GSHAP AND THE PROPOSED AUSTRALIAN EARTHQUAKE HAZARD MAP

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SUMMARY

The AGSO earthquake database of Australia has been compiled over the last 25 years and supplemented with pre-seismograph historical data. Maps of these epicentres superimposed on continent-wide geophysical datasets depicting crustal structure have been plotted to assess earthquake hazard throughout the continent. These maps show little or no correlation of the seismicity with topography or crust/upper mantle structure. Two models, the *past-earthquake* and *uniform hazard* models have been used to assess earthquake hazard in Australia resulting in, on the one hand, a complex contour map subject to potential change with each new unexpected earthquake and on the other, a map depicting uniform hazard at a level that is universally considered sufficiently low that it could be neglected everywhere. A third model, the only physically based one, the *Coulomb* model, is presented. It was derived from the observed pattern of epicentres and continent-scale lineaments and referred back to the plate tectonic model, and will be used to reassess the earthquake hazard.

1 INTRODUCTION

One of *our* challenges in developing the new joint Loading Standard is to reconcile high hazard interplate areas such as Central and Southwest New Zealand with low to moderate hazard intraplate areas such as Australia and Northwest New Zealand. In the active parts of New Zealand the Plate Tectonic model provides a framework for establishing source zones, whereas no physical model has yet been developed to explain the earthquake context of Australia.

The UN's IDNDR Global Seismic Hazard Assessment Program (GSHAP) Committee recommended a procedure(1) for hazard assessment which we have adopted, that is to weight model criteria recommended by diverse *expert* opinion and use Bayesian statistics to compile a unique hazard map. The AGSO earthquake database was distributed by AGSO to cooperating seismological institutions for checking and correction, and compilation into a uniform national database. This database was intended for use by seismologists to independently assess candidate source zones, their activity rates and maximum magnitudes to minimise uncertainty in hazard estimates. The other principal source of uncertainty or variability in hazard estimates stems from both the adopted focal depth range and the attenuation relationship. Relevant attenuation relationships with appropriate built-in uncertainties must be adopted.

The method ensures that the results are reproducible given the same initial conditions, the same experts and expert ratings but there is a real risk that the map will change with time and the occurrence of unexpected earthquakes because there is no universally accepted model that explains the cause of intraplate earthquakes. Each new *unexpected* earthquake results in changes to the model and so changes to the hazard map.

2 SEISMICITY of AUSTRALIA

A map showing the spatial distribution of earthquakes of magnitude 4 or greater, 1897 - 1997 is shown in Figure 1. The data are from the AGSO World Earthquake database which has been compiled by AGSO and state and international seismological agencies; Central Queensland University, Primary Industries and Resources South Australia, Seismology Research Centre, University of Tasmania, University of Queensland, University of Central Queensland, the National Earthquake Information Centre and the International Seismological Centre.

The largest onshore earthquake was the 1941 Meeberrie WA earthquake of magnitude Ms6.9 (a Kobe sized earthquake) and there have been 20 independent magnitude 6 or larger earthquakes in this 100 year sample. Seven large earthquakes since 1967 ruptured surface rock including the three large earthquakes near Tennant Creek NT in 1988. Most of these large earthquakes caused little damage because they were so distant from population centres, another recent example is the 1997 Mw 6.2 earthquake at Collier Bay WA, almost 2000 km from the nearest city, Perth. The two most damaging earthquakes in Australia to date were both of magnitude 5.6; at Adelaide SA in 1954, and near Newcastle NSW in 1989, the latter the most destructive natural disaster in Australia in the last 200 years. In a country that suffers potentially very damaging earthquakes relatively infrequently, one magnitude 5.5 event every two or three year on average, the combination of earthquake and urban proximity is lethal, even for such moderate sized events. This is especially true in Australia where few buildings have been designed to resist earthquakes and where the norm is to build low rise buildings of unreinforced masonry on soft foundations - a vulnerable combination.

