

Effects of Intraplate Earthquakes on Structures

John Wilson, Nelson Lam, and Graham Hutchinson

Department of Civil and Environmental Engineering, The University of Melbourne, Parkville Vic 3001

Introduction

Australian earthquakes are associated with relative slip between geological faults within a tectonic plate and are known as intraplate earthquakes. These faults are generally smaller than the faults associated with a plate boundary and result in maximum credible earthquakes that are smaller in; magnitude, frequency of occurrence, peak ground acceleration, duration of shaking and area of influence than interplate earthquakes. In addition, the fault mechanism of Australian earthquakes is reverse faulting compared with the strike slip faulting that is commonly associated with Californian interplate earthquakes. Consequently Australian earthquakes tend to have a high stress drop and contain a large proportion of high frequency energy resulting from numerous short duration acceleration pulses. The seismic hazard in Australia is principally associated with the near field ground motions of relatively shallow medium sized earthquakes. (Mag 5-7)

In contrast, the earthquake hazard in California is from both near and far field large earthquakes (Mag 6-9) and consequently the earthquake design parameters recommended in these regions have been developed from an ensemble of earthquakes that reflect both the low frequency energy associated with far field events and the high frequency components of near field earthquakes.

ARC Research Project

The new Australian earthquake loading standard, AS1170.4-1993, (Ref 1) is based primarily on Californian experience (Ref 2, 3) and consequently involves a number of seismological and engineering extrapolations for Australian conditions. The most significant extrapolations are associated with the calculation of earthquake forces which essentially comprises two parts:

- i. Selection of the earthquake ground motion in the form of an elastic response spectrum.
- ii. The construction of an inelastic response spectrum from the elastic spectrum using the "Structural Response Factor", or 'R' factor.

Preliminary studies suggest that the UBC (Ref. 3) normalised design response spectra used in AS1170.4 are conservative for the design of buildings greater than three stories in height (Figure 1). Further, the inelastic demand experienced by structures is dependent on both the duration of strong motion shaking together with the size, shape and sequence of acceleration pulses.

Since Australian earthquakes are generally smaller in magnitude, shorter in duration and contain a greater proportion of high frequency components than Californian earthquakes, further investigation is needed to determine the suitability of using Californian based 'R' factors in Australia.

A three year research project, funded by the Australian Research Council, has been initiated which brings seismologists and engineers together to investigate Australian engineering seismological parameters (Ref. 5). Specifically the project aims to:

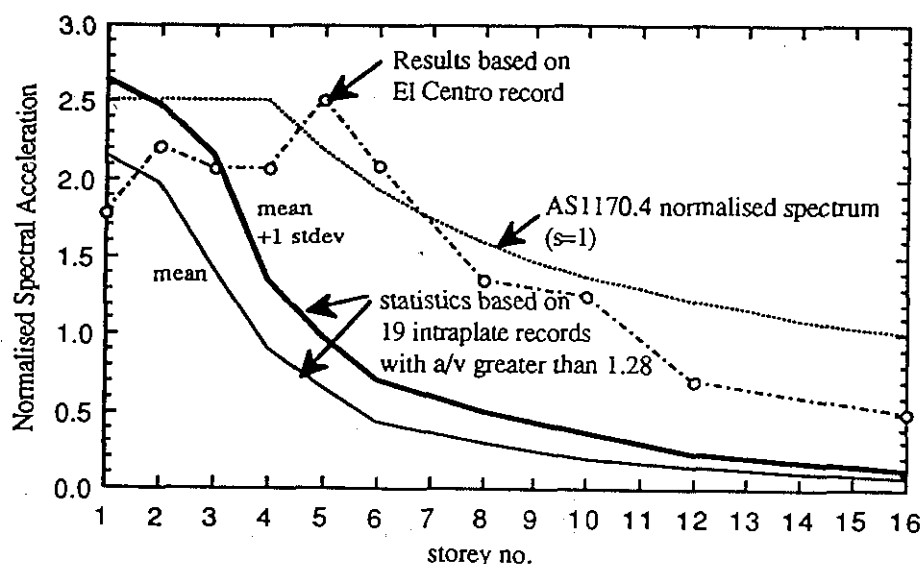


Figure 1 Intraplate earthquake and design response spectra (after Ref. 10)

- i. Develop appropriate earthquake ground motions and response spectra for Australian conditions for rock and a range of soil profiles, and
- ii. Investigate the overstrengths and energy absorption capabilities of commonly used Australian framing systems when subjected to typical Australian earthquakes. (These structural response parameters are measured in the new Earthquake Standard using the 'R' factor).

