The risk to lifelines from earthquakes in Australia and in Canberra in particular

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Introduction

London in England may seem a strange starting point for a discussion on earthquakes in Australia but there are significant parallels. On a recent visit to the European Strong Motion Data Centre at Imperial College London, I came across a new publication documenting earthquakes that have affected that city. To my surprise, significant damage was occasioned by a local earthquake in the 18th century and falling masonry caused one death and several injuries in the city.

This was by no means an isolated event; in Canterbury Cathedral I came across a plaque describing the effects of an earthquake in the 13th century. It was strongly felt in London where the Bishop of Canterbury was attending a church synod meeting. He quickly returned to his See on learning that the earthquake had caused the partial collapse of a bell tower on the cathedral then under construction.

British seismologists have compiled a database of earthquakes spanning the last 1000 years which shows that there is a low but non-negligible earthquake hazard in Britain. And the parallels with Australia are that there is neither total consensus on an earthquake hazard map nor widespread public knowledge of the risk.

In Australia the earthquake hazard is higher than in Britain and most parts of non-plate-boundary Europe, and also higher than that in intraplate Southern Africa, northwestern America and southeastern China. The record shows that few areas of Australia have escaped perceptible shaking from earthquakes in the last two hundred years. In that time the largest known earthquake was that offshore from Geraldton WA in 1906, which was felt over most of the State. It had a magnitude of 7.2.

That there are differing views amongst Australian seismologists as to the location of zone boundaries, the form of an attenuation relationship or the precise estimate of hazard, must not paralyse the engineering community into doing nothing to mitigate damage. Rather, seismologists should be encouraged to spend more effort to understand the nature of Australia's earthquakes; their mechanisms, depth distribution, limiting size and cause. Engineers should contribute to the debate by ensuring that their important structures are instrumented and that more free field strong motion instruments are installed so that appropriate attenuation relationships can be developed and the critical response spectra computed.

Seismicity and earthquake hazard in Australia

Spatial distribution AGSO, with input from State and university collaborators, has compiled a database of Australian earthquakes extending back to 1788. The catalogue is of course incomplete for the early period but should be complete for all magnitude 6 or greater earthquakes since 1890 and for all magnitude 4 or greater earthquakes since 1969. More than 90% of the earthquakes in the database happened in the last 25 years; they are the majority of the epicentres shown in Figure 1 which depicts all magnitude 4 or greater earthquakes.

At a continental scale it is obvious that some parts of Australia are more active than others, large blank areas without seismicity are surrounded by active zones. In addition there have been more large earthquakes in the western part of the continent than in the centre and more large earthquakes in the centre than in eastern Australia. This correlates roughly with both the age of the crust, (age increasing from east to west), and the outward heat flow from the mantle through the crust (high in the east, low in the west).

