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The 2012 National Earthquake Hazard Map of Australia

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ABSTRACT:

Geoscience Australia has recently released the 2012 version of the National Earthquake Hazard Map of Australia. Among other applications, the map is a research product that can inform the hazard component of Australia's earthquake loading code AS1170.4 along with other uses. This paper provides an overview of the new map, or to be more accurate maps, and how they were developed. The maps take advantage of significant improvements in both the data sets and models used for earthquake hazard assessment in Australia since the map currently in AS1170.4-2007 was produced. These include:

- An additional 20^+ years of earthquake observations
- Improved methods of declustering earthquake catalogues and calculating earthquake recurrence
- Ground motion prediction equations (i.e. attenuation equations) based on observed strong motions instead of intensity
- Revised earthquake source zones implementing a multi-layer model
- Improved maximum magnitude earthquake estimates based on palaeoseismology
- The use of open source software for undertaking probabilistic seismic hazard assessment, which promotes testability and repeatability

Hazard curves are presented for a range of response spectral acceleration (RSA) periods between 0.0 and 1.0 s and for return periods between a few hundred to a few thousand years. These curves and maps are compared with the current earthquake hazard values in AS1170.4-2007. For a return period of 500 years, the hazard values in the 0.0 s RSA period map are generally lower or the same as the hazard factor values in the AS1170.4 map. This is also true for most of the other RSA periods up to 1.0s for the cities in Australia with Darwin being the main exception. By contrast, the hazard for return periods above 1000 years is higher than the values derived from the tables in AS1170.4 for all RSA periods.

Keywords: probabilistic seismic hazard assessment, national earthquake hazard map, AS1170.4, earthquake loading code, Australia

Introduction

In July 2009 Geoscience Australia (GA) initiated a project to update the Australian earthquake hazard map using the latest available methods and data. This paper will discuss the work done since that time and presents a new set of earthquake hazard maps and curves for consideration in the next revision of the earthquake loading code AS1170.4 "Structural design actions: Part 4 Earthquake actions in Australia".

The key improvements in the 2012 Australian Earthquake Hazard Map are summarised below. For further information, please see GA Record 2012/71 "The 2012 Australian Earthquake Hazard Map" (upon which much of this paper is based). The report is available from GA's website or from the authors on request. The 500 year, PGA hazard map is available from an online web tool at:

http://www.ga.gov.au/darwin-view/hazards.xhtml

Method

The general approach to estimating earthquake hazard probabilistically requires:

- an earthquake source model(s) that describe the likelihood of an earthquake of a given magnitude occurring in a given location;
- one or more ground motion prediction equation(s) that define the ground-shaking experienced at a given distance from a simulated earthquake of a specific magnitude;

The first aspect requires an up-to-date catalogue of earthquakes and, for this map, neotectonic features. The latter requires an up-to-date catalogue of ground motions. These two aspects will be briefly summarised here, but are covered in more detail in Burbidge (2012).

Earthquake Catalogue and Source Models

The earthquake catalogues used to generate the existing earthquake hazard maps on which the map found in AS1170.4-2007 was based only used events up until the late 1980s, although a later revision in the 1990s also considered earthquakes that had occurred up until then. The earthquake catalogue used for the 2012 revision includes events up until 2011; a total of 8,000 earthquakes above magnitude 3. The catalogue is a combined version of several other regional catalogues provided by external agencies and seismologists. This combined catalogue represents the most complete known catalogue of earthquakes ever compiled for Australia for earthquakes above about magnitude 3.0.

Historically, a variety of local magnitude M_L formulae have been used to measure the size of earthquakes across Australia. Here the catalogue is harmonised through conversion of the various magnitude measurements of the earthquakes into a more consistent 'pseudo M_L' scale. Furthermore, a systematic logic is used to select preferred magnitude types (e.g. moment magnitude M_W, surface-wave magnitude M_S, etc.) when the use of M_L is not appropriate. This "preferred" magnitude was used to calculate the earthquake recurrence probability.

