The Newcastle earthquake '89 : background, causes, effects, implications

the newcastle earthquake '89

background
causes
effects
implications

Workers clearing rubble in Beaumont Street, Hamilton, a suburb of Newcastle. (Photograph by courtesy of the Newcastle Morning Herald)

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A publication of the Munich Re
Service Division

June, 1990

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Preface

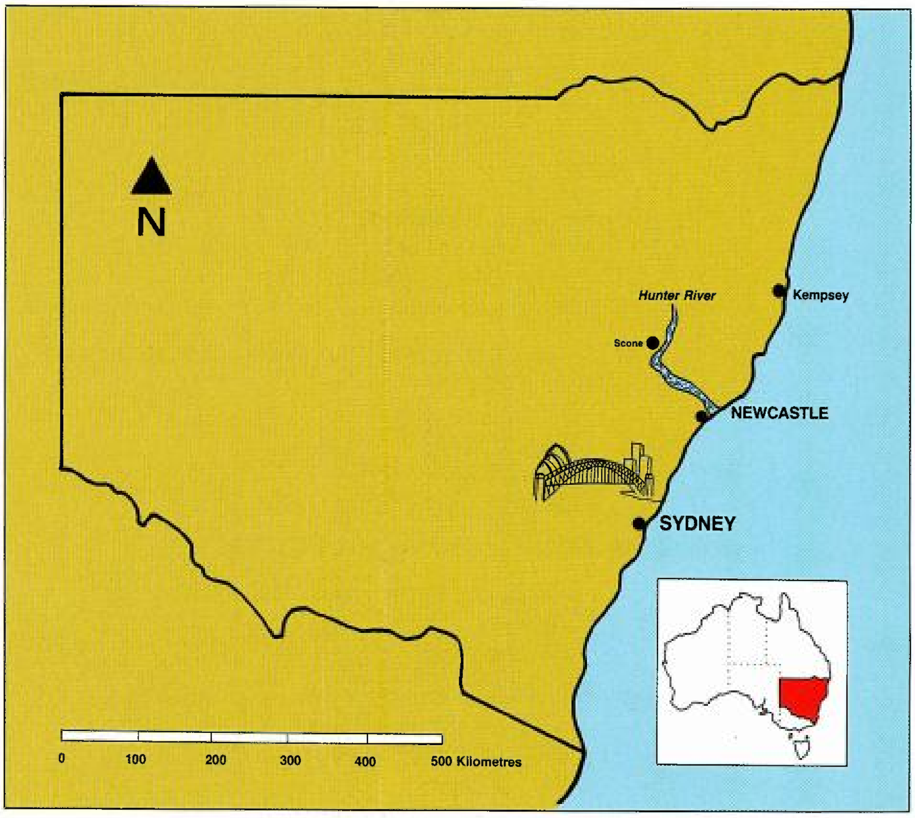
The Newcastle earthquake struck at 10:27 on Thursday morning, December 28, 1989. The 1989 earthquake was not the first experienced in Newcastle, nor was it the first in Australia to cause substantial damage to buildings and other structures. Tragically, twelve people were killed-it was the first earthquake since European settlement in Australia in which people died.

Natural disasters are not simply geophysical events. Disasters result from the interaction of physical and social forces. The consequences of the Newcastle earthquake of December 28, 1989 stem not only from the intensity of the earthquake but also from the historical, social and economic character of the city.

Several hundred commercial and industrial buildings and thousands of dwellings in Newcastle and its suburbs were damaged or destroyed. The earthquake was felt across an area of about 300,000 square kilometres with minor building damage occurring as far afield as Sydney, Scone and Kempsey.

Closure of the Newcastle city centre for 12 days, as debris was removed and buildings were inspected for structural damage, increased the cost of the earthquake to both business houses and the insurance industry and disrupted the lives of many of the inhabitants of the city.

Although Australia is an old, eroded continent built largely of old and resistant rocks and separated by large distances from the active tectonic margins of the great crustal plates which make up the global surface, it is not free of earthquakes. There are also substantial areas of soft recent sediments that amplify ground shaking and exacerbate the likelihood of damage to man-made structures. Newcastle City, built on the alluvial and estuarine sediments deposited at the mouth of the Hunter River during the last few thousand years, is one such area. Heavy industry, much of the town centre, and a number of suburbs have developed on the alluvial flats. Kooragang Island, formed by numerous estuarine islands, was reclaimed in the 1950s as a site for the expansion of industry.



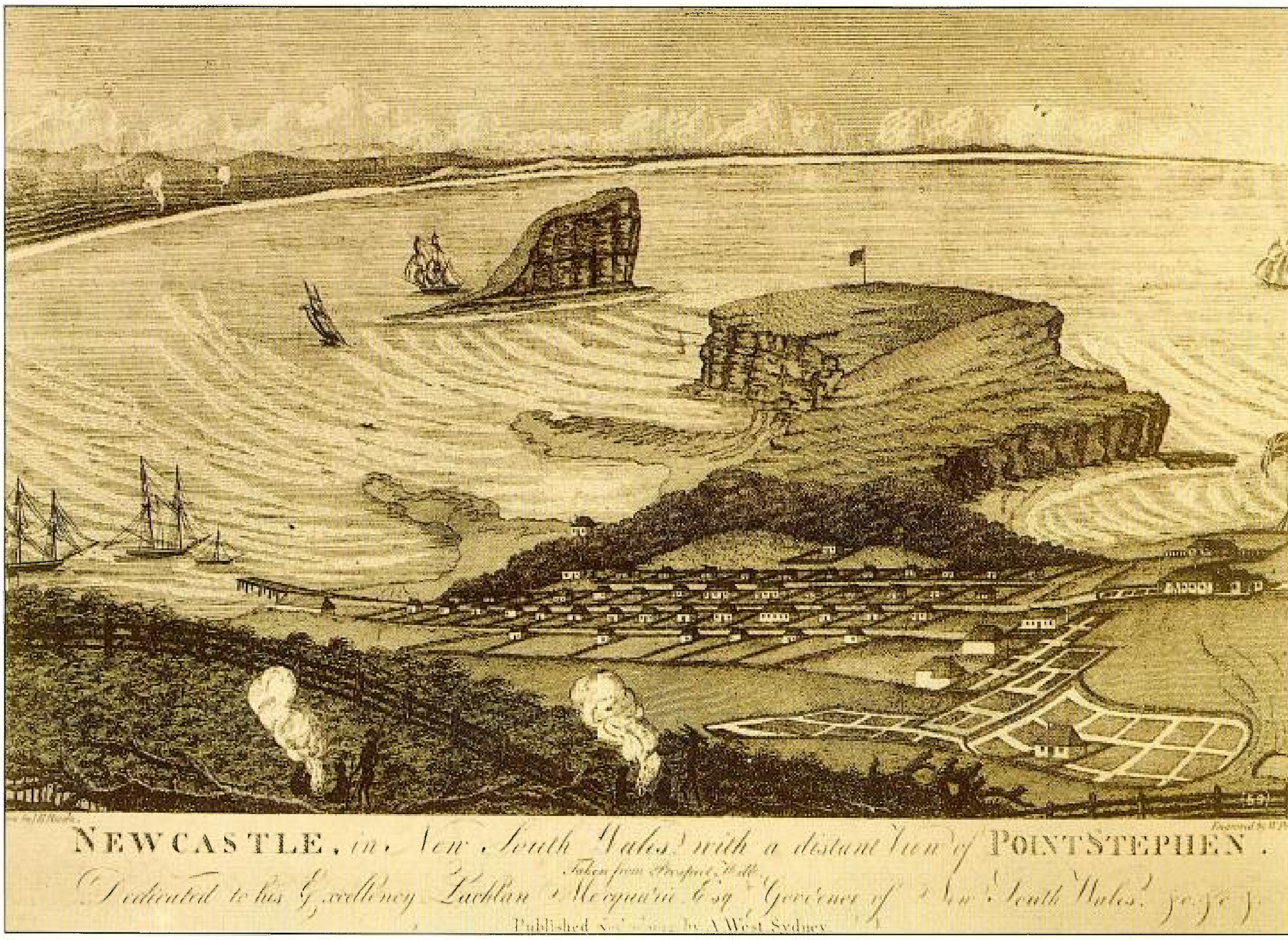
1. Newcastle lies at the mouth of the Hunter River, 125km north of Sydney.

Newcastle City had its origins in the first few decades of the nineteenth century as a convict settlement established to mine coal. Although overshadowed by Morpeth and Maitland in the first fifty years of the last century as agriculture expanded into the fertile lands of the Hunter Valley, Newcastle boomed as demand for coal increased in the second half of the century. Small isolated pit-head towns – Merewether, Hamilton, Wallsend, Lambton, New Lambton, and Adamstown – eventually coalesced as tramways spread to serve the population.

As a result of this and more recent mining activity much of the city area is underlain by abandoned workings. Mine subsidence has always been a problem.

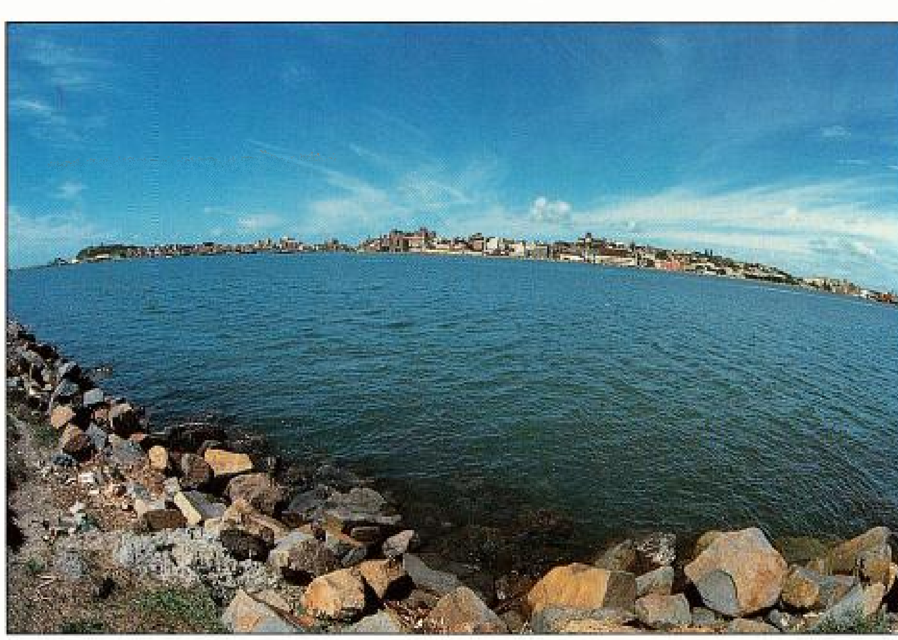
The great depression of the 1930s profoundly affected Newcastle, with large numbers of workers being laid off from the heavy industries which had sprung up shortly after the turn of the century. Newcastle has always been a city of boom and stagnation – strong development in the 1910s, early 1920s and early 1970s and economic depression in the 1890s, 1900s, 1930s and 1980s.

While newer housing and development have prospered around the northern margin of Lake Macquarie, urban stagnation rather than urban renewal has characterised the downtown and inner city areas. As the historian J C Docherty wrote of the downtown area in comparing 1933 and 1982 photos "It is remarkable how little the area has changed in the fifty years since 1933". The concentration of older buildings in downtown and near-city areas has also influenced the pattern and the extent of damage produced by the 1989 earthquake.



2. An early 19th century view of Newcastle. (Photograph by courtesy of the State Library of NSW)

3. A pre-earthquake view of Newcastle from Stockton taken with a fish-eye lens. Notice the general absence of high-rise structures and the proximity of the city to the Hunter River. (Photograph by courtesy of the GIO (NSW))



Present-day Newcastle is the product of both its physical environment, much of it constructed during the last six thousand years since the sea level rose to about its present level, and almost 200 years of social, economic and legislative history. The effects of the 1989 Newcastle earthquake, and the consequences of that event for the insurance industry, are products of that history.

Can the Newcastle earthquake be compared with those in San Francisco (1906), Tokyo (1923), Chile (1960), Alaska (1964), Tangshan (1976), Mexico City (1985), or San Francisco (1989)? The earthquakes on this short list are great earthquakes; either because of the magnitude of the earthquake itself (Alaska and Chile – both 8.4 on the Richter scale), the number of human fatalities (Tokyo – more than 140,000; Tangshan – more than 250,000), the effects on engineered structures (Mexico City (1985) and San Francisco, 1989), or because of the aftermath (fire in the case of San Francisco, 1906 and Tokyo, 1923).
Should Newcastle (1989) be added to this short list of important earthquakes in the 20th century? The answer is yes.
However, the Newcastle earthquake of December 28, 1989 was not a great earthquake in any of the senses suggested above. The earthquake had a Richter magnitude of only 5.6, by no means a large earthquake by world standards and not even the largest earthquake in recent Australian experience. Compared to the world's major earthquakes the number of fatalities was small and even building damage was relatively minor. Although this event might not be a great earthquake it is important to Australia and to the global insurance industry for a number of reasons:

- Twelve people died – they were the first fatalities known in Australia as a result of an earthquake. Additionally, 100-120 people were seriously injured;
- The earthquake demonstrated that "moderate" earthquakes in Australia can result in "large" insurance losses. The earthquake may cost the insurance industry about $800 million, the greatest single loss to the Australian insurance industry. Like Cyclone Tracy in 1974, the Newcastle earthquake is of significance to the insurance industry worldwide;
- The earthquake raises concerns about the seismic resistance of many buildings in Australia and also their exposure to seismic hazard – for example, areas along the east coast of the continent.

It is for these reasons Munich Reinsurance Company of Australia Limited has produced this booklet. The earthquake has highlighted a number of issues with which the insurance industry should be concerned. In order to place these issues in as broad a context as possible, this booklet begins by providing information on the geological setting in which earthquakes occur in Australia – an important issue because it emphasises the differences between earthquakes in Australia and those in, say, New Zealand, Japan and California. The booklet then examines briefly some earlier earthquakes in Australia which have produced both damage to structures and insurance losses or have had an important influence on our understanding of the continent's exposure to seismic activity. Specific details about the 1989 Newcastle earthquake are then presented.
The performance of structures and the associated insurance losses which the Newcastle earthquake produced are then addressed. A commentary is presented on building regulations in so far as they are concerned with seismic risk (noting that they are currently under review), and suggestions are made for reducing the vulnerability of both dwellings and commercial enterprises to seismic hazards. Finally, some implications of the earthquake for the insurance industry are discussed.

Earthquakes in Australia

The tectonic setting

The surface of the globe is composed of a series of tectonic plates which "drift" across the surface at rates of a few centimetres per year. Where the plates diverge, such as in the area between Australia and Antarctica, new volcanic material is added to the plate edge (an oceanic ridge). Earthquakes occur along the rift, but these are usually rather small and since they are distant from population centres (except in the East African Rift Valley and Iceland) they are of little significance.

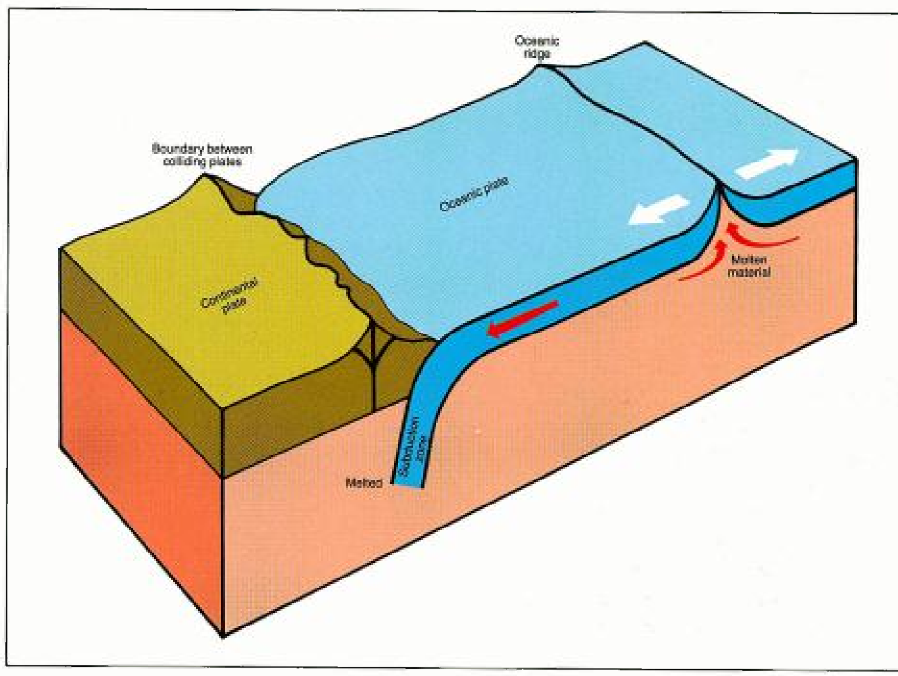
Where two plates collide, as in the area along the north coast of mainland Papua New Guinea, the oceanic plate is pushed beneath the continental plate and mountain ranges rise near the collision zone between the downgoing slab and the overlying crust. Earthquakes that occur along these margins can be amongst the most powerful on earth and very damaging when they occur close to major urban areas (for example, the Chile earthquake near Puerto Montt, Valdivia in 1960 and the Alaska earthquake near Anchorage in 1964) or where long period waves from such earthquakes shake urban centres hundreds of kilometres away that are built on soft, weak sediments (for example, the Mexico City earthquake in 1985).