We do know now that most Australian earthquakes are very shallow in a seismological sense, that is they occur within 15 km of the surface. We also know that most result from near horizontal compression of these upper crustal rocks and that, although the direction of the principal stress is reasonably consistent within a region, it various markedly from region to region. Any physical model of the seismicity should explain these facts.

3 CORRELATION OF EPICENTRES WITH CRUST AND UPPER MANTLE STRUCTURE

We have compiled data to attempt to identify the cause of Australia's intraplate earthquakes by correlating earthquakes with structures such as faults, lineaments, rock type, in both the deep crust/upper mantle and upper crust. We have superposed epicentres on geophysical maps at continent wide scale of the gravity[2] magnetics[3], topography[4] and interpreted crustal elements[5].

There is no obvious correspondence of epicentres with either the geophysical parameters or interpreted structure. Areas of major gravity anomalies in the centre of the continent are not associated with more frequent or larger earthquakes than compensated crustal sections in other parts of the continent. That is there is no likely cause and effect relating earthquakes with deep crust/upper mantle processes. Similarly the magnetics should detect upper crustal structure. A significant electrical conductor inferred from the magnetics[6] which may relate to a major crustal discontinuity is not reflected by the seismicity. Broadscale geological structure as summarised in the crustal elements map does not seem to influence the location of epicentres either and some of Australia's largest mapped faults such as the Darling Fault near Perth are as inactive today as they were when the Mundaring Geophysical Observatory was established in 1959. The same is true of the topography; mountains and basins are each as likely as the other to attract earthquakes.

This was a disappointing result but redirected the search for a model from material properties to internal stresses or external forces.

4 CANDIDATE MODELS

Various suggestions have been made over the last 30 years to model the seismicity in terms of Plate Tectonics[7] or at the other extreme to assume there is no model and apply a uniform probability weighting for all sites in the continent.

The latest proposal[8] claims as did Cleary and Simpson that there is a pattern in the epicentral distribution (Figure 1). In this case that there are two conjugate parallel bands of epicentres, almost orthogonal to each other. These 'shear zones' are about 450 km wide and approximately equally spaced in the two orthogonal directions.

