Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

The use of interplate derived spectra in intraplate seismic regions

A.M.Chandler
University College London, UK

G.L.Hutchinson & J.L.Wilson
University of Melbourne, Australia

ABSTRACT: In this paper, a critical comparison is made of the loading provisions of the draft Australian seismic design standard AS1170.4 (1991) with the United States Uniform Building Code regulations (UBC 1988), and the draft Eurocode 8 (1988). The new Australian standard has in large part adopted the philosophy and detail behind the UBC regulations. The object of this paper is therefore to assess the applicability of extending the UBC approach (which was developed for high seismic risk, interplate regions) to areas which experience intraplate earthquakes. Particular attention is given to a comparison of the shape of normalised design response spectra derived from well known interplate earthquakes with limited intraplate records available from Australia and other such regions.

1. Introduction

Earthquakes occurring in Australia are the result of intraplate movements whereas in other areas such as California, Japan and New Zealand ground shaking is caused by interplate earthquakes as a result of slip between adjacent tectonic plates.

Standards Australia is the Government agency responsible for building Codes and Standards in Australia and it is currently replacing the earthquake code AS2121-1979 (Ref. 1) with a new earthquake code AS1170.4 (Ref. 2). Whilst, AS2121 was legally adopted in only the states of Western Australia and South Australia, AS1170.4 will be mandatory across the country. This revision is part of a general upgrading of all Australian building standards and involves the development of separate limit state loading and material codes, reflecting modern practice. The 1989 Newcastle earthquake (Mag. 5.6, Ref. 3) which killed 13 people and caused extensive damage, occurred in a region previously zoned as seismically inactive. This event has clearly added impetus to the revision process.

The new code has generally adopted the guidelines set out by the Applied Technology Council of the USA (ATC-3-06 1988, Ref. 4), an organisation which has had significant input into the earthquake regulations specified in the USA Uniform Building Code (UBC 1988, Ref. 5). It should be noted that aspects of the draft New Zealand earthquake code (Ref. 6) have been incorporated in AS1170.4 as part of a process involving unifying all codes of practice in Australia and New Zealand by 1995.

In this paper a critical comparison is made of the loading provisions of AS1170.4 with those specified in the UBC 1988 and the draft Eurocode 8 (1988, Ref. 7). Furthermore the applicability of extrapolating the UBC approach (which was developed for high seismic risk, interplate regions) to areas which experience intraplate earthquakes is discussed. In particular the shape of normalised design response spectra derived from well known interplate earthquakes is compared with the limited intraplate records available from both Australia and the east coast of Canada.

2. Interplate versus Intraplate Earthquakes

2.1 Earthquake Ground Motions

Sudden relative movement of two adjacent tectonic plates is the fundamental mechanism for interplate earthquakes. Ground shaking from large magnitude earthquakes is characterized by large peak accelerations, long durations of shaking (in the order of 60 seconds), and intensities that can be felt over a wide region (across several hundred kilometres) depending on the travel path and local soil conditions. Higher frequencies present in ground motions attenuate more rapidly with distance than lower frequencies, and consequently the normalised response spectra associated with a far field earthquake event is characterized by more low frequency energy than a near field event. Consequently large, far field earthquakes may be more damaging than a smaller near field earthquake for structures with a large fundamental natural period.

UBC (1988, Ref. 5) specifies earthquake ground motions in terms of peak ground accelerations and normalized response spectra. These normalised spectra have been constructed from the mean average of an ensemble of near and far field earthquake ground motions (with a magnitude greater than 6) and consequently reflect both the low frequency energy associated with far field events and the high frequency components of near field earthquakes.

In contrast intraplate earthquakes are associated with relative slip across geological faults within a tectonic plate. 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. The seismic hazard at a site due to intraplate events is therefore principally associated with the near field ground motions of medium sized earthquakes. Ground motions associated with these events typically contain a large proportion of high frequency energy resulting from numerous short duration acceleration spikes. It should be noted that, acceleration impulses shorter than 0.1 seconds in duration generally do not have a significant influence on the behaviour of structural systems.