Probable aftershocks, foreshocks and mine blasts have been identified in the catalogue using a combination of methods based on the latest thinking of how earthquakes cluster in intraplate regions. The method uses both manual event classification by an expert and an automatic classification system. While the method has probably not removed every aftershock, mine blast or earthquake swarm event, to the best of our knowledge, the declustered catalogue used here is cleaner than any previous Australian catalogue.

Earthquake source zones applied in the hazard map are developed using a unique combination of three different layers, which capture seismic characteristics at sub-national, regional and high-activity point (hotspot) scales. The zones defined balance the stability and conservatism requirements of a hazard map for the building code while still allowing it to be flexible enough to accommodate a wide range of uses. In each zone the earthquake probability is estimated by fitting the catalogue data to truncated Gutenberg-Richter (Gutenberg and Richter, 1944) relations using a new automatic algorithm (discussed in detail in Burbidge 2012). The method provides robust values for the Gutenberg-Richter values, *a* and *b*, and requires little to no manual adjustment.

The maximum magnitude of earthquakes within the majority of the zones (Mmax) is based on the neotectonic domains work of Clark *et al.* (2011) and the work of Leonard and Clark (2011). This makes the map one of the first in the world to apply a semi-quantitative measure of Mmax for the majority of the source zones in the map rather than simply adding a constant to the observed maximum magnitude from a historic catalogue.

Ground Motion Prediction Equations

Ground-motion prediction equations (GMPEs), also commonly referred to as attenuation relations, relate a specific measure of the expected ground shaking to earthquakes, typically based on the earthquake's magnitude, source-to-site distance and the near-surface geology of the observation site. In active crustal regions with an abundance of recorded ground-motion data, GMPEs are typically derived from empirical regressions of the observed data. However, in stable continental regions, like Australia, observed ground-motion datasets are not sufficient to develop reliable GMPEs based on recorded data alone. Consequently, in these regions, the ground-motion models have to use source and attenuation properties derived from smaller, more abundant earthquakes, and use physical assumptions (or source scaling) to extrapolate observed ground-motions to larger earthquakes through stochastic simulation.

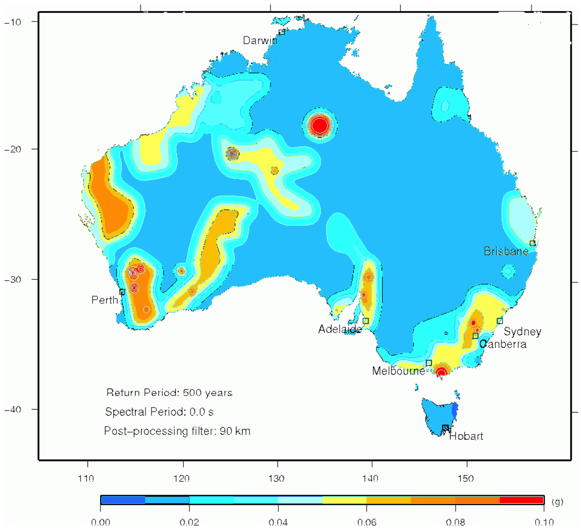
The limited number of high-quality ground motion recordings in Australia has restricted the development of a robust GMPE for Australian conditions. The first GMPEs for PGA based on Australian data were developed by Gaull *et al.* (1990). The Gaull *et al.* (1990) models were developed using the attenuation of mean macroseismic intensity radii, which were converted to PGA using conversion equations developed in Papua New Guinea. This approach was necessary at the time owing to the sparse instrumental data catalogue in Australia. However, since then new Australian-specific GMPEs have become available. Somerville *et al.* (2009a,b) employ earthquake source models representative of Australian earthquakes and regional crustal velocity models to simulate broadband strong-motion records for several tectonic elements across Australia. These simulations were subsequently regressed to develop regionally specific GMPEs. The Somerville *et al.* (2009a,b) approach provides an alternative method to develop GMPEs in regions of low seismicity.

