The revised Australian seismic hazard map, 1991

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Introduction

Large potentially destructive earthquakes have occurred this century in Eastern, Central and Western Australia. Relevant epicentral details are listed in Table 1. One of the largest of these struck Meckering WA on 14 October 1968 and awakened the interest of engineers to the potential hazard to buildings, which were not then specifically designed to resist earthquakes. The activity of this group of engineers ultimately led to the formulation of an earthquake zone map of Australia (Figure 1a) which was incorporated into the current Earthquake code (AS2121-1979; Bubb, 1991). Earthquakes that have occurred since the initial hazard studies were completed, plus study of historical accounts of earthquakes, mostly through newspaper stories, had together more than doubled the available earthquake data set and prompted a revision of the hazard estimate (Gaull & others, 1990; hitherto referred to as the GMR maps, Figure 1b).

The occurrence of a large earthquake at Marryat Creek, SA in March 1986, a series of large earthquakes near Tennant Creek, NT on 22 January 1988, and the moderate magnitude earthquake at Newcastle in December 1989, all in zone zero on the AS2121 map (Figure 1a) and in areas of minimal risk on the not-yet-published GMR maps (Figure 1b), highlighted a significant problem facing risk analysts in Australia; namely that there is no model to explain the occurrence of these so-called intraplate earthquakes. This deficiency was well appreciated by members of a subcommittee of the Standards Australia Loading Committee BD/6/4, charged with producing a hazard map for the Loading Code.

The committee spent the first meeting in Newcastle NSW in early 1990, discussing a stategy for producing the required map or maps given that the process had been hastened by Standards Australia following the Newcastle earthquake. Rather than redo a hazard analysis, they decided to take the GMR maps and smooth them according to their collective experience and knowledge, as was done to produce the the maps in AS 2121-1979.

The smoothing was done after consideration of the gross geology and tectonics of Australia and historical and instrumental seismicity in the period 1856 to 1990, some of which was not available to Gaull & others (1990). The resultant map (Figure 1c) shows broad variations over Australia, no zone zero, and is drawn at a scale which does not resolve individual faults nor variations from average ground conditions (firm foundations but neither rock nor soft soils).

Background

Continental Australia is not subject to the same frequency of potentially damaging earthquakes per unit area as the western USA, Japan or New Zealand. However large earthquakes (magnitude 6 and above) do occur in Australia, the most recent series was near Tennant Creek in the Northern Territory on 22 January 1988 (Jones & others, 1992), where earthquakes of magnitude 6.3, 6.4 and 6.7 occurred in a 12 hour period, buckling a buried natural-gas pipeline and causing building damage at Tennant Creek. They created a complex thrust-fault scarp extending for about 35 km, which in places exceeded 2 m in height . The observed average frequency of an earthquake of magnitude 6 or more in Australia over the last 100 years has been about 1 in 5 years (neglecting aftershocks), although the interval between independent events varied from 2 months, in 1941, to 28 years, between 1941 and 1968 (McCue, 1990).

Whilst these large earthquakes are potentially the most destructive, the highest contribution to earthquake hazard, as measured by the probability of exceedance of some particular ground motion level, comes not from these infrequent large earthquakes, but the smaller more frequent and still potentially damaging earthquakes. This was amply demonstrated on 28 December 1989 at Newcastle where 13 people died and $1.5 billion damage was caused by a magnitude 5.5 earthquake, moderate by world standards. The average frequency of magnitude 5 or more earthquakes throughout Australia, is about 1 in 6 months and, in the populous eastern States, 1 in 2 years.

