DEVELOPING A COMMON AUSTRALASIAN EARTHQUAKE LOADING STANDARD

G. Hutchinson[1], J. Wilson [1,5], L. Pham[2], I. Billings[3,5], R. Jury[3,5], A. King[4,5]

First published by the Institution of Engineers, Australia in the 1994 Australian Structural Engineering Conference Proceedings, August 1994

ABSTRACT

The development of a common Earthquake Loading Standard for Australia and New Zealand which has the potential for most countries in SE Asia is discussed in this paper. An historical perspective of earthquake loading standards in the two countries is introduced for background. In addition, two internationally recognised standards, Uniform Building Code (UBC) and Eurocode 8, covering earthquake loadings for areas of both low and high seismicity are presented. A seismic zoning scheme similar to the UBC approach is tentatively suggested for describing the seismic hazard of Australia and New Zealand. It is suggested that the requirements for design and detailing could vary from nominal tying together to capacity design procedures for the lowest and highest seismic zones respectively.

1. INTRODUCTION

In 1991 the National Committee on Structural Engineering of the Institution of Engineers Australia, and the Structural Engineering Society (New Zealand) set up a Working Group to investigate issues relating to the harmonisation of Structural Standards.

At an early stage, the Working Group identified that a key issue to be addressed was the seismic design philosophy to be used in the Earthquake Loading Standard. The design philosophies in the two countries varies principally because of differing levels of seismic hazard. Since, at this time, there was no suitable data available on the relative seismic hazard in the two countries a subcommittee with members from the Australian and New Zealand Earthquake Engineering Societies was set up to study and report on this issue. The results are set out in the companion paper by Dowrick, Gibson & McCue [1995].

One of the first questions most Australians and New Zealanders ask themselves is, why do we need a common earthquake loadings standard? The answer seems to be that with the declared intentions of both governments for a single common market for the two countries the availability of the key structural material standards in a form readily understood and usable in either country will become essential. Precedents can be seen in the USA and Europe and this is discussed later in the paper.

It should also be noted that the Australian government is actively promoting the use of joint Australian/New Zealand Standards in South East Asia and this should be of significant benefit to both countries. If suitable Australian/New Zealand Standards are not available it is possible the region will become dominated by the Eurocodes.

2. DESIGN PHILOSOPHY

2.1 General

In areas of the world recognised as being prone to major earthquakes, the engineer is faced with the dilemma of being required to design for an event, which has only a small chance of occurring during the life of a facility. If the designer adopts conservative performance criteria for the facility, the client (often society) is faced with costs which may be out of the proportion to the risks involved. On the other hand, to ignore the possibility of a major earthquake could be construed as negligent in some circumstances.

To overcome this problem a dual design philosophy has been developed, by which procedure:

- Moderate earthquake motions, such as may reasonably be expected at the site are used as a basis for the seismic design. The facility should be proportioned to resist such earthquake motions essentially in the elastic range without experiencing significant damage. This serviceability limit state would be set at an appropriate level to provide an acceptable risk for safety, non structural damage, onset of significant structural damage, and the continued performance of facilities and services, particularly those with important post-earthquake functions.

- Severe earthquake motions with an acceptability low probability of occurrence are used to test safety. In this ultimate limit state, significant structural and non-structural damage may occur but the risks of the collapse and loss of life should be at an acceptably low level.

1 *Department of Civil & Environmental Engineering, The University of Melbourne*
2 *CSIRO Division of Building Construction and Engineering, Melbourne*
3 *Beca, Carter, Hollings and Ferner Ltd, New Zealand*
4 *Building Technology Limited, BRANZ, New Zealand*
5 *(Member)*

2.2 Australian Perspective

In Australia, given the level of seismicity expected, a structure designed solely for the ultimate limit state (avoiding collapse) is likely to also satisfy the requirements of the serviceability limit state and therefore only the ultimate limit state need be considered in design. This is because the loads induced under the serviceability limit state criteria will rarely exceed the elastic limits of the structure.