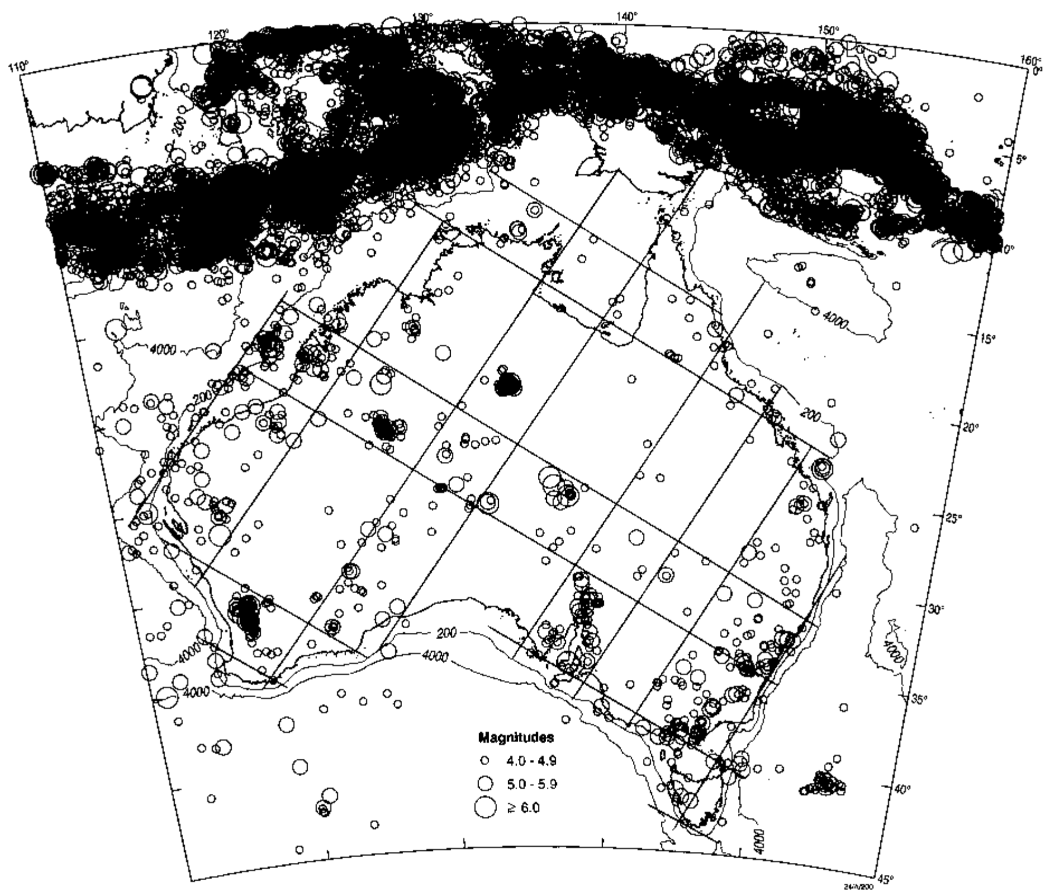

Figure 1 Earthquake epicentres 1900 - 1997, magnitude M ≥ 4 and shear zones

Such a pattern can be explained by simple Coulomb failure under north-south or east-west compression of the continent. Plate tectonics supposes, and direct measurements show, that Australia is drifting north relative to both Antarctica and Eurasia. The preferred principal stress direction would be the meridional one, compression induced by its northerly drift and collision with Eurasia. The epicentres align into characteristic x-shapes oriented northwest and northeast across the continent. Three parallel sets of 'shear zones' can be identified, the most conspicuous running northwest across the centre of the continent from about the central coast of NSW to northwest WA .

This physical model explains most of the past earthquakes but conspicuously fails to explain the Kimberly Block seismicity. We could invoke near plate boundary bending due to the complete subduction of Australian Plate oceanic crust in the region butting buoyant continental crust up against the subduction zone but that is for another study.

Time alone will enable seismologists to verify the most appropriate model and in the meantime we must use *expert opinion* to weight the models. Rather than discounting these disparate models, each of them can be included in the GSHAP scheme.

5 RESULTS

We have tested two of the three models proposed to date using published sources, recurrence relations and attenuation relations in a Cornell(9) analysis. The case studies were for the uniform hazard model which distributes all known earthquakes uniformly across the continent; and the past earthquake model in which earthquakes of the past 50 years are assumed to be the sites of most of the earthquakes expected in the next 50 years.

The latter model(10) was modified by a committee(11) for adoption into the current Australian Loading Code AS1170.4. The resultant 475 year ground acceleration varied from 0.03 g to 0.22 g near Meckering WA.

Their basic assumption has been largely vindicated by the last decade of earthquakes but notable exceptions occurred even before the hazard map was printed; in 1986 at Marryat Creek SA Ms 5.8, 1987 Nhill Victoria ML 4.9, and 1988 Tennant Creek NT Ms 6.3, 6.4 & 6.7 which all occurred where no previous seismicity had been observed.

The uniform hazard model, an extreme model which is favoured by few seismologists was run through the hazard program. The resultant 500 year ground acceleration was 0.04 g throughout the continent. Interestingly this level of ground acceleration is considered low enough by US regulators that earthquake design can be neglected. After Newcastle there would be few Australian engineers who would agree that even basic earthquake design rules could be neglected.

The third AGSO model, the Coulomb model, is being run using a program written by one of us (CS) to extract earthquake lists from any shaped source model. State agencies are still compiling their own variants of the past earthquake model after which the Bayesian analysis will be run.

DISCUSSION

Two moderate earthquakes of magnitude $5^1/_2$ or so have struck Australian cities in the last 200 years and caused great damage, most confined to low rise buildings. For every 10 such disasters we might expect a near hit from a magnitude $6^1/_2$ earthquake with far more serious consequences and for a broader range of structures than observed in 1954 and 1989. Assessment of the risk is essential for our society to judge whether, how and where they ought to implement a Loading Code.