Elastic Design Spectra

This ARC funded research project will develop Australian spectral attenuation functions which present displacement, velocity and acceleration components of ground vibration as a function of frequency for bedrock motion.

From these ground motion spectra, linear elastic design response spectra for Australian conditions will be developed using a number of methods including:

- i. The use of existing Australian data from the 80 seismographs installed and maintained by both the Seismology Research Centre (SRC - RMIT) and the Australian Seismological Centre (ASC - AGSO). The SRC and ASC have been developing the Australian seismograph network using digital seismographs for the past fifteen years and now have a significant collection of small earthquake ground motions (Mag<4).

This data combined with similar overseas data and supplemented with new data recorded from ambient vibrations, artificially induced vibrations and vibrations from blasts and earthquake aftershocks will be processed and extrapolated to develop appropriate Australian ground motion spectra.

- ii. The small data base of recorded ground motions for larger intra plate events (Mag>5) in Australia and overseas will be compared with similar sized interplate earthquake ground motions that have been recorded in the near field.
- iii. The development of synthetic ground motions using programs such as SIMQKE (Ref. 6) and other methods which use the actual fourier phase components of recorded ground motions combined with specified fourier amplitude components of ground spectra (Ref. 7).

b. Soil effects

Another aspect of the research will focus on the effects different soil profiles have on filtering earthquake ground motions. In general soft soils tend to amplify low frequency components and attenuate high frequency components. Analytical studies will be undertaken considering various soil profiles using typical Australian bedrock earthquake ground motions to develop suitable response spectra for different soil profiles for Australian conditions. Specialist software packages such as 'SHAKE' (ref. 8) will be used in the analytical study.

Inelastic Response

The 'structural response factor' or 'R' factor is used to modify results obtained from a linear elastic analysis to approximately account for both structural overstrength and the energy absorption capacity of the structural system (commonly measured using the ductility factor). The 'R' factor is independent of structural period and is based on the 'equal displacement' observation whereby the maximum displacement of a single degree of freedom (SDOF) system responding in the inelastic range is assumed equal to a similar system responding purely elastically (Figure 2).

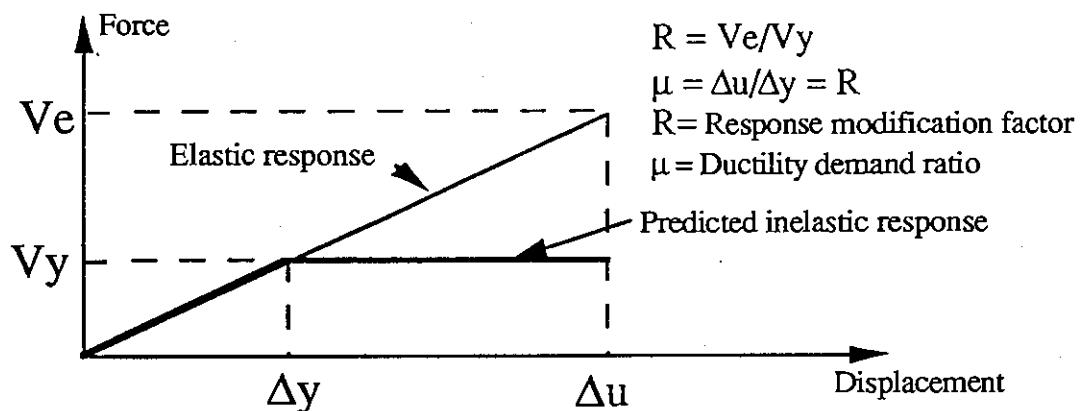


Figure 2 Equal Displacement Response

Miranda (Ref. 9) carried out some 31,000 inelastic analyses using 124 interplate ground motions and concluded that the 'equal displacement' method was reasonable for structures with periods greater than about 0.7 seconds.

