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NEAR FIELD CHARACTERISTICS OF RECENT INTRAPLATE EARTHQUAKES IN AUSTRALIA

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ABSTRACT

A magnitude 5.3 earthquake in Southeastern Australia on 6 August 1994 triggered digital accelerographs in the distance range 39 to 330 km. The peak ground motions on rock were 0.015g and 12.5 mms^{-1} at the nearest station. The ratio of vertical to horizontal acceleration averaged 0.6 but varied widely between 0.4 and 1.0 throughout the distance range.

The distance exponents in a Kanai type attenuation relationship were -1.7 for acceleration and -2.0 for velocity. These data and respective isoseismal maps are used to estimate the ground shaking at Newcastle during the destructive magnitude 5.6 earthquake there on 28 December 1989.

KEYWORDS

Strong Motion; Accelerograms; Attenuation; Intraplate Earthquakes

INTRODUCTION

Earthquakes do occur in Australia and the distribution of epicentres of past earthquakes of magnitude 4 or more to December 1994 are shown in Figure 1. On average over the last 100 years, earthquakes of magnitude 6 or more have occurred every 5 years, but until 1989 few injuries and no deaths had been caused though minor damage is regularly reported.

Thirteen people died under fallen street awnings and the rubble of one partially collapsed building in Newcastle NSW during an earthquake there on 28 December 1989. There is no record of the ground motion within 100 km of the epicentre of this moderate magnitude ML 5.6 earthquake which has prevented retrospective modelling of the structural damage, and postponed the adoption of an appropriate response spectrum in the Building Code of Australia.

In February 1990 the Australian Government provided funds for AGSO to purchase 34 locally manufactured digital accelerographs which were installed between 1992 and 1995 in 17 cities with populations in excess of 50 000. The accelerographs were sited at free-field locations, one on bedrock and the other on typical soil foundations.

The strategy to install wide dynamic range accelerographs in the urban areas has proven its worth with a number of individual triggerings in Newcastle, Canberra, Brisbane and Adelaide by small local earthquakes and one multiple triggering of instruments in the Sydney region from a moderate magnitude 5.3 earthquake. The Darwin accelerographs have also been triggered by a number of large earthquakes in the Banda Sea, the last on 25 December 1995.

AUSTRALIA'S INTRAPLATE EARTHQUAKES

Spatial Distribution

Earthquakes occur throughout Australia as shown in Fig. 1. There have been six earthquakes this century of magnitude 5 or more within about 100 km of Sydney, two of them to the north near the city of Newcastle.