In general, Australian engineers do not have a background in earthquake resistant design and consequently it is necessary to emphasise the importance of detailing. This is especially significant in areas of low seismicity where appropriate detailing, particularly involving tying the building together, can often alleviate most of the problems associated with earthquake activity. Further, such detailing is usually of negligible extra cost.

2.3 New Zealand Perspective

In New Zealand structures have, until recently, been designed solely to meet the requirements of an ultimate limit state. However, for the reasons noted in 2.1 above, the current New Zealand seismic loading standard [SANZ, 1992] requires the designer to also consider a serviceability limit state.

Seismic requirements usually dominate structural design in New Zealand and New Zealand engineers have a good understanding of earthquake engineering principles. They are particularly adept at considering how structures will perform in the post-elastic range and in designing them to perform reliably by following "capacity" design principles. (Refer 3.2 for further details)

3. DEVELOPMENT OF EARTHQUAKE STANDARDS

3.1 Australian Earthquake Standards

The problem of how to design structures to cope with the seismicity of Australia was first addressed with the issue in 1979 of Australian Standard AS 2121 "SAA Earthquake Code" [Standards Australia, 1979]. This Standard was based on United States practice adapted for Australian conditions and consisted of a combination of loading requirements and material specific design guidelines.

The adoption of various building standards is effectively a State responsibility and, in this case, only Western Australia and South Australia adopted AS 2121 in their building regulations. In the remainder of the country it was not mandatory to use this Standard.

As part of a regular updating of Standards in general, Standards Australian empanelled a committee in mid-1989 (prior to the 1989 Newcastle earthquake) to revise AS 2121. The new Standard AS 1170.4 "Minimum Design Loads on Structures, Part 4: Earthquake Loads" [Standards Australia, 1993] was issued in 1993 and, due to a change in legislation, will be mandatory across the country when it is adopted in the Building Code of Australia late this year. Since publication there has been much interest in this Standard and already over nine hundred engineers have attended seminars on AS 1170.4 organised by Standards Australia.

AS 1170.4 is essentially a loading standard and is based on the US document "Tentative Provisions for the Development of Seismic Regulations for Buildings" ATC-3-06 [ATC, 1988] and NERHP documents [FEMA, 1991] modified and amended to suit Australian conditions. The seismic hazard across the continent is represented by a series of contours of peak ground acceleration (see Figure 1). Whilst the Standard is essentially a loading specification, it does incorporate some general, non-material specific detailing requirements. All material specific detailing requirements are incorporated in the relevant material Standards (e.g. AS 3600, Concrete Structures [Standards Australia, 1988], AS 4100, Steel Structures [Standards Australia, 1990]. It should be noted that earthquake provisions in the various Standards are separate from "normal" design requirements.

3.2 New Zealand Earthquake Standards

The Richter Magnitude 7.8 Napier earthquake of February 2nd 1931 was the catalyst for the development of the first New Zealand Earthquake loading standard. The Napier earthquake, the most damaging earthquake this century, resulted in the loss of 256 lives and damage of around NZ $500 million at current prices.

Initially the emphasis of earthquake loading standards in New Zealand was on the provision of minimum lateral strength levels. During the 1960s it became recognised that the toughness (i.e. ability to perform in the post elastic range) and the adequate tying together of components, were at least as important as the strength of a building. These concepts were touched on by the 1964 Seismic Loading Standard NZS 1900 Chapter 8, however, it was not until 1976 with the issue of NZS 4203 that they were applied in a formal and consistent manner.

NZS 4203:1976 required designers to ensure buildings possessed adequate ductility and toughness. It required the designer to consider the failure mechanism under lateral loads and to ensure undesirable mechanisms, such as column sway (i.e. soft storeys) in tall buildings, did not occur. The Standard required the designer to identify the yield zones (e.g. the beam hinges in a tall framed building) and to design the remainder of the structure to have more capacity so that the chosen mechanism was maintained. This process was called 'capacity design'.

