# Historical earthquakes: a case study for the Adelaide 1954 earthquake

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## *Abstract*

The accuracy of a seismic risk assessment is related to the time span of the data base. The longer the seismicity of an area is observed, the better the ability to predict future activity. Historical records of earthquakes stretch back more than four times the period of instrumentally recorded earthquakes, so the value of historical earthquakes and isoseismal maps is of great importance for calibration of ground motion models because the building type is taken into account during assigning of the intensity values and such maps reflect the local geology and soil characteristics.

Of interest to the insurers are also interrelated aspects of risk calculation such as the expected earthquake occurrences, maximum magnitudes and intensities, and anticipated damage. We have used a well-documented case of the Adelaide 1954 earthquake to address these aspects and tried to compare the MM intensities with the damage ratios for the purposes of loss calculation. Our estimates expressed in percentage of the effective loss of the replacement value of insured dwellings in Adelaide are comparable with the results of the recent studies by the insurance industry.

## *Introduction*

Earthquakes have been recorded on Australian seismograph networks only within the last forty years or so (Greenhalgh et al., 1994). Historical records of earthquakes stretch back more than four times the period of instrumentally recorded earthquakes, so the value of historical earthquakes and isoseismal maps is of great importance for research.

Malpas (1991a) presented a list of historical earthquakes in South Australia for the pre-network period 1883-1961 and from 1962-1991. She also reviewed the State's two important events (Warooka 1902 and Adelaide 1954). The general engineering design and construction of buildings was considered in a seismic risk study for South Australia by McCue in 1975 and later in Eastern Australia (McCue, 1977). He gave a series of recommendation regarding the instrumentation, seismic methods and risk calculation.

Of interest to the insurance industry are three interrelated aspects of risk calculation, namely the expected earthquake occurrences, estimates of maximum magnitudes and intensities, and anticipated damage.

Gaull et al. (1990) published the first probabilistic hazard study of earthquakes in Australia and many other studies have since followed. However, the question remains regarding the maximum magnitudes of earthquakes in zones with relatively short seismic history and when the magnitude-frequency relationship is not constrained. The insurance industry has adopted a slightly different approach based on the concept of Probable Maximum Loss (PML) which is a measure of the maximum loss which can be anticipated in a given period (Blong, 1992; Irish, 1992).

While the Loading Standards present the likely ground motion in a region using peak ground acceleration on rock, the insurance industry approach is to use a "design" earthquake to model the expected effects from some likely events. The second approach is dependent on the selected earthquake location and magnitude, as well as a detailed knowledge of the path characteristics, including the local site conditions, which in some cases are difficult to obtain.

The existing isoseismal maps reflect, in addition to the distance from the epicentre and the focal depth of the earthquake, the local geology and the soil characteristics of the area. The actual building response, upon which intensity values are determined, depend not only on the ground motion levels, but also on the building type and height. Each building will have its own natural period of vibration, which may resonate with the earthquake frequency range. After taking account of building type, it is possible to use the isoseismal maps for particular earthquakes to directly calibrate for ground motion models. Microzonation maps exist for the shallow sediments beneath some Australian capital cities (Love, 1996; Jones et al., 2004). When such detailed maps are available, the inclusion of the regolith amplification by using the soil type description and corresponding amplification factors in the earthquake loading standard can be applied in given situations.

## *Adelaide 1954 earthquake*

In the early hours of 1st March 1954, at 3.40am (local time), the city of Adelaide experienced one of the States severest earthquakes, equal only to the events at Beachport 1897 and Warooka 1902 (Malpas, 1991c). From the list of historical earthquakes (McCue, 1975, Malpas, 1991a, Dyster, 1995) it was the first earthquake of such size in the vicinity of the city. The isoseismal map of the earthquake is shown in Fig. 1 (after Kerr-Grant, 1956). The strong shaking woke most residents, cracked walls and loosened plaster from many buildings (Love, 2002). Southern suburbs sustained the worst damage, with fallen chimneys and partial wall collapse of some dwellings. Other hill areas, especially along the Burnside fault, also reported damage, attributed to down-slope slippage of subsoil during the disturbance or perhaps resonance. The maximum intensity of the earthquake has been established as MM VIII.