The earthquake zoning map of Australia published in the Earthquake Code, AS 2121-1979, included four seismic zones; Zero, A, 1 & 2 where different loading factors were to be applied (none in zone zero). For a given return period, the zone boundary was drawn to represent a change of load by a factor of 2. For the reasons outlined below, this procedure has been changed so that the new hazard map is presented as a set of contours and the interpolated acceleration coefficient (a or aS) will be used by the design engineer to compute the loading factor in the base shear equation:

- the basis for this re-evaluation of earthquake risk in Australia is the recently published study of Gaull & others, 1990. Their results for MM intensity, ground velocity and acceleration were in terms of a 10% chance of exceedance in 50 years;
- whilst the Cornell/McGuire probabilistic approach used by them tacitly assumes that the best predictor of earthquake activity over the next 30 to 50 years is its distribution over the past 30 to 50 years, earthquakes can and do occur in places without a previous history of seismic activity. The most recent example of this was the earthquake sequence near Tennant Creek in the Northern Territory in January 1988 (compare Figure 1a and1b with 1c);
- members of the seismicity working group, BD/6/4/1, subjectively smoothed, and where necessary extended the contours of Gaull and others in the light of earthquake activity in the period 1984 - 1990 and recently revised historical earthquakes not considered by them, and the broad correlation with geological, topographic and tectonic features. In recognition of the fact that no part of Australia is free from the possible occurrence of earthquakes (see Figure 1 in Denham's paper this volume), the contours were broadened to include the whole continent and appropriate reductions were made to the `bullseyes' around past areas of high seismicity such as that in the Simpson Desert;
- the old zone boundaries were very imprecise but buildings on opposite sides of the boundary were required to be designed to withstand lateral loads which differed by a factor of two. In the new scheme, interpolation between contours means that such anomalies will no longer occur;
- peak ground velocity was chosen as the contour parameter being a better predictor of damage or intensity than peak ground acceleration. The small number of accelerograms of engineering interest available in Australia to date indicate that peak accelerations are very high compared with those predicted by the attenuation relation used by GMR. The peak ground velocity (mm/s) was divided by a factor of 750 (that recommended by the Applied Technology Council) to determine the acceleration coefficient in the final hazard map and loading equation.

The only Australian territory comparable in earthquake risk to California or New Zealand is Macquarie Island, administratively part of Tasmania. It sits astride the Macquarie Ridge a boundary between the Pacific and Australian plates. In May 1989 a *great* magnitude 8.3 earthquake occurred there, only 230 km north of the island. Fortunately there are few structures on the island, a national park. Specific site studies should be undertaken there, and on other off-shore Territories such as Christmas Island or Heard Island should special structures ever be built there.

Data sources

The main source of data was the Australian Geological Survey Organisation's (formerly the Bureau of Mineral Resources) earthquake datafile which was compiled using data from all State and university seismological agencies and which now contains locations of all known Australian earthquakes between 1856 and 1991. Data are reasonably complete from 1969 for magnitudes above 4, and from 1900 the data are complete only for large earthquakes of magnitude 6 and above.

There may be large uncertainties in the early data, the latitude, longitude, focal depth and magnitude, depending on the distribution of seismographs and their distance from the earthquake focus. If events are grouped in source zones, the precise location may not be too important and if there are many events the uncertainties in magnitude may cancel. The results are sensitive to whether the site is inside or outside a source zone, and particularly on the adopted values of focal depth and the attenuation coefficients. These are all discussed by Cornell (1968), and Gaull & others (1990) who undertook sensitivity tests to determine their effects.

Analysis

Gaull, Michael-Leiba and Rynn (1990) modified a computer program of Basham & others (1985) which uses the Cornell (1968) method to compute earthquake hazard, and details can be found in this reference. Their results apply to average foundation conditions and do not allow for any ground motion modification which may be caused by local foundation conditions. Such conditions are taken into account in the site factor (S). In special cases a microzonation study should be undertaken to determine the likely extent, frequency band and severity of any site amplification.

The method does not take into consideration the proximity of active faults. If active faults could be identified, the ground motion recurrence may be significantly increased in some local areas (and decreased in others).

The long period effects observed in the shaking of tall buildings at great epicentral distances: in Adelaide and Perth during large earthquakes in Indonesia, and Adelaide and Cairns in the Tennant Creek NT sequence; have not previously caused damage and have not been considered in the risk analysis.

