Attenuation of Strong Shaking in Southeastern Australia

Kevin McCue[1], Victor Dent[1], Trevor Jones[1], Peter Gregson[1],
and Gary Gibson[2]

[1] ASC Australian Geological Survey Organisation, Canberra ACT 2601 and Mundaring WA 6009
[2] SRC Royal Melbourne Institute of Technology, Bundoora Vic 3083

Introduction

New valuable recordings of strong ground motion have been obtained following earthquakes at Ellalong near Cessnock NSW and Eugowra NSW. These and earlier data recorded in both eastern and western Australia can be normalised to a common magnitude to compute attenuation in Australia, to compare the attenuation in Eastern and Western Australia and provide better estimates of the ground motion in Newcastle NSW during the magnitude 5.6 earthquake there in 1989.

This data set also provides the basis for a review of earthquake hazards estimates in Australia and the foundation for innovative research into the mechanics of intraplate earthquakes.

Here we confine our study to a preliminary analysis of the Ellalong earthquake dataset.

The recording network

A quantum leap has taken place in the strong motion recording capability in Australia over the last 5 years. This happened in response to the Newcastle earthquake and was made possible by the development in Australia of modern digital recorders over the last 2 decades.

Analogue recorders were installed in Adelaide in 1972 by the University of Adelaide and in Dalton NSW and the SouthWest Seismic Zone WA by BMR in 1974 (Figure 1). A handful of useful records was obtained from these instruments. In the mid 1980's these accelerographs were supplemented with early digital recorders, Australian Yerillas in Eastern Australia and American A700s in Western Australia.

As a result of the Newcastle earthquake and the lack of ground motion data obtained near the epicentre, Commonwealth and State representatives met in Canberra in February 1990 and put together a plan for monitoring the major urban areas. Federal Cabinet approval was subsequently won but the Commonwealth funding was not met by the States and the total amount allocated only allowed for the purchase of accelerographs and a few seismographs. There was no ongoing allowance for maintenance, for installation or running costs, or for the analysis of the extra data.

Fortunately the State Governments of South Australia, Queensland, New South Wales, Victoria and Tasmania have agreed to pay the annual running costs of the instruments which have now been installed in those States.

Digital accelerographs were also installed by the ACTEW on their dams in the Canberra region, by Telecom in Black Mountain Tower, and by the Parliament House Construction Authority. The (Sydney) Water Board has installed a large network of recorders around their dams south of Sydney.

The major engineering requirement was fulfilled so that in the event of a major urban area being shaken, it is at least possible that a measure of the ground motion will be obtained.

The Data

Following implementation of part of the urban monitoring proposals, dividends were almost immediately forthcoming with small local earthquakes being recorded in Brisbane, Adelaide, Newcastle and Canberra. When most of the instruments had been installed and were operational in southeastern Australia, a damaging magnitude ML 5.3 earthquake occurred near Cessnock NSW. This earthquake is discussed elsewhere (Jones & others this volume) but preliminary analysis of the strong motion data is outlineded below.

An accelerograms recorded at North Lambton, NSW at about 43 km from the epicentre of the Ellalong earthquake epicentre is shown in Figure 1 below. The vertical component is the bottom trace and the time scale is in seconds. The record is notable for the short duration of strong shaking of about 5 s, the low amplitude of ground motion 0.015 g, and the normal frequency range - the dominant ground motion has a period near 0.5 s which is lower than expected for Australia.