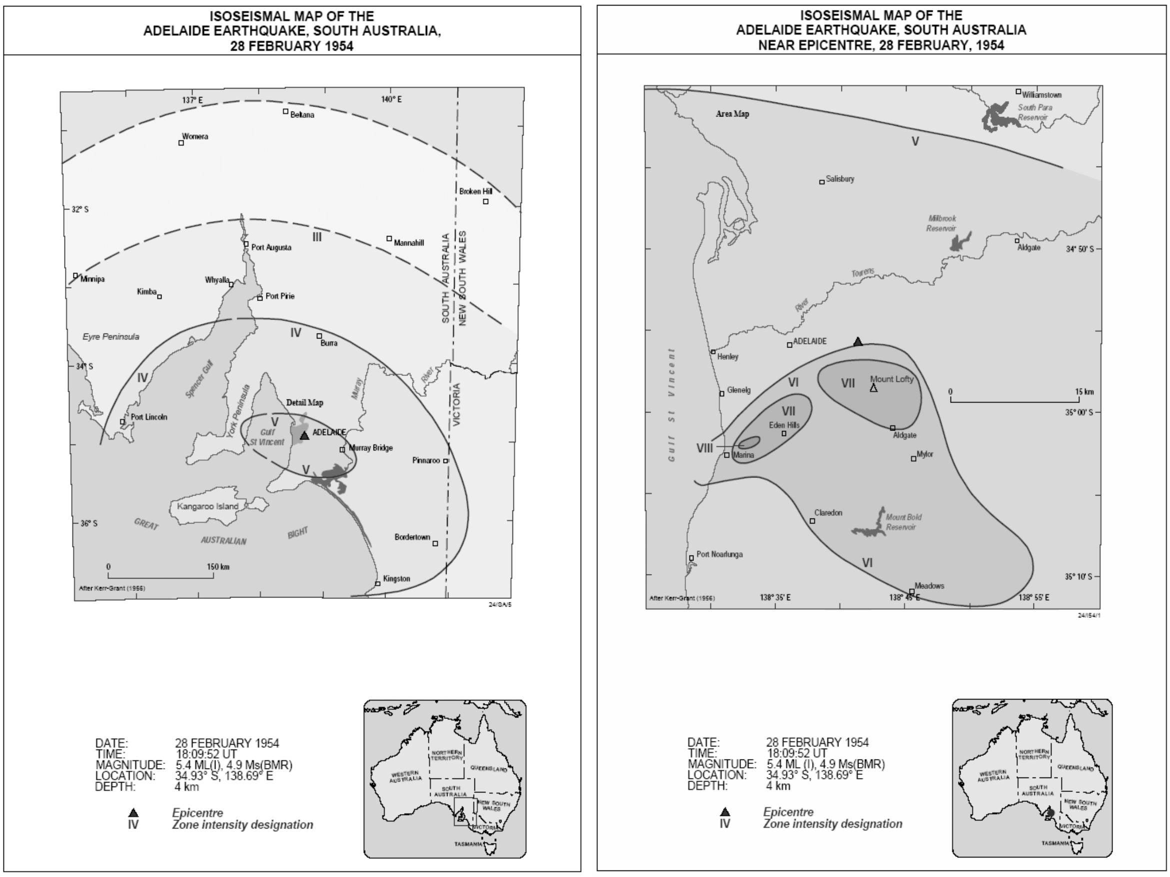


Figure 1: Isoseismal map of Adelaide 1954 earthquake

In view of the importance of the 1954 earthquake, the macroseismic data were reviewed and the isoseismal map redrawn (Fig. 2) based on numerous excerpts from newspaper reports in the Public Library of South Australia and the State Archives (Malpas, 1991b). The new map still retained a maximum intensity of MM VIII, but zones with intensities MM V and MM VI were increased alongside faults.

Seismograms of this earthquake were obtained at Melbourne, Riverview, Perth and Brisbane, though it was not large enough to be recorded in New Zealand nor Manila. Apparently the Adelaide seismograph was still in operation, but had problems with the time marks and was overloaded due to proximity to the epicentre. The initially assigned local magnitude was 5.4 and has been reviewed a few times (Malpas, 1991b, McCue, 1980). In the absence of any instrumental records under a distance of 600km, the isoseismal maps become crucial evidence in deciding the epicentral location. A small aftershock of magnitude 3.2 occurred in the same area the following day at 5.45am local time with a felt radius of around 20km and maximum intensity of MM IV.