Preliminary studies carried out using 19 intraplate earthquakes with an 'R' factor of 4 suggested the 'equal displacement' method was reasonable for structural periods greater than about 0.3 seconds although the results showed large scatter (Figure 3). Of particular interest is the exceptionally high ductility demand associated with the short duration M_L 4.9 aftershock recorded at Tennant Creek (Ref. 11). The high ductility demand was attributed to the sequence of the pulse arrivals.

It should be noted that the aftershock at Tennant Creek was not strong enough to yield buildings above 6 storeys in view of the low elastic response spectral accelerations over that range. (Figure 4). However, this high ductility demand could be of practical significance if a larger earthquake event had a similar but amplified waveform.

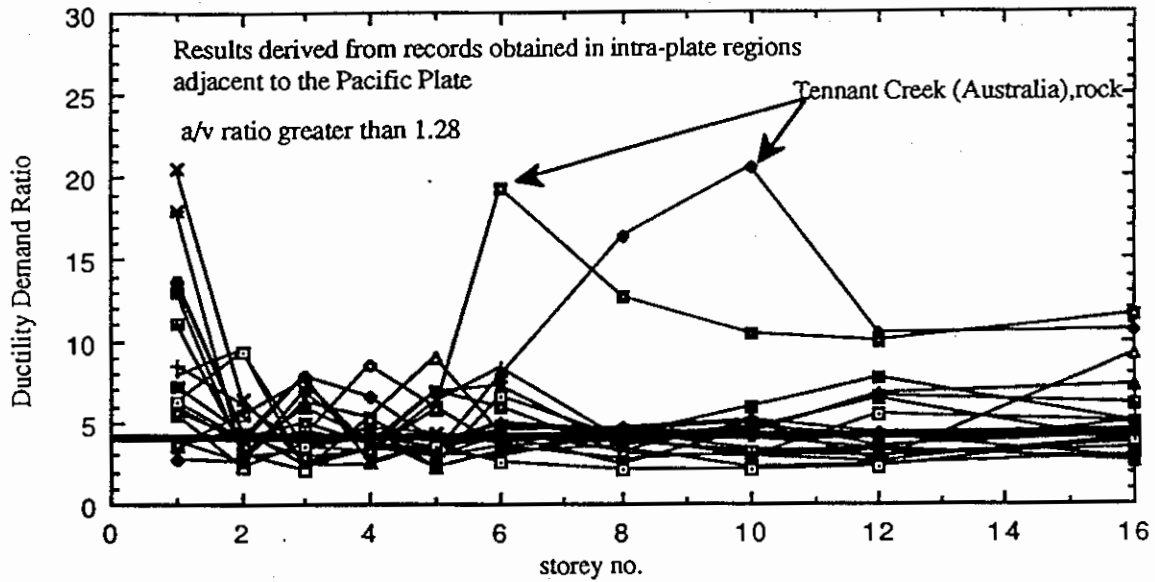


Figure 3 Displacement Ductility Demand (After Ref. 10)