In addition, a new GMPE has been recently completed by GA for eastern Australia. This GMPE is described in detail in a GA Record currently in press at the time of writing

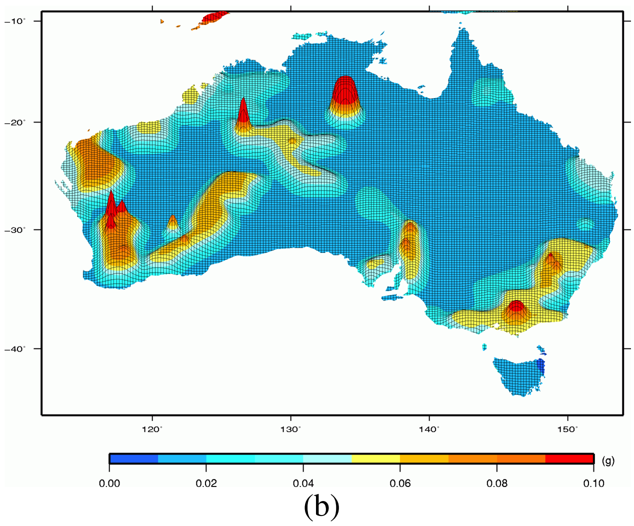
(Allen, 2012). The aforementioned Australian-specific GMPEs, in addition to GMPEs developed recently for North America, are compared with observed Australian ground motions in Burbidge (2012). The comparison was used by Geoscience Australia, in consultation with external stakeholders, to select a weighted set of models for this hazard map for the different geological domains of Australia (as listed in Burbidge 2012).

Results

Using these data sets and models, a suite of maps has been created using GA's Earthquake Risk Model (EQRM, see Robinson et al 2006 for details). EQRM is open-source, allowing the results to be tested or modified independently. The input files for the model are available from the authors on request. In addition to determining earthquake hazard (i.e. likelihood of ground-shaking), the use of EQRM also provides the capability to calculate earthquake risk (e.g. likelihood of damage) in the future, provided the necessary site classification, exposure and vulnerability models are available. The preferred map for a return period of 500 years and a response spectral acceleration (RSA) of 0.0s is shown in Figure 1 as this most closely approximates the current map in AS1170.4. The 2D version is shown in Figure 1a, and Figure 1b shows the map in 3D perspective.



(a)



(b)

Figure 1: The preferred 500 year return period PGA hazard map. The map is shown in 2D in (a) and in 3D perspective in (b). The State and Territories capital cities are labelled in (a). This map is the authors' preferred weighting and smoothing (from GA record 2012/71). Figure taken from Burbidge (2012).

For the major cities, the earthquake hazard was also calculated at a range of return and RSA periods. This allows the calculation of hazard curves, which show the change in hazard as function of return period for different RSA periods. Some hazard curves for selected cities are shown in Figure 2. These values were taken from the version of the map with no smoothing (i.e. essentially identical from the maps shown in Figure 1 except near the very edges of some zones).

For most of the points considered here, the hazard factor (*Z*) in the current code (orange dashed curve) crosses the 0.0 s (PGA) curve between 500 and 1000 years (solid red). However this general statement depends on the exact location chosen for the comparison. For example, in Perth the hazard in this assessment is lower than the *Z* factor values for return periods below about 2500 years (see Figure 2e). However, it should be noted that in this case the hazard increases rapidly the further from the coast the site is located. This means that the hazard for "Perth" is sensitive to the longitude of the point selected to represent the hazard for the city. However, even points selected considerable to the east of Perth are still lower in hazard than the Z values given in the current code.

For all locations, the RSA for the periods 0.1s, 0.2s and 0.3s (purple, blue and cyan curves in Figure 2) is always higher than the RSA hazard for a period of 0.0s (red curve). The hazard for the 1.0s curve is always lower for all return periods shown here (solid black curve).

