Measurements of PGA and attenuation in southeastern Australia

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ABSTRACT: Damaging earthquakes are frequent enough in Australia that design precautions are warranted, especially in major urban areas and for critical facilities. One of the more significant contributors to the uncertainty in estimates of earthquake risk stems from our lack of knowledge of the earthquake process, in particular the attenuation of ground shaking with distance.
After the Newcastle NSW earthquake of December 1989, the Joint Urban Monitoring Program was implemented to instrument major urban areas with accelerographs. Whilst no large earthquakes have yet been recorded, several earthquakes in the magnitude 3.0 to 5.2 range have triggered accelerographs in southeastern Australia over distances from 0 to 350 km.
Overseas researchers have recently published attenuation relationships from earthquakes that include these low to moderate magnitudes. Comparison of local data with attenuation functions developed for North America is discussed.

1 INTRODUCTION

Compared to most countries, Australia has a relatively low level of earthquake hazard. However, recent history has shown that while large earthquakes may be infrequent in Australia, there is still a substantial risk associated with moderate sized earthquakes. This level of risk warrants the consideration of earthquake hazard in the design process, especially in major urban areas or for critical facilities.

A key factor in the development of the earthquake loading code is the estimation of recurrence of strong ground motion. The recurrence of strong ground motion is sensitive to both the seismotectonic model and the attenuation function used. In the past, attenuation functions from other regions with similar tectonic conditions, such as North America, have been used to determine the earthquake hazard.

Until recently there have been few strong motion recordings in southeastern Australia, making it difficult to assess the applicability of North American attenuation functions. Similarly the development of attenuation functions for southeastern Australia has been hindered by the lack of strong motion data (Gaull & others 1990, Sarma & Free 1995).

After the 1989 Newcastle earthquake, which killed thirteen people, the community awareness of the need for strong motion recordings was increased. The Australian Geological Survey Organisation (AGSO) and state authorities developed and implemented the Joint Urban Monitoring Program (JUMP), aimed at placing accelerographs in major cities throughout Australia. The JUMP network in southeastern Australia has recorded several earthquakes in the past ten years, including three of about magnitude 5.0.

Using the data recorded on both the JUMP sites and other bedrock accelerographs in southeastern Australia, the attenuation for magnitude ML 3.0, 3.5, 4.0, 4.5, and 5.0 earthquakes has been compared to attenuation functions used both in the current Australian earthquake loading code and in earthquake hazard studies throughout southeastern Australia.

2 SEISMICITY IN SOUTHEASTERN AUSTRALIA

Seismicity in southeastern Australia is low to moderate by world standards. The current seismograph networks in southeastern Australia record approximately 400 earthquakes a year above ML 0.0, and approximately one magnitude ML 5.0 every three years.

Figure 1 shows the earthquake activity in southeastern Australia from January 1788 to December 1989 for magnitude ML 3.5 and above. The earthquakes are scattered throughout southeastern Australia, with a higher concentration of activity in the mountains that form the Great Dividing Range. A number of these earthquakes have occurred within or close to major urban centres.

A few of the earthquakes that occurred in urban areas have caused damage, including the 1897 Kingston ML 6.6 earthquake which damaged houses in Kingston, Robe and Beachport. In 1903 a ML 5.3 and a ML 5.6 earthquake badly damaged many buildings in Warrnambool. More recently, the 1973 Burragorang ML 5.5 earthquake caused an estimated A$500,000 (1973 values) damage just south of Sydney (Denham 1973). The Newcastle ML 5.6 earthquake was the first earthquake in Australia with confirmed fatalities. Thirteen people were killed, hundreds were injured and the total damage bill was in excess of A$1 billion (McCue & others 1990).

In the eleven years since the Newcastle earthquake there has been several earthquakes equal to or larger than magnitude ML 3.5 in southeastern Australia (Figure 2). Four of these earthquakes were close to major urban centres. The 1994 Ellalong earthquake, located just 20 km west of the 1989 Newcastle earthquake, caused nearly A$34 Million damage (McCue & others 1995).