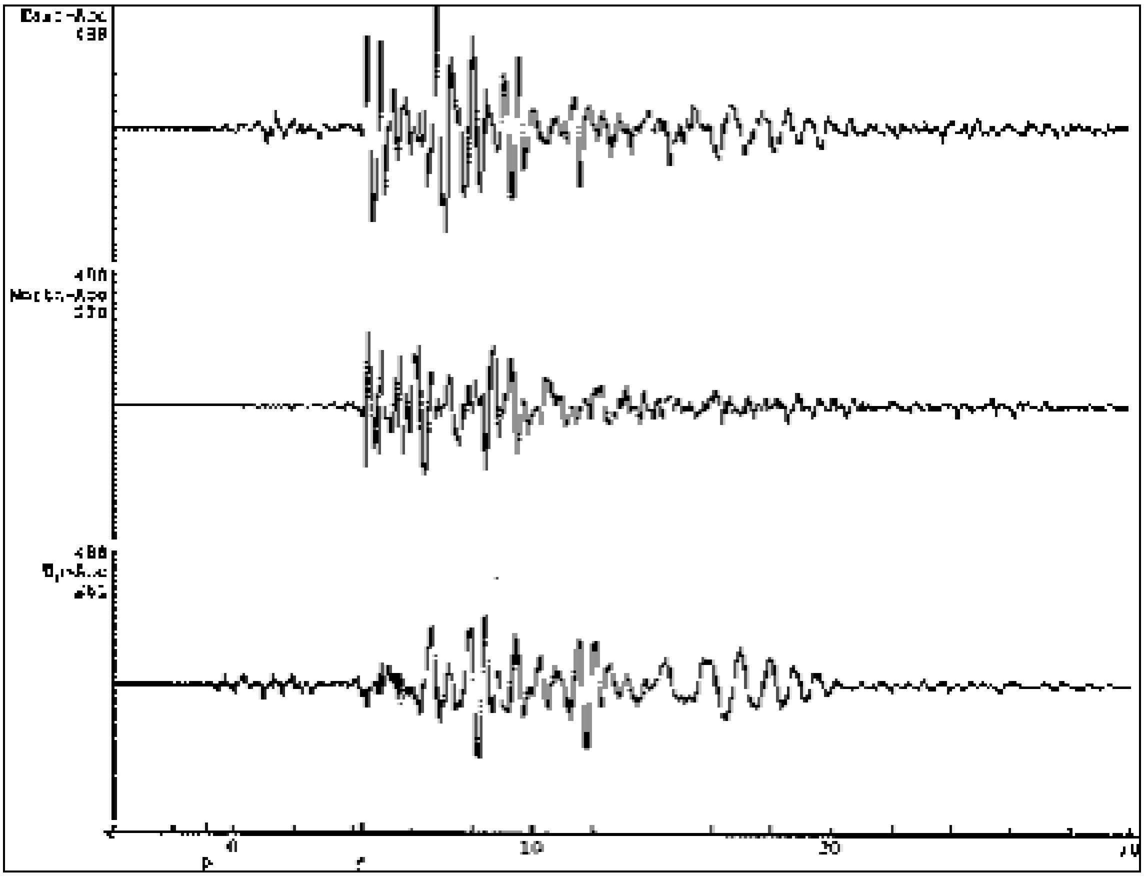

Figure 1 Accelerogram recorded at North Lambton NSW, 43km from the epicentre of the Ellalong earthquake

As the instruments were being retrieved from Cessnock, a swarm of small earthquakes commenced near Eugowra NSW, so the instruments were reinstalled there. (Granite was mined near Eugowra for the new Parliament House in Canberra. When the overburden was removed, pop-ups occurred in the granite and the cut facia slabs were found to later deform with removal of the in-situ stress.) This earthquake swarm, with a largest earthquake of magnitude ML 4.0, has provided hundreds of interesting and useful accelerograms (Gibson & others, this volume). The Ellalong earthquake dataset has allowed some early estimates of attenuation in the distance range 40 - 350 km.

Attenuation

A plot of peak horizontal ground accelerations versus distance *R (km)* recorded from the ML 5.3 Ellalong earthquake is shown below in Figure 2. Only those accelerographs sited on rock were used, some of the instruments at greater distances were in basements of buildings and these have been deleted. The axes have log-log scaling so the amplitudes show considerable scatter. A least squares curve has been fitted to the data and appears to be a reasonable fit (R = 0.94) though underestimating accelerations *a (g)* at the closer stations compared with those observed:

$$a = 5.12 * R^{-1.8}$$

The relatively low ground motions are rather surprising, the imputed peak ground acceleration is already below 0.1g only 10 km from the epicentre but there were no recordings closer than 43 km.