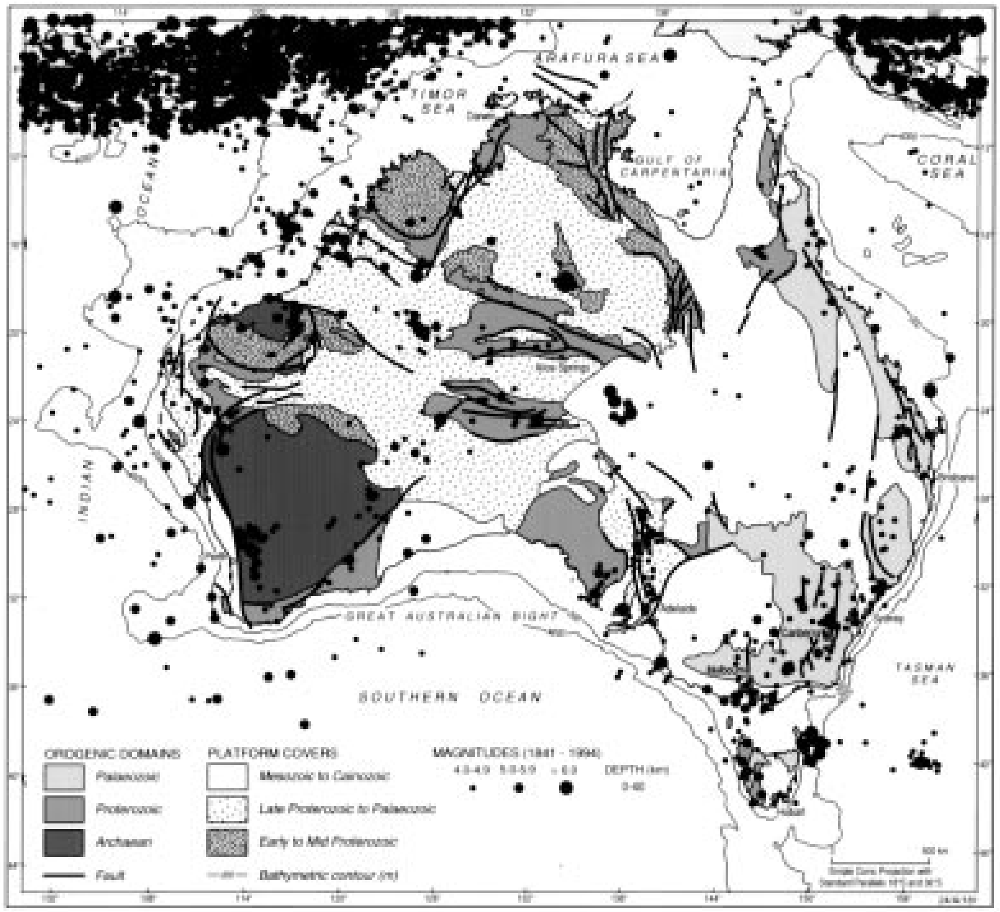

Fig. 1. Australian earthquakes, M ≥ 4.0, 1841 - 1994.

Frequency

Only a few percent of the world's earthquakes occur intraplate, but large potentially destructive earthquakes can and do occur within the plates. In the last 100 years, there have been 20 earthquakes of magnitude 6.0 or greater in continental Australia, including the continental shelf, and there are between 2 and 3 earthquakes per year on average of magnitude 5.0 or more which are large enough to cause serious damage (McCue, 1993).

One factor contributing to the greater potential for destruction in Australian earthquakes than say those in New Zealand, is their very shallow focal depth, but a mitigating factor for damage in Australia in the past has been the low population density. The population has doubled in the last 40 years causing a commensurate rise in earthquake vulnerability and hence earthquake risk.

Focal Depth range

With a few notable exceptions, the fault planes of most of the larger well-constrained Australian earthquakes are in the upper 10 km of the crust (Fredrich, McCaffrey and Denham, 1988). So shallow are they, that five of the large earthquakes since 1960 have been accompanied by surface faulting (McCue, 1990). Relatively few earthquakes have occurred in the lower crust to about 40 km depth (McCue and Michael-Leiba, 1993).

Magnitude limit

The largest earthquake in Australia, where the observation period for the whole continent is not much greater than 100 years, was the magnitude Ms 7.2 earthquake in the Indian Ocean off Geraldton WA in 1906

(Gregson and Everingham, 1991). Such an earthquake has a computed return period of about 100 years for continental Australia (McCue, 1993) and linear extrapolation of the magnitude/frequency relation predicts a return period of about 500 years for a magnitude 8 earthquake. In the Eastern United States which is, like Australia, a stable continental region but where the observation period is nearly 400 years, three earthquakes of about magnitude 8.0 have occurred. The stable continental region of China has also suffered earthquakes of this size in historical time but there is no evidence to indicate that a great earthquake has occurred in Australia in the last 10000 years. A magnitude of about 7.5 is usually accepted as a reasonable upper bound to magnitude in Australia (Gaull, Michael-Leiba and Rynn, 1990).

Source mechanisms

The five fault scarps observed and mapped during earthquakes in the last 30 years in Australia were all thrust-type scarps caused by compression, and resulting in crustal shortening. Studies of the focal mechanisms of these and other earthquakes in Australia using either seismic wave inversion techniques or first motion polarity confirm the surface geometry and that earthquakes are caused by rock failing under compressive loading. The direction of σ_1 appears to be reasonably uniform within seismic zones but varies markedly from one zone to another within continental Australia (Denham, and Windsor, 1991).

The principal stress σ_1 is oriented east-west in south-western Australia, north-northeast to south-southwest in central Australia, and east-southeast to west-northwest in southeastern Australia.

THE DATA

Pairs of free-field, wide dynamic range digital accelerographs have been installed in Canberra and state capitals; Sydney, Melbourne, Adelaide, Brisbane and Perth, and in Newcastle,Wollongong, Geelong, Albury-Wodonga, Gold Coast, Rockhampton, Port Augusta, Launceston and Darwin.

On 6 August 1994 a magnitude 5.3 earthquake struck the NSW central coast only 20 km west of the epicentre of the 1989 earthquake at Newcastle and 0.3 of a magnitude unit smaller. This time there was no damage in Newcastle but small towns such as Ellalong in the epicentral region were badly hit though free of casualties, and the insured loss as of late 1994 was nearly $A34M - the second largest dollar loss from an Australian earthquake in the last 200 years.