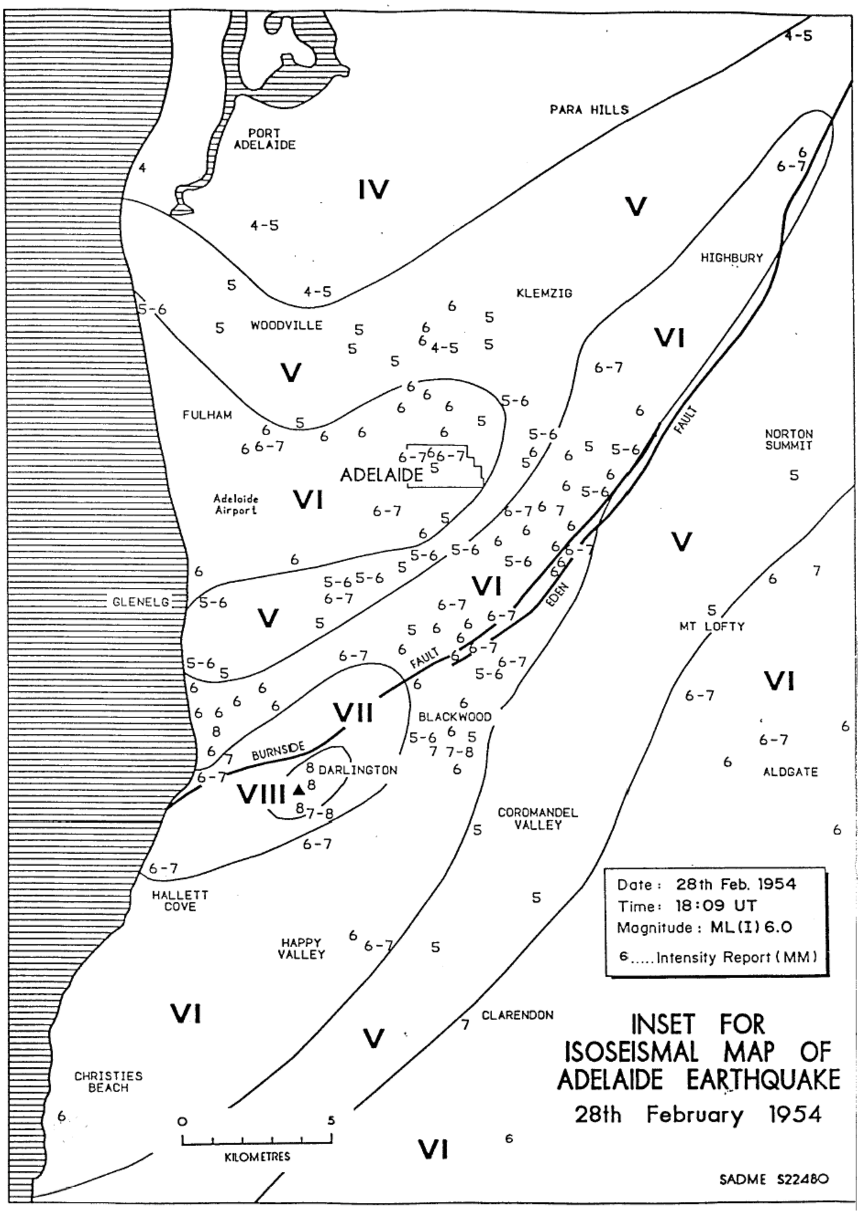


Figure 2: Enlarged isoseismal map of Adelaide 1954 earthquake (after Malpas 1991)

## Damage calculation process

Damage ratios which relate MM intensities to building types and loss ratios are relatively recent, and usually not very constrained, because building codes and construction types may vary from area to area. However, there are some general empirical relationships regarding attenuation of seismic waves from given earthquakes in Australia, and the vulnerability of common building structures.