Table 1 shows the hazard values at a range of cities in this new assessment for a return period of 500 years when compared to the values of Z in AS1170.4. When the hazard varies spatially across a city, the hazard at the highest point is shown in the table. For most locations, the difference between *Z* and the 500 year, 0.0s PSHA are typically <0.05 g. Generally the probabilistic hazard values are lower than the Z values in the code for the majority of these cities, although there are some locations where they are the same (e.g. in the Latrobe Valley in Victoria). The differences are also generally larger in the west compared to the east, mainly due to the new magnitudes used for earthquakes in that area, the new source zones in this map and the new ground motion equations (see Burbidge (2012) for further details of these changes).

Figure 3 shows the rate of increase of the 0.0s probabilistic hazard values with return period for several capital cities. The curves have all been normalised to the hazard at 500 years. As can be seen, the hazard increases faster in the cities with the lowest 500 year, 0.0s hazard values (e.g. Brisbane). However, in all cases the hazard increases much faster than the K_p curve derived from Table 3.1 in AS1170.4 (orange) and is clearly continuing to increase quite rapidly even at 5000 years. This could be due to either a higher Mmax or possibly to higher uncertainties in the GMPEs used here compared to the values typically used in the early 1990s.

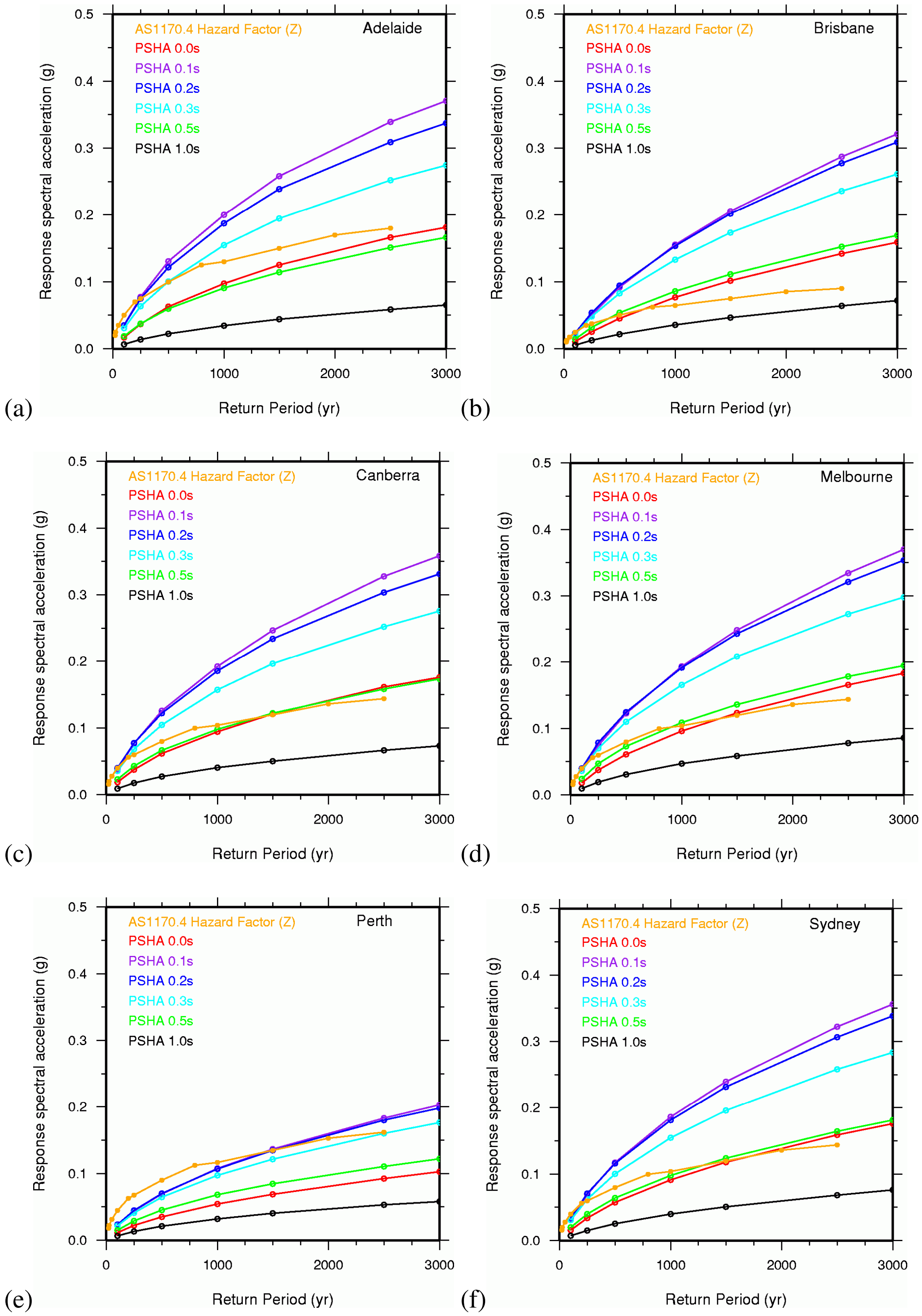