2.2 Interplate and Intraplate Response Spectra

The 1940 El Centro (Mag. 6.7) and 1971 San Fernando (Mag. 6.4) interplate earthquakes are plotted in Figure 1 in the form of normalised response spectra with 5% damping. The design spectrum for a rock site as proposed in AS1170.4 and used in UBC 1988 is also plotted and indicates a generally conservative fit for this data.

In contrast the normalised elastic spectra for the 1988 Saguenay intraplate earthquake on the Canadian east coast (Mag. 6.0) and the 1989 Tennant Creek intraplate earthquake in Central Australia (Mag. 5.0) are plotted in figures 2.1 and 2.2. The Tenant Creek record was the aftershock to a significant Magnitude 6.8 earthquake in the region.

Strong motion instruments at some 10 different locations recorded the Canadian event and enabled the attenuation characteristics to be evaluated (Ref. 8). Selected normalised response spectra which clearly demonstrates the effect of high frequency attenuation with distance are also plotted in figs 2.1 and 2.2. These intraplate spectra indicate that for the periods of structural significance, the code design spectra developed from interplate earthquakes appear to be very conservative.

The Tennant Creek record clearly demonstrates the care needed when deriving normalized response spectra using the peak accelerations occuring in an accelerogram. In this case the peak of 0.4g corresponds to a very short pulse (Fig. 3) with insufficient duration and energy to affect most structures. However using this peak value rather than a peak effective value (which would have structural significance (Ref. 9)) results in an unduly scaled down normalized spectra.

3. Overview of Codes

The rare occurrence of severe seismic loading at a site suggests that structures should be designed to allow yielding and damage but prevent collapse. This philosophy is explicitly assumed in Refs. 2, 5 and 7, each of which specifies similar procedures for calculating earthquake load. They also present special detailing requirements to encourage ductility and building survival during an extreme earthquake event.

The codes are minimum standards and are intended for the design of ordinary buildings and not special structures. Special structures include facilities that could prove hazardous in the event of failure, industrial facilities of high economic important and other non-building type structures.

The codes specify earthquake loads to be calculated using either a static analysis or a dynamic analysis depending on the type of structure, building configuration and seismic zone.

In the new Australian code (Ref. 2) the static equivalent base shear, V, is similar to the formulation presented in UBC 1988 (Ref 5) and Eurocode 8 (Ref. 7) and is given by:

$$V = \left(\frac{ICS}{R}\right)W$$

where I, C, S, R, and W represent the importance factor, the seismic design coefficient (including seismic zone), the soil factor, the structural response modification factor and weight of the structure respectively.

4. Comparison of Code Provisions

4.1 Return Period

AS1170.4 (Ref. 2) like the UBC 1988 (Ref. 5) and Eurocode 8 (Ref. 7) specify the seismicity of a site in terms of the peak ground acceleration expressed as a proportion of gravity.

The return period associated with the ultimate earthquake event specified in AS1170.4 is 500 years compared with UBC 1988 which assumes a range between 250 and 500 years (Ref. 10). The draft Eurocode 8 does not specify the return period associated with the ultimate event as this will be determined by the respective national code-drafting authorities.

4.2 Importance Factor

AS1170.4 specifies an importance factor of 1.25 for essential and hazardous facilities and 1.0 for all other structures. These values are the same as those specified in UBC 1988. By comparison, Eurocode 8 specifies a wider range from 0.8 for minor structures to a more conservative 1.4 for essential and hazardous facilities.