This time the ground motion was well recorded. More than twelve accelerographs were triggered during the earthquake. Ten of them were free field instruments, seven accelerographs on rock and one on alluvium, two were wide dynamic range seismographs on rock and the rest accelerographs on or in structures. The epicentral distance of these recorders ranged from 39 to more than 500 km.

Though a number of individual accelerograms have been obtained in the last 10 years from larger earthquakes or with larger amplitude from smaller earthquakes at shorter epicentral distances, this is the most complete dataset recorded from a single event in Australia.

Horizontal ground acceleration

Individual accelerograms look 'normal'; there are several cycles of strong shaking at frequencies of about 2 Hz, which is different from near focus accelerograms of small earthquakes recorded in Australia that are characterised by a single large amplitude, high frequency pulse (eg Gibson & others, 1995). The high frequency ground motion is quickly attenuated as can be observed on isoseismal maps.

A remarkable difference is observed in Fig. 2 between the accelerograms at the two near stations and the distant stations where there is a significant high frequency component which is not present on the nearer recordings. The geometry of Sydney Basin sediments is poorly defined but the waves recorded at distant stations to the south may have travelled through a thinner sequence of sediments than those at closer stations to the east and so suffered lower attenuation of high frequencies.

A previous analysis of peak horizontal ground accelerations recorded in Australia on single accelerographs from many small earthquakes yielded a magnitude scaling factor b in the Kanai type attenuation function e^{bM} of 1.72 ± 0.16, and a distance exponent of 1.69 ± 0.16 (McCue, Gibson and Wesson, 1988). This b value is double the 0.8 of Esteva (1974) (1.0 for peak ground velocity), and the distance exponent is lower than the value of 2.0 (1.7 for velocity) which he obtained from the study of large earthquakes in the Western US.