Figure 2: Response spectral acceleration as a function of return period at six different spectral periods for locations in (a) Adelaide, (b) Brisbane, (c) Canberra, (d) Melbourne, (e) Perth, and (f) Sydney for the hazard map without spatial smoothing (see Burbidge (2012) for details). The red, cyan, blue, light blue, green curves and black are the RSA values for 0.0 s, 0.1s, 0.2 s, 0.3 s, 0.5s and 1.0 s from the relevant earthquake hazard map. The orange curve is the hazard factor, Z, calculated using the appropriate tables in AS1170.4-2007. Figure taken from Burbidge (2012).

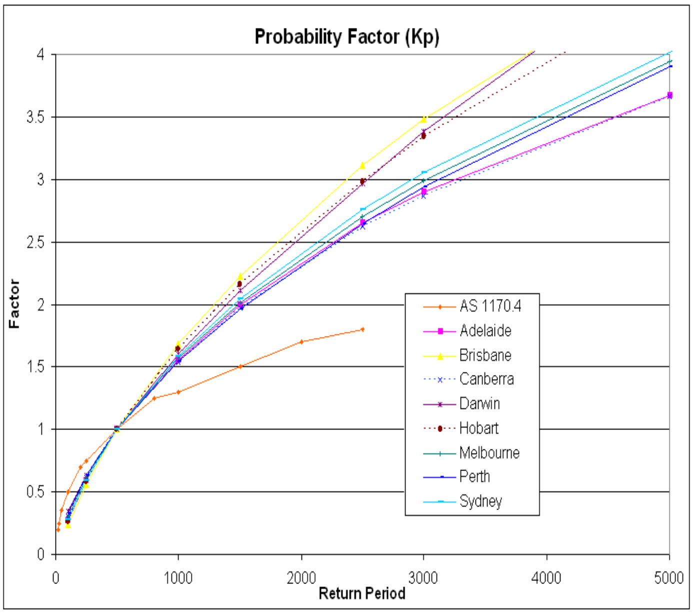


Figure 3. The Probability Factor (K_p) in AS1170.4 (orange) compared to the increase in the probabilistic hazard at an RSA period of 0.0s in the new map. In all case the probabilistic hazard increases faster (has a higher K_p value) in the new assessment than the Kp factors in AS1170.4 would indicate. K_p is also generally higher for the lower hazard areas (e.g. Brisbane and Hobart) than for the areas with a higher 500year PGA hazard like Adelaide or Sydney.

Figure 4 shows the spectral shape of the 500 year probabilistic hazard values as a function of RSA period for points within several capitals in different parts of Australia. It is compared to the C_h (T) values in AS1170.4. Generally, the spectral shape factors obtained here are lower than the C_h (T) values for all periods up to 1.0s and is much lower in this assessment for the lower RSA periods between 0.1 and 0.3s. One exception is Darwin, where the hazard for RSA periods above 0.6s is higher in this assessment than the C_h (T) values used in the code. This is due to the distant, but frequent and large, earthquakes in the Banda Sea and Timor that increases the longer RSA period hazard for Darwin and for the other areas in the far north of Australia. As they are distant, the effect of these events at RSA periods is considerably less.