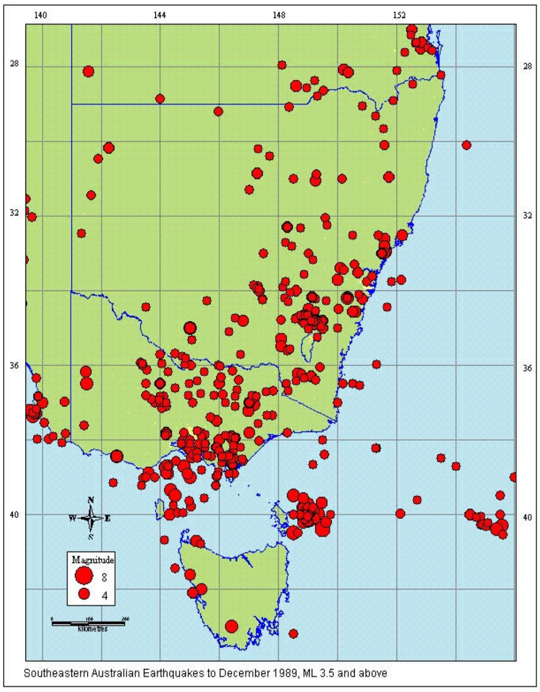

Figure 1: Southeast Australian Earthquakes to 1989 (ML 3.5 and above)

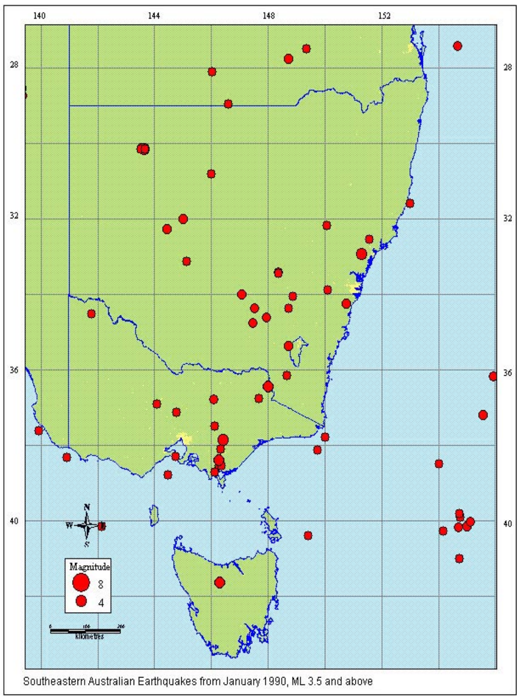

Figure 2: Southeast Australian Earthquakes from 1990 (ML 3.5 and above)

3 ACCELEROGRAPHS IN SOUTHEASTERN AUSTRALIA

Since the Newcastle earthquake in 1989, there has been a significant increase in the number of installed bedrock and structure mounted accelerographs. Figure 3 shows the distribution of accelerograph currently operational in southeastern Australia. The yellow diamonds are accelerographs that are part of the Joint Urban Monitoring Program (JUMP).