Aftershock Activity

Following an earthquake large enough to cause damage, aftershocks occur in the focal region of the mainshock but their pattern can show great variability as follows:

- a classical exponential decay of activity with time constant varying from months for a magnitude 5 earthquake to years for a magnitude 6 or greater mainshock. Examples include the 1968 Meckering WA and 1979 Cadoux WA earthquakes. The largest aftershock is often about half a magnitude unit smaller than the mainshock;
- Virtually no aftershocks or only a few micro-earthquakes in the weeks following the mainshock. The 1989 Newcastle NSW and 1990 Meckering WA earthquakes characterised this behaviour;
- a few micro-earthquakes in the weeks following the mainshock but another mainshock sized earthquake 3 to 6 months after the first. This occurred in 1903 near Warrnambool, Vic and in Central Australia at Marryat Creek NT in 1986;
- multiple large earthquakes occurring over hours to a year with thousands of smaller aftershocks during and after the sequence. The 1988 Tennant Creek NT and

1883/6 West Tasman Sea earthquake sequences are the type events for this behaviour. The Tasmanian sequence was apparently over when another isolated large earthquake occurred there in 1892.

At this stage there is no way to predict which particular pattern any earthquake sequence will follow but engineers and counter disaster personnel should be aware of the risk of cumulative damage following any earthquake above magnitude 5.

The future

As new earthquakes occur, these contour maps are bound to change until a cause for intraplate earthquakes is found. If sufficient strong motion data is recorded in intraplate regions over the next few years, later versions of the code should be further modified to produce appropriate design response spectra.

Acknowlegment

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References

ATC, (1984) Tentative provisions for the development of seismic regulations for buildings, ATC 3-06, Applied Technology Council, Palo Alto.

Basham, P.W., Weichert, D.H., Anglin, F.M., & Berry, M.J. (1985) New probabilistic strong ground motion maps of Canada. *Bulletin of the Seismological Society of America*, **75**, 563-595.

Bubb, CTJ. (1991) Presidents column. *Australian Earthquake Engineering Society Newsletter*, 1/1991.

Cornell, A. (1968) Engineering seismic risk analysis. *Bulletin of the Seismological Society of America*, **58**, 1583-1606.

Denham, D., Small, G.R., Cleary, J.R., Gregson, P.J., Sutton, D.J. & Underwood, R. (1975) Australian earthquakes (1897-1972). *Search*, **6**(1-2), 34-37.

Gaull, B.A., Michael-Leiba, M.O., & Rynn, J. (1990) Probabilistic earthquake risk maps of Australia. *Australian Journal of Earth Sciences*, **37**, 169-187.

Jones, T.D., Gibson, G., McCue, K.F., Denham, D., Gregson, P.J., & Bowman, J.R. (1992) Three large intraplate earthquakes near Tennant Creek, Northern Territory, Australia, on 22 January 1988. *BMR Journal of Australian Geology & Geophysics*, 12 339-343.

McCue, K.F. (1973) On the Seismicity of Western Australia - Parts 1 and 2. Commonwealth Department of Works (Australia), Report, 1973.

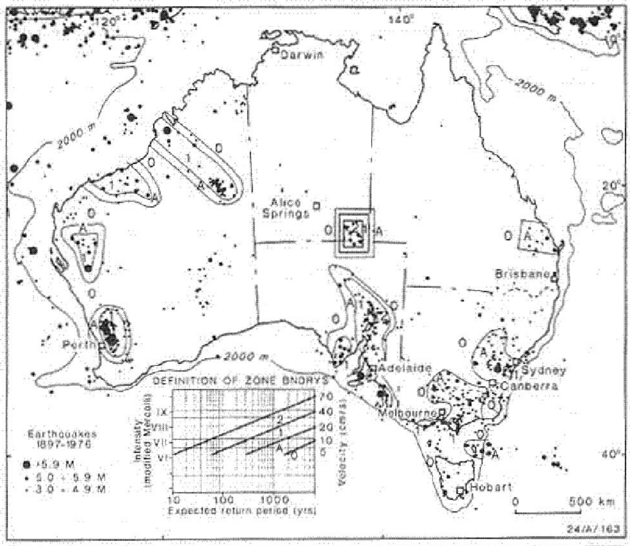
McCue, K.F. (1975) Seismicity and Seismic Risk in South Australia. *University of Adelaide*, Report ADP 137.

