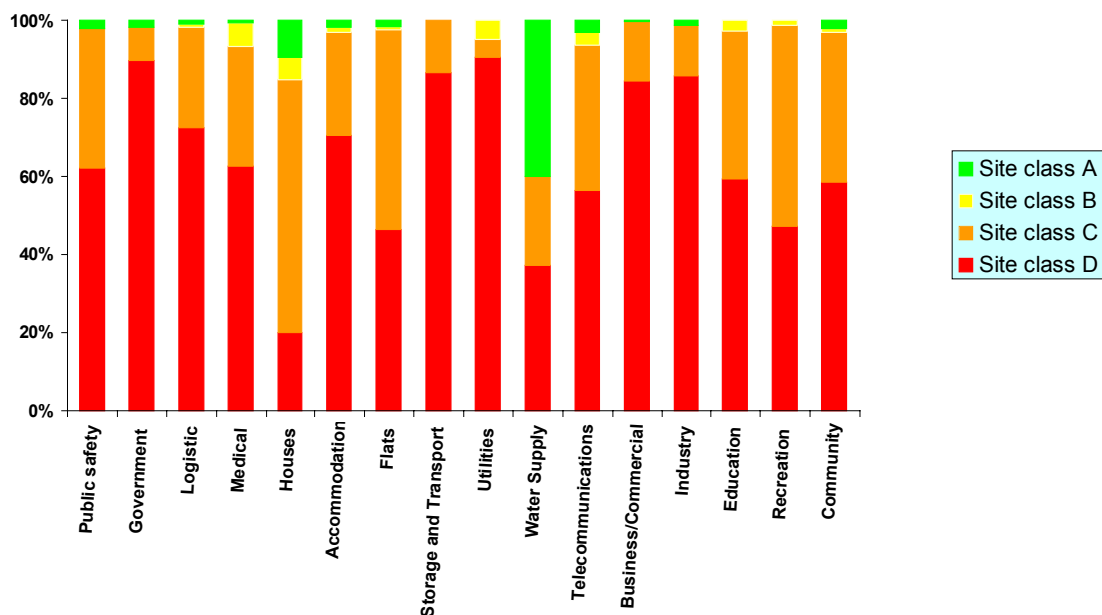


Figure 4.12: Building usage and earthquake site class relationships

Interpretation

The earthquake hazard in Cairns is moderate by global standards, but it is not negligible. Gaull and others (1990) constructed a seismic source zone in northern Queensland that included Cairns. Cuthbertson and Jaume (1996) identified a seismic source zone with one of the highest rates of activity in Queensland extending several hundred kilometres south-east from Cairns.

In many places of Australia, probably including Cairns, moderate to strong earthquakes of magnitudes in the range 5 to 6 comprise around 90% of the total contribution to the overall earthquake hazard. The occurrence of such an earthquake close to Cairns would be a rare event. However, the impact of such an event could be very high. An earthquake in this magnitude range (ML 5.6) near Newcastle in 1989 caused arguably Australia's most costly 20th Century natural disaster.

The impact would be aggravated by extensive thick sediments at Cairns that, beneath coastal suburbs, are also 'soft'. These sediments are expected to behave unfavourably in strong earthquakes.

As a contrast, the modern, cyclone-resistant building stock in Cairns would perform better in earthquakes than the buildings in many Australian cities where significant proportions are older and constructed of unreinforced masonry. This cyclone-resistant stock comprises about two-thirds of the total number of buildings in Cairns.

However, the risk to other one-third of buildings comprising the most vulnerable buildings in Cairns is compounded because they are located overwhelmingly on the two least favourable ground conditions – Site Class C and Site Class D. These buildings are the older concrete block and older timber frame buildings, unreinforced masonry buildings and, of medium-rise buildings, those with concrete frames and unreinforced masonry infill. In any future earthquake affecting Cairns, the most pronounced direct damage may occur to these buildings because of their construction type, their condition, and their location.

Limitations and Uncertainty

We consider the earthquake hazard maps for Cairns and the revised building inventory to be reasonably well developed and appropriate for their usage. We are, none-the-less, mindful that future building inventories undertaken under the *Cities Project* will need to contain information on frame or load bearing wall type and floor type if they are to be more useful for earthquake risk calculations.

The methods used to calculate earthquake risk require considerably more development. Earthquake risk methods need to assess:

- direct economic losses;
- direct social losses;
- indirect economic and social losses; and
- the impact of secondary hazards including fire, hazardous material spills, debris and inundation by tsunami or seiche.

To achieve this, the assessment methods must address the impact of earthquakes on essential facilities and engineering lifelines as well as on the general building stock.

The suburb-by-suburb ranking of earthquake risk for Cairns is useful, but it is no substitute for rigorous risk assessment using quantitative data on building and engineering lifeline performance under a range of earthquake scenarios.

AGSO's *Cities Project* is actively developing these risk assessment methods.

Remarkably, because we have ranked earthquake risk suburb-by-suburb rather than quantified risk in this chapter, the effects of uncertainties in the risk assessment process are less evident than they otherwise would be.

Large uncertainties certainly do exist. Briefly, they 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, which is certainly the case for Cairns. The 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, and the scatter of the data used to measure this attenuation;
- the definition of earthquake source zones; and
- the level of earthquake activity within these source zones.

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

Uncertainties in estimates of urban earthquake hazard

- the appropriateness of Californian data for Australian conditions needs to be investigated further;
- the Cairns urban earthquake hazard maps were prepared by a medium-level process which included the use of limited geotechnical and geophysical data but did not employ computer waveform modelling or empirical local earthquake recordings. The inclusion of these data and techniques would improve the rigour of the results.

Uncertainties in the assessment of building performance

- the performance of different construction types of buildings in earthquakes needs to be investigated further;
- we did not account for building condition and nor did we assess the effect of soft storeys or asymmetries in building configuration although the Cairns building database contains information that could be used for this purpose. These factors may be of primary importance on an individual building basis in any future earthquake.

The effect of the uncertainties in building performance are masked by our use of a building performance ranking instead of the preferable method of using fragility curves and building capacity curves to calculate building vulnerability.