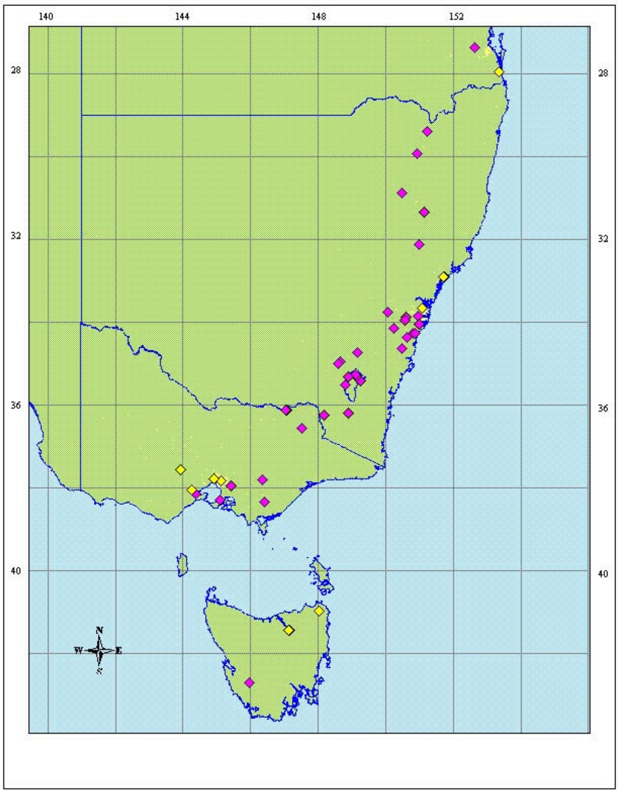

Figure 3: Accelerographs in Southeast Australia, 2001

Thirty-four accelerographs were purchased by AGSO between 1992 and 1995 as part of JUMP. With the help of state agencies these have been installed in 17 cities throughout Australia with populations in excess of 50,000. In southeastern Australia, they have been installed in Launceston, Sydney, Melbourne, Newcastle, Wollongong, Geelong, and Ballarat.

A number of small to moderate earthquakes have been recorded on JUMP accelerographs and on accelerographs run by other authorities. These recordings provide valuable information about the attenuation of ground shaking with distance, but are as yet insufficient to separate site effects or determine a local spectral attenuation function including magnitudes approaching the regional maximum credible magnitude (usually considered to be in the range Mw 7.0 to 7.5).

Since the commencement of JUMP several earthquakes of magnitudes greater than 3.5 have occurred in southeastern Australia, including three earthquakes of about magnitude 5.0.

4 ATTENUATION IN SOUTHEASTERN AUSTRALIA

Earthquake hazard analysis using the Cornell method requires the selection of an attenuation function. In areas like Australia, where local peak ground velocity, peak ground acceleration or spectral attenuation functions are limited, attenuation functions from areas that have a similar tectonic environment are used. The tectonic environment in southeastern Australia has reverse faulting due to horizontal compression, and attenuation that is average or above average due to the predominance of Paleozoic and younger sedimentary rock. Typically most earthquake hazard analysis undertaken in Australia uses functions derived in North America.

4.1 *Strong motion data*

Accelerograms have been collected from these moderate magnitude earthquakes to use in an analysis of PGA attenuation in southeastern Australia. The earthquakes occurred at various depths ranging from 1 to 20 km, and epicentral distances from 15 to 350 km.

Using triaxial accelerograms, the peak ground accelerations from the two horizontal channels have been averaged (arithmetically) to reduce any directional effects that may be present due to source radiation patterns, topography or geological boundaries. The average horizontal peak ground acceleration has been plotted against hypocentral distance, so that the recorded data can be compared to some of the published attenuation functions commonly used in earthquake hazard analysis.

4.2 *Comparison of local attenuation and published functions*

The published attenuation functions selected for comparison with the southeast Australian data were by; Esteva & Rosenblueth 1964, Sadigh & others 1997 and Toro & others 1997. All three functions have been developed using shallow crustal events in North America.

Esteva & Rosenblueth (1964) is an older function that used data collected from California and has been included because it has been used in previous versions of the Australian Loading Code.

Toro & others (1997) was derived using data from central and eastern North America for earthquakes with moment magnitudes 5 to 8, and with distances of 1 to 500km, with special emphasis on the first 100 km.

Sadigh & others (1997) was developed using earthquakes from western North America, predominantly from California, for moment magnitudes 4 to 8, and distances up to 100km. The Sadigh & others function has been optimised for either strike-slip or reverse faulting events. This makes it an attractive function for southeastern Australia, as most earthquakes in the area occur on reverse faults.

The Sadigh & others (1997) function also attempts to take into account the variation of frequency content of earthquakes with magnitude and distance. Typically smaller earthquakes, with short duration and high frequency content, can have high peak ground motions but of short duration which are of no significane to well engineered structures. The Sadigh & others function, as seen in figure 4, shows how the motion from small earthquakes can be incorporated into a standard attenuation function. The incorporation of these smaller magnitude events provides meaningful insights into the nature of attenuation in places of low to moderate seismicity.