City/Town	State	AS1170.4 Z-value	500 yr, PGA hazard value (g)	City/Town	State	AS1170.4 Z-value	500 yr, PGA hazard value (g)
Adelaide	SA	0.10	0.08	Noosa	QLD	0.08	0.04
Albany	WA	0.08	0.03	Orange	NSW	0.08	0.059
Albury	NSW	0.09	0.04	Perth	WA	0.09	0.036
Alice springs	NT	0.08	0.02	Port Augusta	SA	0.11	0.046
Ballarat	VIC	0.08	0.032	Port Lincoln	SA	0.10	0.048
Bathurst	NSW	0.08	0.059	Port Hedland	WA	0.12	0.045
Bendigo	VIC	0.09	0.026	Port Macquarie	NSW	0.06	0.02
Brisbane	QLD	0.05	0.04	Port Pirie	SA	0.10	0.062
Broome	WA	0.12	0.053	Robe	SA	0.10	0.023
Bundaberg	QLD	0.11	0.049	Rockhampton	QLD	0.08	0.014
Burnie	TAS	0.07	0.017	Shepparton	VIC	0.09	0.044
Cairns	QLD	0.06	0.025	Sydney	NSW	0.08	0.055
Camden	NSW	0.09	0.055	Tamworth	NSW	0.07	0.017
Canberra	ACT	0.08	0.068	Taree	NSW	0.08	0.022
Carnarvon	WA	0.09	0.04	Tennant Creek	NT	0.13	0.147
Coffs harbour	NSW	0.05	0.012	Toowoomba	QLD	0.06	0.04
Cooma	NSW	0.08	0.054	Townsville	QLD	0.07	0.015
Dampier	WA	0.12	0.031	Tweed Heads	NSW	0.05	0.017
Darwin	NT	0.09	0.02	Uluru	NT	0.08	0.05
Derby	WA	0.09	0.05	Wagga Wagga	NSW	0.09	0.04
Dubbo	NSW	0.08	0.049	Wangaratta	VIC	0.09	0.051
Esperance	WA	0.09	0.032	Whyalla	SA	0.09	0.041
Geelong	VIC	0.10	0.051	Wollongong	NSW	0.09	0.052
Geraldton	WA	0.09	0.039	Woomera	SA	0.08	0.017
Gladstone	QLD	0.09	0.028	Wyndham	WA	0.09	0.018
Gold Coast	QLD	0.05	0.021	Wyong	NSW	0.10	0.055
Gosford	NSW	0.09	0.054	**Meckering region**			
Grafton	NSW	0.05	0.013	Ballidu		0.15	0.1
Gippsland	VIC	0.10	0.1	Corrigin		0.14	0.072
Goulburn	NSW	0.09	0.056	Cunderdin		0.22	0.12
Hobart	TAS	0.03	0.012	Dowerin		0.2	0.12
Karratha	WA	0.12	0.027	Goomalling		0.16	0.12
Katoomba	NSW	0.09	0.056	Kellerberrin		0.14	0.12
Latrobe valley	VIC	0.10	0.1	Meckering		0.2	0.12
Launceston	TAS	0.04	0.012	Northam		0.14	0.085
Lismore	NSW	0.05	0.013	Wongan Hills		0.15	0.1
Lorne	VIC	0.10	0.057	Wickepin		0.15	0.072
Mackay	QLD	0.07	0.017	York		0.14	0.1
Maitland	NSW	0.10	0.053				
Maitland	SA	0.10	0.032				
Melbourne	VIC	0.08	0.06				
Mittagong	NSW	0.09	0.054				
Morisset	NSW	0.10	0.057				
Newcastle	NSW	0.11	0.055				

Table 1 The maximum probabilistic hazard values within each city/town for a return period of 500 years and a RSA period of 0.0s compared to Z from Table 3.2 in AS1170.4.