Where two tectonic plates "slide" past one another, usually in a stick-slip fashion, the plates stick (lock) together as stresses develop in the rocks and then slip as the stress becomes greater than the inter-plate friction producing an earthquake and releasing the accumulated stresses. The Alpine Fault and its northern extensions through Wellington, New Zealand is of this type and indicates the margins of the Indo-Australian Plate and the Pacific Plate. However, the best known example is the San Andreas Fault in California, adjacent to both Los Angeles and San Francisco. In the 1906 San Francisco earthquake the Pacific Plate "slipped" northwestwards up to 6.5 metres relative to the North American Plate. Obviously, great earthquakes can occur in these areas where tectonic plates slide past one another.

Most of the more than 100,000 earthquakes that are felt each year somewhere on the earth's surface occur along the margins of the tectonic plates. A very large proportion of these occur along the Pacific Rim. Most of the subduction and stick-slip margins around the Pacific have experienced great earthquakes, Magnitude 8.0 or more on the Richter scale, this century.

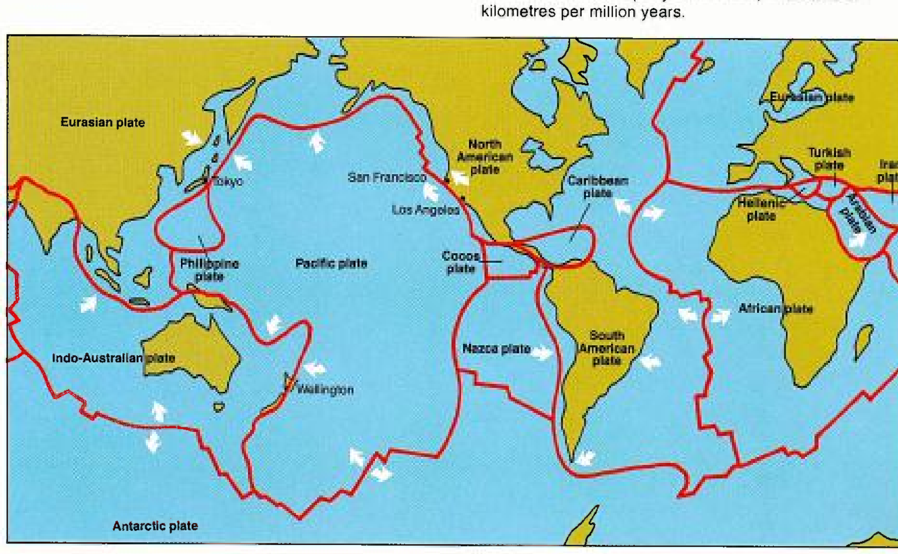
Australia lies near the centre of the Indo-Australian Plate. The spreading margin south of Australia indicates that the continent is drifting away from Antarctica.

In fact, the Indo-Australian plate is moving northwards at a rate of 7 to 8 cm per year. At the western end of the plate the collision of India with the Eurasian Plate has produced the Himalayas (and some great earthquakes). To the north of Australia, collision has produced the mountain ranges of Papua New Guinea – in effect Papua New Guinea is the bow-wave of the Australian continent!



4. Molten material rises at the oceanic ridges and is added to the oceanic plate's "conveyor belt". At subduction zones oceanic plates are pushed beneath continental plates. Collision of the plates produces mountain ranges along the plate margin. Some of the downgoing slab of oceanic plate is re-melted, then rises to form volcanoes (modified after Mallory and Cargo, 1979).

5. World map showing major tectonic plates. Arrows indicate the directions in which the major plates are "drifting" at rates of a few centimetres per year – that is, a few tens of kilometres per million years.



The Richter scale

The magnitude (M) of an earthquake is a measure of the total energy of the seismic waves. The number M=5.6 (or whatever), is a measure of the maximum amplitude of the trace recorded on a specific type of seismometer at a distance of 100 km from the earthquake epicentre (the point on the surface of the earth vertically above the focus, or origin, of the earthquake). As the specific type of instrument, a Wood-Anderson torsion seismometer, is rarely located at the appropriate distance from the epicentre, simple formulae are used to calculate the correction required. Although the Richter scale is open-ended the largest magnitude recorded is about M=8.6. The scale was devised by Professor Charles Richter of the California Institute of Technology in 1935.

The scaie is not linear but logarithmic – an earthquake with a magnitude M=5.6 is 10 times larger in terms of the amplitude of ground shaking than a M=4.6 earthquake at the same location. However, in terms of total energy released by the earthquake, a M=5.6 is approximately 30 times larger than a M=4.6 earthquake. The San Francisco 1906 and Tokyo (Kanto) 1923 earthquakes both had magnitudes of M=8.3, 500 times greater in terms of the amplitude of ground shaking, and 13,500 times greater in terms of total energy released than the Newcastle earthquake!

Intra-plate earthquakes

Australia is isolated from these tectonic margins yet, earthquakes still occur. The reasons for these so called "intra-plate" earthquakes are not clear but they probably result from compressive forces. Flexing of the crust as the Indo-Australian plate moves northward, erosion and deposition of the landmass and changes in sea level may all contribute to stresses in the crust. These processes operate slowly during geological time (thousands or millions of years), but sooner or later the accumulated stresses are relieved by the movements along subsurface fault lines which produce earthquakes.

Although, as previously mentioned, most of the great earthquakes that have occurred in the last century have been located on plate margins, there is a growing body of evidence showing that large intra-plate earthquakes can also occur. In 1811-1812 a series of earthquakes known as the New Madrid earthquakes occurred in the Mississippi Valley in the United States. The largest of these, on December 16, 1811, is amongst the largest earthquakes to have occurred in the continental United States since European settlement, and affected a far larger area than the plate margin earthquakes so far recorded on the San Andreas Fault. As George Eiby noted in his 1989 book "Earthquakes", both the size and the location of the New Madrid earthquakes present a challenge to tectonic theory.

Whatever the reasons for the occurrence of intra-plate earthquakes, it is clear that such earthquakes occur more frequently in some areas than others. While Australia, for example, is regarded by many as aseismic (earthquake-free) the continent experiences about 500 earthquakes per year. Most of these are recorded instrumentally with only a small proportion of the 500 being "felt" by the general population.

Magnitude and frequency of damaging earthquakes

Prior to the Newcastle earthquake, Australia's earthquake exposure did not seem to present a major risk. In fact, earthquakes of the size of the Newcastle earthquake (M=5.6) occur on average once every 18 months in Australia.

In the first 89 years of this century 20 earthquakes with Richter magnitude of M=6.0 or greater were recorded in Australia. While only one earthquake with Richter magnitude greater than M=7.0 (Western Australia, November 19, 1906, M=7.2) has been recorded it is estimated that M=7.5 (or M=8.0 in some areas) would be a probable extreme for Australia.

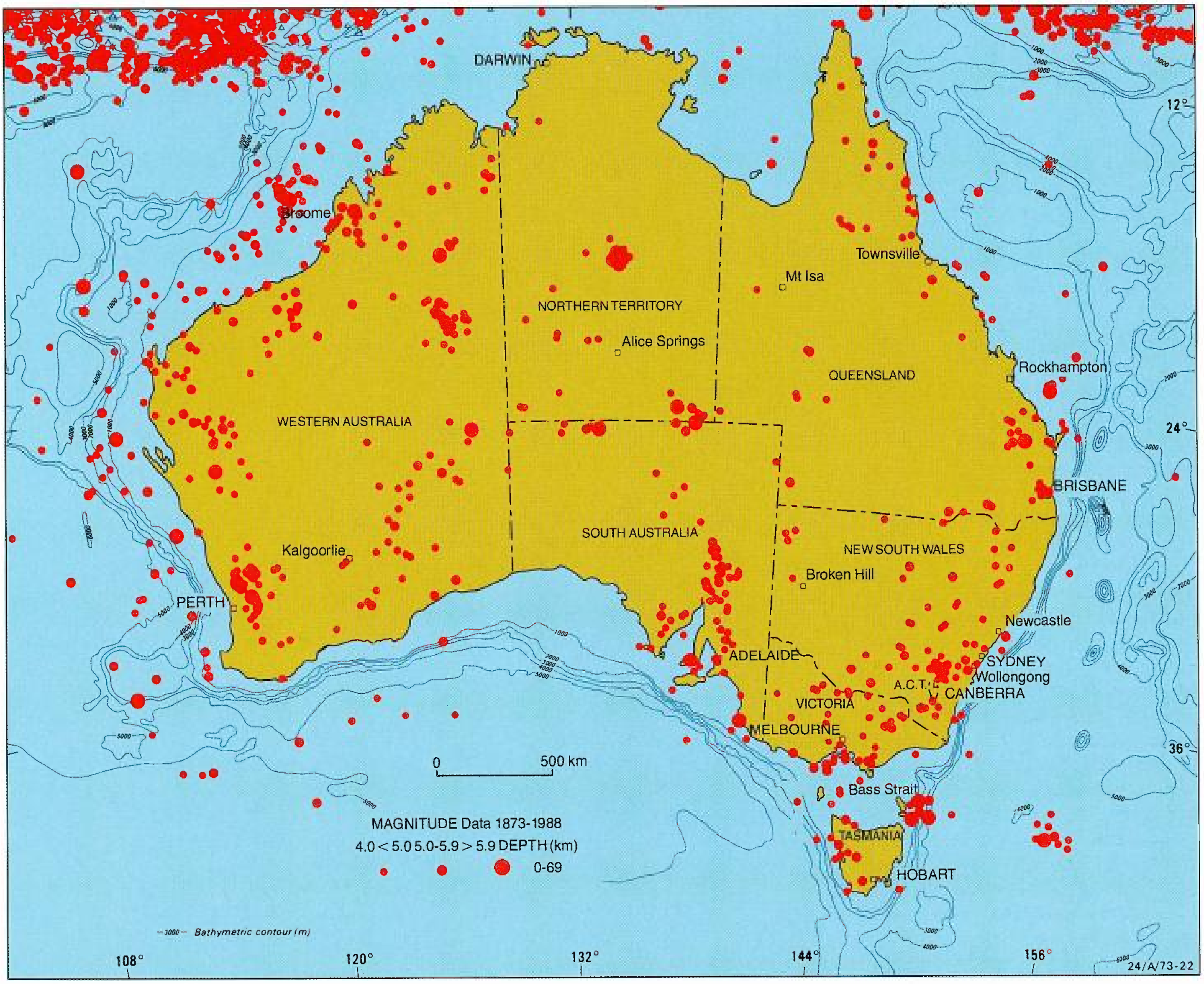
The majority of earthquakes in Australia have occurred in seven loosely defined areas:

- the Simpson Desert (south east of Alice Springs)
- the south west seismic zone, an area east and north of Perth – including the Meckering (1968), and Cadoux, (1979) earthquakes
- south eastern South Australia including the Adelaide area
- the northern part of Western Australia (the Canning Basin – north west to south east of Broome)
- the Dalton-Gunning area to the north of Canberra and extending toward Sydney
- the Wide Bay-Burnett area of central eastern Queensland
- Bass Strait and eastern Victoria

The last three areas are parts of a broad zone extending along the east coast of Australia.

It should also be noted that areas in Indonesia and Papua New Guinea have very high frequencies of damaging earthquakes and there is some potential for major earthquakes in these zones to produce damage in Australia either as a result of long period shock waves or tsunami (often erroneously called 'tidal waves').

While the majority of earthquakes in Australia can be expected to occur in the zones mentioned above, damaging earthquakes also occur outside these zones – the Lithgow earthquake of February 1986 (M=4.3), the Tennant Creek earthquake of January 1988 (M=6.7) and the Newcastle earthquake are all examples. It is not certain whether other areas shown on the map as having experienced no earthquakes in the period 1873-1988 are free of seismic activity or merely reflect the very short seismic history available in Australia.



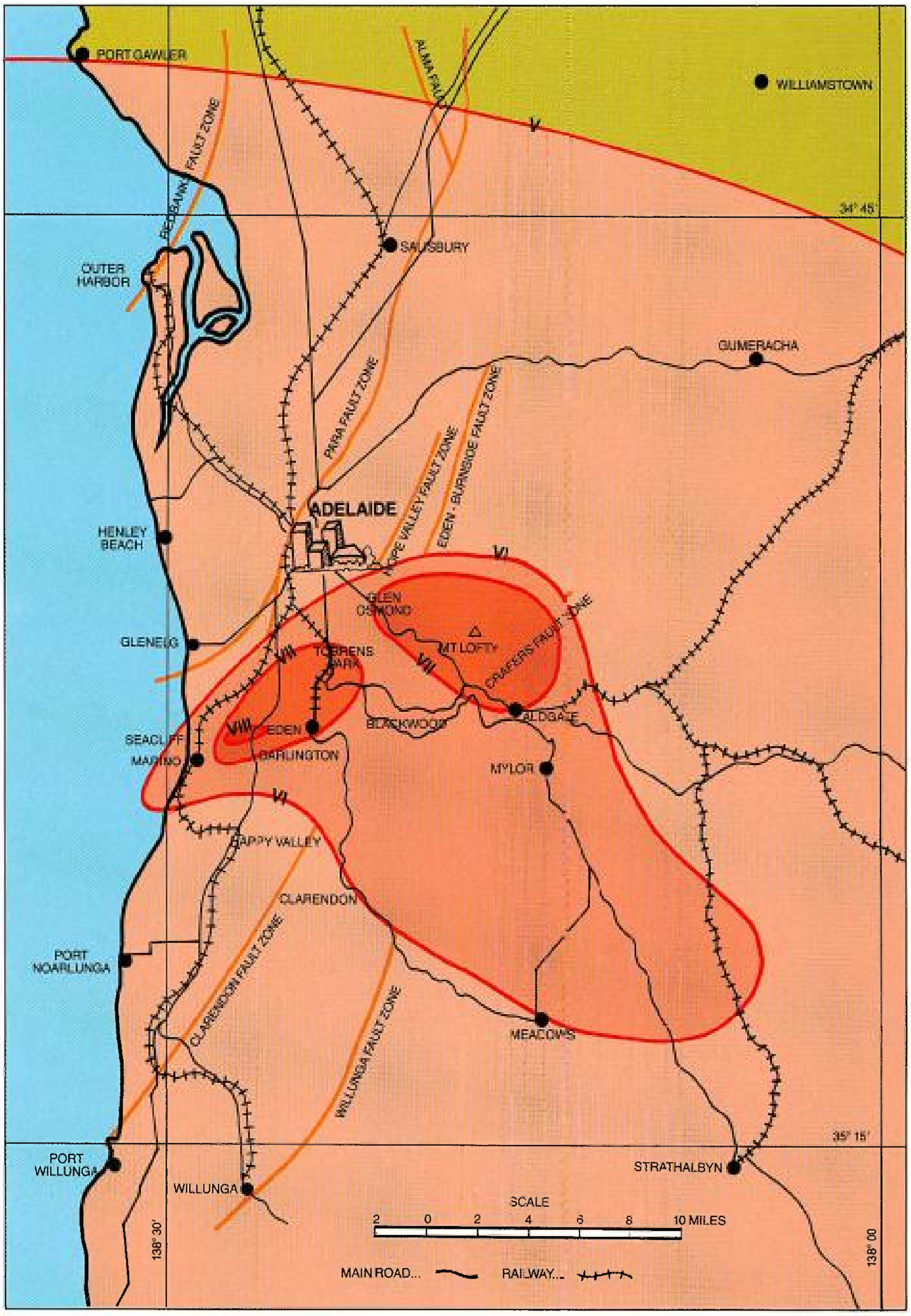
6. Locations of earthquakes in Australia 1873-1988 with Richter magnitudes greater than M=4.0. Most earthquakes in Australia occur in the seven zones (see fig 44) listed in the text but damaging earthquakes can occur elsewhere as the Newcastle event demonstrated. The heavy concentration of earthquakes along the southern margins of Indonesia and Papua New Guinea indicate that Australia, by contrast, is relatively earthquake free. (Map by courtesy of the Australian Seismological Centre, Bureau of Mineral Resources)

Historical earthquakes – Australian case studies

Adelaide, 1954

This earthquake occurred at 3:40 am on March 1 1954. The epicentre was close to Seacliff on the Eden-Burnside Fault Zone, one of the numerous NE-SW trending faults in the Adelaide area. Any movement on the fault plane must have been small, of the order of a few cm. Instrumentation at the time of the earthquake was poor but the Richter magnitude has been estimated at M=5.5 – very similar to that of the 1989 Newcastle earthquake. Ground shaking lasted five to twenty seconds in the northern suburbs of the city but only two or three seconds near the epicentre. It is believed that the quake was of shallow (less than a few kilometres) depth. The earthquake was the first moderate-sized earthquake to have originated near Adelaide in almost one hundred years. The maximum Modified Mercalli (MM) intensity (see page 11) reached VIII in the vicinity of Darlington and Seacombe Park, and a few houses were damaged beyond repair. Older houses with lime mortar were particularly prone to damage while nearby wooden buildings generally suffered damage only to chimneys. A secondary area with MM VII seems to have occurred in the vicinity of Beaumont. Maximum damage was confined to zones less than one hundred metres wide in these three suburbs. Damage in Blackwood was probably the result of shallow landslides or subsidence.

In downtown Adelaide some chimneys on a bank building and many objects in the South Australian Museum were rotated 10 to 15 degrees in an anti-clockwise direction. Most of Adelaide experienced a ground shaking intensity of MM V. Despite this low intensity and the short duration of the earthquake 30,000 insurance claims were received, the average claim amounting to about $200 (1954 values). The astonishing fact is that about one house in every three or four in the Adelaide area made an insurance claim. Most of the damage was to ceilings and plasterwork and to goods and possessions stacked on shelves. At Glenelg a lift jammed when the counterweight jumped out of its guide rails. Concrete floors bulged and gaps 120 mm wide were found in a brick building at Happy Valley. Little damage occurred to water, sewage and other underground services.