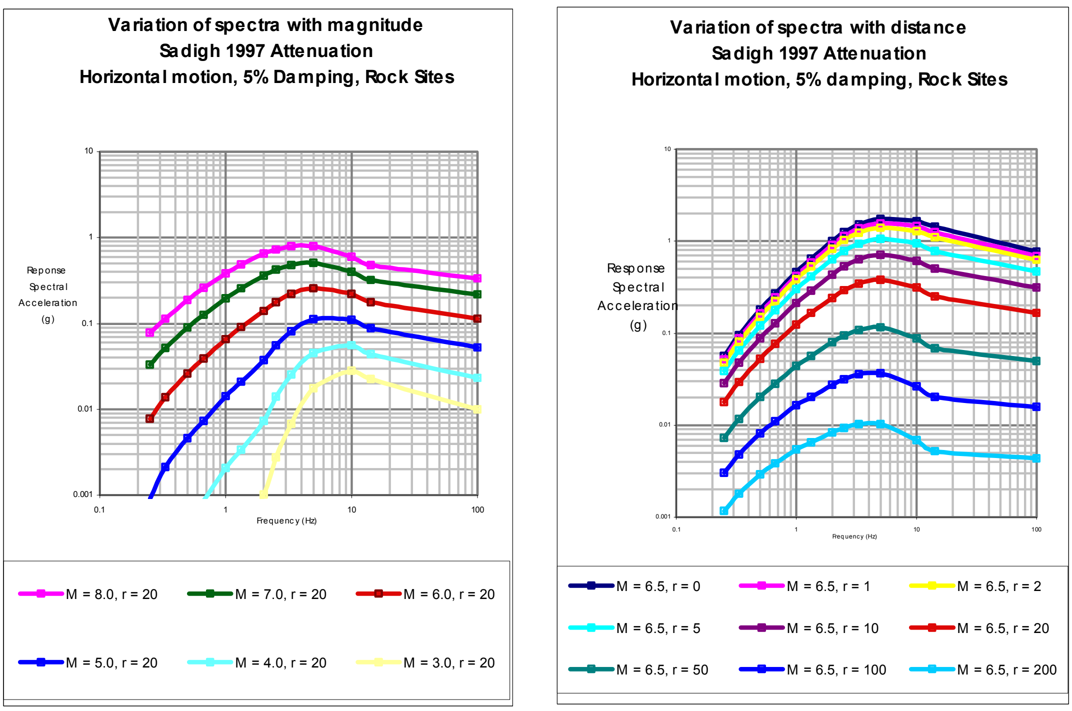

Figure 4: Sadigh & others 1997 attenuation function

Any comparison made using smaller earthquakes may introduce discrepancies due to the published functions not being valid for smaller magnitude earthquakes.

Figure 5 compares the strong motion data collected in southeastern Australia to December 2000, in the magnitude range 3.3 to 5.2, with the three published attenuation functions for North America. The graphs show that the best fit to local data is given by the Sadigh & others attenuation function, suggesting that attenuation in southeastern Australia is similar to that in western North America.

The scatter is due to several causes. One is the normal scatter in the peak values caused by radiation pattern and a variety of non-quantifiable factors. Another cause of scatter is that the plots cover a range of surface geological conditions, including Mesozoic sediments, Palaeozoic sediments and granites. A third cause is that each of these plots covers the range from the nominal magnitude –0.2 to nominal magnitude +0.2.

4.3 *Implications for earthquake hazard analysis in Australia*

The comparison made between strong motion data in southeastern Australia and the published functions for North America, figure 5, suggest the Sadigh & others PGA attenuation function, derived using western North American data, best describes the attenuation in southeastern Australia. The functions derived using eastern North American data predicts lower attenuation then that found in southeastern Australia. The use of a eastern North American PGA function in assessment of earthquake hazard in southeast Australia would be over conservative. Similarly, the use of older western North American functions like Esteva & Rosenbleuth also would produce earthquake hazard estimates that are over conservative. This covers the range of magnitudes from ML 5.0 to ML 3.5.

On the contrary, for earthquakes with magnitudes about ML 3.0 the attenuation in southeastern Australia seem to be over predicted by all the PGA attenuation functions, as shown in figure 6, regardless of the location of the data used to develop them. An attenuation function developed for southeastern Australia, in the future, will need to use data from smaller earthquakes and should take this apparent change in attenuation behaviour into account.

Other recently published attenuation functions using western North American data are also good analogues of the PGA attenuation in southeastern Australia. Figure 7 shows PGA data for magnitude 5.0 (+/- 0.2) in southeastern Australia and several recent published western North American PGA attenuation functions. All three functions are in good agreement with the local data suggesting that any PGA function developed using western North American data would be suitable when undertaking a hazard analysis.