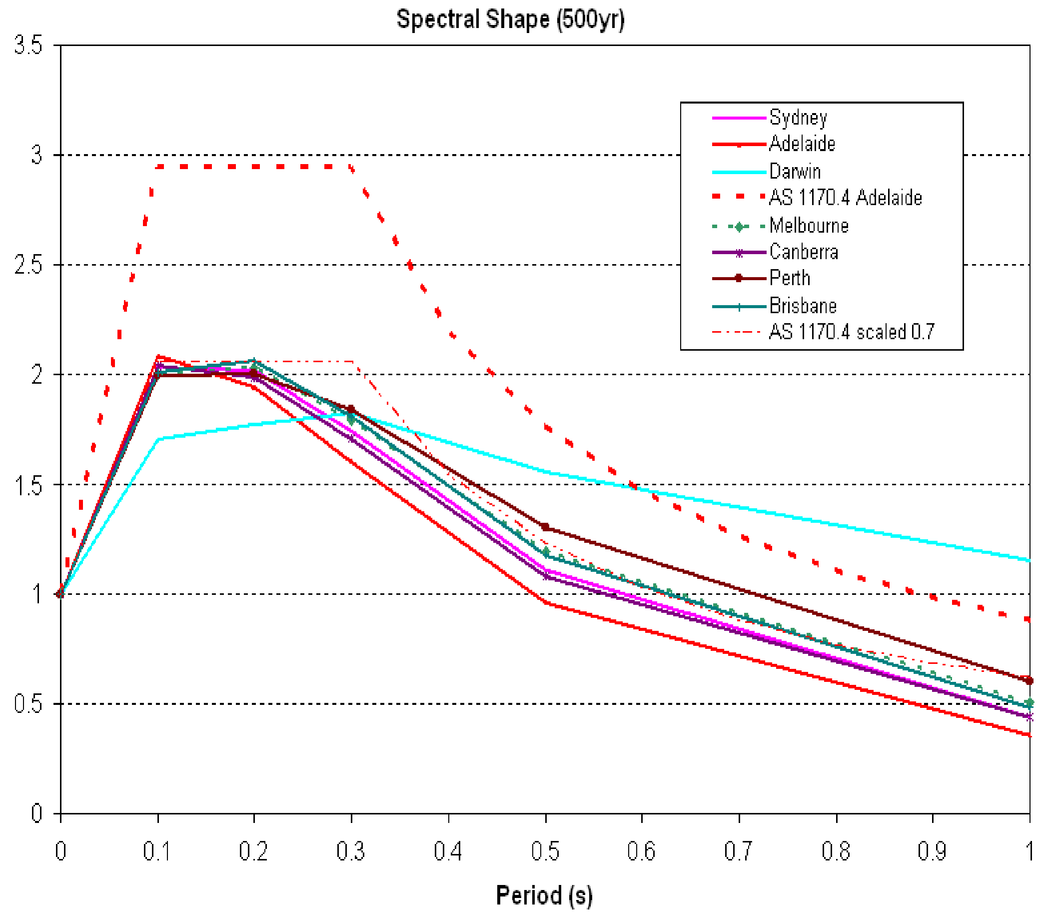


Figure 4. The normalised spectral shape for several major metropolitan areas in Australia at a return period of 500 years compared to the shape of the C_h (T) curve in Table 6.4 of AS1170.4 for Site sub-soil class Be.

Figure 5 shows the spectral shape of several other locations across Australia. For the hotspots like Meckering and Tennant Creek (brown and blue curves) the C_h (T) values decrease much more rapidly with increasing RSA period than is typical for a city like Melbourne (pink curve). This is due to the smaller Mmax (maximum magnitude) used in these areas. The smaller Mmax values mean there are more (relatively) small earthquakes generating high frequency ground motions than large earthquakes generating low frequency ground motions. Hence the shape is more peaked at the lower RSA periods for hotspots like Tennant Creek than for most cities. This difference is particularly marked when the probabilistic spectral shape is compared to spectral shape for Darwin.