7. Isoseismal map showing areas affected by Adelaide, 1954 earthquake. About 30,000 insurance claims were made – one for every three or four houses in Adelaide at the time. (Isoseismal map modified after Kerr-Grant, 1956)

The total insured loss of about $6 million (variously reported at $4 to $8.8 million) would represent more than $100 million at 1990 prices without allowing for any increase in the size of Adelaide, variations in construction standards or changes in styles of policies written.

Modified Mercalli Intensity Scale

The Modified Mercalli Scale was developed as an index of the intensity of ground shaking based on effects, particularly the effects on man-made structures. Building and other damage is much more related to modified Mercalli intensity than it is to Richter magnitude. The abridged version presented here is modified after Eiby (1966; 1989). The Modified Mercalli (MM) scale is usually written with Roman numerals

- I Felt only by a very few people under especially favourable circumstances.
- II Felt only by a few people at rest, especially on the upper floors of buildings. Suspended objects may swing.
- III Felt quite noticeably indoors. Standing motor vehicles may rock slightly. Vibration like the passing of a truck.
- IV Felt indoors by many, outdoors by a few. At night, some awakened. Crockery, glassware, windows, doors rattle.
- V Felt by nearly everyone. Unstable objects displaced or overturned. Some crockery, glassware, windows broken. Disturbance of tall objects sometimes noticed.
- VI Felt by all. Some heavy furniture moved. Some instances of cracked or fallen plaster. Slight damage to poor quality masonry, particularly chimneys.
- VII Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly-built or badly designed structures. Weak chimneys broken; unbraced parapets and architectural ornaments may fall.
- VIII Damage slight in specially designed structures; partial collapse of some ordinary substantial buildings; great damage in poorly-built structures. Fall of chimneys, awnings, monuments, walls; brick veneers damaged.
- IX Damage considerable in specially designed structures; well-designed frame structures distorted; great damage in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously; underground pipes broken.
- X Most masonry and frame structures destroyed; some well-built wooden structures seriously damaged or destroyed. Ground badly cracked; rails bent; landslides common.
- XI Few, if any, masonry structures remain standing. Wooden frame structures destroyed. Great damage to railway lines and underground pipes.
- XII Damage total. Practically all works of construction destroyed or greatly damaged.

Other earthquake intensity scales in common use around the world are shown below. This table, from Munich Re World Map of Natural Hazards (1988) also shows the ground accelerations experienced with each Modified Mercalli Intensity. It must be emphasised that this relationship is only approximate as other factors such as the spectrum of seismic waves and the duration of shaking can also have important influences on intensity.

Earthquake Intensity Scales

MM 1956	Descriptive Term	Acceleration %g	MSK 1964	RF 1883	JMA 1951
I	Imperceptible	<0.1	II	II	
II	Very slight	0.1-0.2			I
III	Slight	0.2-0.5	III	III	
IV	Moderate	0.5-1	IV	IV	II
V	Rather strong	1-2	V	V	III
VI	Strong	2-5	VI	VI	IV
VII	Very strong	5-10	VII	VII	
VIII	Destructive	10-20	VIII	VIII	V
IX	Devastating	20-50	IX	IX	VI
X	Annihilating	50-100 (≈1g)	X		
XI	Disaster	1-2g	XI	X	VII
XII	Major disaster	>2g	XII		

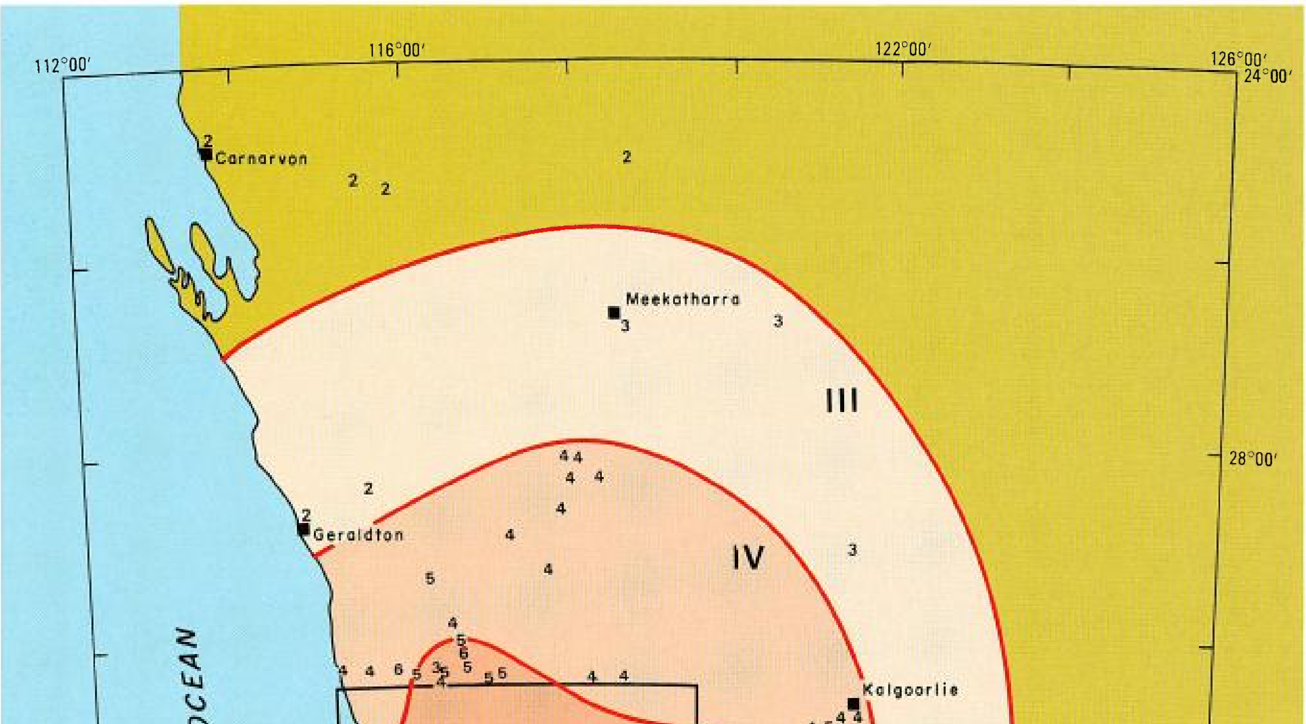
MM 1956 Modified Mercalli · MSK 1964 Medvedev-Sponheuer-Karnik
RF 1883 Rossi-Forel JMA 1951 Japan Meteorological Agency

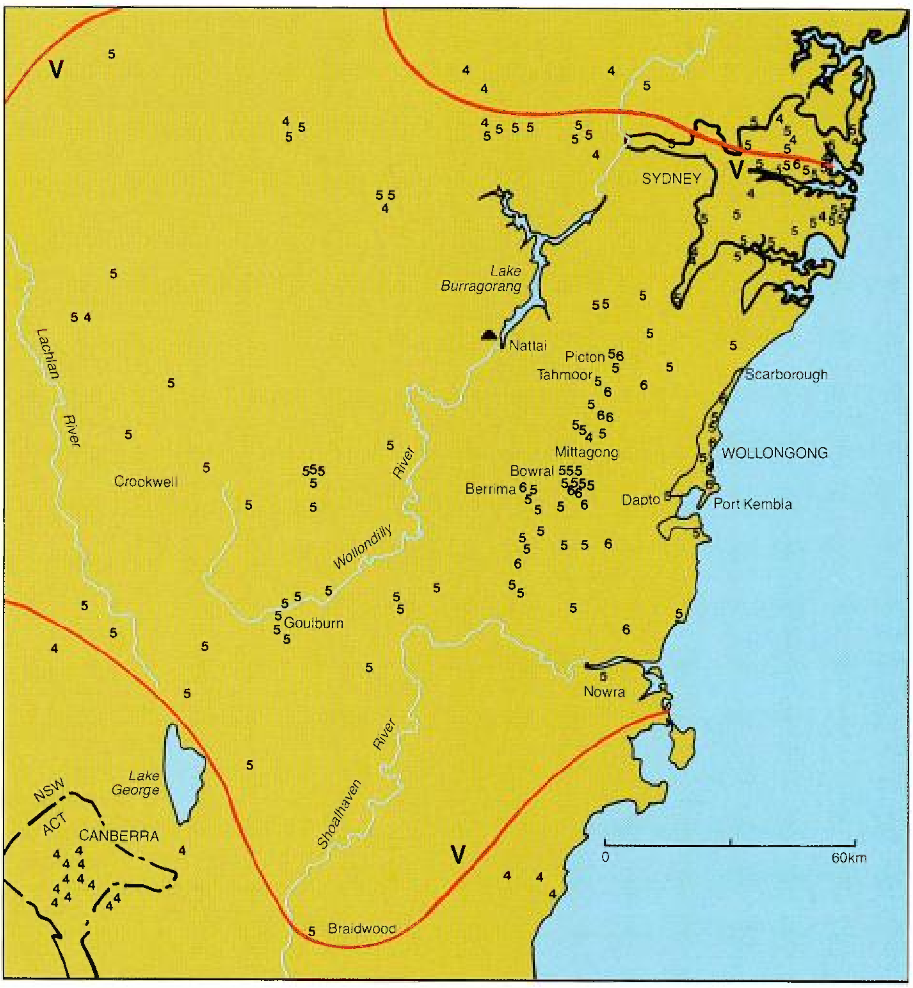
Meckering, 1968.
The so called Meckering Earthquake occurred in Western Australia on October 14, 1968. The earthquake occurred at 10.59 am local time. It was a shallow focus earthquake of Richter magnitude M=6.8. and the quake caused extreme damage to the town of Meckering.
This quake is remarkable in that it is one of the few earthquakes in Australia that can be clearly associated with surface faulting. Faulting was clearly seen at the surface along a zone some 32 kilometres in length, trending in a north-south direction. To the east of this fault the land was uplifted by up to 1.5 metres and overthrust to the west by a maximum of 2 metres.

Within approximately 100 metres of the fault all rigid structures were flattened but several more flexible structures, (i.e. timber frame sheds and verandahs) remained upright. In the town of Meckering intensities as high as MM IX were recorded and many buildings were totally destroyed. It was reported that the bank, hotel, shire hall, three churches and 60 of approximately 75 houses were severely damaged. Very few of the remaining buildings were habitable, the exception being the more flexible timber framed structures.

In the region surrounding the town, which generally experienced intensities of MM VII, most old brick and stone buildings were unsafe to enter. It was reported that the earthquake was easily noticed by car passengers in this region and there were also several reports of observers having seen ground waves. Many public services including railway-lines, pipe-lines and roads were all severely fractured close to the fault zone. Extensive cracking of the ground immediately surrounding the surface fault was also noticed.
Damage is estimated to have cost approximately $2.2 million (1968 prices).

8. Isoseismal map of the Meckering earthquake of October 14, 1968. The map shows the high intensities experienced in the immediate vicinity of the epicentre. (Isoseismal map courtesy of Everingham et al., 1982)





9. Isoseismal map of the near epicentre region for the Picton earthquake, March 9, 1973. 423 insurance claims were paid by members of the Fire and Accident Underwriters Association of New South Wales. About 80% of the claims came from areas more than 30 km from the epicentre. About half of the claims came from Sydney suburbs. (Isoseismal map by courtesy of Everingham et al., 1982)

Picton, 1973.

The Picton earthquake occurred at 5.09 am on March 9, 1973. The magnitude of the earthquake which originated at a depth of about 20 km, approximately 90 km south west of Sydney, was M=5.5. Several aftershocks were also felt.

The earthquake was felt across an area of about 200,000 square kilometres while light damage was experienced across about 4,000 square kilometres. Denham (1976) has provided a summary of the earthquake and its effects.

Although very limited areas (near Tahmoor, for example) experienced MM intensties of VI or, possibly, VII, most of the area around the epicentre reached only MM V.

Damage to buildings of normal construction standard was minimal with very few buildings experiencing structural damage. Walls cracked in substantial old masonary buildings, particularly banks and hotels, in Berrima, Mittagong and Picton. Most other damage was limited to plasterwork and the tops of chimneys, although moderate damage occurred in various buildings between Port Kembla and Scarborough, i.e. in respect of roofs of top floor flats, failure of thin iron lintels, overflow of ceiling hot water cylinders. Damage to contents seems to have been minor; even where hotel walls cracked in Mittagong and Berrima, bottles on shelves were not dislodged. The only substantial contents damage occurred in a glassworks in Wollongong.

The Picton earthquake was an important one for the insurance industry as it demonstrated again the potential for a moderate earthquake to cause damage in and near a major population centre. Total (insured and uninsured losses) were estimated at about $500,000 (1973 dollars). 423 insurance claims were admitted by member companies of the Fire and Accident Underwriters Association of New South Wales with a total value of $196,355 (1973 dollars). While the average claim was only $464, more than half of the claims came from Sydney suburbs, 50 to 105 km from the epicentre! A further 24% of the claims came from Wollongong and other areas of the south coast more than 60 km from the epicentre. Still other claims came from centres such as Blue Mountains, Bathurst, Orange, Young, Goulburn, Cowra, Canberra and Newcastle, so that less than 20% of claims actually came from within 30 km or so of the epicentre.

Marryat Creek, 1986.

On March 30, 1986 at 6:24 pm a Richter magnitude M=5.8 earthquake occurred at Marryat Creek 300 km south of Alice Springs. A boomerang shaped fault scarp 13 km long was produced during the earthquake with a maximum vertical displacement of 0.6 m and a maximum horizontal movement of 0.8 m. During the next 12 days 17 aftershocks occurred, each large enough to be recorded in Alice Springs. The largest of these had a Richter magnitude of M=4.3. Details of the earthquake and its effects have been summarised by McCue et al. (1987). Hundreds of rabbit warrens adjacent to the fault scarp collapsed but because of the sparseness of human population in the area, damage was limited to cracked walls in the nearest homestead, 35 km from the epicentre. Minor shaking was reported from Ayers Rock, 200 km to the north west and from Alice Springs.

A search of the available records for previous earthquakes in the same region revealed only one known earthquake within 100 km of the epicentre of the 1986 earthquake. This earthquake, along with other recent events, indicates that intraplate earthquakes of medium size are highly unpredictable in both location and frequency of occurrence.

This was only the fourth Australian earthquake, to that time, which was definitely known to have produced a surface fault. The other three all occurred in the south west of Western Australia – Meckering, 1968 with M=6.8, Calingiri in 1970 with M=6.0, and Cadoux, 1979 with M=6.2. In 1988 the Tennant Creek earthquake also produced a fault scarp. The small number of fault scarps identified in Australia may be more a reflection on the accuracy of records than it is on the rarity of the phenomenon.

Tennant Creek, 1988

Three earthquakes near Tennant Creek, 850 km south east of Darwin, on January 22, 1988 had Richter magnitudes of M=6.3, 6.4 and 6.7 respectively. A fault scarp with a length of 35 km and a maximum surface displacement of 1-2 metres was produced. Several thousand aftershocks occurred in the next 24 hours and the sequence continued up to 1990. The earthquakes and their effects have been described by Jones et al. (in press). Near the western end of the fault scarp MM intensities reached VIII. In Tennant Creek, 30 km away, walls were cracked in well-constructed buildings, objects fell from shelves and furniture shifted. The pipeline linking gas fields west of Alice Springs to Darwin was shortened by 0.97m where it crossed the fault line. If lost production from local underground gold mines is included, the damage bill is estimated at about $1 million.

The Tennant Creek earthquakes occurred outside the known zones of major seismic activity in Australia. The magnitude of these earthquakes, with an amplitude of ground motion up to ten times that experienced in the Newcastle earthquake suggests that "background" seismicity, away from the areas of reasonably frequent earthquakes, may be much greater than previously recognised. The Tennant Creek earthquake has important implications for estimates of Probable Maximum Loss from earthquakes in Australia.

10. Damaged portions of the natural gas pipeline which extends from production fields west of Alice Springs to Darwin. The pipeline was shortened by almost one metre where it crossed the faultline. (Photo by courtesy of K. McCue, Australian Seismological Centre, Bureau of Mineral Resources)

Newcastle earthquakes before 1989

(Compiled from reports in The Newcastle Morning Herald, The Newcastle Morning Herald and Miners' Advocate, The Sydney Gazette, The Sydney Morning Herald, data from the Australian Seismological Centre, Bureau of Mineral Resources and elsewhere).

September 1 1829
Several sharp shocks among some of the mountain ranges in the Lower and Upper Hunter districts.

August 2 1837
Between 10 and 11 pm. "At Newcastle, ... a considerable earthquake was felt ... Men at work in the coal mines 23 fathoms below the surface of the earth did not perceive it, although those above ground, and especially in the higher parts of the country, could not have failed to notice it." Felt on the Paterson River and in Sydney.

January 28 1841
7.55 am. It shook the houses and the walls trembled visibly for five seconds. Also felt at Singleton, Paterson River and at Illawarra. Felt for 6-8 seconds at Maitland; some people reportedly thrown to the ground; furniture shook in West Maitland; crockery broken.
A local report reads "at about a quarter after seven o'clock am, I was aroused from my slumbers by a violent tremulous motion of the bed on which I lay, accompanied by an uncommon noise, like that of a coach driving furiously over a recently macadamised road. The noise and undulations, if they may be so called, lasted for from ten to fifteen seconds, during which period I observed all the moveables in the house vibrating".