During the 1980s, it was recognised that there was a trade-off between strength and ductility, that is, structures could be designed for high lateral forces and little ductility, or somewhere between lower lateral forces and higher ductility. These concepts were embodied in the latest loading standard NZS 4203:1992 [SANZ, 1992]. This standard also introduced requirements for serviceability level seismic events, recognising that society is demanding limitation of property damage, as well as the protection of life, the main thrust of earlier earthquake loading standards.

4. PRINCIPLES AND ISSUES

4.1 Principles

The various items listed below have been discussed by representatives of both countries and agreed as the basis for the development of common standards.

- Common format enabling adoption by regulatory authorities.

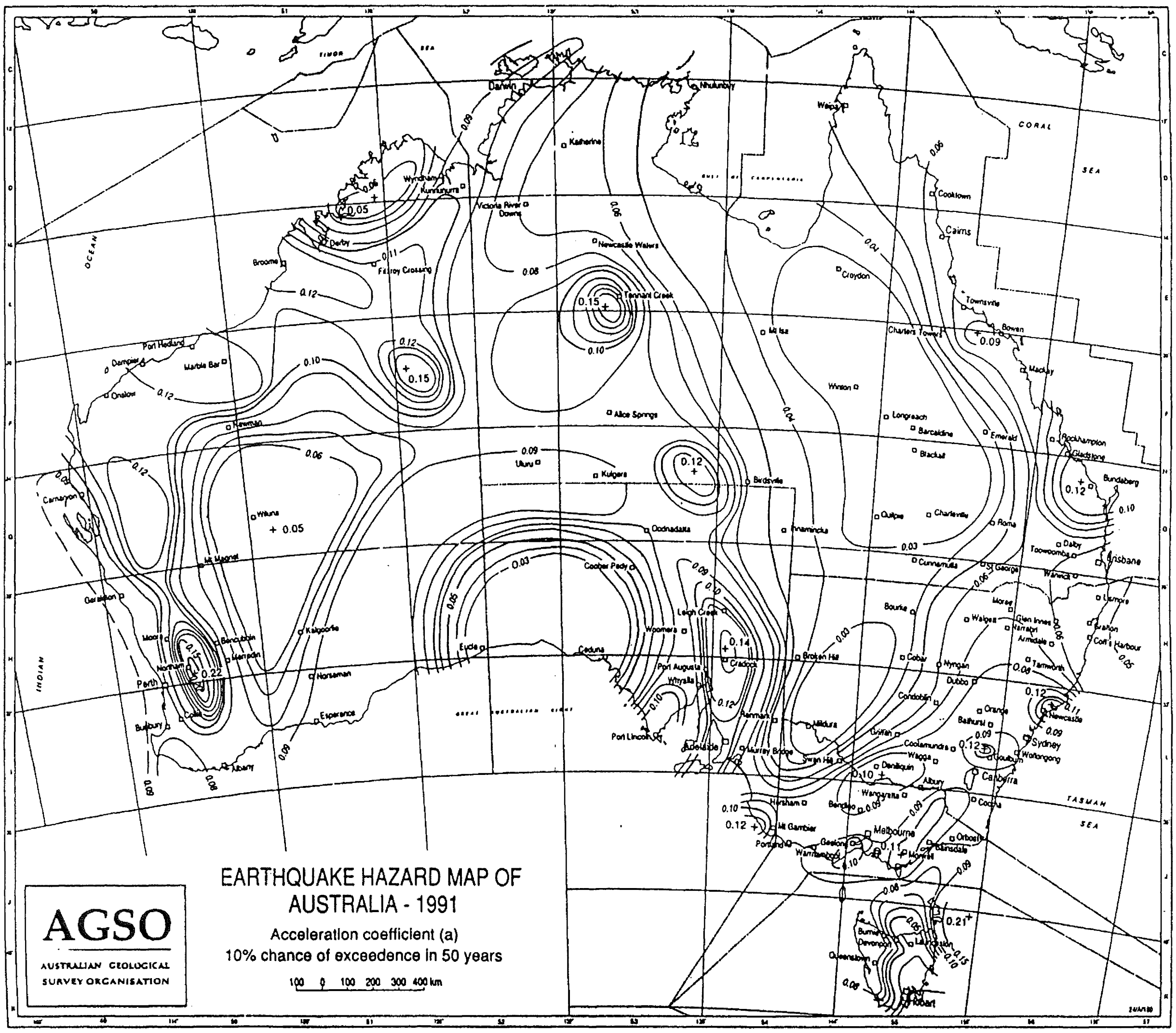

FIGURE 1 Seismic hazard map for Australia (after Standards Australia [1993])

- Common definitions including probabilistic definitions of technical matters e.g. return periods.
- Overall common philosophy.
- Structuring of the Standard to accommodate the design requirements for low and high seismic areas.
- Development of the Standard in the context of global "harmonisation".
- Ability of the Standard to be adapted with minimal change to areas outside Australasia.

4.2 Issues of Resolution

It has not yet been possible to address a number of issues. These include:

- A final format. In particular, whether the materials specific Standard should incorporate separate earthquake design sections, as is Australian practice, or be included with each structural action as is New Zealand practice.
- Establishment of appropriate hazard zones for the ultimate limit state. A comparison of the relative seismic hazard of Australia and New Zealand is reported by Dowrick, Gibson and McCue [1995]. The study indicates that the seismic hazard varies from low in Australia to relatively high in New Zealand and that there is an overlap between the higher hazard Australian regions and lower hazard New Zealand regions.
- Needs for differing intra and inter-plate design response spectra. Typically moderate magnitude intra-plate earthquake events, such as in Australia, are characterised by high frequency and short duration ground motions. By comparison, inter-plate earthquakes such as occur in parts of New Zealand, tend to be larger in magnitude and have a longer duration and wider frequency content. It appears that these differences lead to typical response spectra with differing characteristics [Chandler et al, 1992; Hutcinson et al, 1994]. Consequently, it may be necessary to provide different response spectra appropriate for each region.