The total damage bill will depend on the maximum intensity of the earthquake and the decay of intensity with distance from the epicentre. The areal distribution of intensity levels depends on the magnitude of the event and its depth, and the attenuation function of seismic waves within the region. Local geological conditions such as soil thickness and type and proximity to faults, can alter the degree of ground shaking and hence the damage pattern. In general, the shallower the earthquake, the greater the maximum reported intensity $I_{max}$, but the lower the total area affected. From a systematic study of available intensity information for Australian earthquakes, the average relationship between local magnitude ML, maximum observed intensity $I_o$ and radius of perceptibility $R_p$ was determined by Greenhalgh et al., (1989) through the following formulas:

$ML = 1.35(\pm0.34) + 0.57(\pm0.06)\ I_o$ and
$ML = 0.35(\pm0.12)\ (\log R_p)2 + 0.63(\pm0.41)\ (\log R_p) + 1.87(\pm0.36)$

The formulas predict that for a shallow earthquake producing a maximum intensity Imax=VIII (comparable to the 1954 Adelaide event), the area shaken at MM intensities VIII, VII and VI would be 250, 900 and 3100 km$^2$ respectively, though the comparative areas for such an event in Western Australia might have been somewhat different (Sinadinovski and McCue, 2003). Intensity MM VI is generally taken as the engineering threshold for building damage (plaster cracks, chimney damage).

Thus the likely number of insurance claims to be expected following a particular earthquake according to these formulas can be specified with a certain probability depending on the housing density and the size of the epicentral zone.

The average levels of damage for houses of brick construction as a fraction of property value at different Modified Mercalli intensities have been assessed by the Australian Government Actuary as:

| MM Intensity | V | VI | VII | VIII | IX | X | XI |
|---|---|---|---|---|---|---|---|
| Fractional Value of Damage | 0.01 | 0.03 | 0.09 | 0.25 | 0.75 | 0.95 | 1 |

For timber or fibro dwelling (brick chimneys, concrete block etc.) the damage would be less by a factor of 3 at intensity MM VII, and a factor of 5 at intensity MM IX.

In Australian conditions unreinforced masonry (URM) is a common form of building construction. A team from the University of Adelaide has developed a two-step vulnerability assessment procedure for URM buildings that considers both the global in-plane and local out-of-plane URM building response. Data from the Newcastle earthquake were used to verify the accuracy of that approach. Their results showed good correlation with the observed damage on a suburb-by-suburb basis (Brezezniak et al., 2003).

The quantification of the earthquake load (demand) on potential structures in the study region was represented as the earthquake demand curve. Vulnerability was then defined as a response of different buildings types to a given event by finding the displacement corresponding to the intersection of the earthquake demand and the capacity curve. The values typically correspond to the displacement at which the cracking occurs (usually ultimate strength) and the point at which the wall's loss of strength becomes significant. For in-plane wall response, values were expressed on the basis of the storey drift, i.e. dividing lateral displacement by the height. For out-of-plane wall response, the concept of drift was taken as the wall deformation divided by the wall span.

The drift ratios for URM buildings with tile roof and metal roof were considered for low- and mid-rise building heights, i.e. 4.5 and 10.7m. The authors also specified four URM threshold drift ratios for the slight, moderate, extensive and complete damage state. Almost every assessment indicated that out-of-plane damage was significantly more than in-plane damage. The assumptions for the vulnerability part of the model have to account for building degradation, quality of construction, and local out-of-plane failure mechanisms in URM buildings.

## *Loss results*

The Adelaide 1954 earthquake produced intensities of MM VI or greater over an area of about 600km$^2$, with two areas totalling about 100km$^2$ experiencing MM VII in the south, and one very small area near Darlington sustained MM VIII. Most of the urban area experienced an intensity of MM V. The majority of the dwellings in Adelaide at the time of the 1954 earthquake were of brick or stone construction and many were vulnerable to damage from an earthquake producing intensities greater than MM VI. The 1954 Census showed the population of Metropolitan Adelaide as 483,500, and a total of less than 137,000 dwellings (Greig Fester report, 1996). Records maintained by the Fire and Accident Underwriters Association of South Australia indicate that by the end of September 1957 a total 30,303 claims had been paid. That suggests that claims were made for 22% of buildings for earthquake damage. Many of the claims paid were for cracks in the walls of houses and some cracks were probably initiated by earlier movements of subsoils and foundations.

In 1954 there was generally no excess applied to earthquake claims. Most claims were relatively minor, with the total payout for all claims around $6 million – an average claim of $200. Unfortunately, no information remains concerning the location of buildings on which claims were paid or the distribution of the claims amounts. However, the number of claims paid by the 63 insurer companies range from 1 to 2622, while the claims paid range from $54 to $352. A February 1955 memo of the Fire and Accident Underwriters' Association of South Australia gave the aggregate statistics of Earthquake Losses compiled from individual returns submitted by all Members of the Association. The total number of claims lodged as at 31st December 1954 was 30,098 with a total value of £2,777,517.