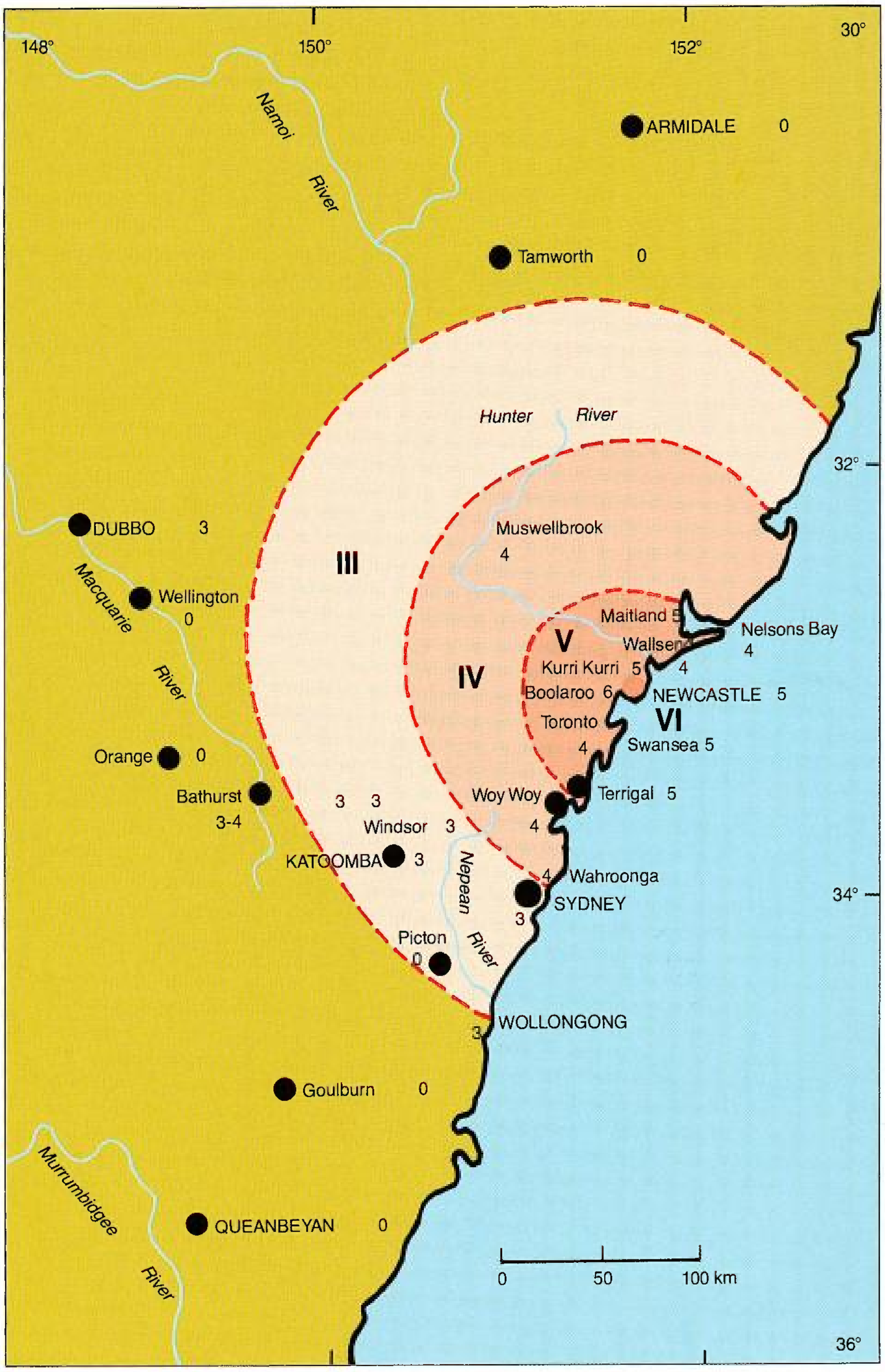
October 28 1842
5.30 am. Felt more or less in most parts of NSW – slightly at Paramatta, more distinctly at Windsor, and most violently at Newcastle, Port Stephens and Port Macquarie. In Sydney nothing was noticed. Many people were awakened in Newcastle by the shaking of walls and furniture. "The district of the Hunter has several times been visited by shocks, but such a severe and extensive one as the present had never perhaps been known".

11. Isoseismal map for the 1868 Maitland earthquake. (Isoseismal map by courtesy of McCue et al.(in press))

June 18 1868
(M=5.3) The Maitland earthquake
The epicentre for this earthquake was somewhere in the Newcastle-Maitland area.

The earthquake occurred a few minutes before midnight. In Newcastle "The shock only lasted a few seconds, and was accompanied by a low rumbling sound, the houses rocked to and fro, the windows, doors – in fact the whole of the buildings – were shaken with alarming violence, such that the inmates for the moment expected them to fall; after the shock was over a number of people were rushing about the streets, apparently under the idea that some new houses in course of erection in King or Newcomen streets had fallen to the ground; but although the shock was severe, no accident of the kind took place."

In Singleton, crockery in many houses was broken and a few chimneys came down. In Maitland and Morpeth the ceilings of many houses were damaged with heavy pieces of plaster falling from cornices. Plaster fell from a ceiling in the hospital. At least two chimneys fell (in West Maitland?). House walls gave way in Bulwer Street, in Church Street and at Kaloudah. At the railway station in Elgin Street one of the walls was cracked.The portico of the Bank of Australasia in East Maitland was cracked on either side where it joins the main building, and a portion of the exterior cornice gave way. Other walls were also cracked in East Maitland. The very old office of the police superintendent suffered severe damage. "Many other instances of trifling damage are reported, including the breakage of windows, sashes, and lamps at various places".



12. Isoseismal map for the 1925 Boolaroo earthquake. The epicentre for this earthquake was probably quite close to that for the 1989 event. (Isoseismal map by courtesy of Rynn et al., 1987)

December 18 1925
(M=5.3) The Boolaroo earthquake
8.47 pm. Lasted 6-7 seconds. Felt in many Sydney suburbs, Windsor, Woy Woy, Lithgow, Bathurst, Blue Mountains and Dubbo. Randwick police received reports of cracks developing in walls, chairs overturning, and breakage of crockery. At Roseville windows and doors rattled and crockery smashed. Plaster fell from a ceiling in Wahroonga. Plaster cracked in Mosman. At Terrigal glass was broken, pots and pans were thrown about, and fowls were thrown from their perches. At Swansea some tanks burst and goods fell from shelves. At Kurri Kurri bottles were dislodged from shop shelves. At Richmond Main and Cessnock crockery moved on shelves. In Newcastle the Anglican Cathedral was damaged.

This list is almost certainly incomplete but includes the major earthquakes known to have caused damage in the lower Hunter Valley. Many milder earthquakes will have gone unreported. As McCue et al. (1990) noted: "Since 1960 55 earthquakes with magnitude exceeding 2.5 have occurred within 100 km of Newcastle but none were as close as the 28 December 1989 earthquake and none exceeded M=4.1."

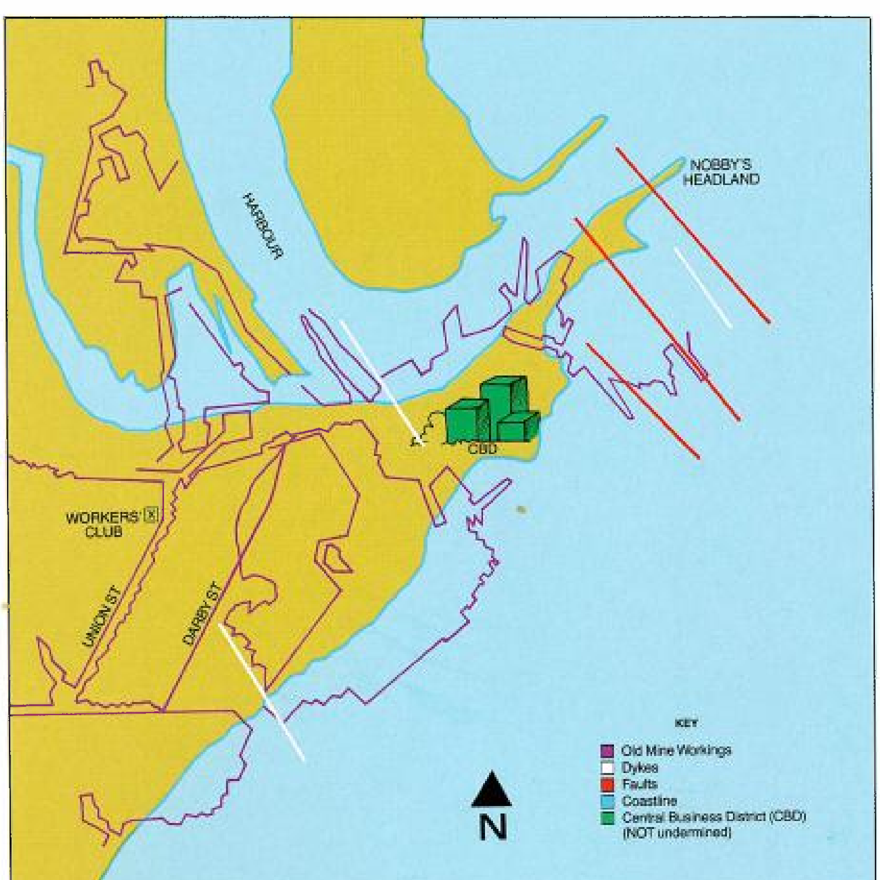
The earthquake of December 28 1989

Geology

The Newcastle area lies in a sedimentary basin between an old stable block to the west and a relatively active tectonic plate margin two thousand kilometres to the east. The sedimentary layers, the Newcastle Coal Measures, consist of a number of different rock types ranging from conglomerates through sandstones, siltstones and mudstones to coal. These sedimentary rocks were originally laid down at the earth's surface as near-horizontal layers. Subsequent deposition buried these sediments by as much as 3.0 to 3.5 km. Significant folding, the intrusion of dykes and fracturing of the rocks also occurred. Erosion of the overlying rocks over millions of years has now brought the Coal Measures close to the surface. Differential erosion has created ridges and valleys over long periods of time acting, in part, on rocks that have been mechanically weakened by folding and faulting. The near-horizontal layers in the Coal Measures and the near-vertical fault planes and dykes will have modified the propagation of seismically generated shock waves and produced a variety of seismic velocities.

The pattern of ridges and the erosion of valleys has also been strongly influenced by dramatic and repeated changes in sea level during the last few hundred thousand years. During the last Ice Age, which reached a maximum about 18,000 years ago, sea level was more than 100 metres lower than at present so that the Hunter River near the present site of Newcastle flowed in a deeply incised valley. As sea level rose toward its present level, which was achieved about 6,000 years ago, the valley of the Hunter and its tributaries near the coast was progressively backfilled with alluvial and other recent unconsolidated sediments. The presence of such soft sediments significantly amplified ground shaking and was one of the main factors contributing to the pattern of building damage in the December 28th earthquake.

Underground mining of coal in the Newcastle area began more than 150 years ago. In some areas a number of seams have been mined so that an intricate pattern of pits, underground workings at various levels, and barrier pillars between the workings of adjacent collieries underlie the city. One of the few areas that has not been mined extensively underlies the Central Business District. Although it has been suggested that this intricate pattern of workings may have had some effect in amplifying and absorbing the seismic energy produced during the December 28 earthquake, no mine collapses and only limited mine stability problems are known. Furthermore, there seems to be little relationship between areas of significant damage and known areas of mining activity.



13. Sketch map of underground coal mines in the Newcastle area. One of the few extensive land areas that has not been worked underlies the Central Business District (Map by courtesy of Dr Konrad Moelle, Institute of Coal Research, University of Newcastle)

Seismology

Details provided by Mr Kevin McCue of the Australian Seismological Centre, Bureau of Mineral Resources, indicate that the earthquake occurred on Thursday December 28, 1989 at approximately 10:27 a.m. local time. The earthquake originated at a shallow depth of 11 to 12 km beneath the surface. This depth is also below the base of the Newcastle Coal Measures and little is known about the underlying rocks. The epicentre for the earthquake probably lay in an area about 12 km west south west of the city of Newcastle, near the suburb of Boolaroo. The maximum ground surface velocities in areas where basement rock occurs near the surface were probably of the order of 50 mm per second. In areas of deep alluvium, such as in the city centre, maximum ground surface velocities were probably of the order of 200 mm per second. Maximum accelerations at coal mines about 100 km west of the epicentre appear to have been about 3% of gravity (g). Unfortunately no accelerographs exist closer to the source area so it is not possible to evaluate fully ground motions experienced in Newcastle.

One aftershock, with a magnitude M=2.1 occurred at 7:08 pm on Friday, the day after the main shock. The epicentre for this event was in the same area as the main earthquake and at a depth of 13-15 km. This earthquake was felt by many people in the Newcastle area, and strongly in the Hamilton area. Another earthquake, with a magnitude of M=2.9 occurred on Friday, February 23, 1990 at about 11:43 pm. The epicentre seems to have been about 20km further west of the original epicentre and was very shallow. In the strict sense, this event was probably not an aftershock of the December 28, 1989 earthquake. This earthquake lasted approximately 40 seconds. No new damage was reported as a result of the aftershocks.

14. Seismograms of the December 28th, 1989 earthquake recorded in Scotland, United Kingdom. The seismograms indicate different arrival times and differing peaks for the various types of seismic waves. These records are used to calculate the epicentral location and the magnitude of the earthquake. The times shown are Greenwich Mean Time (GMT). (Seismograms by courtesy of the Australian Seismological Centre, Bureau of Mineral Resources and the British Geological Survey)

It is rather surprising that only two aftershocks were recorded as similar earthquakes in eastern Australia have been followed by numerous aftershocks. No explanation for this apparent anomaly can be offered at the present time.

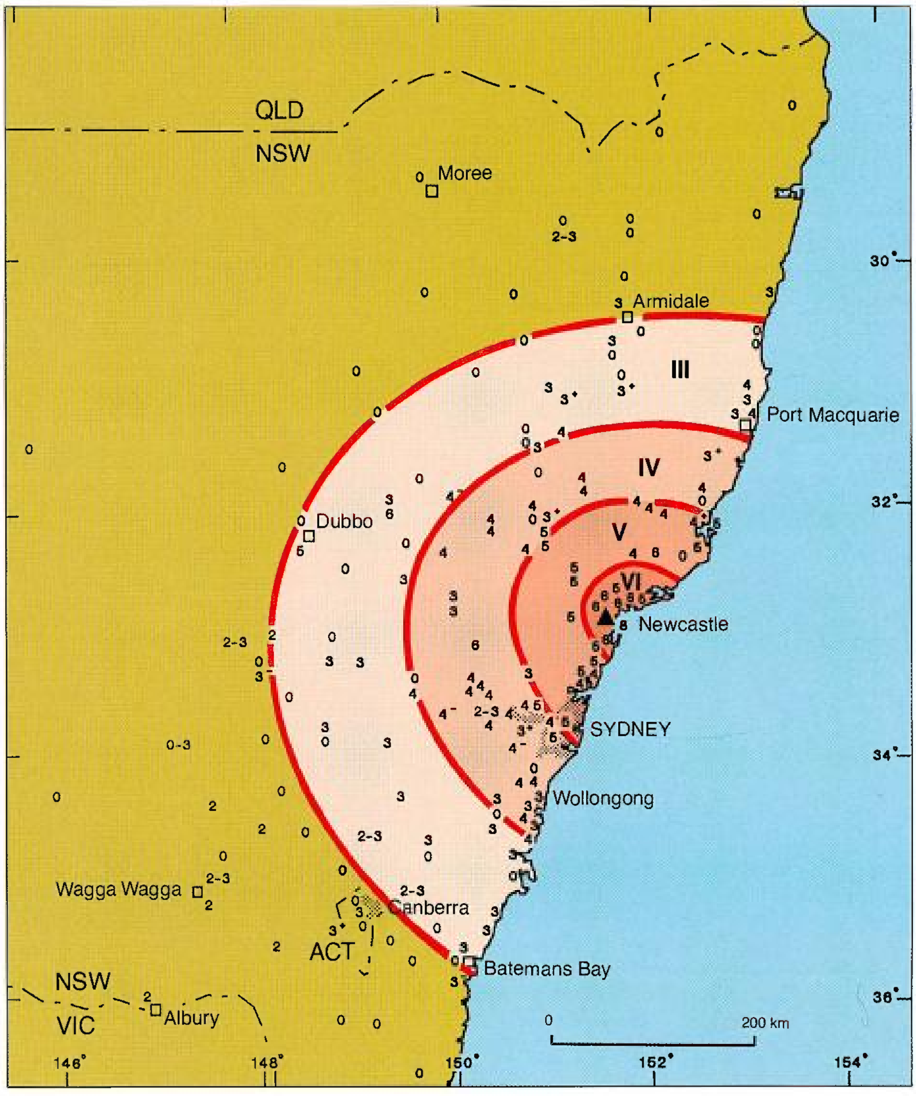
The December 28th earthquake probably occurred along a steeply dipping fault oriented northwest-southeast but no surface faulting was observed. It appears that the direction of maximum seismic wave propagation was toward the north-east; in effect, towards the areas of alluvium along the Hunter River valley in the vicinity of Newcastle.

The earthquake caused considerable damage in Newcastle and was felt across an area of about 300,000 square kilometres, including Sydney, Canberra, Dubbo and Armidale.

The maximum assigned Modified Mercalli intensity, based on hundreds of questionnaires returned to The Australian Seismological Centre, reached MM VII to VIII in parts of the inner city area and adjacent suburbs – masonry buildings of average quality were damaged, some suffering severe damage. Some brick veneer buildings were also damaged. Much of the rest of Newcastle, the northern part of Lake Macquarie and the lower Hunter Valley including Maitland experienced Modified Mercalli intensities as high as MM VI – in some of these areas below average quality masonry buildings were damaged.

The Modified Mercalli intensity in the epicentral region around Boolaroo was VI, two intensity units less than that experienced in the downtown area of Newcastle and adjacent suburbs. Kevin McCue and his co-workers, from the Australian Seismological Centre, Bureau of Mineral Resources, suggest that this difference indicates that the peak ground velocity was magnified fourfold by the presence of alluvial fill along the Hunter River. Such magnifications are commonly experienced on unconsolidated river and lake sediments and on reclaimed land.