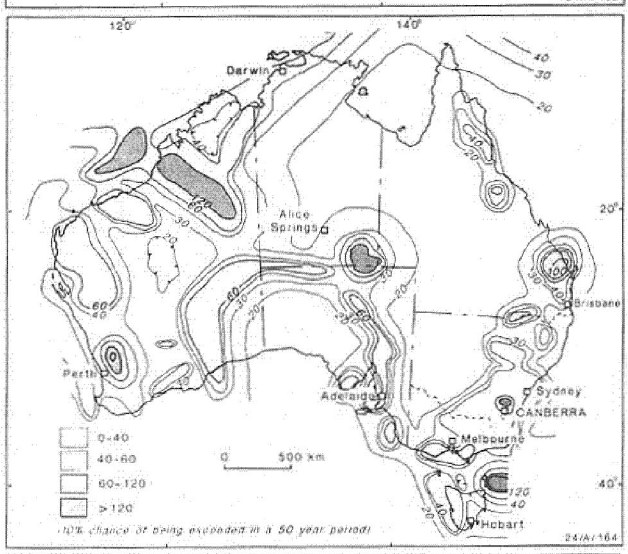
McCue, K.F. (1978) Earthquake Risk in Eastern Australia. *University of Adelaide*. Report ADP 153

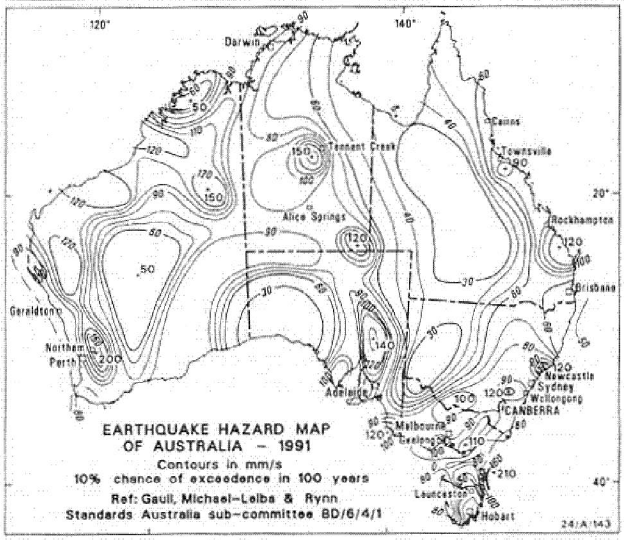
McCue, K.F. (1990) Australia's large earthquakes and Recent fault scarps. Journal of Structural Geology, 12, 5/6, 761-766.

McCue, K.F., Wesson, V, & Gibson, G. (1990) The Newcastle New South Wales earthquake of 28 December 1989. *BMR Journal of Australian Geology & Geophysics*, **11**, 559-567.

McEwin,A., Underwood, R., & Denham, D., (1976) Earthquake Risk in Australia. *BMR Journal of Australian Geology & Geophysics*, 1 (1), 15-21.


Darwin
Alice Springs
Brisbane
Sydney
Canberra
Perth
Adelaide
Melbourne
Hobart
2000 m
DEFINITION OF ZONE BNDRYS
Intensity (modified Mercalli)
Velocity (cm/s)
Expected return period (yrs)
Earthquakes 1897-1976
>5.9 M
5.0 - 5.9 M
3.0 - 4.9 M
500 km
24/A/163


Darwin
Alice Springs
Brisbane
Sydney
CANBERRA
Perth
Adelaide
Melbourne
Hobart
0-40
40-60
60-120
>120
500 km
10% chance of being exceeded in a 50 year period
24/A/164


Darwin
Tennant Creek
Alice Springs
Cairns
Townsville
Rockhampton
Brisbane
Geraldton
Northam
Perth
Adelaide
Newcastle
Sydney
Wollongong
CANBERRA
Melbourne
Geelong
Launceston
Hobart
EARTHQUAKE HAZARD MAP
OF AUSTRALIA - 1991
Contours in mm/s
10% chance of exceedence in 100 years
Ref: Gaull, Michael-Leiba & Rynn
Standards Australia sub-committee BD/6/4/1
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