Most researchers agree that there is a fundamental change in the nature of an earthquake when the magnitude is greater than somewhere in the range of 5.5 to 6.0. This is partly due to the fault rupture approaching the full depth of the seismogenic zone, usually the top 15 to 20 kilometres. How the strong motion and the PGA attenuation of larger earthquakes in southeastern Australia compare to that predicted by western North American functions can not yet be tested. It may be that due to difference in crustal thickness, Australian earthquakes may exhibit this change in characteristics sooner.

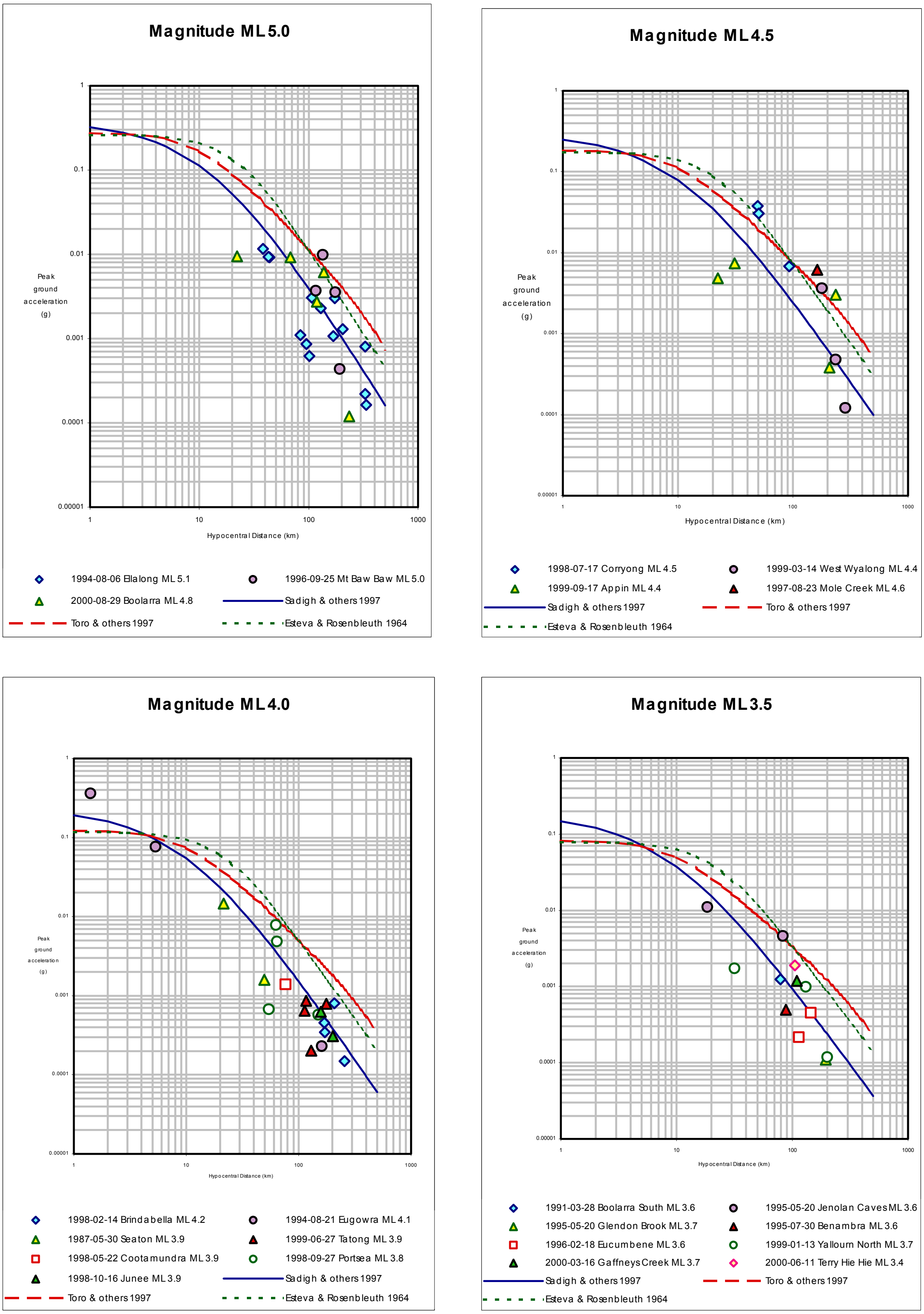

Figure 5: Peak ground acceleration attenuation in southeast Australia for magnitude 5.0, 4.5, 4.0 and 3.5