15. Isoseismal map for the 1989 earthquake compiled by McCue et al. (1990). The small figures refer to felt Modified Mercalli intensities. Zeros indicate that the earthquake was not felt.



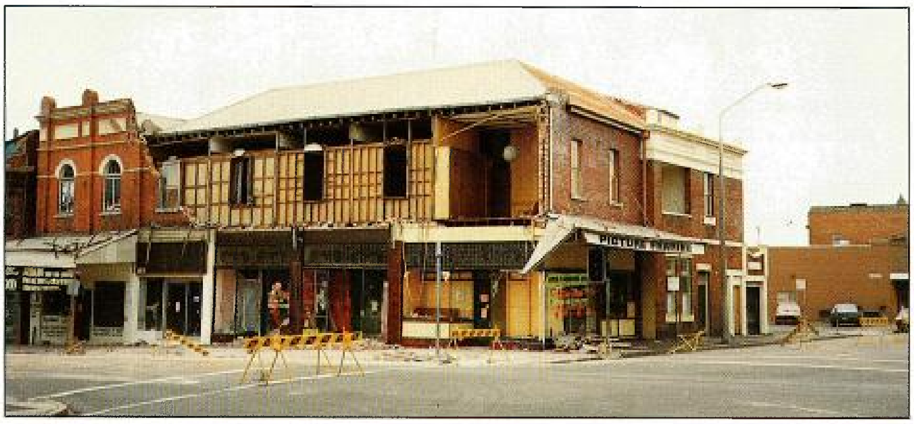
Performance of buildings and other structures

Analysis of damage

Estimates compiled by the Insurance Council of Australia of the value of insured losses resulting from the Newcastle earthquake are in excess of $800 million. While minor damage was reported from as far afield as Sydney, Scone and Kempsey, most of the damage was in Newcastle itself. At the time of publication a total of about 35,000 insurance claims have resulted from the earthquake. Less than 5,000 of these are on commercial and industrial policies.

The great majority of buildings in Newcastle survived the earthquake unscathed. Of those buildings that suffered damage most experienced only limited damage and required only relatively minor repairs. However, many brick buildings exhibited major damage to one wall with only moderate cracking in adjacent walls. This damage pattern seems to indicate greater damage occurred on walls oriented at right angles to the direction of maximum propagation of seismic waves. For example, the serious damage to Beaumont Street was probably as much due to the fact that it was at right angles to the direction of the shock waves, as it was to the underlying alluvium, and the age and condition of the masonry construction.

Although individual companies had varying experience, the average household claim for building damage was of the order of $14,000.

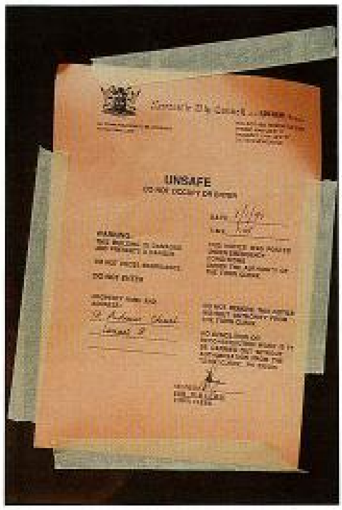


17. Wall failure in an older unreinforced masonry building in Cooks Hill. Failures of this type occurred particularly in walls oriented at right angles to the direction of propagation of seismic waves. (Photograph by courtesy of C. Featherstone)

18. In earlier days lime mortar was used extensively in construction in Newcastle and other Australian cities and towns. The low strength of this mortar contributed to many losses. Similar problems with lime mortar were identified after the Adelaide, 1954 and Picton, 1973 earthquakes. (Photograph by courtesy of the GIO (NSW))

Amongst commercial structures only 20 buildings in Newcastle are more than 6 storeys high. In the commercial areas of the city centre and Hamilton, where extensive damage and much of the insurance loss occurred, more than 60% of the buildings are single storey. The majority of the remaining commercial structures are two storey, walk-up, brick buildings. Many of these buildings were constructed before 1950. It was these buildings that sustained the majority of the damage. The remaining class of buildings are post-1950 commercial buildings taller than two storeys and of steel or reinforced concrete construction with brick infill panels between the structural frame members.

In general, damage was caused to elements of buildings rather than to whole buildings. Brittle elements caused the most problems but total collapse was rare. Parapets, suspended awnings, corners, facades and gable ends suffered the most damage.

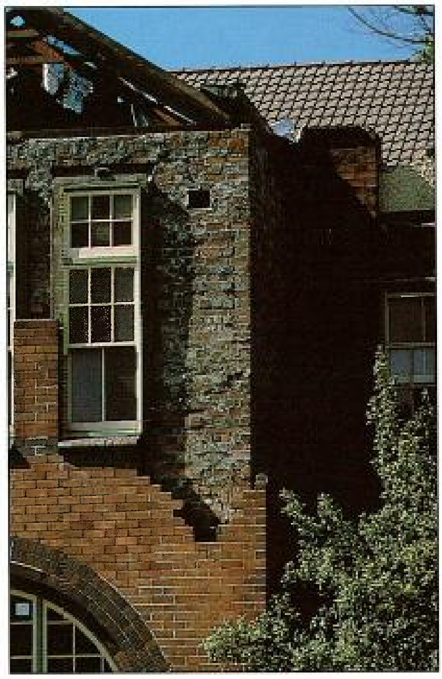


16. An "unsafe" notice, indicating that the structure has been inspected and found to be dangerous. In suburbs such as Cooks Hill, many buidlings had notices similar to this one. (Photograph by courtesy of C. Featherstone)

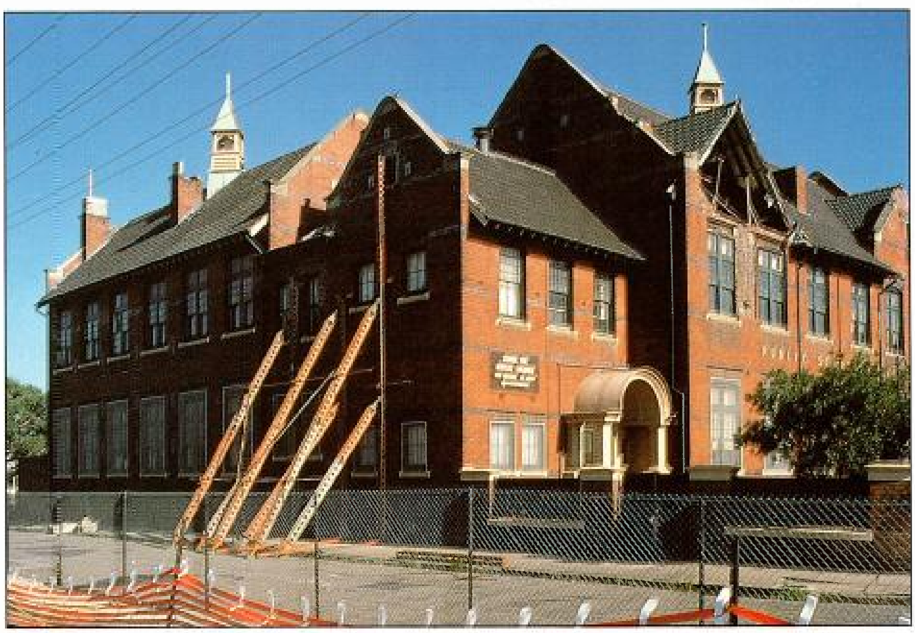
19. The QBE Insurance building. This modern high rise reinforced structure suffered damage to the top floor and part of the parapet, emphasising that damage is concentrated at the top of the building. (Photograph by courtesy of C. Featherstone)

In newer commercial buildings there were also problems with ties and anchorages which affected parapets, gable ends and facades. Other failures occurred in cladding and to infill panels. Non-structural damage in some buildings included broken glass, damage to sprinkler systems, and the loss of tiles from stairwells.

Steel structures, reinforced and timber framed buildings performed well but there was some minor damage to reinforced concrete buildings where beams and columns were spaced too widely to sustain shear forces. However, the majority of the damage was to unreinforced masonry elements, both structural and non-structural. Damage resulted from insufficient anchorage of walls to frames, from excessive drift of structural frames which caused damage to infill wall panels, and from excessive diaphragm deflection where ties were inadequate.



21. Failure of the outer skin of an unreinforced masonry wall at Junction Public School. Such failures were typical of those observed in older masonry buildings (Photograph by courtesy of the GIO (NSW))



22, 23. The top of this wall at Wickham Public School leans outwards by 7-10 cm. The gable on the front of the building has also been damaged producing large amounts of debris in the school playground. If the earthquake had occurred on a normal school day many children may have been injured. (Photographs by courtesy of the GIO (NSW))

20. Close-up of damage to light-coloured modern bricks at Kotara High School constructed in 1968. These bricks are generally underfired to produce the light colour. (Photograph by courtesy of GIO (NSW))

Although no public buildings collapsed 469 of those inspected suffered some damage. While none of these collapsed, the level of damage sustained is of concern in view of the functions of many of these buildings. Damage to hospitals resulted in the closure of 200 out of 430 beds, cancellation of elective surgery, and the delayed opening of the new Rankin Park Hospital. Numerous schools sustained structural damage and the ambulance service headquarters building and the co-ordination centre also suffered damage.

Relatively high levels of damage were also reported from buildings owned by religious organisations. More than 80 structures owned by the Catholic Church were damaged with some minor problems being reported from Taree and Pennant Hills (a Sydney suburb) as well as from towns in the Hunter Valley including Singleton, Muswellbrook, Dungog, Raymond Terrace and Maitland. Damage also occurred to the Anglican Cathedral in Newcastle. While no church buildings collapsed the level of damage is again of concern as many of the buildings are used as schools and as communal residences.

A survey of building damage produced by the Master Builders Association in early February, 1990 provides an indication of the severity of damage and the widespread distribution of damaged structures. However, given that the survey includes only 4,915 buildings, and that there were about 35,000 insurance claims, it is clear that the sample is relatively small.

Four damage codes were recognized in the survey:

- Red: building presents an immediate public danger.
- Amber: building has been severely damaged and presents a possible danger.
- Blue: the building is damaged but habitable.
- Green: only minor damage.

Three types of building were recognised: residential, non-residential (largely commercial), and other. Only 17 structures came into this last category and they are not considered further. The percentages of residential and non-residential buildings are shown in the table. In total 71.3% of the structures included in the sample were classified as residential buildings.

Almost half of the damaged properties reported in the survey are located in just three areas – Newcastle, Hamilton, and Mayfield. The first ten suburbs listed experienced more than 80% of the damaged buildings reported here. While those data suggest that the damage was confined to a few areas, isolated buildings were damaged across a wide area as the map indicates (see fig 24). In fact, buildings presenting an immediate or possible danger were reported from 24 of the 32 suburbs surveyed.

Although earthquake damage was widespread, areas of Newcastle such as the city centre, Cooks Hill and Beaumont Street, Hamilton experienced disproportionate amounts of damage. Even within these areas many buildings were untouched. While these variations are anything but random it is not yet possible to be precise about the mechanism of failure. Factors involved certainly include:

- differences in the amount of seismic energy received at the ground surface, variations occurring with distance from the epicentre among other factors;
- differences in the amount and frequency of ground shaking as a result of local variations in sediment type, sediment thickness and water content; and
- differences in the susceptibility of buildings to ground shaking at particular frequencies, depending on building height, age, stiffness, shape, orientation, foundation, materials, maintenance and quality of workmanship.

These data indicate that while the majority of the buildings in the sample suffered only minor damage nearly one in four was so severely damaged that it presented some danger. It is also interesting that the severity of damage in non-residential buildings was generally higher than in residential buildings with 35% of the former presenting some damage. This high proportion may well be an artifact of the timing of the survey – it seems likely that most of the building claims not included in this early February survey would have experienced only minor damage.

A total of 32 suburbs were represented in the survey but the vast majority of the damage was confined to only a few suburbs. The distribution of damage between suburbs is as follows:

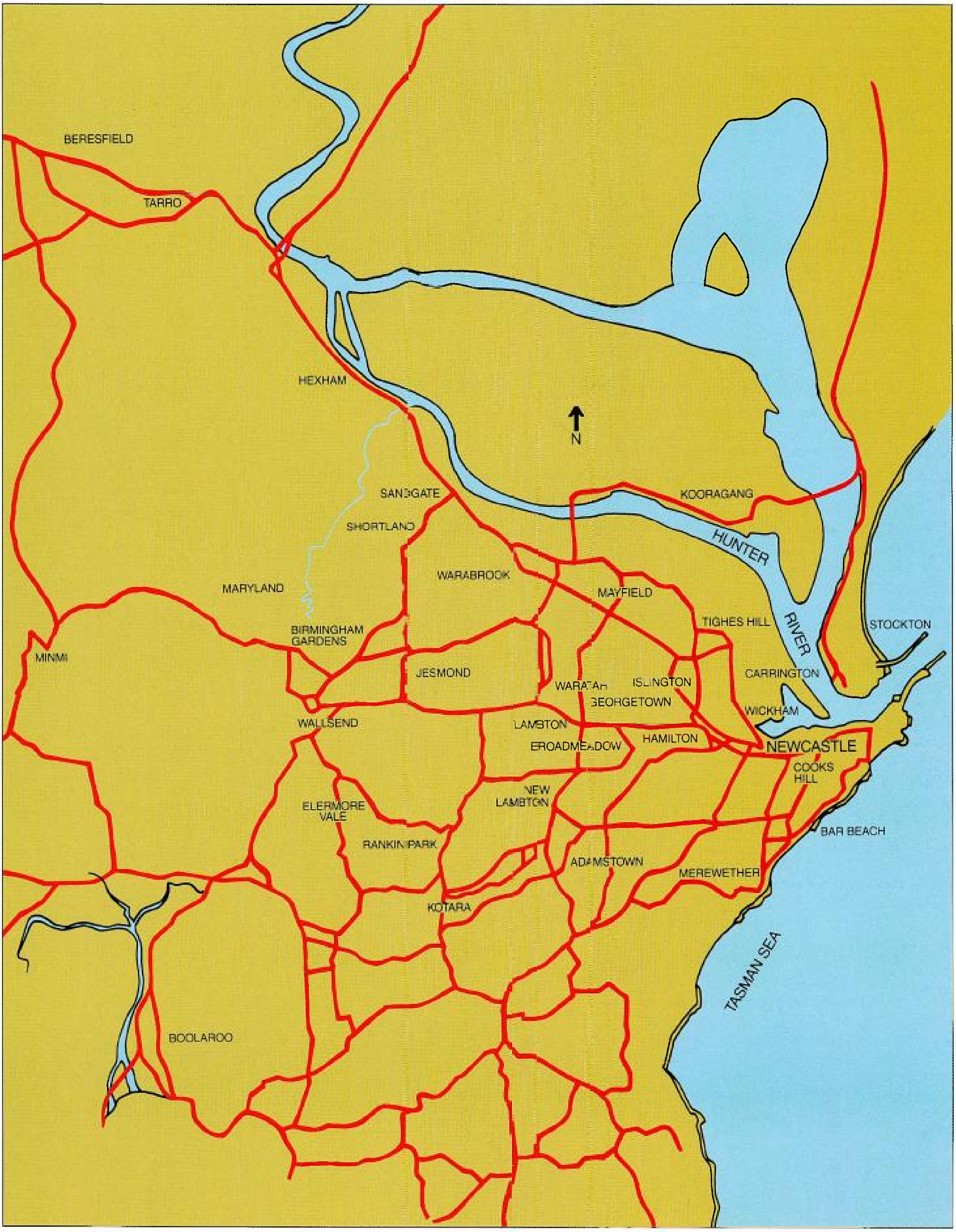
Newcastle	20.40%
Hamilton	14.50%
Mayfield	13.20%
Merewether	8.20%
New Lambton	6.80%
Adamstown	4.80%
Broadmeadow	4.40%
Islington	3.50%
Wallsend	3.40%
Waratah	3.30%
Lambton	2.70%
Wickham	2.60%
Cooks Hill	2.00%
Stockton	1.60%
Carrington	1.50%
Georgetown	1.10%
Kotara	0.90%
Shortland	0.90%
Tighes Hill	0.90%
Birmingham Gardens	0.70%
Jesmond	0.60%
Maryland	0.50%
Bar Beach	0.40%
Beresfield	0.20%
Elermore Vale	0.20%
Rankin Park	0.20%
Tarro	0.20%
Minmi	0.10%
Sandgate	0.10%
Warabrook	0.05%
Hexham	0.03%
Kooragang	0.02%

(See fig 24 for locations of the suburbs.)

Percentages of structures in each damage category, for example, 6.9% of residential buildings surveyed presented an immediate public danger

Damage Code	Residential	Non-residential	Total
Red	6.9	17.0	10
Amber	11.6	18.3	13
Blue	14.6	16.3	15
Green	66.9	48.4	62
Totals	100.0	100.0	100.00

24. Newcastle and several surrounding suburbs are shown on the map opposite.


BERESFIELD
TARRO
HEXHAM
N
SANDGATE
SHORTLAND
KOORAGANG
HUNTER
RIVER
WARABROOK
MARYLAND
MAYFIELD
TIGHES HILL
STOCKTON
BIRMINGHAM GARDENS
MINMI
JESMOND
CARRINGTON
WARATAH
ISLINGTON
GEORGETOWN
WICKHAM
WALLSEND
LAMBTON
HAMILTON
NEWCASTLE
BROADMEADOW
COOKS HILL
NEW LAMBTON
ELERMORE VALE
BAR BEACH
RANKIN PARK
ADAMSTOWN
MEREWETHER
KOTARA
TASMAN SEA
BOOLAROO

Building damage reported in the Newcastle area can be divided into the following broad categories:

- major structural failures
- wall failures
- minor damage
- contents damage
- damage to lifelines
- other damage

Each of these is discussed in greater detail.

