RECURRENCE RELATIONSHIPS FOR AUSTRALIAN EARTHQUAKES

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ABSTRACT:

The relationship between the number of earthquakes and their magnitude in any time interval is routinely approximated by a Gutenberg and Richter formula which leads to a straight line in log-linear coordinates. Worldwide data are often better fitted by a bi-linear curve over the recorded magnitude range and the discontinuity point can be explained in physical terms.

The bi-linear pattern emerges on both large scale such as the whole of Australia and small (zone) scale, such as southeast Australia. In that case usage of the straight-line fit will overestimate the occurrence rate of large events and underestimate the rate in the mid-magnitude range. This is an important consideration when estimates of maximum magnitude are required for periods much longer than the observation time, especially in zones where few large earthquakes have been recorded.

1. INTRODUCTION

The seismicity of the Australian continent is typical of that experienced for intra-plate environments. Australian earthquakes are shallow and most of the focal mechanisms are consistent with horizontal compression. The earthquakes in continental interiors are associated with high local stress concentration and relatively short fault rupture lengths. In the last hundred years, 26 earthquakes with a magnitude of 6.0 or greater were recorded in Australia, and on average there were two to three earthquakes per year with a magnitude of 5.0 or more (AGSO Earthquake Database).

The frequency distribution of earthquakes as a function of their magnitude is of primary importance for seismic investigations. Hazard outputs depend on the definition of the seismogenic areas or zones. In situation where faults and other tectonic structures are not obvious at the surface the shape of the seismic zones can not be clearly defined. If some region is too small for the period of monitoring then the apparent frequency of large events can only be obtained by extrapolation of the frequency of observed small events, but the uncertainty in the estimated frequency is very high. Instead, a larger area can be taken to compensate for the short time interval provided the tectonics and underlying geological processes are similar. Zones can be chosen according to the criteria of earthquake clustering in the continental crust. The pattern of earthquakes with magnitude M≥4.0 is sufficient for zoning in Australia (Fig.1).