- Design procedures. Current earthquake design procedures in Australia depend on the severity of the risk involved.

This varies from observing basic detailing rules to requiring a full-scale dynamic analysis. In New Zealand, design procedures are based on the concept of controlled performance under earthquake induced loading irrespective of the risk. Because of the large differences in seismicity that exist across Australasia it may be necessary to adopt both procedures in a combined Standard. The appropriate procedure will depend on the level of seismicity. In the small areas of both countries where the levels of seismicity are similar the approach to be adopted has yet to be resolved.

5. COMPARATIVE INTERNATIONAL STANDARDS

It is important to compare the Australian and New Zealand situation with other areas where the issues to be addressed have already been considered.

Two major internationally recognised standards covering earthquake loadings for both high and low seismicity areas are commented on below.

Seismic Zoning

The Uniform Building Code (UBC 1991 [ICBO, 1991]) is a comprehensive structural design code covering the USA. Seismic zones are determined primarily from seismic hazard maps of peak ground acceleration with a return period of 475 years (i.e. 10 percent probability of exceedance in 50 years). The seismic hazard maps developed for comparison of Australia and New Zealand by Dowrick, Gibson & McCue [1995] were also based on a return period of 475 years for peak ground acceleration. Using these maps the two countries can be assigned tentative UBC Seismic Zones and these are indicated in Figure 2. The US Zones contained in the UBC are included for reference in Figure 3. It is immediately obvious that there is a seismicity overlap between Australia and New Zealand, and that the total seismicity range of the two countries is similar to that covered by UBC 1991 [ICBO, 1991].

Eurocode 8 - Structures in Seismic Regions - Design [CEC, 1988] is still in draft form. Seismic zoning is recommended to be determined using seismic hazard maps based on annual probabilities of exceedance of seismicity parameters. In Eurocode 8, the seismicity parameters are related to peak ground acceleration.