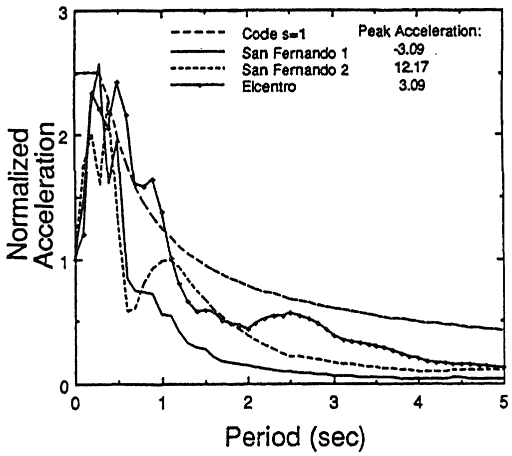

Figure 1 Interplate earthquake and design response spectra

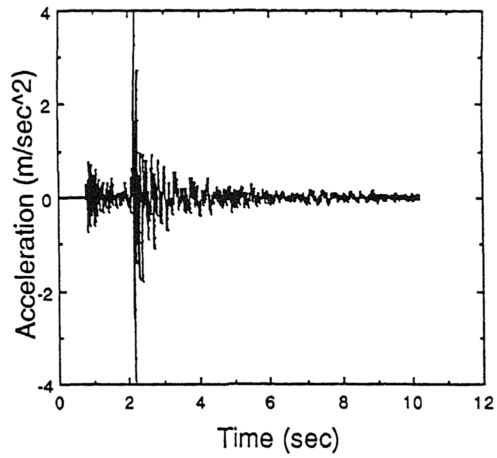

Fig. 3 Tennant Creek earthquake aftershock accelerogram

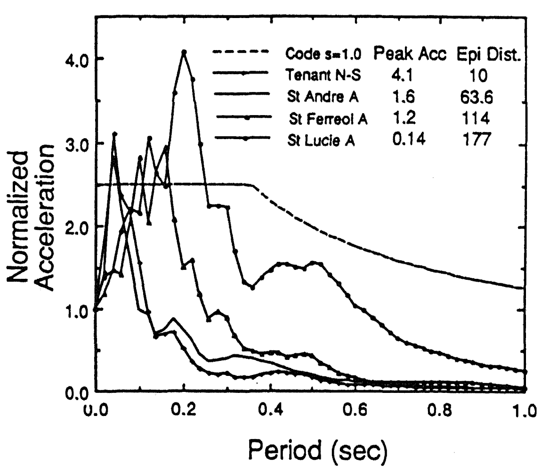

Fig. 2.1 Intraplate earthquake and design response spectra

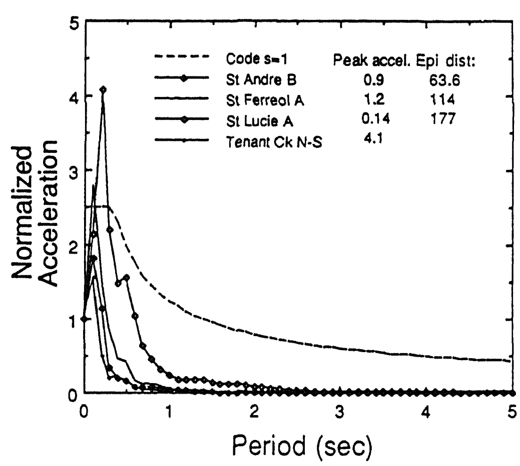

Fig. 2.2 Intraplate earthquake and design response spectra

4.3 Normalised Elastic Response Spectra

AS1170.4 specifies normalised response spectra which are consistent with those presented in the UBC 1988. Eurocode 8 presents very similar spectra but makes some refinements for structures with damping which differs from 5%, and further modifications for the response of structures sited on very soft soils.

4.4 Ductility and Detailing

All three codes effectively reduce the elastic force demand imposed on a structure by the ductility factor appropriate for the structural system in use. The ductility is commonly defined as the ratio of displacement at the top of a structure (that can be sustained under inelastic cyclic loading without significant strength degradation) to the corresponding displacement at first yield. Typical ductility values specified in AS1170.4 and UBC 1988 range from 3 to 8 depending on the energy absorbing capability of the structural system.

Eurocode 8 presents a more detailed and conservative measure of the energy absorbing capabilities of a structure. The ductility value associated with a structural system is dependent on the standard of detailing specified (represented by three ductility classes; low, medium and high) and the regularity of the building configuration. Eurocode 8 ductility factors are significantly lower than those specified in AS1170.4 and UBC 1988 for similar structural systems; particularly for structures with a low standard of detailing. Consequently structures designed to Eurocode 8 have higher seismic forces compared with the loads calculated from AS1170.4 and UBC 1988, and impose a lower inelastic demand on the structure at the ultimate earthquake event, assuming the same return periods for each code.