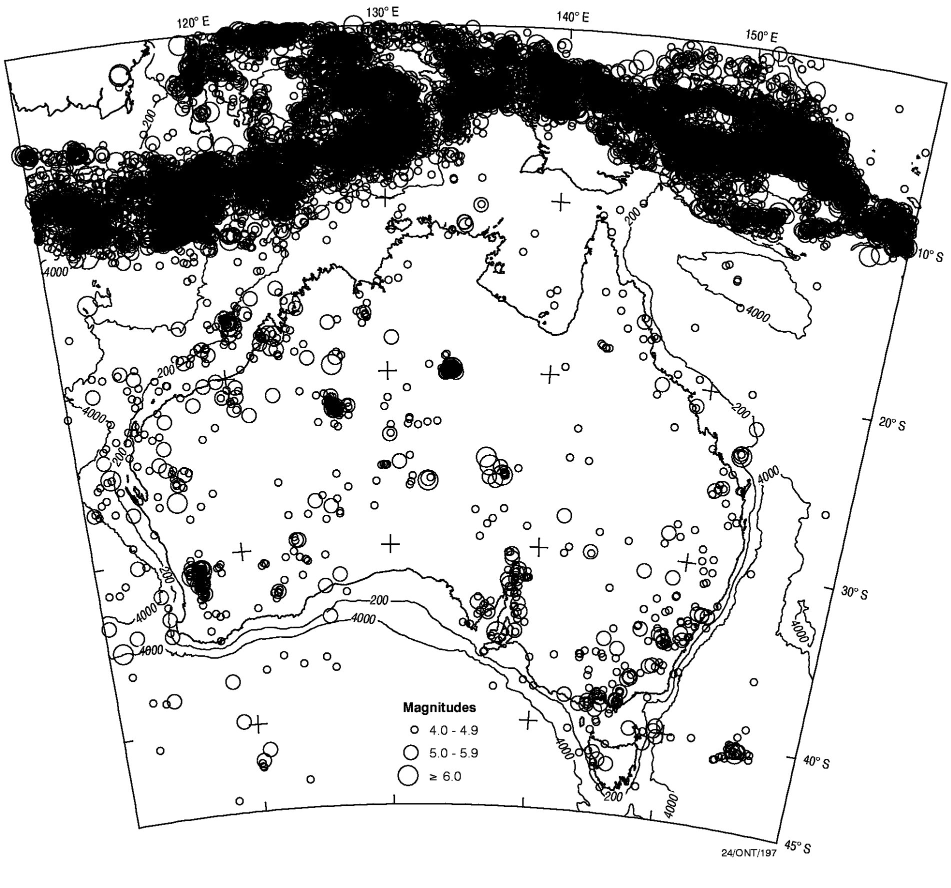


Fig.1. Epicentral map of all earthquakes in the last 100 years with magnitude M≥4.0

One recent model (McCue at al., 1998), defines the zones according to the pattern of shear failure under north-south compression of the continent. Statistics also show that Western, Central and Eastern Australia are different and these areas can be considered to be separate zones for assessing earthquake recurrence times (Sinadinovski, 2000).

2. DATA

The data used for this study comprise a subset of the AGSO earthquake database for Australia between 10 and 45°S and 110 and 155°E. Analysis was restricted to only those time intervals in which the seismic network was able to consistently record all earthquakes of the specified magnitude in the Australian continent. On our assessment, the periods of completeness were 1901-1999 for M $\geq$ 6.0, 1959-1999 for M $\geq$ 5.0, 1965-1999 for M $\geq$ 4.0, and 1980-1999 for M $\geq$ 3.2.

Numbers of earthquakes were counted for the declustered dataset of magnitude 3 and more in magnitude intervals of 0.2 which is about the uncertainty in magnitude. The dataset referred to as a declustered data set, has the same magnitude ranges but the identifiable foreshocks or aftershocks have been removed. A quake was considered to be a foreshock or an aftershock and was removed if:

- it was within a certain distance *d* km of the main shock (McCue, 1990) where

$$d = 10^{(M-4.11)/1.65} \qquad ..(1)$$

and M is the magnitude of the main shock and

- if the quake occurred within 10 years for magnitude 7, within 1 year for magnitude 6, within 3 months for magnitude 5, and within 10 days for magnitude 4 (McFadden *et al.*, 2000).

3. METHODOLOGY

The relation between the number of earthquakes and their magnitude is routinely approximated by the Gutenberg and Richter empirical formula (Gutenberg and Richter, 1949) represented by a single straight line in log-linear coordinates

$$\log N = a - bM \qquad ...(2)$$

where N is the cumulative number of earthquakes per year, M is the local or Richter magnitude and a, b are constants related to the level and the slope. Data are treated by grouping of N according to the magnitude range.

The coefficient b usually takes a value around 1. In general this relationship fits the data well on a global scale, but not for particular tectonic regions. Various authors have discussed the spatial variation in b. For example, Kárník (1971) mentioned that in some cases for the weakest and the strongest earthquakes, the (log N, M) distribution deviated significantly from linearity. Recently, some other approximation formulae have been applied (Utsu, 1999, and Kagan, 1999).

For use in prediction and comparative mechanism studies, standard errors of b must be supplied for statistical tests. Because earthquakes are stochastic processes and the b value is a random variable, knowledge of the probability distribution and the variance of b are essential in studying its temporal and spatial variation. The b value can be calculated by least-squares regression, but the presence of even a few large earthquakes influences the resulting b value significantly. Alternatively, the maximum likelihood method can be used to estimate b because it yields a more robust value when the number of infrequent large earthquakes changes.

There are cases, however, where the least-squares method is more suitable. The distribution of the best estimate can then be tested against a standard ξ_n, a chi-squared distribution for n degrees of freedom, where n is the number of events above certain magnitude threshold.