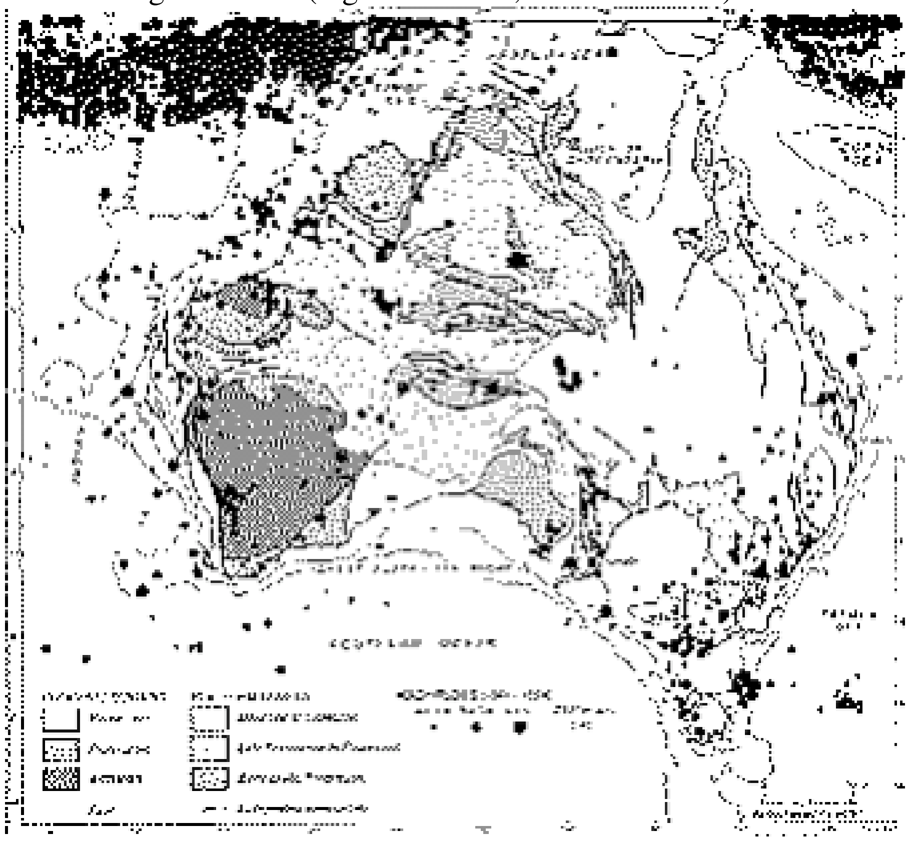


Figure 1 Epicentres of known Australian earthquakes to 1994

At a State scale this pattern is repeated, the epicentres are clustered in zones surrounding inactive areas. The Eastcoast Seismic Zone is a good example, it forms an active eastern boundary to the relatively inactive Murray and Darling Basins. But within that zone there are areas of above average activity or *hotspots*, Newcastle is a good example with 6 earthquakes of magnitude 5.0 or more within 50 km since 1840, compared with Sydney where there were none of this magnitude within 50 km. Both cities are built on sediments of the Sydney Basin, the same broad geological province. Sixty kilometres north of Canberra near the town of Dalton is another of the active hotspots where there have been 4 earthquakes of magnitude 5 or more in the last 100 years, but in the same time there were none of this size within 50 km of Canberra. Unlike Sydney, small earthquakes are relatively common within the Canberra region as will be discussed later.

Temporal distribution In Australia there have been more than 20 independent earthquakes (not aftershocks or multiple events) of magnitude 6.0 or more in the last 100 years (Table 1). The time between events has been anything but periodic, varying from months to nearly 3 decades but the average inter-occurrence time or return period is about 5 years. The last earthquake of this size was at Tennant Creek NT on 22 January 1988, more than 6 years ago at the time of this seminar.

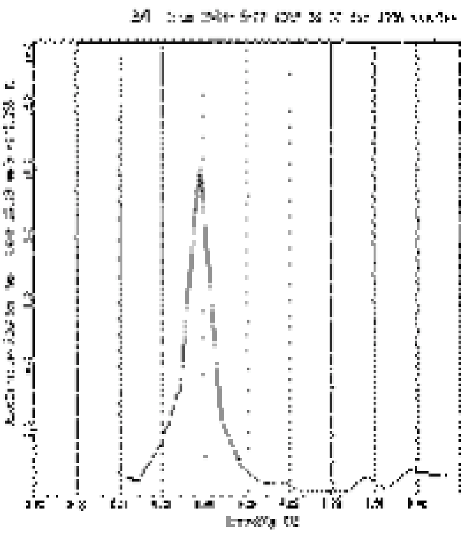
In eastern Australia only the 1918 earthquake offshore from Rockhampton and a series of earthquakes off northeastern Tasmania in the 1883 - 1892 period were of magnitude 6 or more. Recent fault scarps (postdating the last ice age at about 10 000 years) near Lake Edgar Tasmania, Echuca on the NSW/Victoria border, Bendigo Victoria and Snowy Mountains NSW show that large earthquakes have occurred recently in a geological sense but before written records were kept.