Major structural failures

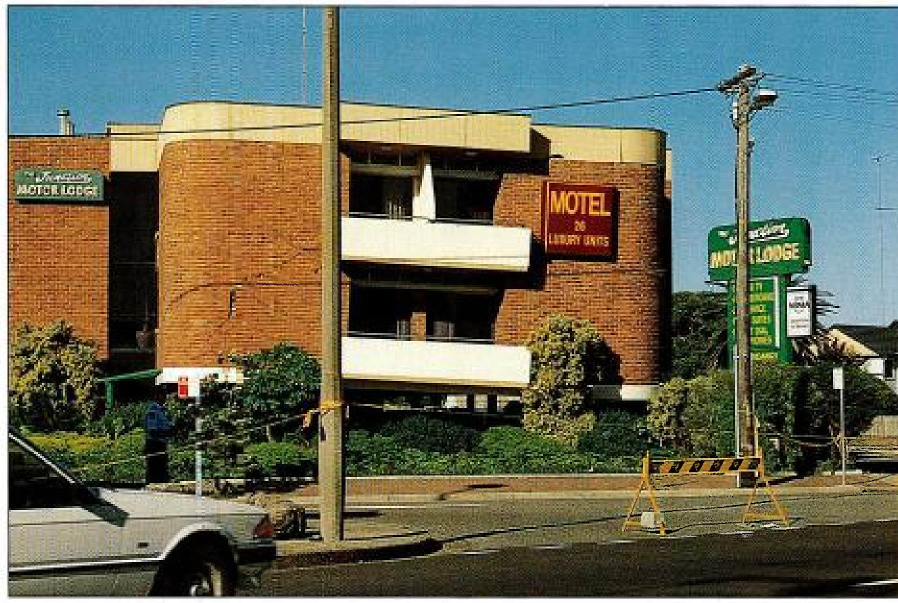
In this publication major structural failure refers to collapse of part or all of the structural frame of the building. Thankfully, only a few buildings suffered this catastrophic level of failure.

The most dramatic example was the collapse of the Newcastle Workers' Club in which 9 people were killed. The Workers' Club was really two separate buildings, modified several times between 1937 and 1972; an older unreinforced masonry part and a more recent (1972) concrete-framed building which was four storeys tall. The newer section was constructed of concrete slabs supported by concrete columns. The collapse of part of this building is, at the time of publication, the subject of a coronial inquiry.

25. A large section of the Newcastle Workers Club collapsed leading to the deaths of nine people. In the photograph workers tear down a damaged wall that was hampering efforts to get heavy machinery into the Workers Club. (Photograph by courtesy of the Newcastle Morning Herald)

Severe structural damage also occurred to the Junction Motor Lodge, built in about 1980, with a reinforced concrete frame, concrete slab floors and brick infill wall panels above the ground floor level. The building was open at the ground floor level for parking access. The damage to the Junction Motor Lodge was due to local failure of the concrete columns just below the concrete first floor slab at the eastern end resulting in disintegration of the concrete and subsequent buckling of the reinforcement. Structural failures of this type in reinforced concrete frame buildings with limited lateral stiffness at the ground floor level have been quite common in earthquakes elsewhere. Though the Junction Motor Lodge did not collapse it was demolished. Had the upper stories not been unreinforced masonry it is quite possible the building could have been jacked up and restored. It appears that other major structural collapses were confined to older buildings where failure of unreinforced masonry walls occurred. Examples include:

- Kent Hotel, Beaumont Street, Hamilton – an old brick unreinforced masonry building which had undergone substantial architectural renovations in the previous 18 months. Although most of the front of the building fell into the street, evidently more than 20 people inside the hotel escaped unharmed. However, the collapse of the front wall and the awning into Beaumont street killed two people.
- Broadmeadow Hotel – this hotel had also recently undergone substantial non-structural renovations. The building was declared a total loss and demolished.



26. Severe cracking of the front wall of the Junction Motor Lodge resulted when local column failure occurred at the right hand (eastern) end of the ground floor carpark. This building was subsequently demolished. (Photograph by courtesy of G. Johnson)

27. The gable end, parapet and front wall of the Kent Hotel in Beaumont Street, Hamilton fell into the street, demolishing the awning and killing two people. (Photograph by courtesy of C. Featherstone)

Wall failures

Wall failures occur where walls are twisted in the direction of the plane of the wall or where they bend under the action of ground motion at right angles to the plane of the wall.
Four types of wall failures can be recognised:

- racking failures
- transverse panel failures
- parapet/awning failures
- corner failures

28. Wall failure at the Hamilton R.S.L. Club, a steel-framed building with brick in-fill panels. After the earthquake it was possible to push bricks out from the inside by hand. (Photograph by courtesy of C. Featherstone)

Racking failures

Racking failures occur as a result of shear forces in walls that are parallel to the direction of motion of the ground. The failure pattern often appears as a pair of diagonal cracks connecting opposite corners of the wall. Wall damage resulting from racking failures usually occurs in the lower storeys of a building.
In Newcastle, infill panel walls in a number of multi-storey buildings failed in this way. The framework of these buildings is designed to resist horizontal shear failures. The masonry infill panels between individual members of the structural frame absorb most of the earthquake forces until they fail, particularly where there is excessive drift of the frame during shaking. While these failures do not usually threaten the structural stability of the building they can result in damage that is costly to repair.

29. Brick in-fill panels at Rankin Park exhibit severe cracking typical of transverse wall failures. The reinforced concrete frame structure of the building was undamaged. "US" written on the walls means "unsafe". (Photograph by courtesy of C. Featherstone)

Transverse panel failures

Transverse wall failures occur where a wall panel bends out of alignment as a result of forces generated by ground motions acting dominantly at right angles to the plane of the wall. Internal walls are also prone to these types of failures.
The risk of failure is affected by the height of the wall because wall movement in response to ground motion increases with height, by wall strength and reinforcing, by the size and position of wall openings, and by the number and quality of wall ties. Unreinforced masonry walls are particularly prone to such failures. Walls that are aligned at right angles to the direction of strongest ground motion are at greatest risk.

30. The failure of wall ties was a common cause of damage in older buildings in Newcastle. Most wall ties are made of 3.5 mm soft galvanised wire which corrodes readily in coastal environments. (Photograph by courtesy of the GIO (NSW))

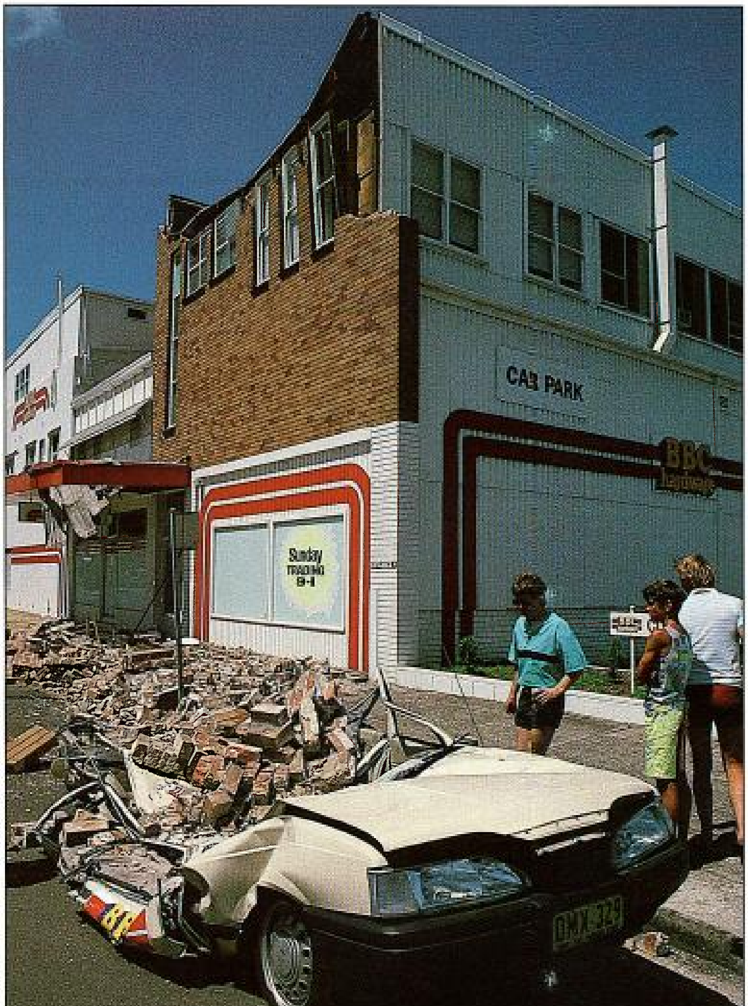
Depending upon the strength of the wall and the severity and duration of the earthquake, transverse panel failures may be limited to minor cracking or involve total panel failure and collapse. Parapet failures (see below) are a special type of transverse panel failure. Wall collapse may result, particularly where awnings are tied to the wall panel. An important example of this form of damage occurred at Rankin Park Hospital, 10 km south west of the city centre. This new hospital, originally scheduled to open early in 1990, is a reinforced concrete frame structure with concrete slab floors. The interior panel walls are unreinforced concrete block walls for fire resistance.
Earthquake damage to the hospital was mainly limited to the infill concrete block walls in the atrium, some of which were severely cracked and will require replacement. Wiring and piping which was attached to some of the infill walls will also require replacement. One estimate of the total damage to this building, including considerable damage to mechanical plant on the top floor and to expensive sealed painted surfaces in operating theatres, was 5% of the replacement cost.
In Newcastle, pre-1950s unreinforced masonry walls with lime mortar were particularly prone to transverse panel failure. In general, such damage resulted from insufficient anchorage of walls to frames and excessive deflection of the walls because of inadequate ties. Ties appear to have been a particular problem. Most ties are made of 3.5 mm soft galvanised wire. In some cases, the number of ties between inner and outer skins was inadequate; in others the ties had corroded with time. Some investigators argue that stainless steel ties should be used in the future, galvanised ties being inappropriate in the sea-side Newcastle environment.

Parapet/awning failures

Parapets are external walls that extend up to 2 metres above the edges of the roof. Although commonly regarded as purely ornamental features, they were utilised as fire protection features on many buildings constructed before non-flammable roofing materials became available. They were incorporated into buildings either to slow the spread of fire to adjacent structures or to prevent roofing materials from being ignited by heat and/or flames issuing from windows and other openings.

As many of the commercial buildings in Newcastle are relatively old (pre-1950s), many have unreinforced brick parapets. Failures of parapets represent a special case of transverse panel failures.

32. Ground motions are greatest at the tops of buildings. Parapets commonly fail because they are poorly supported, producing large amounts of debris in the streets. (Photograph by courtesy of K. Schreiber)



31. Failures of parapets and building facades resulted in a lot of debris in the streets, some lucky escapes, and expensive claims on motor vehicle policies. (Photograph by courtesy of K. Schreiber)

Failures of unreinforced brick parapets are common because the tops of buildings experience greater motion in an earthquake than the lower portions of the structure and there is little weight on top of them. As a parapet is weakest in the direction at right angles to it's length, parapet failures probably most frequently occurred where the strongest ground motion was also in this direction. Buildings with high parapets, with lime rather than cement mortars, and built on alluvium or other soft sediments were most prone to parapet failure. One report suggests that between 200 and 300 buildings experienced parapet failure. In some of these, cracked parapets remained balanced above streets and pavements forming a continuing danger. In other cases, parapets fell, sometimes causing damage to adjacent lower buildings.

In still other cases, bricks from parapets fell onto awnings as much as three or four metres wide, many of which also collapsed as a result of the combined dynamic load of ground shaking and the imposed brickwork. Often, vertical supports for awnings on the outer edges of footpaths had been removed years ago, apparently because it was believed that failure of the supports as a result of traffic accidents would threaten the safety of those beneath the awnings. These awnings were tied back to the parapet or some other part of the brickwork with steel hanger rods. Many of these connections were made close to building corners which were also subject to failure.

Failures of parapets and awnings were the most visible forms of building damage resulting from the Newcastle earthquake. They contributed, it appears, to the death of three people. Parapet/awning failures produced most of the debris that fell into streets which increased markedly damage to cars, the clean-up costs, and caused significant insurance losses.

Corner failures

Corner failures occur where ground motion produces alternate compressive and tensile forces in walls, particularly those walls oriented at right angles to the dominant direction of ground motion. Once these forces generate cracks in the walls, widening of the cracks occurs as ground motion continues. As movement is greatest near the top of a structure, failure tends to be initiated near the tops of the walls.

Two storey buildings in the city centre and the Beaumont Street, Hamilton areas were particularly affected by corner failures. Some buildings in these areas suffered from complete wall failures initiated at the corners, while others suffered from severe cracking of brickwork at the upper corners.

33. This view along Union Street emphasises the extent of parapet, wall and awning failure in limited sections of the city. (Photograph by courtesy of G. Johnson)

34. Road closures occured in the Central Business District and in Beaumont Street, Hamilton because facades, awnings and parapets had fallen in some areas and because the structural safety of some buildings was suspect. Street closures, which lasted up to twelve days caused large losses on business interruption policies. (Photograph by courtesy of K. Schreiber)

Minor damage

Large numbers of buildings in Newcastle and the surrounding area suffered only minor damage as a result of the earthquake. This minor damage consisted of broken glass, cracked plaster on walls, cracked roofing tiles and loss of chimneys. This damage is not structural and is often easy to repair but the large number of buildings, particularly residential dwellings, that were damaged in this way have produced an enormous total repair bill. The average insurance claim for damage to domestic buildings was of the order of $14,000.

36. Cracking of brick and plasterwork in a typical older unreinforced masonry residence in the suburb of Merewether. While often not serious, such damage can be expensive to repair. (Photograph by courtesy of C. Featherstone)

35. Window glass broke in several shop fronts in Hunter Street during the earthquake. In other cases, rubber seals holding windows in place worked loose, necessitating removal of the glass in order to make repairs. (Photograph by courtesy of C. Featherstone)

37. Numerous homes suffered minor damage. Typically unreinforced masonry walls moved, cracking plaster. Fallen cornices were a common form of damage. (Photograph by courtesy of C. Featherstone)

38. In many cases, damage to contents in homes was limited to that caused by bottles and books falling from shelves. Insurance claims for such damage were generally very limited with typical household contents claims being only a few hundred dollars. (Photograph by courtesy of K. Schreiber)

Contents damage

Although separate statistics are not available at the time of publication, it appears that damage to contents was relatively minor. Typical contents insurance claims were for less than $1,000 even where building claims ran to $10,000 and more. In many cases damage was limited to the fall of bottles, books and the like from shelves resulting in little expensive damage.

Other contents damage resulted when walls and roofs that had been inadequately sealed leaked during the heavy rains of early February, 1990.

Damage to lifelines

Lifelines include generation, storage and reticulation systems for public utilities including electric power, natural gas, water supply and the telephone system. In general, the public utilities performed well in the Newcastle earthquake.

The most significant damage to the electrical supply system occurred to the Newcastle and Waratah substations. At the Newcastle substation at Killingworth, located about 20 km south west of the epicentre, oil-filled circuit breakers tripped when some porcelain insulators were damaged or when falling circuit breakers pulled down attached components. Despite the damage, the substation was able to resume transmitting power approximately two hours after the earthquake and full load was restored in 6.5 hours.

At the Waratah substation two circuit breakers and current transformers failed at insulator bases, causing some damage to associated equipment. The circuit breaker supplying the Alcan Aluminium Smelter at Kurri was also damaged but power to the refinery was restored after two hours by re-routing the supply.

One positive aspect of the failure of the circuit breakers may have been significant. It appears that the power was tripped off by the initial seismic wave, so that the power went off before the main shock waves hit. It is probable that this was a significant factor in the very low incidence of fire as a result of the earthquake.

In Newcastle there were several instances of damage to overhead lines as a result of wall failures and numerous service connections pulled away from houses. Electricity feeder lines to the mid-north coast were damaged and power was off to Port Macquarie, Kempsey, Taree and Forster for more than an hour.

There were no major failures of gas mains. Apparently, some minor failures of old cast iron pipes occurred in inner suburban areas resulting in minor gas leaks, but these were quickly repaired. Some household connections to mains were reported as being shaken loose causing minor gas leaks. No fires resulting from gas leaks were reported.

There were no reports of significant damage to water distribution and sewerage systems. However, some minor leakages in older systems in the inner city area were reported.

No damage appears to have occurred to the telephone system although the Telecom exchange building in Hamilton suffered some damage and had to be evacuated. All equipment remained working however and very little disruption was experienced to the network as a whole.

39. Damage resulting from a fire at Newcastle TAFE College. The fire occurred in a laboratory where chemicals were spilled by the ground shaking. This was the only reported example of fire resulting from the Newcastle Earthquake. (Photograph by courtesy of the GIO (NSW))

40. This airconditioning unit, on the top floor of a modern building moved off its mounting during the earthquake. The workmen are using hydraulic jacks to move the unit back into position. (Photograph by courtesy of C. Featherstone)

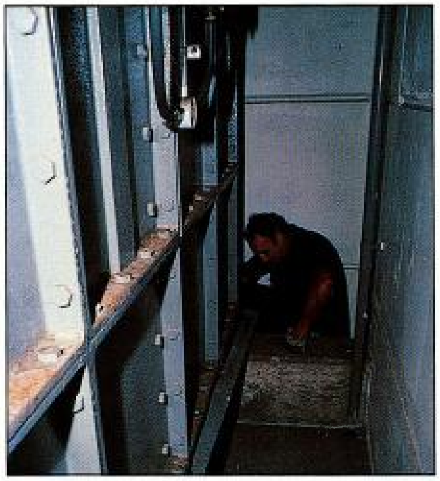
Other damage

Damage, other than that to buildings and lifelines, affected a number of organisations in the Newcastle area.