4. ANALYSIS

Data extracted from the AGSO earthquake database were declustered within the described parameters. The magnitude ranged from ML3.2 to ML7.2. Figure 2 is a plot of the cumulative number of counted earthquakes per year in Australia against magnitude.

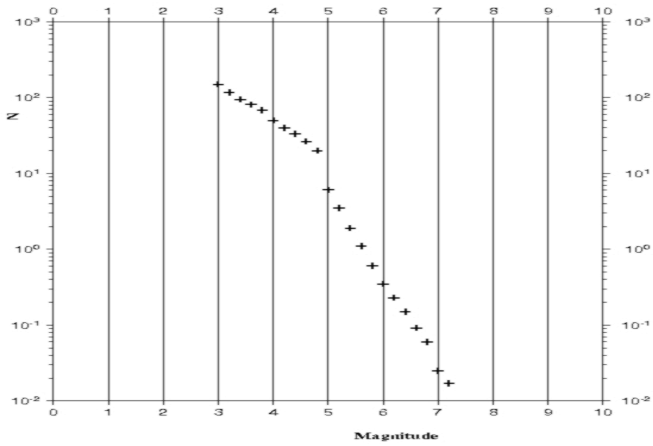
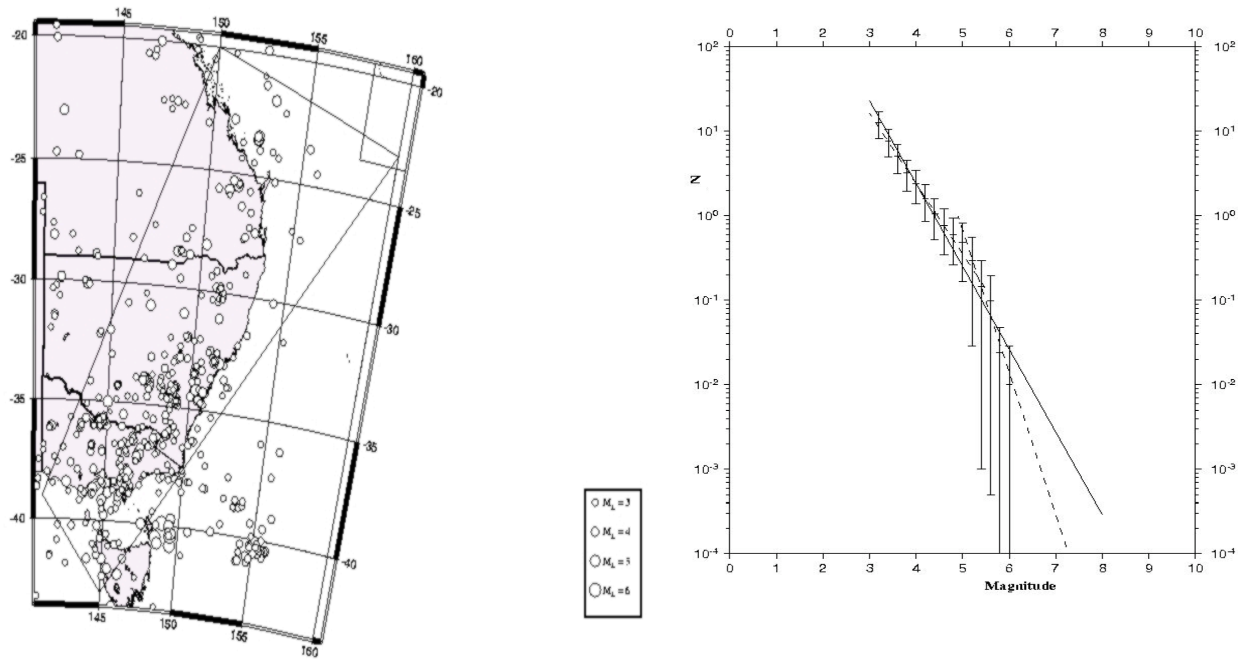


Fig. 2. Plot of the cumulative number of earthquakes per year in Australia against the magnitude (declustered data)

From the diagram it is obvious that a straight line is not a good fit, particularly for the larger earthquakes, and approximation with two linear segments is more representative. There is a significant change of slope around magnitude 5.2±0.1 and that position was also noticed for the three zones identified as Western, Central and Southeastern Australia (Sinadinovski, 2000).