On the assumption that earthquakes are independent and the activity stationary in time, it is a simple matter to compute the probability of a magnitude 6^+ earthquake occurring within say 50 km of any site within this Eastcoast Seismic Zone.

Canberra at risk?

The first assessment of earthquake hazard in Canberra was undertaken by Bubb (1976) during design of the Telecom Tower on Black Mountain by the then Commonwealth Department of Works (CDW). This study considered earthquakes on the Lake George fault, in the Dalton region, and a distant magnitude 7.0 earthquake, but not earthquakes closer than 32 km. The structural analysis assumed a lumped mass model of the tower and used modal superposition to compute the maximum response. Results indicated that, shaken by the modelled earthquakes, the steel mast atop the tower would yield but the tower structure would survive intact.

Figure 2 Vibration analysis of Telecom Tower Canberra



Gaull, Michael-Leiba and Rynn (1990) also used a Cornell analysis to estimate the hazard in Canberra and they did assume some background seismicity. Isolated cases of damage were reported in Canberra suburbs after the 1973 Picton NSW earthquake and earthquakes down to magnitude 4 in the Dalton seismic zone are felt in Canberra. Several microearthquakes have caused localised alarm in Canberra suburbs over recent years, the most interesting was a small ML 2.4 earthquake right under Black Mountain in the centre of Canberra in November 1985 (prior to the installation of the accelerographs of course). Too small to cause damage, it was widely felt (Leiba, 1993).

AGSO now monitors the city with seismographs and accelerographs and utilities such as Telecom and ACTEW monitor some of their critical facilities in and near the ACT.

Damage to lifelines in the past

Most large damaging Australian earthquakes have occurred in isolated areas and caused little damage. The Meckering WA earthquake on 14 October 1968 shook the general complacency in the engineering sector and gave rise eventually to AS2121 - the first Australian earthquake code. This code introduced an importance factor *I* in recognition of the need for certain structures housing critical services to remain operational for post-earthquake recovery.'

Prior to that time, when lighthouses were so important for shipping navigation, the Troubridge Lighthouse in South Australia and the Seal Rocks Lighthouse in NSW suffered damage during earthquakes in 1902 and 1912 respectively that rendered them inoperable. The lighthouses are designed to withstand 210 km/h gale force winds and suffered little structural damage but lost mercury from the lens flotation and rotation system.
A similar fate struck the Norah Head lighthouse at Port Nelson NSW during the 1989 Newcastle earthquake. It was reported that the 20 m high cylindrical stone tower vibrated and the optic shook violently for 12 to 15 seconds. Sixty kg of mercury splashed out of the bath but the light continued to rotate. The tower was undamaged though the station buildings, toilets garages and workshops, were cracked. To my knowledge there was no resultant loss of shipping in any of these cases.

Bridge performance is the topic of a later address by Bill Boyce at this Seminar. The only bridges suffering damage in Australia as far as I am aware are one over the Merri River at Warrnambool Victoria which was destroyed in the 1903 earthquake there - a footbridge, and the Stockton Bridge NSW which suffered minor abutment damage in the 1989 Newcastle earthquake.

Buried structures normally fare very well in earthquakes unless they cross the earthquake fault break. Long pipelines and fibre-optic communications cables however are particularly vulnerable because of their great exposure and rigidity, as are surface utilities