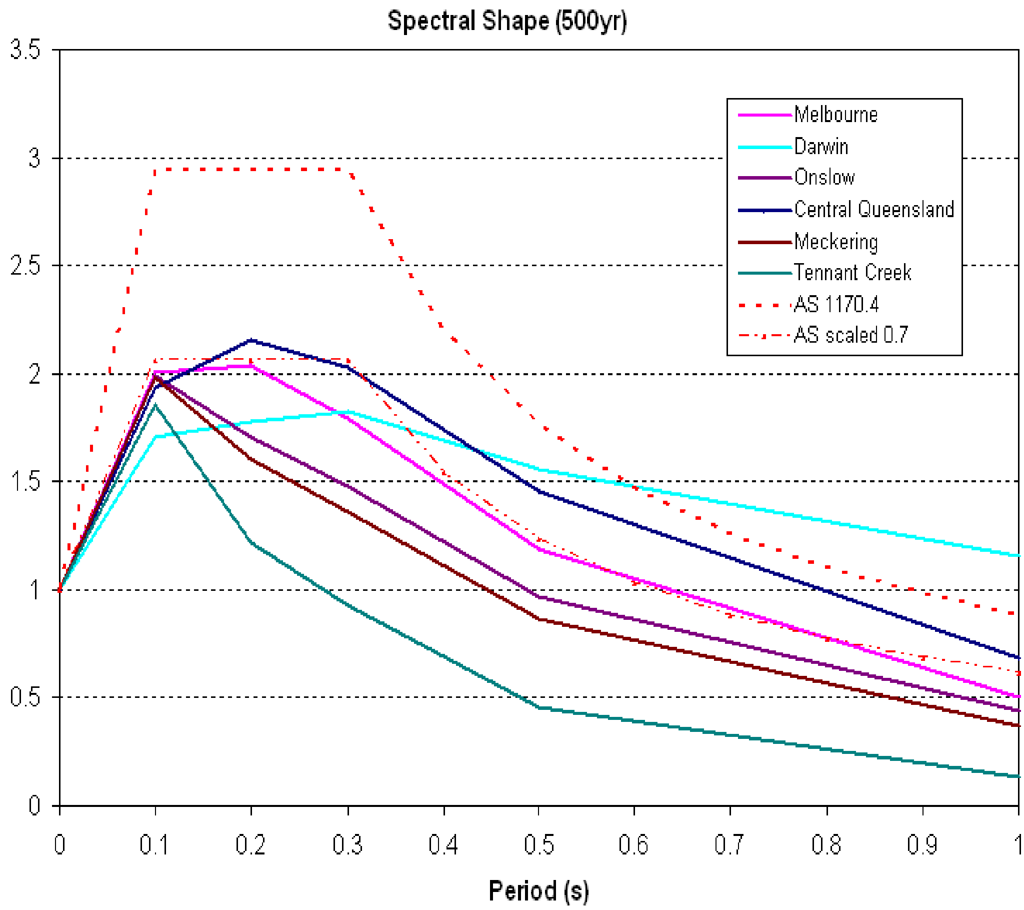


Figure 5 The normalised spectral shape for several smaller cities, two hot spots and for Central Queensland. The spectral shape is for a return period of 500 years. Also shown is the shape of the Ch(T) curve in Table 6.4 of AS1170.4 for site sub-soil class Be (dashed orange line).

Conclusions

Geoscience Australia has released a new probabilistic national earthquake hazard map and assessment of Australia after a period of approximately a year of internal and external peer review. An online tool has been provided to show the earthquake hazard at a return period of 500 years and a RSA period of 0.0s. Other maps for other combinations of return and RSA period have also been calculated and can be provided on request. For almost all locations in Australia the new PGA, 500 year hazard values in the new assessment are lower than the Z values in the code. However the difference is small (within 0.05g) for the majority of locations and tends to be higher in the western parts of Australia than in southeast Australia. Hazard is generally lower across all RSA periods for most locations with the notable exception of Darwin where the hazard is higher for RSA periods above about 0.6s. For return periods above about 1000 years the 0.0s RSA hazard values in this assessment are all higher than those derived from the tables in AS1170.4.

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