Design Philosophy

UBC 1991 design requirements vary from no seismic detailing requirements in zones 0 and 1 to full ductile seismic design and detailing for zones 3 and 4. This is similar in philosophy to that set out in the current Australian seismic loading standard.

Eurocode 8 requirements are still under development, however it is of interest to note that the requirements for the higher seismicity zones are very similar in philosophy to that set out in the current New Zealand seismic loading standard. The standard recognises different structure and material performance categories together with their associated ductility and detailing requirements. For high ductility structures capacity design is required.

6. PROPOSALS

Preliminary proposals for several key aspects of a joint Australian/New Zealand Seismic loadings standard are briefly set out below.

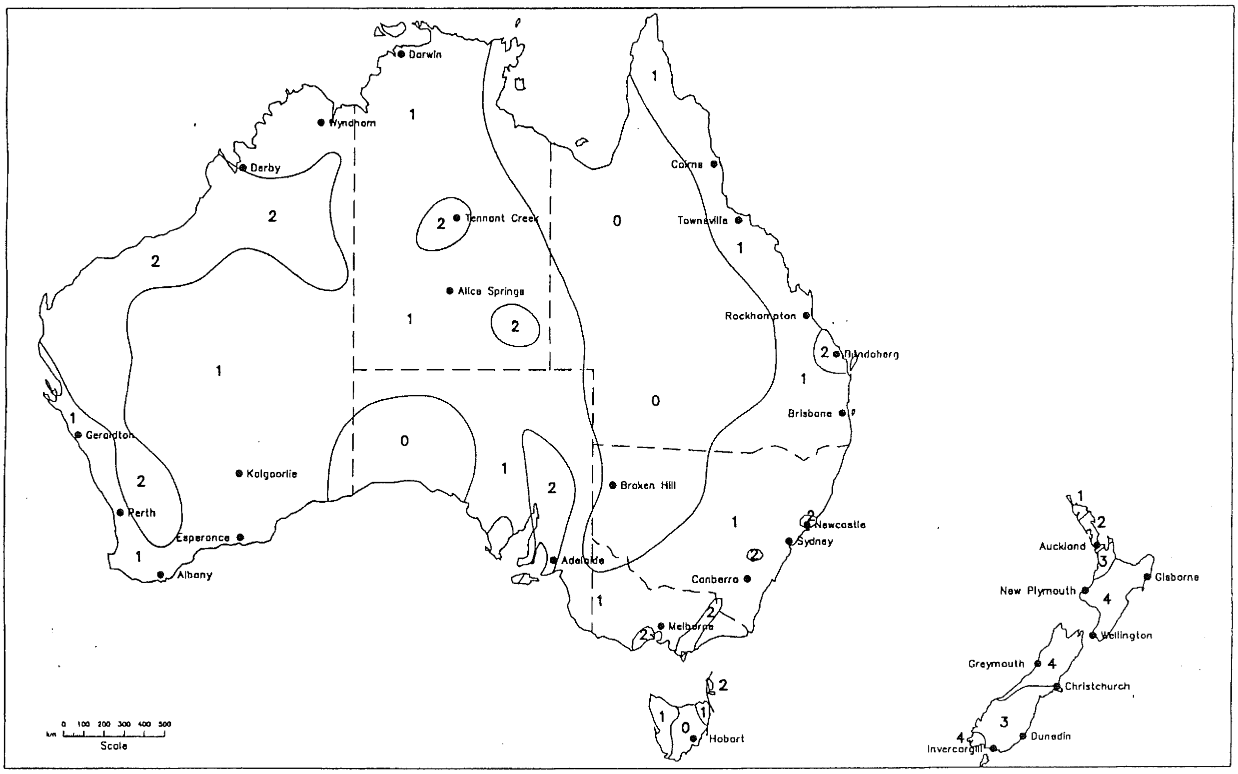

FIGURE 2 Tentative UBC seismic zones for Australia and New Zealand

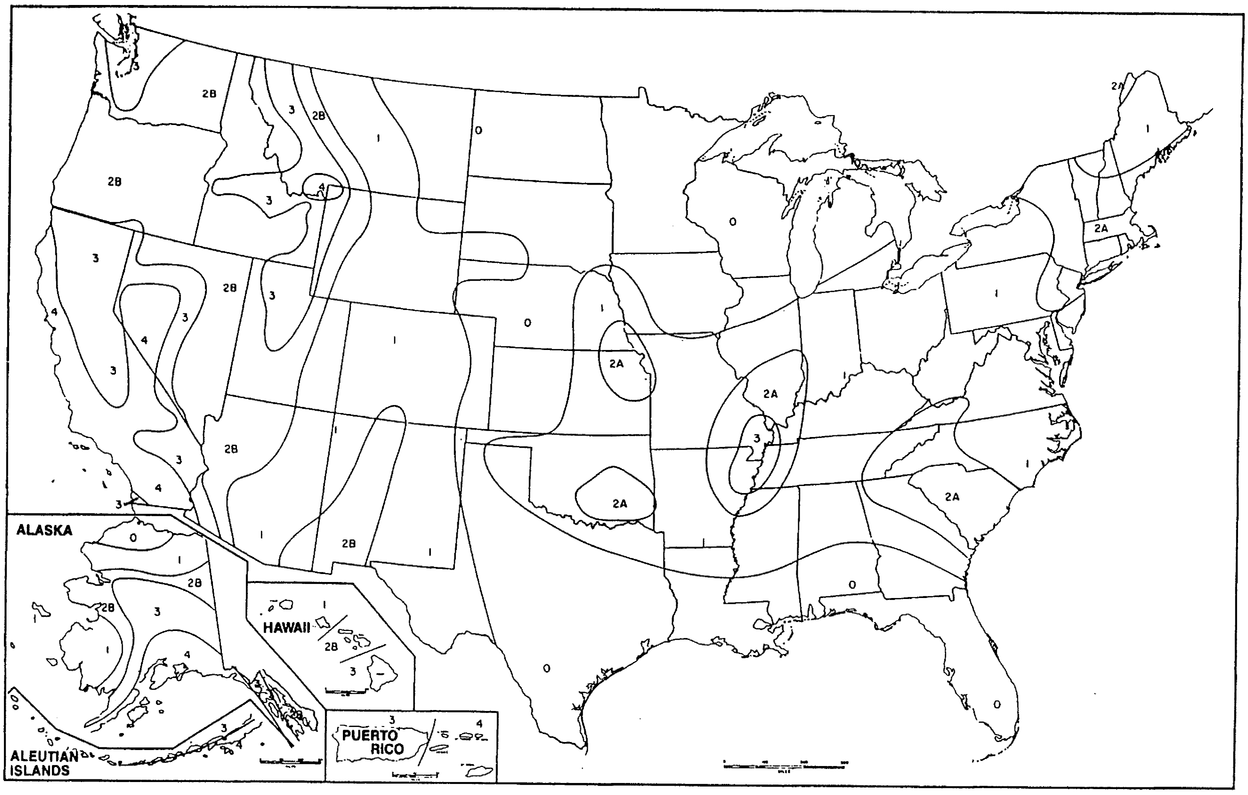

FIGURE 3 UBC Seismic zones for the USA (after ICBO [1991])

Purpose

The objectives of the standard would be:

- To reduce to an acceptable level the risk of death and injury caused to people by earthquake effects on building structures.
- To limit to an acceptable level the total cost of earthquake damage to building structures in areas of high seismicity.

Design Philosophy

The objectives set out above can be satisfied by the setting of appropriate levels for the ultimate limit state and the serviceability limit state. Definition of both levels on a statistical risk basis consistent with other loadings (e.g. wind) is desirable. For a structure of normal occupancy and importance to society a serviceability limit state corresponding to seismic events with a return period of 20 years (5% chance of exceedance in 1-year), seems reasonable. The ultimate limit state, implicit in the current Australian [Standards Australia, 1993], New Zealand [SANZ, 1992] and UBC-91 [ICBO, 1991] seismic loading standards corresponds to seismic events with a return period of about 475 years (10% chance of exceedance in 50 years). The setting of this level in future joint loading and material standards will require care as it is widely recognised that the return period for the event that will cause collapse of the structure is (and needs to be) much larger than the nominal design ultimate limit states of 475 year return period.