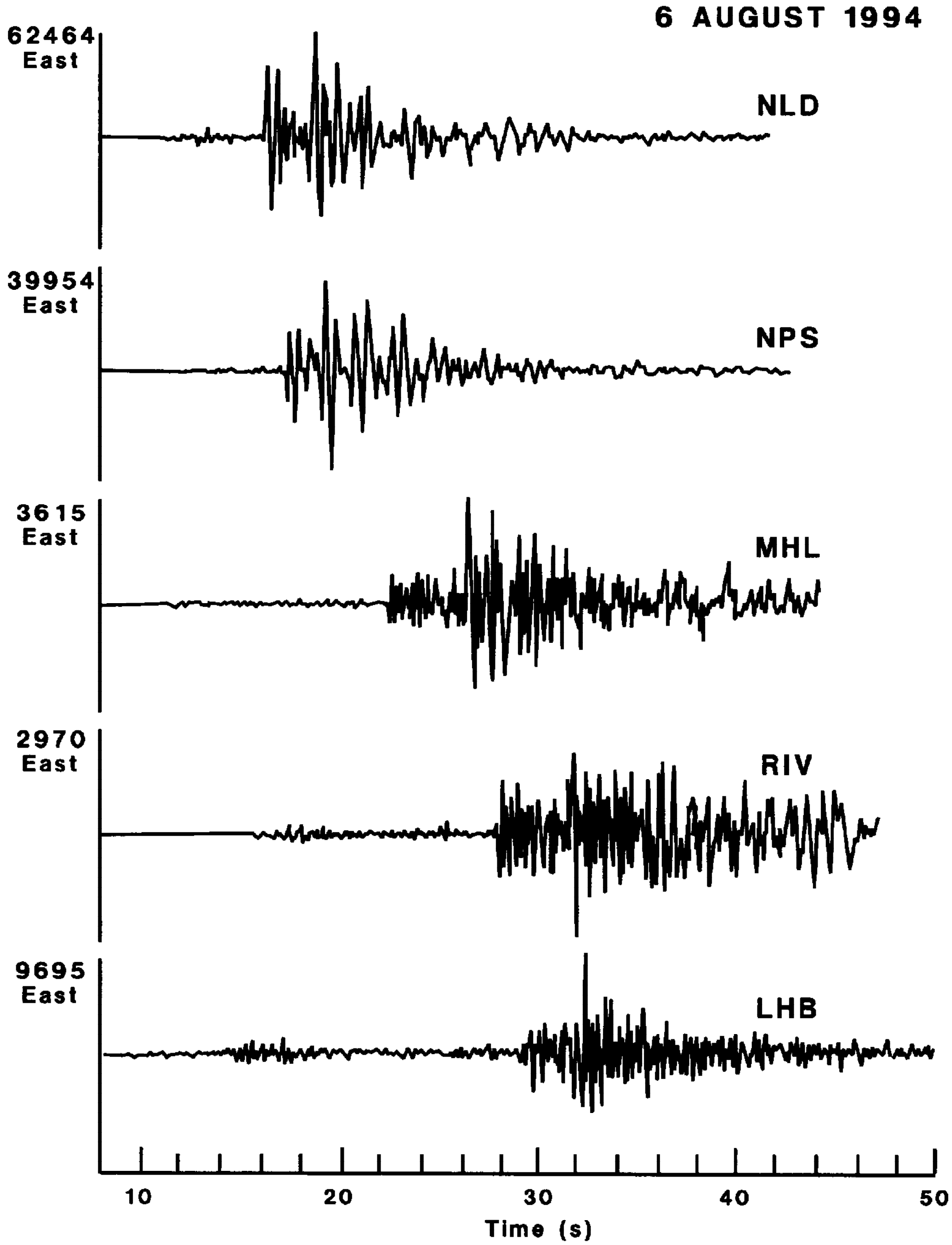

Fig. 2. The 'east' component of accelerograms recorded during the ML 5.3 Ellalong earthquake, details are in Table 1. The time scale is the same for each trace but the amplitude have been scaled as shown.

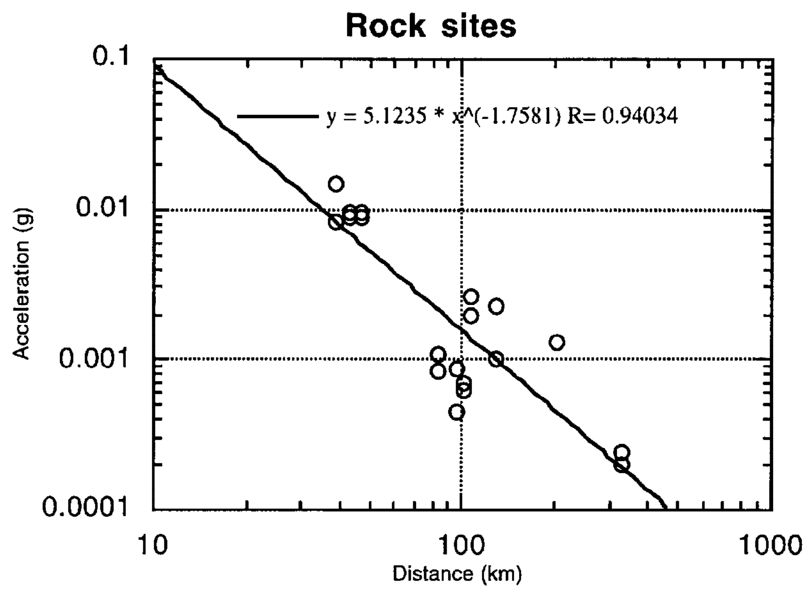

Fig. 3. Peak ground acceleration recorded at free-field bedrock sites during the 1994 Ellalong NSW earthquake

A plot of peak ground accelerations versus distance *R (km)* recorded on rock from the ML 5.3 Ellalong earthquake is shown in Fig. 3. The axes have log-log scaling and the amplitudes show considerable scatter. A