UBC 1988 and AS1170.4 together with the respective Australian Standards materials codes (Refs. 11 and 12) and UBC 1988 specify special detailing requirements for members and connections which contribute to the development of a ductile structure, but do not guarantee the formation of a rational yielding mechanism. In contrast, Eurocode 8 presents both local ductility provisions and global capacity design criteria to ensure that the seismic energy can be dissipated without structural collapse. Moreover Eurocode 8 presents a very comprehensive set of aseismic design rules for detailing reinforced concrete, steel, composite construction, timber, masonry and mixed structures.

Importantly, the other significant factors that contribute to the ductile behaviour of a structure including; regular form, the use of ductile materials and good quality construction, are all covered in the respective earthquake codes. It is critical that these earthquake resistant design principles are understood and included at the conceptual design stage.

4.5 Distribution of Static Shear Force with Height

The distribution of static shear force with height specified in AS1170.4, lies between a straight line for rigid buildings and a parabola for very flexible structures. This is a reasonable representation and reflects the influence of the higher modes for flexible structures. UBC 1988 accounts for the whipping effect of the higher modes by applying a force at the top of the structure. Eurocode 8 assumes the shear distribution is a straight line with height for all structures and consequently does not account for the higher mode effects.

5.0 Conclusion

It is concluded that:

1. Comparison of the new Australian earthquake standard AS1170.4. (Ref. 2) with other seismic loading provisions (Ref. 5, 7) has revealed no fundamental deficiencies in its overall formulation.

2. The extrapolation of interplate derived design spectra to intraplate regions appears conservative, particularly for structures with periods greater than 0.3 seconds. This corresponds to buildings on average greater than 3 storeys in height. This observation will be further tested once a significant number of appropriate intra-plate records have been obtained.

3. Great care must be taken in adopting design spectra based on Australian data because of the scarcity of reliable strong motion earthquake records.

6. Acknowledgements

The authors wish to acknowledge Rick Micich for processing the accelerograms records and Phillip Institute of Technology, Australia and McMaster University, Canada for the supply of the Australian and Canadian earthquake records respectively.

7. References

1. Standards Association of Australia. AS2121-1979; "SAA Earthquake Code" SAA, 1979.

2. Standards Association of Australia. Draft AS1170.4; "Minimum Design Loads on Structures, Part 4: Earthquake Loads", SAA, 1992.

3. Chandler, A.M., A.W. Coburn and J.W. Pappin "The 1989 Newcastle Australian Earthquake" field report by EEFIT, March 1991.

4. Applied Technology Council "Tentative Provisions for the Development of Seismic Regulations for Buildings" ATC-3-06 Palo Alto, 1988.

5. Uniform Building Code. UBC 1988. International Conference of Building Officials, California, 1988.

6. New Zealand Standard, Draft 2/DZ 4203/6, Part 4, Earthquake Provisions.

7. Commission of the European Communities and Industrial Process. Draft Eurocode No. 8. "Structures in Seismic Regions - Design" May 1988.

8. EQE Engineering "The Saguenay, Quebec Earthquake of November 25, 1988, A Preliminary Summary" San Francisco, 1988.

9. Hutchinson, G.L. and Wilson, J.L., "Aseismic Design of Structures in Australia", Civil Eng. Trans. I.E. Aust., Vol. CE29, No. 1 1987, pp 1 - 11.

10. Donovan, N.C, Bolt, B.A. and Whitman, R.V. "Development of Expectancy Maps and Risk Analysis", Journal of the Structural Division, ASCE, Vol. 104, No. ST8, 1978, pp 1179 - 1192.

11. Standards Association of Australia. AS3600 - 1988. "Concrete Structures", SAA, 1988.

12. Standards Association of Australia. AS4100 - 1990. "Steel Structures", SAA, 1990.