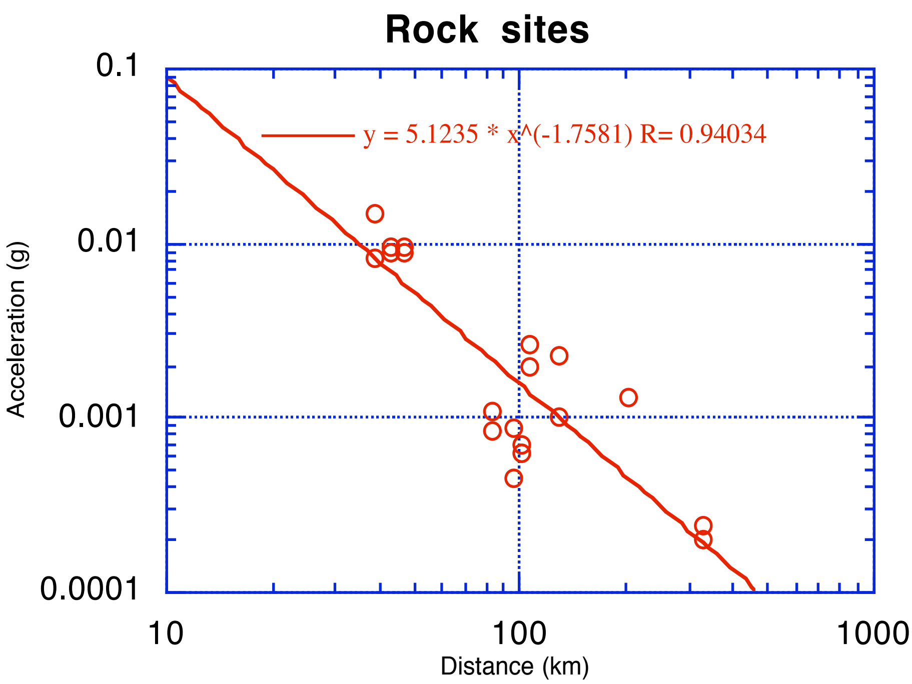

Figure 2 Peak ground acceleration (g) recorded on digital accelerographs on rock in Southeastern Australia during the Ellalong earthquake.

The computed ground motion at Hamilton during the Newcastle earthquake

An important question which the Cessnock data allows us to examine is: 'what was the ground motion in Hamilton and the Newcastle CBD during the 1989 Newcastle earthquake?'. There were no instruments, neither seismographs nor accelerographs, capable of recording the shaking in Hamilton or the Newcastle CBD at the time.

McCue (1991) made an estimate of the peak ground motion and concluded that *the strong motion lasted only 1 or 2 seconds and had a peak acceleration in the range 0.3 to 0.8 g at a frequency near 10 Hz.*

The Cessnock earthquake dataset enables a check of this educated guess. The epicentral distance of the closest recorder at North Lambton from the focus near Ellalong was 43 km compared with 15 km during the 1989 Newcastle earthquake. The ground motion at 15 km can be estimated by extrapolation of the mean line of best fit to the observed data. This gives 0.05 g with a standard deviation range of 0.02 - 0.14 g.

The Cessnock earthquake magnitude was 5.3 compared with 5.6 for the Newcastle earthquake. To convert the accelerations (a) from one magnitude (M_1) to another (M_2) at the same distance, Esteva's (1974) relation was used. This gives the ratio of the accelerations as $\exp\{0.8 (M_1-M_2)\}$ which is 1.27 in this case.