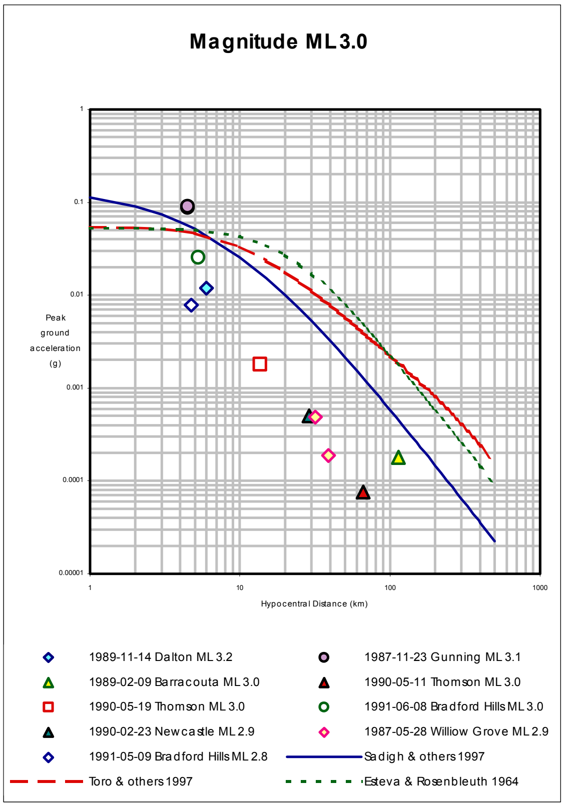

Figure 6: Peak ground acceleration attenuation in southeastern Australia, using magnitude 3.0.

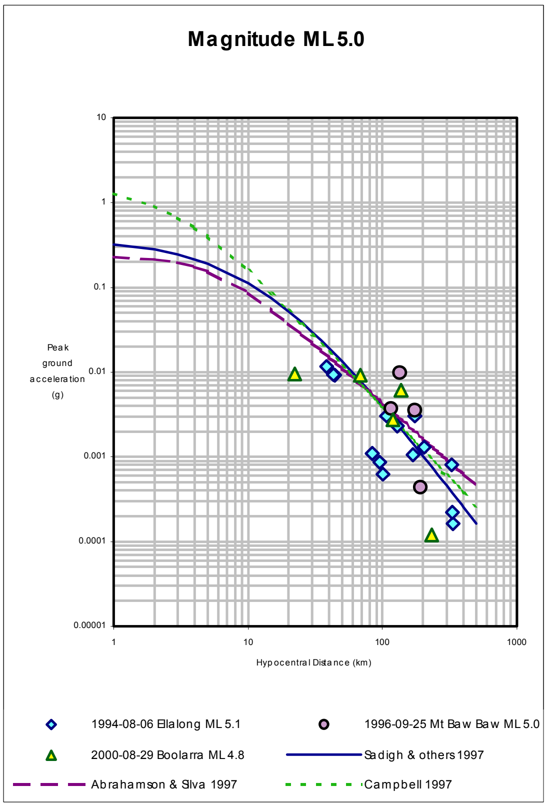

Figure 7: Peak ground acceleration attenuation in southeastern Australia compared to functions derived in only western North America

5 CONCLUSION

The implementation of JUMP has provided valuable data on the nature of earthquake ground motion attenuation in Australia. The data collected has been compared to attenuation functions from both eastern and western North America. PGA attenuation in southeastern Australia was found to be higher than that predicted by the eastern North American function but agreed well with the western North American function.

The attenuation of ground motion from larger magnitude earthquakes (M6+) still remains uncertain and while the lack of data for these events will continue, earthquake hazard analyses made with western North American functions especially those with reverse fault mechanisms should provide the best estimates for ground motion recurrence in southeastern Australia.

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6 **RETURN TO INDEX**