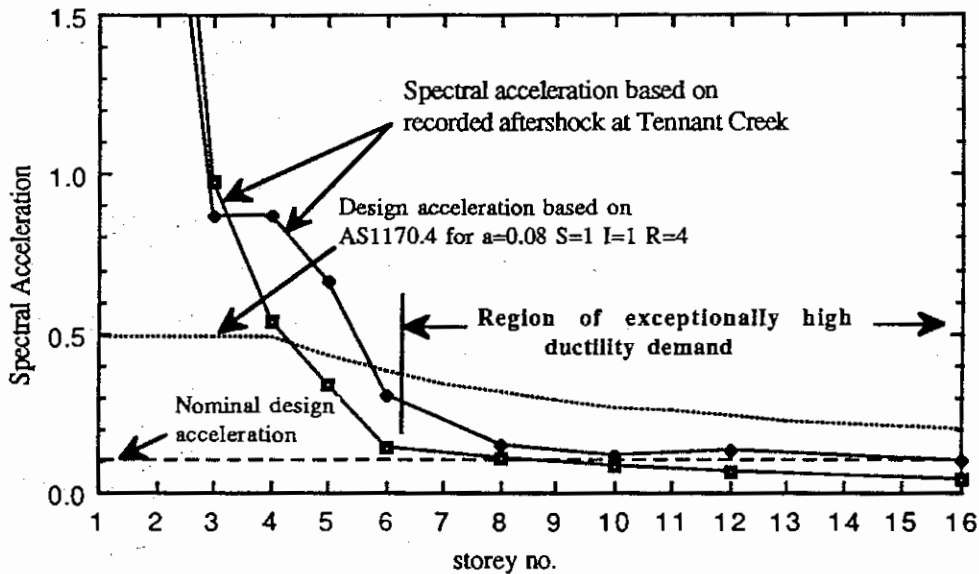


Figure 4 Tennant Creek and Design Response Spectrum

The investigation into the response of SDOF to both intraplate and interplate earthquakes is continuing and will be extended to include:

- i. multidegree of freedom systems
- ii. overstrength factors associated with typical framing systems.
- iii. appropriate detailing to reduce earthquake vulnerability

Conclusions

This paper has described an ARC funded research project between seismologists and engineers which aims to provide appropriate earthquake loading and detailing provisions for Australian conditions.

In particular, the research has two primary objectives:

- i. Develop appropriate earthquake ground motions and response spectra for Australian conditions for both rock and a range of soil sites.
- ii. Investigate the overstrengths and energy absorption capabilities of commonly used Australian framing systems when subject to typical Australian earthquakes.

In addition, the research project will examine appropriate detailing measures to improve the earthquake resistance of structures in a cost effective manner.

Acknowledgements

The work reported in the paper forms part of a joint project between the authors and Gary Gibson and Vaughan Wesson of RMIT funded by the Australian Research Council (Large Grant No. AB9330945).

References

1. Standards Australia, Australian Standard AS1170.4 - Minimum design loads on structures, Part 4, Earthquake Loads, 1993.
2. Applied Technology Council "Tentative Provisions for the Development of Seismic Regulations for Buildings" ATC-3-06, Palo Alto, 1988.
3. International Conference of Building Officials, Uniform Building Code, 1992 Edition, Whittier, California, 1991.
4. Chandler, A. M., Hutchinson, G. L., and Wilson, J. L., "The use of interplate derived spectra in intraplate seismic regions", Earthquake Engineering, Tenth World Conference, Madrid, July 1992 pp 5823-5827.
5. Hutchinson, G. L., Gibson, G. M., and Wilson J. L., "Earthquake Engineering Ground Motions and Structural Ductility Factors for Australian Conditions", ARC Large Grant No. AB9330945, 1993.
6. Vanmarcke, E. M., Cornell, C. A., Gasparini, O. A., and Hou, S. N., "SIMQKE - A program of artificial ground motion generation", Massachusetts Institute of Technology, 1976.
7. Gibson, G. M., "Artificial Ground Motions", Proceedings of AEES Seminar, October, 1993 pp 83-86.
8. Schnabel, P. B., and Lysmer, J., "Shake 91 - A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites", Report No. EERC 72-12, Earthquake Engineering Research Centre, University of California, Berkeley, 1972; and modified 1991 by Idriss I. M. and Sun J.I.

9. Miranda, E. "Evaluation of Site-Dependent Inelastic Seismic Design Spectra", *Journal of Structural Engineering*, American Society of Civil Engineering, vol. 19 no. 5, 1993.
10. Lam, N. T. K., Wilson, J. L., Hutchinson, G. L., "Ductility Demand in Areas of Low Seismicity", EASEC-95 to be presented Wollongong, 25-27 July, 1995.
11. Jones, T. D., Gibson, G., McCue, K. F., Denham, D., Gregson, P. J., and Bowman, J. R., "Three Large Intraplate Earthquakes near Tennant Creek, Northern Territory on 22 January 1988", 1991, *BMR Journal*, 12, 4, 339-343.