In Australia contributing agencies are preparing their own preferred seismicity models, source zones, maximum magnitudes and attenuation relationships which will then be used to compute earthquake hazard prior to running the Bayesian statistical analysis on all contributions. The resultant map, a compromise of all models, will represent all seismological viewpoints but may at worst please none of the contributors. Perhaps it is time now to broaden the input from other professionals, especially engineers who will be using the new code.

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Table 1. Large or damaging Australian earthquakes, 1788 - 1998

Date UTC	*Time*	*Lat °S*	*Long °E*	*ML*	*Ms*	*$AUS loss (1994$)*	*Location*
1873 12 15	0400	26.25	127.5		6.0		SE WA
1884 07 13	0355	40.5	148.5		6.2		NE Tasmania
1885 01 05	1220	29.0	114.0		6.5		Geraldton WA
1885 05 12	2337	39.8	148.8		6.5		NE Tasmania
1892 01 26	1648	40.3	149.5		6.6		NE Tasmania
1897 05 10	0526	37.33	139.75		6.5		Kingston SA
1902 09 19	1035	35.0	137.4		6.0		Warooka SA
1903 04 06	2352	38.43	142.53	4.6			Warrnambool Vic
1903 07 14	1029	38.43	142.53	5.3			Warrnambool Vic
1906 11 19	0718	21.5	104.5		7.3		Offshore WA
1918 06 06	1814 24	23.5	152.5	6.0	5.7		Gladstone Qld
1920 02 08	0524 30	35.0	111.0		6.0		Offshore WA
1929 08 16	2128 23	16.99	120.66		6.6		Broome WA
1935 04 12	0132 24	26.0	151.1	5.2	5.4		Gayndah Qld
1941 04 29	0135 39	26.92	115.80	7.0	6.8		Meeberrie WA
1941 06 27	0755 49	25.95	137.34		6.5		Simpson Desert
1946 09 14	1948 49	40.07	149.30	6.0	5.4		West Tasman Sea
1954 02 28	1809 52	34.93	138.69	5.4	4.9	107M	Adelaide SA
1961 05 21	2140 03	34.55	150.50	5.6		3M	Bowral NSW
1968 10 14	0258 50	31.62	116.98	6.9	6.8	31M	Meckering WA
1970 03 10	1715 11	31.11	116.47	5.1	5.1		Calingiri WA
1970 03 24	1035 17	22.05	126.61	6.7	5.9		L Mckay WA
1972 08 28	0218 56	24.95	136.26		6.2		Simpson Desert
1973 03 09	1909 15	34.17	150.32	5.6	5.3	2M	Picton NSW
1975 10 03	1151 01	22.21	126.58		6.2		L Mckay WA
1978 05 06	1952 19	19.55	126.56		6.2		L Mckay WA
1979 04 23	0545 10	16.66	120.27	6.6	5.7		Broome WA
1979 04 25	2213 57	16.94	120.48		6.1		Broome WA
1979 06 02	0947 59	30.83	117.17	6.2	6.1	10M	Cadoux WA
1983 11 25	1956 07	40.45	155.51	6.0	5.8		Tasman Sea
1985 02 13	0801 23	33.49	150.18	4.3		.09M	Lithgow NSW
1986 03 30	0853 48	26.33	132.52		5.8		Marryat Ck SA
1988 01 22	0035 57	19.79	133.93		6.3	1.3M	Tennant Ck NT
1988 01 22	0357 24	19.88	133.84		6.4		Tennant Ck NT
1988 01 22	1204 55	19.94	133.74		6.7		Tennant Ck NT
1989 12 27	2326 58	32.95	151.61	5.6	4.6	1 270M	Newcastle NSW
1994 08 06	1103 52	32.92	151.29	5.3		34M	Ellalong NSW

1997 08 10	0920 35	16.10	124.38	6.3	Collier Bay WA