In the 1996 confidential report on historic exposure and loss data for the Adelaide 1954 earthquake by New Zealand's Works Consultancy Services Ltd, the total domestic exposure of houses and flats (owner occupied and rented) was 94,865, with a total replacement value of $606 million. The average construction cost per house was estimated at $5,500 at time of completion (excluding land) and did not in general include carports, fences or other subsequent additions and alternations. Other comparisons suggested that the average replacement value for the metropolitan area is likely to have been closer to $6,000-$6,500 per house.

Historical loss data for the 1954 earthquake were available only for domestic risks, as very few commercial risks were covered by earthquake insurance at the time. Two figures commonly used for the loss are 30,300 insurance claims at an average of $200 per claim, and a total claim of $6.2 million, and a total loss of $8 million which included the insurers outside the group. Also, the losses quoted above included domestic contents losses (generally minor) as well as damage to dwellings, whereas the exposure figure of $606 million includes the value of the dwellings only. Earthquake cover without excess was automatic under the Householders policies applying at the time and many smaller claims were apparently related to re-opening or enlargement of pre-existing cracks.

However, as the insurance policies at the time provided indemnity cover only, the loss figures do not include any betterment. So, allowing the first amount of $6.2 million, the corresponding effective loss would have been 1.02% of the replacement value of insured dwelling in Adelaide at the time. Discussion in the files of the Fire and Accident Underwriters' Association of South Australia suggests that there was general agreement that industry treatment of claims had been generous, but that the industry was interested in avoiding future claims for damage caused by subsidence and soil movement.

## *Summary and discussion*

Here we have used the Adelaide 1954 earthquake to calculate the risk and compared the MM intensities with the damage ratios for the purposes of loss estimation. Our estimates are about 1% of the effective loss of the replacement value of insured dwellings in Adelaide. Earlier results of the Probable Maximum Losses studies (Greig Fester, 1996) based on aggregation of losses for several regions of MMI produced estimates in the range of 1.9 to 4.8% for a shallow earthquake with magnitude 5.6 below postcode 5000, with uncertainties in the results attributed to the modelling of the subsoils and choice of attenuation function.

By 1957 most of Adelaide Plains had been urbanised with expansion of low density housing (about 20 persons per hectare) after World War II with the growth of outer centres at Elizabeth, Salisbury, Tea Tree Gully, Morphett Vale, Noarlunga and southwards along the coast. Dwellings are defined as separate houses, semi-detached row or terrace, townhouses and 1-2 storey blocks of flats. With the southerly development of Adelaide's suburbs (Fig. 3), an event of similar size recurring today might be expected to cause significantly higher loss.