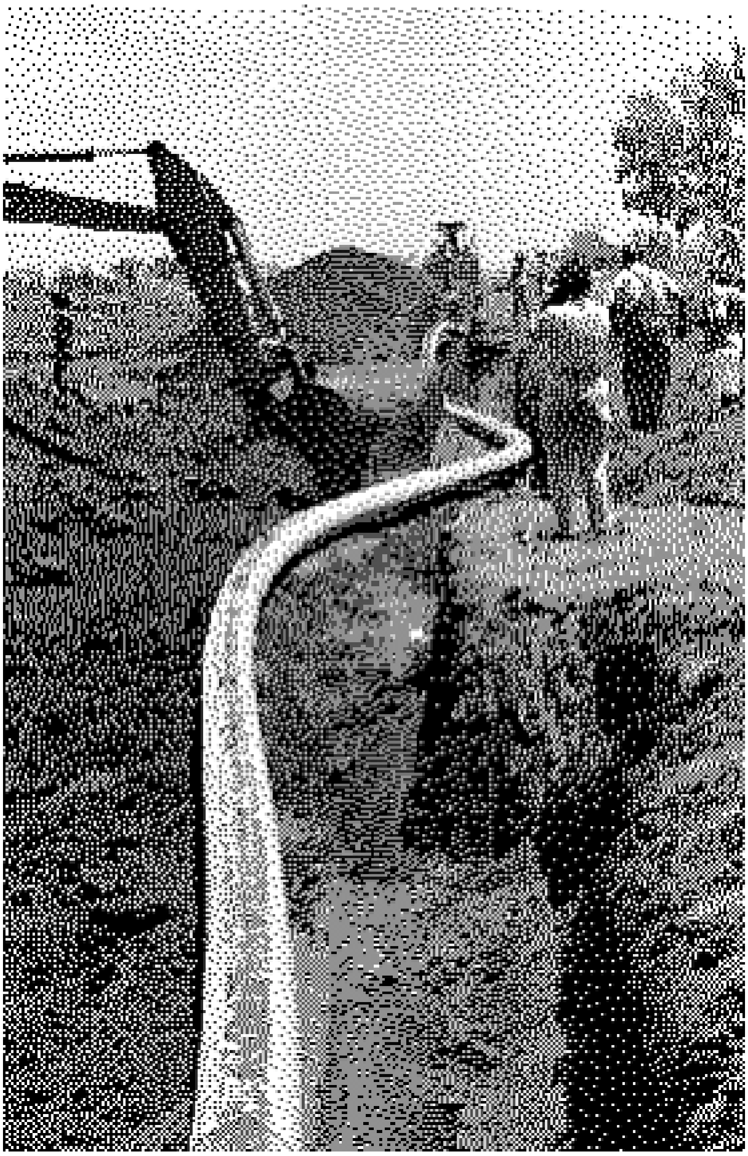


Figure 3 Damage to the natural gas pipeline near Tennant Creek NT, January 1988

such as roads and power lines. In less than 30 years, 7 Australian earthquakes have ruptured the ground surface, seven of only 10 worldwide in intraplate regions. Classic pipeline failures near Meckering WA in 1968 and Tennant Creek NT in 1988 are well documented. The first was a brittle failure in a cast iron water pipe, the second a ductile failure in a mild-steel gas pipeline (Figures 3).

The long gas pipeline servicing the Sydney, Woolongong, Newcastle and Canberra regions from the Cooper Basin on the SA/Qld border region crosses the Dalton Seismic Zone and proposed gas pipelines in WA also traverse earthquake prone areas.

Critical emergency facilities such as hospitals, ambulance and police stations, and communications buildings have also suffered under earthquake loading in Australia. The Children's hospital in Adelaide suffered minor damage in the 1902 Warooka SA earthquake as did a police station at Darlington in the 1954 Adelaide SA earthquake. Both the old masonry Royal Newcastle and still unopened reinforced concrete John Hunter hospitals in Newcastle suffered badly in the Newcastle earthquake. The Newcastle telephone system was apparently not damaged but was severely overloaded immediately after the earthquake rendering communications impossible for several hours.

The 1902 earthquake in South Australia caused severe damage in a small stone country school at Warooka SA, fortunately at night when students and teachers were at home. Large stone blocks fell onto unoccupied desks. Authorities were also lucky in the Newcastle earthquake in that it was Christmas break time for schools and colleges. Many Newcastle schools and the TAFE college were badly damaged, some not repaired in time for the new school term in late January.