At the BHP Rod and Bar Products Division plant, located about 5 km north of the epicentre, damage resulted from power loss. Two blast furnaces had to be halted to repair damage. Considerable loss of production resulted. Damage was also caused to the Basic Oxygen Steelmaking shop roof and some metal froze in a continuous caster.

At Port Waratah the earthquake derailed one of the loading heads on the coal loader and power cuts delayed loading for seven hours.

Additional damage to a number of structures also became apparent in the weeks after the earthquake. In some cases, slow movements of parts of buildings continued for some weeks, with cracks in walls becoming more apparent with time.



41, 42. The water tank at the Police Centre which was displaced during the earthquake. The tank had to be emptied before it could be moved back into position. The water tank moved only a few mm but relocation was expensive for the insurer. Simple measures could have prevented movement. (Photograph by courtesy of the GIO (NSW))

In other cases, repeated measurements of crack widths showed no changes other than those associated with daily temperature changes. Progressive movements probably resulted from changes in soil pore water pressure, particularly in areas underlain by clay soils. The tropical depression resulting from the decay of Cyclone Nancy in early February 1990 dumped large amounts of rain on Newcastle. This rainfall evidently increased rates of movement in some structures and promoted the discovery of leaks in many residences that had seemed previously to have sustained little damage. Wall movements of up to 30 mm per week were reported in some buildings in mid-February, more than 6 weeks after the earthquake.

In some cases, landslides occurred, on steep slopes. Whether these failures should be attributed to the earthquake in some measure, or solely from the rainfalls accompanying Cyclone Nancy, or have other origins is not known. However, eight or nine houses have been affected by landslides.

43. A typical displaced mounting. (Photograph by courtesy of the GIO (NSW))

Building regulations

The SAA Earthquake Code

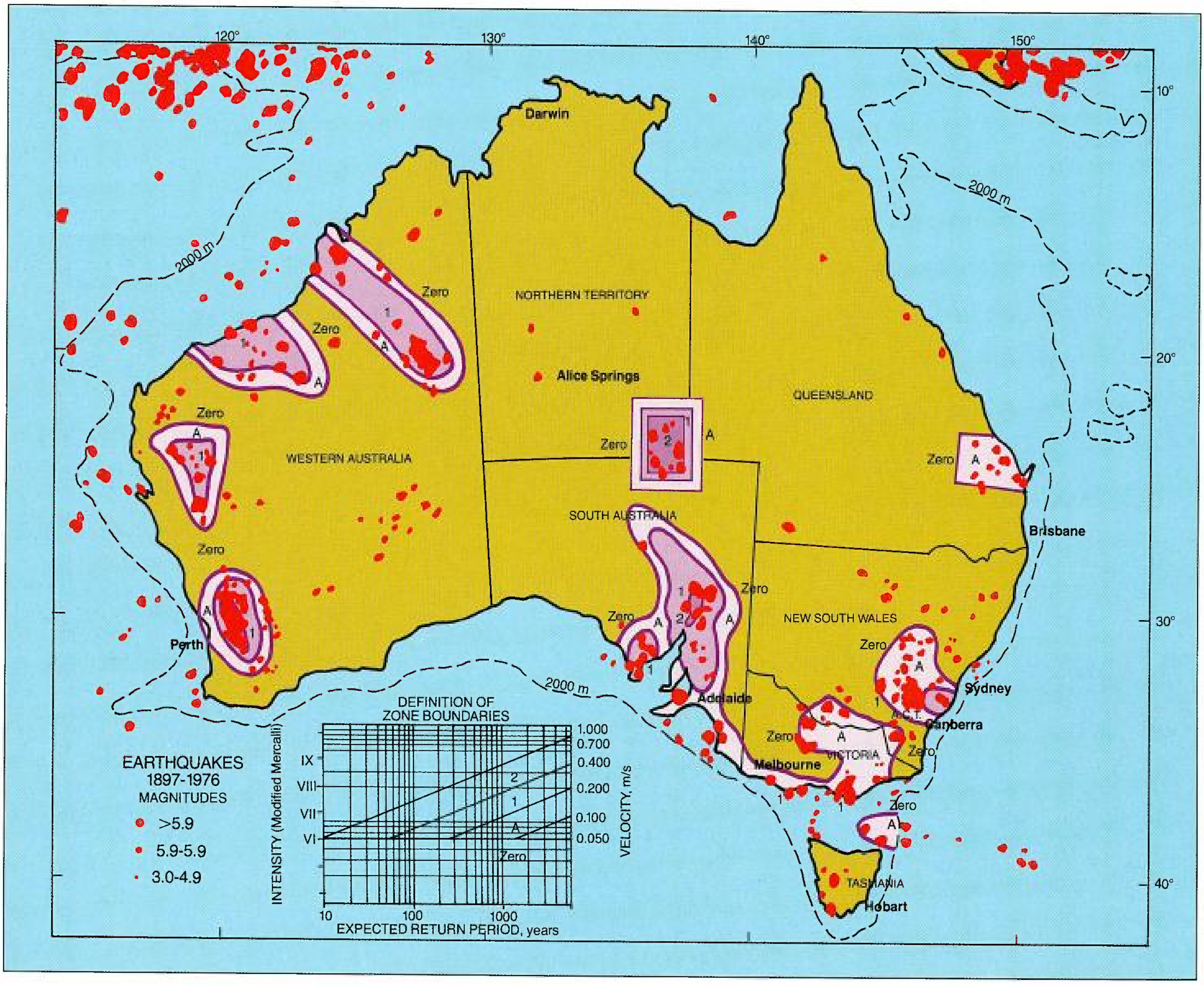
Building design throughout Australia is controlled through a variety of State legislation and Local Government by-laws. The new "Building Code of Australia" which is coming into force progressively in all Australian States is intended to supersede the existing State Uniform Building Regulations.

The term "State Uniform Building Regulations" was introduced when building regulations were made uniform throughout a State, which is now the case in all States in Australia. There is a considerable degree of similarity between current State building regulations as most are based on the Australian Model Uniform Building Code, a predecessor of the Building Code of Australia. The adoption of the Building Code of Australia, albeit with local variations, will mark just another step in the movement to national uniformity which has been occurring over the past 20-30 years.

The Standards Association of Australia published, in November 1979, Australian Standard AS2121-1979 entitled "The Design of Earthquake Resistant Buildings", commonly known as the SAA Earthquake Code. AS2121 sets minimum standards with respect to public safety to safeguard against major structural failure and loss of life. The prime aim of the standard is therefore prevention of collapse rather than prevention of damage (especially non-structural damage).

Prior to the issue of AS2121 there was no Australian Standard for earthquake design, although various Government departments and private consultants adopted overseas rules for areas where earthquakes were known to be a hazard. An example of this was the practice of structural consulting engineers in Perth, following the Meckering 1968 earthquake in Western Australia, of adopting aspects of New Zealand building codes for the design of structures in Perth.

Australian Standards are only of an advisory nature; for a Standard to have any legal effect it must be adopted by Commonwealth, State or Local Government. The new Building Code of Australia adopts the SAA Earthquake Code, whereas the New South Wales Buildings Regulations, Ordinance 70 (soon to be superseded), does not require compliance with that Standard.



44. The seismic zone map which formed the basis of Standards Association of Australia AS2121-1979 "The Design of Earthquake Resistant Buildings".

Neither the SAA Earthquake Code nor any State or Local Government building regulations make any provision for the upgrading of previously constructed buildings to comply with the SAA Code. Consequently, only buildings for which the design had not been completed in November 1979 were required to provide seismically resistant design in compliance with the SAA Earthquake Code. Furthermore, the Code does not apply directly to dwellings and single storied residential developments, to special structures such as dams and bridges, or to special purpose industrial or commercial buildings with unusual hazards. The Code also recommends against it being used, in an unamended form, for tall structures such as chimneys, transmission towers and irregular or asymmetrical buildings. Given these exclusions, it is clear that the SAA Earthquake Code did not apply to the great majority of structures present in the Newcastle area in late 1989.

The Code divides Australia into four zones. Approximately 80% of the Australian landmass is classified as Zone 0 – a low risk area, where the probability of earthquake occurrence is such that it need not be taken into account in the design of structures. Nonetheless, the Code does recognise that it is possible that damaging earthquakes may occur in this zone at some time in the future. The other three zones in ascending order of potential earthquake severity are: Zone A, Zone 1 and Zone 2. The boundary between Zone 2 and Zone 3, or the upper limited of Zone 2, is based on criteria established under the California U.S.A. Uniform Building Code 1976 edition. Technically, Macquarie Island (part of the Shire of Esperance in Tasmania) is now regarded as the only Zone 3 exposure in Australia. On the other hand, Zone A is a uniquely Australian concept introduced into the Australian earthquake code to encourage designers to consider earthquakes in areas where the risk was assessed less than normally regarded internationally as significant, but was considered high enough to cause concern about the performance of non-ductile structures – a concern that the Newcastle earthquake has shown to have been justified.

Ductile and non-ductile buildings

Flexible buildings generally perform well in earthquakes not because they are ductile but because their natural frequencies of vibration are much less than the dominant frequencies of the ground vibration, under which conditions the ground tends to move while the building tends to stay still. If for any reason the dominant ground frequencies are similar to the natural frequencies of the buildings then resonance can occur leading to amplification of vibration. This occurred in Mexico City where most of the structures destroyed were moderately flexible 8-10 storey buildings. Rigid one and two storey buildings performed much better. This had nothing to do with ductility – just the relative dynamics of the ground motion and building motion. Earthquake motion at a long distance from earthquakes also tends to have much lower dominant frequencies than that close to the epicentre. This is the reason that high flexible structures in Sydney and Canberra experienced much more vibration than small buildings in these centres during the Newcastle earthquake.

Ductility is a measure of the ability of the structural components to be overstressed without breaking apart. If a nail is bent it does not break even though it is overstressed, though it may remained permanently deformed. If a piece of chalk is bent it breaks when the stresses reach the maximum limit of the material. A nail is ductile, chalk is brittle. A structural system that acts like a nail is described as ductile, one that acts like a piece of chalk is described as non-ductile.

Ductility is not related to flexibility. The Junction Motor Lodge was a flexible structure, but it was a non-ductile structure. Reinforced concrete columns must have close spaced ties around the reinforcing near their ends if they are to act in a ductile manner. On the other hand a very rigid masonry structure can act in a ductile manner if it is properly reinforced. It is important to realise that utilising the concept of ductility in design implies that some permanent deformation and cracking may occur, but the risk of collapse of structural elements will be very small.

The inset to the seismic zone map, on which the SAA Earthquake Code was based, (see fig 44) indicates the boundaries between the different zones in terms of expected return periods and earthquake intensities, or ground movement velocities. Since ground movement velocities below 50 mm per second (roughly equivalent to Modified Mercalli MM VI) are not expected to cause damage to normal buildings, this velocity is used as the upper limit to Zone 0. Additionally, it is presumed that since normal buildings are designed to resist dynamic loads, such as those imposed by wind and the live loads moving within the building, the inherent strength of the building resulting from compliance with those other design requirements will be such as to give the structure a degree of earthquake resistance. As Newcastle was located in Zone 0 on the 1979 Earthquake Code map it is certain that few structures were designed to meet the Modified Mercalli MM VIII conditions experienced in some areas of the city.

In Zone A, buildings of "ductile" (see inset) construction are not required to comply with the Code, but buildings of "non-ductile" construction, including those of unreinforced brick or masonry, are required to be given special consideration.

Buildings in Zones 1 and 2, whether ductile or non-ductile, are required to meet specific Code requirements so as to improve their resistance to earthquake loads. In Zone 2, the Code prohibits the construction of buildings which are required to perform post-disaster functions in non-ductile construction forms because of the probable collapse of such structures in the event of the building's elastic strength being exceeded.

There are also provisions for consideration of the distribution of horizontal shear at various levels in the building, the horizontal torsion which can be created by building asymmetry, overturning moments and structural ties between footings.

The code also makes provision for determination of the earthquake forces, both horizontal and vertical, on parts of a building such as cantilever parapet walls and awnings, exterior and interior ornamentation, external cladding, and interior ceiling framing systems. Special mention is made of the detailing of inserts in concrete which are required as ties to support external elements of the building.

Developments since 1979

The 1979 Earthquake Code is currently being reviewed by a committee which was empanelled in mid-1989 as part of the Standards Association of Australia's programme for reviewing codes every ten years. One of the major tasks of this committee will be the re-drafting of the seismic zone map of Australia in the light of the recent publication of "Probabilistic earthquake risk maps of Australia" by Gaull, Michael-Leiba, and Rynn (1990). From this research, undertaken before the 1989 earthquake, it appears that Newcastle, along with almost all the major cities in Australia, will be classified as higher earthquake risks.

A number of other significant changes are likely to be included in the new version of the Code. More stringent design rules are also likely to be adopted for essential facilities (post-disaster buildings) – hospitals, schools, emergency service buildings and the like.

The new Code, which will be published as Part 4 of the Loading Code – that is, as AS 1170.4 – will deal only with loading. Design aspects will appear in the relevant material codes – that is, the steel, concrete, masonry and timber codes. The current earthquake code does not really address the subject of earthquake-resistant masonry design but this will be considered within the masonry code as part of the overall revision process.

As pointed out earlier, this prospective change to the 1979 SAA Earthquake Code would only affect the seismic resistance of structures yet to be built and which are of the types covered by the recommendations of the new code. Furthermore it is likely to be another one or two years before the new seismic code is released.

With these problems in mind, and recognising that significant amounts of building and rebuilding are underway in Newcastle at the present time, Newcastle City Council adopted interim building requirements in March, 1990. The significant point about the requirements is that a number refer to existing buildings but allow owners up to five years to comply with new provisions relating to awnings and parapets adjacent to or over public areas. Although consideration was given to adding requirements for steel reinforcing in the upper brick courses on new dwellings, it was thought that this would provide additional corrosion and failure points in Newcastle's coastal environment. Stricter supervision and closer adherence to the current building codes were thought to be better solutions, at least until the new version of the SAA Earthquake Code is released in a few years time.

Interim building regulations – Newcastle

1. In accordance with Clause 30.2 Ordinance 70, Local Government Act, 1919 Council adopts the following interim requirements for the design of new buildings and the upgrading of existing buildings within the City of Newcastle. Certification of such design shall be required by a qualified practising structural engineer at building application stage.
   (a) New buildings, additions and alterations to existing buildings excluding detached single dwellings and multiple dwellings side by side and not on top of another, shall comply with Australian Standard 2121-1979 SAA Earthquake Code, Zone A with the exception of essential facilities (post-disaster buildings) which shall comply with the requirements for buildings in Zone 1.
   (b) Single and multiple dwellings of masonry construction and in excess of one storey construction shall be designed strictly in accordance with AS 1640-SAA Brickwork Code.
   (c) Where considered necessary for public safety existing buildings incorporating repairs and restoration shall be strengthened to resist earthquakes to a minimum standard as determined by Council in the particular case.
2. A further report be provided by the Director of Health and Building Services in regard to the supervision of domestic housing pertaining to the strict adherence to current regulations and standards.
3. An earthquake hazard mitigation programme be implemented in regard to masonry parapets and awnings adjacent to or over public areas. Such structures where necessary to be upgraded and structurally certified within five (5) years.
4. Regular reports be provided to Council in regard to legislation review and the earthquake hazard mitigation programme.

Mitigation of the earthquake problem

One of the factors that most affects the distribution and degree of building damage in moderate earthquakes, such as that experienced in Newcastle, is foundation conditions. It is clear that buildings on alluvium, estuarine and other soft or recent sediments fared poorly in comparison with those on older harder rocks. Similar patterns are commonly experienced in earthquakes elsewhere and have led to "microzonation" studies whereby ground conditions are mapped so that:

(i) particular attention can be paid to design, maintenance and strengthening of structures on poor ground; and/or

(ii) insurance premiums can be adjusted in accordance with expected loss levels.

Although detailed analyses of the relationships between loss experience and ground conditions are not yet available from Newcastle, consideration should be given to the need for such microzonation studies. Such analyses are fundamental to any studies of Probable Maximum Loss in other Australian cities.

Clearly, the Newcastle earthquake has demonstrated that many buildings in Australia have to be able to withstand greater ground shaking than they are capable of at the moment or society must be prepared to tolerate occasional substantial losses to building stock and significant numbers of human casualties. These comments are particularly true of unreinforced masonry structures.

For existing commercial and industrial buildings the sorts of recommendations contained in the Newcastle City Council interim building regulations would certainly assist in loss reduction. The Newcastle experience suggests that removal or strengthening of parapets and awnings, the addition and maintenance of wall ties, the improvements of connections between walls, roofs and floors, and the reinforcement of chimneys would reduce significantly the incidence of future losses.

However, revision of the SAA Earthquake Code and the interim building regulations will do little to reduce the incidence of non-structural and contents damage. While the code applies to the design and construction of buildings, parts of buildings, fittings, non-structural elements and building services, it is not directed at preventing damage, only at limiting damage and reducing the risk of major failures. As with most other earthquake codes around the globe, neither the SAA Code nor the interim regulations address adequately prevention of damage to non-structural parts of buildings such as infill panels, partition walls, sanitary and electrical installations, and wall and floor covers. Experience overseas indicates that it is frequently the non-structural and contents items which contribute a major proportion of total earthquake losses. Suggestions are made here for the reduction of non-structural losses to private dwellings, contents, and business enterprises.