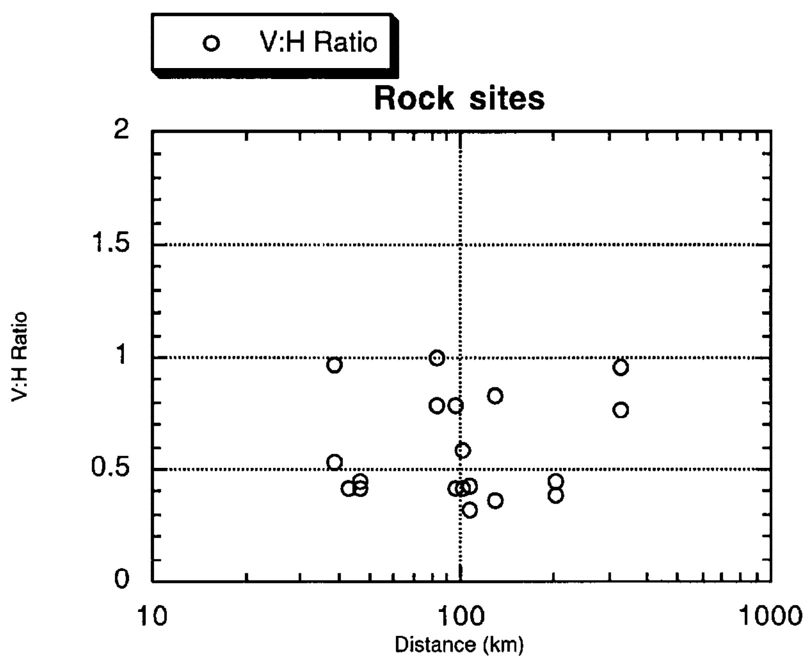

Fig. 4. The ratio of recorded peak vertical to horizontal ground accelerations

least squares curve has been fitted to the data and appears to be a reasonable fit though underestimating accelerations *a (g)* at the closer stations:

$$a = 5.12 * R^{-1.76}$$

The distance exponent of 1.76 is in the range computed from the analysis of pre-1988 data.

Vertical ground acceleration

The simple ratio of peak vertical to peak horizontal ground motion was computed separately for each horizontal component recorded during the Ellalong earthquake as shown in Fig. 4. Again the scatter is very large, with a mean value of 0.6 over the distance range of 39 to 330 km. Ratios close to 1.0 were observed across this whole range. Other near-source accelerograms recorded in Australia have shown higher vertical than horizontal accelerations.

Ground Velocity

Peak ground velocities were measured from the seismograms or computed from the accelerograms and are plotted in Fig. 5 as a function of distance. Where there were seismographs and accelerographs in close proximity the results were remarkably similar. The highest recorded velocity of 170 mm/s, was recorded on a blast vibration monitor near the epicentre at the Ellalong Coal Mine but the recorder was saturated so the actual velocity is stronger than this. On the nearest accelerograph at North Lambton, the computed velocity was a mere 12.5 mm/s and at Merewether and the CBD in Newcastle about 10 mm/s. In Sydney, about 100 km from the epicentre, the velocity had decreased to about 1 mm/s.

The coherence in the waveforms at Riverview (RIV) and Manly (MHL) in Sydney's northern suburbs are remarkable. There is a large 2 sec period pulse late in the codas of the east-west components which is not apparent on the Lucas Heights record in a southern suburb of Sydney.

A linear least squares fit to the recorded data in the distance range R of 39 to 330 km resulted in the following equation for velocity v in mm/s:

$$v = 14\,396\, R^{-2.08}$$

The value of the exponent -2.08 is close to the value of -2.0 expected for spherical elastic radiation.

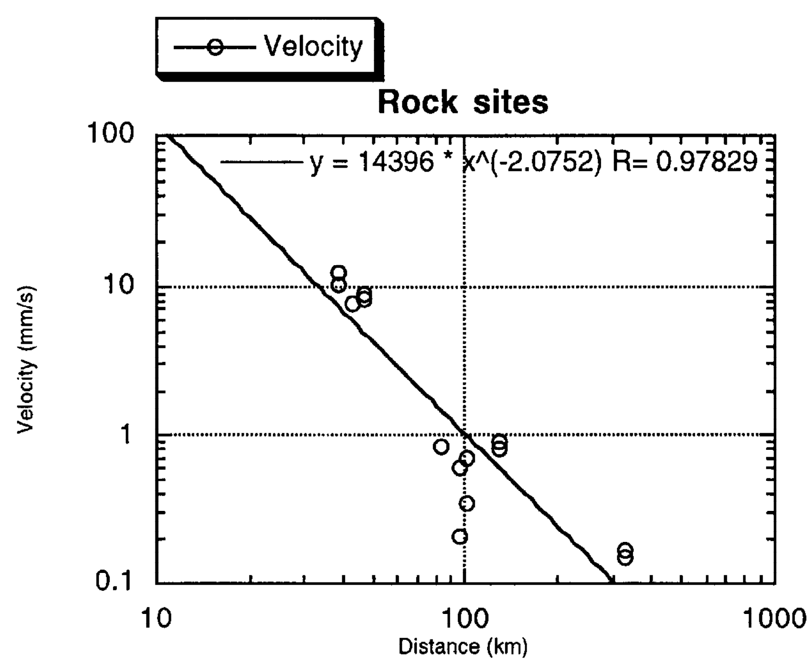

Fig. 5. Peak ground velocities recorded during the 1989 Ellalong NSW earthquake

Intensities

The felt radii of the Newcastle and Ellalong earthquakes were 300 and 200 km respectively. The highest intensities were MMVIII and MMVII respectively. Comparing the velocity attenuation plot with the isoseismal maps it is observed that the MMIV/MMV change was at a velocity of about 8 mm/s and the MMV/MMVI change at a velocity (extrapolated) of about 80 mm/s.