Water storage facilities Several dams have been strongly shaken by earthquakes in Australia: Warragamba and Eucumbene dams in NSW, the Canning and Serpentine dams in WA and the Chichester dam NSW on two occasions. They all performed well. A large water tank near Cadoux WA is the only real earthquake casualty to date, it moved substantially on its foundation during the large Ms 6.2 Cadoux earthquake on 2 June 1979. The impounding of some reservoirs has caused earthquakes, such reservoir induced seismicity has been observed at Talbingo Dam NSW, Thomson Dam, Vic and the Ord River Dam WA. Thousands of small earthquakes were recorded shortly after filling commenced and then the activity tailed off with time.

Like pipelines, railways and roads are vulnerable because of their extent. They may be damaged by either foundation failure (landslide or settlement) or faulting. Faulting associated with the 1968 Meckering earthquake cut the main highway east, and spectacularly buckled both the standard gauge and narrow gauge railways linking Perth and Kalgoorlie and eastern States. Faulting during the 1979 Cadoux earthquake also buckled a railway. The 1986 Marryat Creek earthquake in northern SA caused faulting with a 0.5 m scarp across a local road. The damaged road and rail links were restored within 24 hours.

An electrical transformer station near Newcastle suffered considerable damage during the 1989 earthquake (see Rod Caldwell's talk at this seminar). This caused a loss of power for several hours threatening furnaces at the BHP steelworks and pots at an Aluminium refinery. Fortunately power was restored in a short time. There were no reports of damage to the large coal-fired power generators locat ed between Sydney and Newcastle.

New submarine cables laid for TELSTRA between Australia and New Zealand, and Australia and Guam are particularly vulnerable because they cross plate boundaries, the latter twice and at the Marianas trench it sits in an 8 km deep trench. Both faulting and submarine slides cause great damage to these cables as shown by the experience of the OTC whose cables into the Madang cable station on the north coast of Papua New Guinea were regularly broken by large earthquakes under the Finisterre and Adelbert Ranges.

Recent intraplate earthquakes worldwide

On January 15, 1994 small earthquakes of magnitude 4.0 and 4.6 struck the US east coast city of Reading. They damaged more than 200 houses and lifelines, including a sewerage treatment plant, a bridge and a water main causing an estimated loss of $US3.5M. They were preceded by an earthquake swarm in the spring of 1993.

Amongst other notable intraplate earthquakes was the magnitude 6.2 earthquake near Killari India where almost 10 000 people were killed in September 1993. This earthquake, like that at Tennant Creek NT, was preceded by a yearlong foreshock swarm.

A magnitude ML 5.8 earthquake near Liege on the Dutch side of the Netherlands/German border on 13 April 1992 caused significant damage costed at 150M ECU (0.8 ECU @ 1.0 US$). One person died of a heart attack in Bonn.

A magnitude Mb 5.7 earthquake was recorded in South Africa on 31 October 1994 but no damage was reported.

Discussion on the future

Earthquakes do occur in Australia, which is now recognised to be one of the world's most active intraplate regions. The ground motion close to a magnitude 6 earthquake in Australia can be expected to be as strong as the ground shaking from a shallow magnitude 6 earthquake anywhere on earth, be it California or New Zealand.

On a number of occasions in the past, the Australian community has been lucky to escape serious damage and lifeloss; because of the sparsity of population, the time of day or school holidays. The urban areas are expanding rapidly, infrastructure growing at great speed and the complexity and size of vulnerable structures increasing daily. We cannot continue to rely on that luck.

Schools and hospitals should be treated separately to other structures as was done in California after the 1933 Long Beach earthquake. The Field Act ensured that schools were strengthened long before general building codes were introduced there. In Australia retrospective strengthening for pre-code buildings should be considered and all schools and hospitals strengthened to resist horizontal shaking to an agreed minimum level, regardless of the acceleration coefficient.

Where pipelines, particularly gas or oil filled ones, cross known seismic zones or faults, provision should be made for deformation similar to that at Tennant Creek. This is not a difficult engineering problem.

AGSO is addressing some of these issues by: (a) upgrading the National Seismographic Network (b) providing representation on the Standards Loading Code Committee (c) responding to a Commonwealth Government initiative with the States to monitor the urban areas where the vulnerability is high, and (d) participating in microzonation studies to identify and map foundations liable to cause ground motion amplification in urban areas.