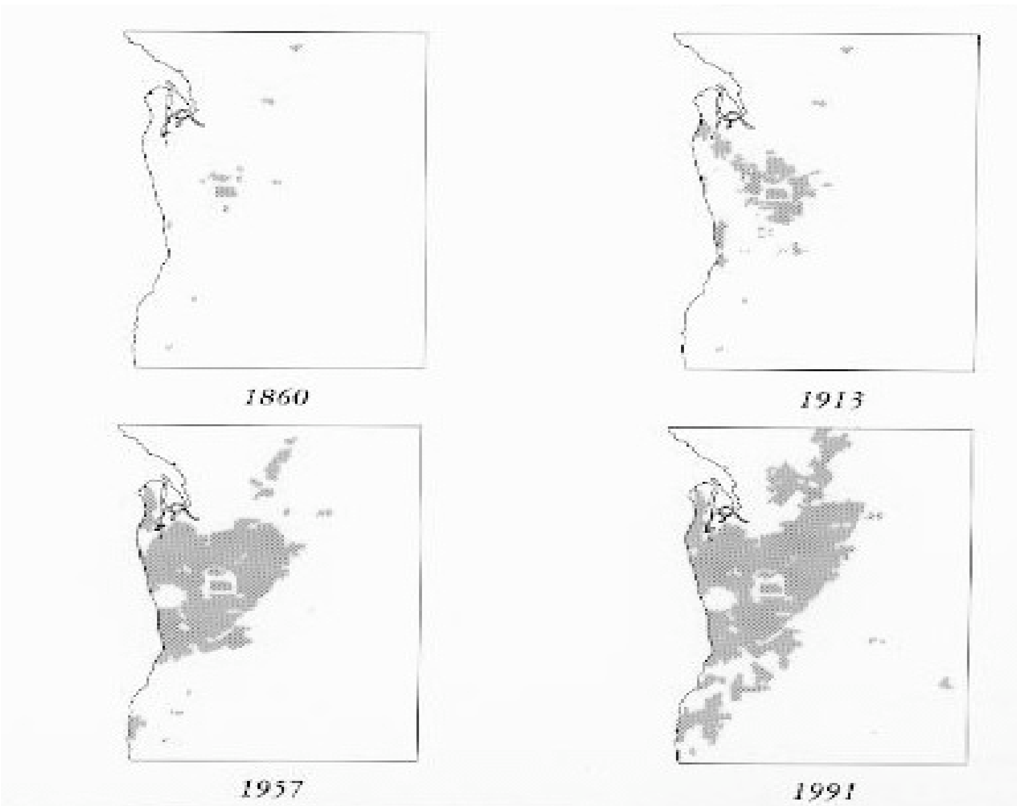


Figure 3: Adelaide and its suburbs

## References

Blong, R.J., 1992. Domestic Insured Losses and the Newcastle Earthquake, Earthquake Resistant Design & Insurance in Australia, AEES and Specialist Group on Solid-Earth Geophysics Conference, Sydney.

Brezezniak, N., Lynch, T., Moore, C., Rollison, C., and Griffith, M., 2003. Improved Vulnerability Models for Regional Earthquake Risk Assessment, AEES Conference, paper 23, Melbourne.

Dyster, T., 1995. Strong Shock of Earthquake – The Story of the Four Greatest Earthquakes in the History of South Australia, Mines and Energy South Australia, Report Book 95/47, Adelaide.

Gaull, B.A., Michael-Leiba, M.O., and Rynn, J.M., 1990. Probabilistic Earthquake Risk Maps of Australia, Australian Journal of Earth Sciences, 37, pp 169-187.

Greenhalgh, S.A., Denham, D., McDougall, R. and Rynn, J., 1989. Intensity Relations for Australian Earthquakes, Tectonophysics, pp 166, 255-267.

Greenhalgh, SA, Love, D. and Sinadinovski, C., 1994. Thirty years of seismic network recording in South Australia, Phys.of Earth Plan. Int. 86, pp 277-299.

Greig Fester 1996. Earthquake PML, Household Buildings, Adelaide.

Irish, J.L., 1992. Earthquake Damage Functions for Australian Houses and the Probable Maximum Loss for an Insurance Portfolio, Earthquake Resistant Design & Insurance in Australia, AEES and Specialist Group on Solid-Earth Geophysics Conference, Sydney.

Kerr-Grant., C., 1956. The Adelaide Earthquake of 1st of March 1954. Transactions of the Royal Society of South Australia, 59, pp 177-185.

Jones, T., Middelmann, M., and Corby, N., 2004. Natural Hazards in Perth, Western Australia, Comprehensive report, Geoscience Australia.

Love, D., 1996. Seismic Hazard and Microzonation of the Adelaide Metropolitan Area. Department of Mines and Energy South Australia, Report 27, Adelaide.

Love, D., 2002. Earthquake Photo Collection, Primary Industries and Resources South Australia, CD.

Malpas, K.L., 1991a. Seismic Risk of South Australia, Honours Thesis, Flinders University.

Malpas, K.L., 1991b. Adelaide 1954 earthquake, South Australia, unpublished record, Flinders University.

Malpas, K.L. 1991c. Warooka 1902 Earthquake South Australia, unpublished record, Flinders University.

McCue, K.F., 1975. Seismicity and Seismic Risk in South Australia, ADP 137, The University of Adelaide.

McCue,K.F., 1977. Seismic Risk in Eastern Australia. ADP 153, The University of Adelaide.

McCue, K.F., 1980. Magnitude of Some Early Earthquakes in Southeastern Australia, Search 11, No. 3, pp 78-80.

Sinadinovski, C., and McCue, K.F., 2003. Comparison of Two Earthquakes with Similar Magnitudes in Dissimilar Tectonic Regimes, Proceedings of the European Conference on Earthquake Engineering, Skopje-Ohrid, Macedonia.