The resultant peak ground motion on rock at 15 km distance from a magnitude 5.6 earthquake is 0.063 g with a standard deviation range of 0.025 - 0.18 g

At the surface of a soil layer such as that at Hamilton, the estimated magnification factor is 2 to 4, from the intensity difference between Hamilton and the epicentral region (McCue & others, 1990; Somerville & others, 1993). Using the mean value of 3, the estimated mean peak ground acceleration at ground level under Hamilton is 0.19 g with a standard deviation ranging from 0.08 - 0.54 g.

The nearest recorder was at 43 km focal distance and we are extrapolating linearly to 15 km to compute the ground motion at Hamilton. If we scale up the Eugowra data (ML4.0, 0.43 g at 1.1 km) to magnitude ML 5.3 then we get a ground acceleration of 1.2 g at 1 km. Compare this value with the acceleration obtained by extrapolating the curve in Figure 2 to a distance of 1 km, 1.7 g, which suggests that linear extrapolation and the Esteva scaling factor may not be too far wrong though the line of best fit passes below and not through the cluster of closest points representing the Newcastle instruments (Figure 2).

Comparison of Western and Eastern Australian data

The peak ground acceleration from a few WA accelerograms of earthquakes of magnitude 3.5 or more were normalised using the Esteva scaling relation above to convert to peak ground accelerations for a magnitude ML 5.5 earthquake. A low magnitude cutoff of 3.5 was adopted to minimise the uncertainty in the normalising factor used. These data were then plotted with the NSW data from the Cessnock earthquake.

The few data points for the two regions are virtually inseparable out to 100 km though there is some suggestion that beyond this distance the WA amplitudes may be systematically higher than those in Eastern Australia. The largest amplitude waves on seismograms of local earthquakes recorded in WA are those of the surface waves, much larger normally than either the P or S body waves, and relatively larger than those observed in Eastern Australia. More data is needed to confirm this apparent similarity in the attenuation rates in eastern and western Australia.

For an earthquake of magnitude 5.5, the expected mean peak acceleration is 0.1 g or more to distances of about 10 km from the focus. The scatter in the data is large however and the 0.43 g horizontal acceleration recorded at Tennant Creek in 1988 at 8 or 9 km from a magnitude ML 4.9 earthquake (McCue & Paull, 1991) is within the scatter.

Discussion

An acceleration attenuation relation has been developed for southeastern Australia, (strictly for a magnitude ML 5.3 earthquake):

$$a(g) = 1.70 \exp(M-5.3)\, R^{-1.49}$$
$$M \leq 5.6$$

This relationship has been used to estimate the ground motion on 28 December 1989 on alluvium in the Hamilton region of Newcastle where the magnification factor was estimated to be about 3. On this model the peak ground acceleration was estimated to be in the range 0.08 - 0.54 g with a mean at about 0.19 g. The scatter is large about this mean value, as it is in other countries with large datasets such as the USA and New Zealand.

Comparison of the data from southwest WA and southeastern Australia shows agreement out to a distance of about 100 km.

References

Esteva, L., 1974 — Geology and probability in the assessment of seismic risk. 2nd international conference of the International Association of Geologists, Sao Paulo, Brazil.

McCue, K.F., Wesson, V., & Gibson, G., 1990 — The Newcastle NSW earthquake of 28 December 1989. BMR Journal of Australian Geology & Geophysics, 11, 559-567.

McCue, K., 1991 — The strength, frequency contentand duration of strong motion in Australia. Institution of Engineers Conference, Australian Disaster & Emergency Management - How good?, Sydney 4 - 6 March 1991, 27-33.

McCue, K., & Paull, E., 1991 — Australian Seismological Report, 1988. Bureau of Mineral Resources, report 1988, 53pp.

Somerville, M.R., Kagami, H., & McCue, K., 1993 — Seismic amplification determined from microtremor monitoring at alluvial sites in Newcastle. Bulletin of the New Zealand National Society for Earthquake Engineering, 26 (2), pp 175 - 184.

Figures