The Southeastern Australia zone was defined as rectangle extending from northern Bass Strait into Queensland (Fig. 3-a). The coefficients for its straight line least-squares-fit (solid line on Fig. 3-b) were calculated as $a = 4.3$ and $b = 0.98$.



a b

Figure 3: Southeastern Australia zone, seismicity and its magnitude-frequency relationship

5. RESULTS AND DISCUSSION

From the graph it is evident that a straight line does not fit well and earthquakes above magnitude 5 have much larger error bars because they are so few. Therefore an approximation with two linear segments represented by dashed lines is much more suitable. For the upper segment with magnitudes between 3.2 to 5.1 the calculated *b* value was 0.83±0.09, while for the lower segment with magnitudes $M \geq 5.2$, the calculated *b* value was 1.7± 0.48.

Again there is a significant change of slope around magnitude 5.2, which is consistent with the our previous observations. Kárník (1971) related the discontinuity point to the fracturing of the material subjected to stress, while Aki (1999) explained the discontinuity through physical terms of source size saturation effects. It is accepted that most earthquakes in stable continental regions only occur in the brittle upper crust and that above a certain magnitude at which the whole width of the brittle crust is ruptured the magnitude can only increase by rupturing a longer fault zone at constant width. That situation should occur at a magnitude around 6 where one could expect another cusp.

A chi-squared ξ_n -test was performed to assess which of the linear and bi-linear recurrence relations best matched the observed distribution of events in the Southeastern Australia zone with magnitudes greater than 5. The test results show that the probability of the observed distribution being produced by the bilinear fit is much higher than with the straight line, namely 98% as opposed to only 18%.

We have revised the *b* values for Southeastern Australia using new information which became available following a recent AGSO marine geophysics cruise off the coast of Tasmania. A large sequence of felt earthquakes off Flinders island in the 1880's and 1890's and a later event in the 1940's were excluded from our original analysis because they were thought to be associated with a hypothesised hotspot under northern Tasmania. The marine cruise found no evidence that a hotspot exists there, no submarine volcanoes or major faulting on the continental shelf.

We concluded that the earlier observed seismicity should be included in a slightly modified source zone in Southeastern Australia. Including the declustered events, the largest of the sequence and the 1946 event resulted in a remarkable reduction in both the *b* value and its apparent uncertainty. The revised analysis produced a *b* value of 1.14± 0.08, the upper limit of the range, 1.22 overlaps with the lower limit of range of the previous findings.

Because the value of *b* is observed to change with time and space, its mean and variance might also be expected to change. In other words, *b* should be regarded, in general, as a non-stationary stochastic process. When sampling with a small time and space window, however, *b* can usually be taken as stationary and with constant consideration of its characteristics.

On the basis of these results it can be concluded that the straight-line fit overestimates the frequency of large events and underestimates the frequency of moderate size events and the bi-linear model better fits the recurrence of Australian earthquakes. This is especially critical when estimates of maximum magnitude are required for periods much longer than the observation time in zones where only a few large earthquakes have occurred. For example, the values of maximum magnitude defined in Southeastern Australia as the 10,000-year magnitude are 7.1 and 8.4 respectively. The effects on the 500-year pga as used for the Australian Building Code AS1170.4 are minor. This study shows that the same pattern emerges on both large (whole country) and small (zone) scale. However, the statistics are only a quantitative indication as it is not possible to estimate in detail the crustal stress in a region, nor to determine its exact physical status.

6. REFERENCES

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