Table 1. Details of strong motion recorded during the Ellalong NSW earthquake

Station	Distance km	Acceleration g	V:H Ratio	Velocity mms^{-1}
NLD	3.90e+01	1.50e-02	0.53	12.50
NLD	3.90e+01	8.20e-03	0.97	10.10
KIM	4.30e+01	9.40e-03	0.41	7.60
NPS	4.70e+01	9.50e-03	0.42	8.70
NPS	4.70e+01	9.00e-03	0.45	8.30
CHI	8.40e+01	1.10e-03	0.79	
CHI	8.40e+01	8.40e-04	1.0	0.85
MHL	9.50e+01	8.60e-04	0.42	0.61
MHL	9.50e+01	4.60e-04	0.79	0.21
RIV	1.01e+02	6.20e-04	0.41	0.69
RIV	1.01e+02	7.10e-04	0.59	0.35
PHD	1.06e+02	2.64e-03	0.32	
PHD	1.06e+02	1.97e-03	0.43	
LHB	1.29e+02	2.30e-03	0.36	0.92
LHB	1.29e+02	1.00e-03	0.83	0.82
FTZ	2.04e+02	1.30e-03	0.38	
FTZ	2.04e+02	1.10e-03	0.45	
PHB	3.31e+02	2.43e-04	0.77	0.17
PHB	3.31e+02	2.00e-04	0.96	0.15

EXTRAPOLATION TO NEWCASTLE, 1989

This then gives us some information on which to estimate the ground motion on rock in Newcastle where the intensity has previously been assessed. If we assume the magnitude exponent term in the attenuation of velocity is between 1.0 and 1.7 as intimated above, then the magnitude scaling factor for velocity would vary from 1.3 to 1.7 for a magnitude difference of 0.3. From the above velocity/distance equation at a focal distance of 15 to 20 km, the peak ground velocity on rock would have been in the range 40 to 85 mm/s. The effect of the alluvium in the Hamilton and CBD areas is to double or even treble the peak ground velocity, putting our estimate of the peak ground velocity in the areas of greatest damage in the range 80 - 255 mm/s.

These estimates indicate that the ground motion in Newcastle during the 1989 earthquake was quite strong for several seconds, certainly strong enough to account for the damage observed in unreinforced masonry buildings which had been poorly maintained, badly designed, shoddily built or on alluvium.

COMPARISON WITH NEW ZEALAND AND CALIFORNIA

New Zealand strong motion data recorded between 1965 and 1992 has recently been published (Cousins, 1993) after normalisation to a magnitude 6 earthquake. The scatter in data is very large about the Japanese attenuation curve superposed (Fukushima and Tanaka, 1990), and which was used for the normalisation. The Australian data was similarly scaled up to a magnitude 6 earthquake using $e^{b\Delta M}$ with b values of 1.0 and 1.7 corresponding to factors of 2.0 and 3.3, and the two curves superposed on the New Zealand data. The result was that the Australian accelerations were within the extreme bounds of the New Zealand data and almost parallel to the Japanese curve, but below it. On average the ground accelerations from this single Australian earthquake are lower than expected for a similar sized earthquake in New Zealand over the distance range 39 to 300 km.

Maps of computed hazard in Australia used early attenuation relationships developed for western United States earthquakes (Esteva, 1974) and the comparison is made with this relationship rather than one of the myriad of alternative relationships published since. In this case the raw Australian accelerations, when plotted on the attenuation curve for a US magnitude 5.3 earthquake, are lower than would have been observed in the US from a similar sized earthquake.

DISCUSSION

The lack of Australian strong motion data will be remedied when more strong motion recorders are installed in Australia and this should be a high priority of the local Earthquake Engineering profession following the lead of the Federal Government. The New Zealand and recent Australian experience suggests that useful data is soon obtained if instruments are installed and properly maintained. Selected 'typical' buildings in the major cities should be instrumented next to determine their response, natural frequency and damping characteristics.

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