The Commonwealth and State Governments or instrumentalities are the only ones participating in the strong motion recording program which will ultimately benefit everyone. It is time the engineering profession convinced some of their clients to take an active role in long-term monitoring; perhaps by collectively instrumenting a few special or even typical Australian structures and nearby free field locations. There is no doubt these activities are reaping unexpectedly quick rewards (see McCue et al. this volume).

References

Bubb, C.T., 1976 - Dynamic response of Black Mountain Tower to estimated ground motion. in Seismicity and earthquake risk in Eastern Australia, Symposium held Canberra 5 December 1973, Ed. D Denham. BMR Bulletin 164.

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Table 1. Large or damaging Australian earthquakes, 1788 - 1990

Date UTC	Time	Lat °S	Long °E	ML	Ms	$AUS loss (1994$)	Location
1873 12 15	0400	26.25	127.5		6.0		SE WA
1884 07 13	0355	40.5	148.5		6.2		NE Tasmania
1885 01 05	1220	29.0	114.0		6.5		Geraldton WA
1885 05 12	2337	39.8	148.8		6.5		NE Tasmania
1892 01 26	1648	40.3	149.5		6.6		NE Tasmania
1897 05 10	0526	37.33	139.75		6.5		Kingston SA
1902 09 19	1035	35.0	137.4		6.0		Warooka SA
1903 04 06	2352	38.43	142.53	4.6			Warrnambool Vic
1903 07 14	1029	38.43	142.53	5.3			Warrnambool Vic
1906 11 19	0718	21.5	104.5		7.3		Offshore WA
1918 06 06	1814 24	23.5	152.5	6.0	5.7		Gladstone Qld
1920 02 08	0524 30	35.0	111.0		6.0		Offshore WA
1929 08 16	2128 23	16.99	120.66		6.6		Broome WA
1935 04 12	0132 24	26.0	151.1	5.2	5.4		Gayndah Qld
1941 04 29	0135 39	26.92	115.80	7.0	6.8		Meeberrie WA
1941 06 27	0755 49	25.95	137.34		6.5		Simpson Desert
1946 09 14	1948 49	40.07	149.30	6.0	5.4		West Tasman Sea
1954 02 28	1809 52	34.93	138.69	5.4	4.9	107M	Adelaide SA
1961 05 21	2140 03	34.55	150.50	5.6		3M	Bowral NSW
1968 10 14	0258 50	31.62	116.98	6.9	6.8	31M	Meckering WA
1970 03 10	1715 11	31.11	116.47	5.1	5.1		Calingiri WA
1970 03 24	1035 17	22.05	126.61	6.7	5.9		L Mckay WA
1972 08 28	0218 56	24.95	136.26		6.2		Simpson Desert
1973 03 09	1909 15	34.17	150.32	5.6	5.3	2M	Picton NSW
1975 10 03	1151 01	22.21	126.58		6.2		L Mckay WA
1978 05 06	1952 19	19.55	126.56		6.2		L Mckay WA
1979 04 23	0545 10	16.66	120.27	6.6	5.7		Broome WA
1979 04 25	2213 57	16.94	120.48		6.1		Broome WA
1979 06 02	0947 59	30.83	117.17	6.2	6.1	10M	Cadoux WA
1983 11 25	1956 07	40.45	155.51	6.0	5.8		Tasman Sea
1985 02 13	0801 23	33.49	150.18	4.3		.09M	Lithgow NSW
1986 03 30	0853 48	26.33	132.52		5.8		Marryat Ck SA
1988 01 22	0035 57	19.79	133.93		6.3	1.3M	Tennant Ck NT
1988 01 22	0357 24	19.88	133.84		6.4		Tennant Ck NT
1988 01 22	1204 55	19.94	133.74		6.7		Tennant Ck NT
1989 12 27	2326 58	32.95	151.61	5.6	4.6	1 270M	Newcastle NSW
1994 08 06	1103 52	32.92	151.29	5.3		50M	Ellalong NSW

Figures