Private dwellings

Numerous simple tasks can be undertaken relatively cheaply which will reduce non-structural damage, decrease the likelihood of damage or destruction of building contents, and lower the chances of human casualties as a result of a moderate earthquake. The suggestions listed here are applicable to many dwellings and small business houses but they apply particularly to those on relatively soft foundations such as alluvial and estuarine sediments and other recently filled land. Even more particularly they apply to older unreinforced masonry buildings. While these suggestions may seem excessively cautious in the light of earthquakes of the magnitude of the Newcastle event, it should be remembered that earthquakes with Richter magnitudes of 7.5, or even 8.0, are considered probable extremes for Australia.

Simple tasks which will reduce the impact of an earthquake include:

1. Chimneys should extend as little as possible above the roof line and be reinforced with steel rods if of masonry construction. Where the chimney stands against an exterior wall it should be strapped to the house structure at several points, particularly at the top of the wall. Maintenance is necessary as both lime mortar and steel reinforcing lose strength over time.
2. Water heaters and gas appliances should be strapped to a wall and/or bolted to the floor to prevent toppling.
3. Utility lines – water, electrical, gas, sewage – are likely to sever when ground and building shaking are severe. A residual current interrupter (earth leakage circuit breaker) should be installed for electricity as broken wiring is especially dangerous in areas where spillage of liquids can occur; for example, in the kitchen, bathroom or laundry and near waterbeds. In the event of an earthquake gas and water mains should be turned off immediately as rupture of lines is very likely if structural damage occurs to the dwelling.

Business interruption

Many of the issues raised in relation to non-structural and contents damage and human casualties in the home surroundings are also pertinent to business enterprises. It must be recognised that a disaster such as an earthquake can wipe out a thriving business overnight. Questions concerning the adequacy of insurance coverage for contents damage, business interruption and/or denial of access certainly arise but continued profitability may well depend on re-establishment of operations with the minimum of delay. Each business needs to critically review the impact of an earthquake on its ability to function. What would be the consequences of building and/or contents damage and disruption of business operations? What actions can be taken to mitigate these impacts? Each business needs to identify the earthquake hazards to which it is exposed, to assess the risks that stem from those hazards, to note the consequences, and to then work towards minimising or even eliminating the risks. It should be recognised that earthquakes are often accompanied by secondary hazards such as fire and/or water damage.

Not all of the relevant issues are raised here but the following questions require consideration by most businesses:

1. Which earthquake-induced hazards could affect business operations – for example, ground shaking, building collapse, building damage, fire, chemical spill, dust, flood, landslide, subsidence, rain penetration?
2. How vulnerable are the various components of the firm's operations – for example, employees, records, computer systems, communication facilities, machines, inventory, other assets?
3. What would be the consequences of utility loss – power, telephone, gas, water, sewage disposal – on the various components of business operations?
4. Is the sum insured adequate, particularly considering the escalation in building costs which follow a disaster?
5. What effects would denial of access to the premises have on business operations/survival?
6. What would be the effects of these consequences on the marketplace – for both this firm and competitors?
7. Can valuable equipment be replaced or repaired?
8. Can emergency premises be identified and outfitted?
9. How would customers/clients use alternative plans?
10. Is it possible to develop plans for mutual assistance with other businesses if one or both are damaged?
11. What other steps need to be put into practice now in order to minimise the time required for recovery from disaster?

As many individuals and businesses have found in the aftermath of the Newcastle earthquake, recovery from disaster is not easy. Those enterprises which have developed plans to identify and minimise risks and formulated recovery strategies which are reviewed regularly are likely to suffer least.

45. Older unreinforced masonry homes may have low seismic resistance. Some of the points that should be checked are shown (modified after Home Buyer's Guide to Earthquake Hazards).

Earthquakes and insurance

The Newcastle experience

At the time of publication (June, 1990) it is predicted that the Newcastle earthquake may cost the insurance industry about $800 million. As the destruction of Darwin on Christmas day by Cyclone Tracy cost the industry $650 million calculated in January 1990 dollars, the earthquake has proved to be the most expensive event in the history of the Australian insurance industry.

The total cost of the earthquake, as opposed to the cost to the insurance industry is unknown but is assumed to be well in excess of $1 billion, taking into account such factors as the indirect costs associated with disaster relief and recovery.

The great majority of the likely $800 million cost to the insurance industry resulted from damage in Newcastle, but insurance claims have been registered from a wide area including Sydney, Kempsey, Scone, and up to 300 km from the epicentre. A total of about 35,000 claims have been made.

Claims were still coming in to insurance companies in mid-April, 1990 at the rate of some 60 per day. The fact that claims were still arriving at such a rate more than three months after the earthquake stems in part from the continued ground movements resulting from the very wet summer and autumn on the east coast of New South Wales.

By the end of March, 1990 only $60 million of the claims had been paid.

It was often necessary to re-assess damage on several occasions where continuing ground movements and building damage occurred. The problem was also exacerbated by the very large number of claims, many of which had to assessed several times, and by the Sydney hailstorm of March 18, an event which resulted in more than an estimated $450 million in insurance claims (also a record for a hailstorm in Australia!).

There is no doubt that the loss assessors and claims officers worked hard and under great pressure for some months as a result of the earthquake, and then the hailstorm. The circumstances, as we have come to expect in the aftermath of such large events generating so many claims, have been very trying on the resources of the insurance industry and it is to the industry's credit that most claims were handled expeditiously.

Many small businesses in the downtown portion of Newcastle and elsewhere did not carry business interruption insurance. Insurance Council of Australia statistics suggest 70 per cent of business had no business interruption cover and nearly 20 per cent had no insurance whatsoever. As right of entry to many premises was denied for periods of twelve days or more, some enterprises that experienced little or no damage suffered considerable financial losses.

It appears that the average insurance policy for a dwelling in Newcastle was for only $46,000. This amount, to cover building damage, removal of debris and temporary accommodation, was often inadequate. Even without allowing for the considerable inflationary rises in building repairs in the aftermath of the earthquake – another recurring problem – this average amount is clearly inadequate for most of the dwellings in the Newcastle area. An Insurance Council of Australia Special Bulletin noted:

> "The majority of policy holders were only covered for up to 50 per cent of the true cost of replacing their home while many had no insurance at all".

Pensioners, in particular, appear to have suffered from inadequate insurance cover. To ameliorate the problem in the domestic situation many insurers agreed to waive co-insurance provisions following the earthquake where the under-insurance was not a deliberate attempt to minimise premium.

Under-insurance has been a problem in every major natural disaster in Australia, at least since Cyclone Tracy destroyed Darwin in 1974. Despite publicity campaigns by companies and indexation of householder policies, it appears that more needs to be achieved in this area.

Although only limited amounts of data are available at present, it appears that about $540 million in claims is for property damage. A further $160 million stems from business interruption policies. The remaining $100 million relates to workers' compensation, personal accident, public liability and motor vehicle policies.

Although a detailed analysis will have to await the arrival of further information several issues worthy of comment have already arisen:

Some general issues

In New South Wales earthquake cover was deleted from most insurance policies in 1927 and then reintroduced in 1947. In 1956 the Insurance Association set a rate of 0.013% for New South Wales except for shires within a 50 km radius of Gunning where the rate was set at 0.050%. Since the Insurance Council's (then the Fire and Accident Underwriters Association) rating tariffs were abandoned in the mid-1970s specific loadings for perils such as earthquakes on standard fire policies have virtually disappeared. As John Staveley, Managing Director of AMP Fire and General, noted in The Insurance Record in January, 1988:

> "The abolition of loadings for additional perils has served to eliminate any margin for the infrequent but potentially expensive catastrophe loss. No specific catastrophe reserves exist for most companies which rely on their free reserves and reinsurance arrangements to finance the very large losses. It could be argued that the loading in the rates required to cover the cost to insurers of catastrophe reinsurance constitutes the rating component for extraneous perils."

Virtually all Domestic Property, Fire and Extraneous Perils and Industrial Special Risks (ISR) policies have earthquake cover as a standard (and automatic) inclusion. The earthquake deductible was set at $200 in 1977 for domestic policies and one percent or $20,000 (which ever is the lesser) for ISR policies. These deductibles would still apply in many cases today.

Despite the fact that earthquake has traditionally not been seen as a major insurance exposure the risk has not been entirely forgotten. A 1978 report by a major company reported:

> "Earthquake is fortunately less of a hazard in Australia than in many parts of the world. Nevertheless, the earth tremor which shook the Southern Highlands of New South Wales on May 22, 1961 produced insured claims in excess of $500,000 and a second tremor in the Picton area on March 10, 1973 which was of similar intensity cost probably $250,000.

It is interesting to note that the NSW earth tremors which measured 5.5 on the Richter scale were of the same order which have led to deaths and damage in other more densely populated parts of the world and it is by geological good fortune that Australia has escaped an earthquake loss of major dimensions."

As noted earlier, the 1973 Picton earthquake resulted in claims across a wide area of New South Wales, ringed by Canberra, Young, Cowra, Orange and Speers Point (near Newcastle) and including the majority of suburbs in Sydney. This earthquake evidently made such an impact on the industry that a report issued in 1974 by the Insurance Conference Committee stated:

"Insurers are conscious that, if a major earthquake were to occur in a major Australian capital city, the damage could run into several hundred millions of dollars and could face some insurers with the prospect of insolvency.
On the basis of our insurability criteria, it is obvious that the risk of earthquake does not measure up as being an insurable risk."

Despite early recognition of some of the problems associated with automatic inclusion of earthquake cover in policies in Australia, competition has meant that little has been done to charge adequate rates. In California, where the earthquake risk is much greater than in Australia, earthquake insurance is an option offered to home policy holders. However, only about 30 percent of homeowners avail themselves of the opportunity to purchase the cover, largely because rates of 1-4%. including a deductible of 10% of total sum insured are unattractive. Furthermore, it is often not possible to obtain cover for masonry veneer and unreinforced masonry construction, the main types of buildings to suffer damage in Newcastle. Damage to window and door glass is also often excluded from earthquake cover.

Construction on poor ground, for example, alluvium and other recent sediments as well as reclaimed land, often incurs a 25% increase in premium.

In Australia, earthquake premium zonation – if it can be considered to exist through reinsurance rates – depends almost entirely on historical seismicity as represented by a record often little more than 100 years in length and takes no account of ground conditions. Furthermore the only account taken of building construction in most domestic policies is based on flammability with timber dwellings attracting higher premiums than masonry construction. For earthquake premium calculation it should be noted that earthquake resistance increases in the order unreinforced masonry, brick veneer, timber. This decrease in vulnerability to earthquake is opposite to that for vulnerability to fire.

As noted earlier, the problem of underinsurance is fundamental, particularly with domestic and small business policies. Carefully orchestrated, well-targeted, and persuasive education campaigns should be developed to encourage policy holders (and those with no insurance) to purchase adequate cover. Regulations, such as those in Germany, which stipulate minimum values per square metre of floor area, could be considered.

Finally, it is clear that at least 20 percent of the insurance loss arising from the Newcastle earthquake stems from business interruption. One of the major causes of business interruption was the complete closure of major sections of the central business district for twelve days and of the Hamilton business area for a great deal longer. These closures were community decisions and outside the control of individual owners. With improved post-disaster planning and better priorities for damage inspection, community disruption and business losses could be reduced. It is in the insurance industry's interests to ensure that the lessons learnt in the aftermath of the Newcastle earthquake are implemented in counter-disaster plans across the nation.

Probable Maximum Loss

The problem with a Probable Maximum Loss (PML) study for the peril of earthquake or, indeed, for the calculation of earthquake insurance rates is the lack of available data as pointed out by the Technical Committee for Technical Aspects of a National Scheme for Natural Disaster Insurance (February, 1978). Calculations that were made in that study to estimate gross premiums are based on questionable assumptions regarding relationships between damage rates and Modified Mercalli intensities and about the ratio of buildings to contents losses. It was also assumed that variations in earthquake risk with subsoil conditions were covered by a contingency loading of 10 per cent.

Although detailed analyses of losses as a result of the Newcastle earthquake have not yet been undertaken it is clear that sufficient data are available to establish the relationships between losses and building types, Modified Mercalli intensities, subsoil conditions and epicentral distance. Such an analysis together with a breakdown of building damage, contents damage and business interruption losses would provide the basic technical input for a PML study.

The possibility that a similar earthquake could occur near (or in) Sydney, Melbourne, Adelaide, Perth, Gold Coast, Canberra, or Wollongong needs to be reviewed carefully by the insurance industry. The Newcastle earthquake, together with those at Adelaide (1954), Meckering (1968) and Picton (1973), provide some basis for the calculation of Probable Maximum Losses. However, worthwhile estimates of PML values for these cities will depend, as each of the above earthquakes demonstrated, on careful assessments of the character and extent of alluvial and other soft sediments, and on the proportions of unreinforced masonry and other vulnerable buildings. Such studies should also establish the PML values associated with earthquakes of magnitudes up to M=7.5 along the eastern seabord of the continent, and the possibilities and consequences of serious fires following such earthquakes. Efforts must also be encouraged to estimate more satisfactorily the return periods associated with damaging earthquakes.

Conclusions/Findings

1. The Newcastle earthquake measured 5.6 on the Richter scale. It was a moderate earthquake releasing only one twenty thousandth of the energy (or less) of the great earthquakes that will one day strike California and Tokyo. Yet the Newcastle earthquake caused total damage of more than $1 billion, with approximately $800 million incurred by the insurance industry. Although the large damage bill from a moderate earthquake at first surprises, it should not – the El Salvador earthquake in October 1986 (M=5.4) killed about 14,000 and produced economic losses of about US$2 billion, the Agadir earthquake in 1960 (M=5.9) killed more than 12,000, and the Adelaide earthquake in 1954 (M=5.5) produced 30,000 insurance claims. There is ample evidence that moderate earthquakes can cause large economic losses and huge death tolls. Losses are not confined to less developed countries or to areas that have made no attempt to develop seismic resistance in their building codes.
2. The traditional view has been that areas of Australia that are at greatest seismic risk have experienced historical seismicity and have been placed in the higher risk zones in the AS2121-1979 Earthquake Code. The 1988 Tennant Creek and the 1989 Newcastle earthquakes indicate that the historical record is too short and that other parts of the continent, as yet unsuspected, may be at risk from intraplate earthquakes. Given that the revised earthquake risk maps produced in 1989, and used in the Australian Earthquake Standard, place Newcastle into Zone A of the SAA Code, many would argue that this change, as events have shown, still underrates seismic risk for the area. An approach to seismic risk assessment that takes into account both existing structures and the nature of the subsoil foundations is required. Consideration should also be given to placing all cities in Australia into Zone A as a minimum requirement.
3. There is little doubt that buildings on alluvium and other soft recent sediments performed poorly in comparison to most of those on older more compact sedimentary rocks. This is not surprising – investigations in Wellington, New Zealand, for example, suggest that the damage rates for buildings on alluvium are about ten times those on the older rocks for equivalent ground shaking. Such microzonation studies have not been carried out in Australia on any scale but need to be considered in any revision of the Earthquake Code. Preliminary results from Newcastle suggest that microzonation assessments are at least as important in seismic risk assessment as imprecise analyses of whether expected return periods for Modified Mercalli VIII ground shaking should be once in 500 or once in 1000 years.
4. The Newcastle earthquake produced significant damage to public buildings, in particular schools and churches. Buildings used by the Ambulance Service and Telecom also experienced damage. Whilst many of these buildings have, or could have, a disaster recovery or disaster relief function, the SAA Earthquake Code does not require them to have enhanced seismic resistance because Newcastle lay in Zone O (had Newcastle been in Zone 2, the increased seismic resistance of buildings with a post-disaster function would have been required). While the age of many of these public buildings was undoubtedly a factor in their relatively poor performance, the levels of damage sustained indicate that design and maintenance requirements of buildings which have post-disaster functions, which have large numbers of people in occupation for some hours on most days, or which form places of refuge for many, need to be reconsidered.
5. Unreinforced masonry structures sustained the greatest amount of damage in Newcastle. Careful consideration needs to be given to the problem with especial reference to wall ties, parapets, awnings, and chimneys. The Newcastle City Council interim building regulations form an important step in the right direction, but application of similar regulations to other urban areas requires consideration.
6. Under-insurance has proved to be a significant problem in the aftermath of the earthquake. There are two aspects to the problem. Firstly, it appears that many homes and other structures were grossly underinsured before the earthquake. Secondly, inflation in building repair costs occurred immediately after the earthquake, with the result that even those whose cover appeared adequate before the event, were underinsured.
   This second problem was not unique to Newcastle. It was widely reported after Cyclone Tracy, after the Brisbane hailstorm of 1985 and after the Mexican earthquake in the same year.
7. Existing regulations about seismic resistance do not apply to individual dwellings anywhere in Australia. While damage to domestic structures does not appear to have contributed to any loss of life in the Newcastle earthquake, such damage has produced the greatest number of insurance claims and a very significant proportion of the property damage payout.

It is instructive to place the aftermath of the earthquake in the same context as Cyclone Tracy. The aftermath of Tracy, which produced the largest insurance payout until the Newcastle earthquake, resulted in the upgrading of design requirements for wind forces for all structures in northern Australia. As a result it is unlikely that the intensity of devastation associated with Tracy will be experienced again for equivalent wind forces – in the long term both the Australian community and the insurance industry have benefited, and will continue to benefit, by the improvement in building standards resulting from the 1974 cyclone. A repeat of Tracy in Darwin would almost certainly result in less damage, fewer deaths, little need for evacuation, and lower social and economic costs.
Will it be possible to make a similar evaluation of the Newcastle earthquake in a decade or two? Will the insurance industry and the community "benefit" in the long term from the disaster?

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The authors would like to acknowledge the significant contribution of Dr Kevin McCue of the Australian Seismological Centre, Bureau of Mineral Resources, to this publication.

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