Seismic Zoning

A seismic zoning scheme based primarily on seismic hazard mapping is the suggested approach, however the actual parameters to be used may require further debate. In general terms a zoning scheme along the lines of the UBC-91 standard is suggested as a starting point as it indicates how a possible rational linkage between the two countries could be achieved.

A preliminary map showing how such a scheme would fit Australia and New Zealand is indicated in Figure 2. However, the contour approach currently used in the Standards for both Australia and New Zealand has particular advantages over the zone approach of Figure 2, particularly in the area of rapidly changing seismic hazard in New Zealand.

Design Requirements

Design and detailing requirements would vary from nominal tying together for the lowest zone (in line with the current Australian standard) up to the detailed analysis, design, and seismic detailing for the highest zone (in line with the current New Zealand Standard). As implied by the current Australian Standard [Standards Australia, 1993] and UBC-91 [ICBO, 1991] but stated explicitly by the current New Zealand Standard [SANZ, 1992] and Eurocode-8 [CEC, 1988], the joint standard should specify requirements for a range of structural systems/material performance categories. These would vary from elastic brittle structures (e.g. unreinforced masonry) to highly ductile structures (e.g. capacity designed concrete or steel). Limitations should be applied to the structures of lower ductility in the higher seismic zones. For example in the highest seismic zone elastic brittle structures of proven poor seismic performance should be prohibited and storey/height limitations be applied to limited ductile structures.

7. CONCLUSIONS

It seems both feasible and sensible to develop a common Earthquake Loading Standard, incorporating areas of both high and low seismicity for Australia and New Zealand. Such a Standard would have the potential to be applicable for most countries in South East Asia and beyond.

Any Standard that is developed should be consistent with international developments in the area of Standards.

A possible common approach should be possible and has been briefly discussed in this paper.

8. REFERENCES

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

CEC, 1988, Draft Eurocode 8: *Structures in Seismic Regions - Design, Part 1 General and Building Report*, EUR 12266 EN, Commission of the European Communities, Luxembourg.

Chandler A.M., Hutchinson G.L., Wilson J.L., 1992, *The use of Interplate Derived Spectra in Intraplate Seismic Regions*, 10th World Conference on Earthquake Engineering, Madrid, pp5823 - 5827.

Dowrick D., Gibson G., McCue K., 1995, Seismic Hazard in Australia and New Zealand, *Bulletin NZ National Society for Earthquake Engineering*, 28(4):279-287.

FEMA, 1991, NEHRP *Recommended Provisions for the Development of Seismic Regulations for New Buildings*, Federal Emergency Management Agency, Washington, DC.

Hutchinson G.L, Gibson, G.M., Wilson J.L., 1994, *Earthquake Engineering Ground Motions and Structural Ductility Factors for Australian Conditions*, ARC large grant no. AB 9330945.

ICBO (International Conference of Building Officials), 1991 *Uniform Building Code: 1991 Edition*, Whittier, California.

Standards Australia, 1979, *Australian Standard 2121-1979: SAA Earthquake Code*, Standards Association of Australia, Sydney.

Standards Australia, 1988, *AS 3600: Concrete Structures*, Standards Association of Australia.

Standards Australia, 1990, *AS 4100: Steel Structures*, Standards Association of Australia.

Standards Australia, 1993, *AS 1170.4: Minimum Design Loads on Structures Part 4: Earthquake Loads,* Standards Association of Australia.

SANZ, 1992, *NZS 4203: Code of Practice for General Structural Design and Design Loadings for Buildings*, Standards Association of New Zealand, Wellington.