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Earthquake Hazard Reduction in the Central and Eastern United States:
A Time for Examination and Action

LIMITATIONS OF THE CORNELL-McGUIRE EARTHQUAKE RISK METHOD - AN ENGINEERING VIEWPOINT FOR AUSTRALIA

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ABSTRACT

The need to consider earthquake loading as an important element in building design in Australia, especially when undertaking designs for emergency and critical facilities and high-occupancy type structures, is now accepted. For the purpose of integrating such earthquake load parameters into designs, recommendations in the form of regulations or as a Code are required. These technical and indeed legally binding regulations have received little attention in the past because of the perception that Australia has "low" seismicity and hence a "low" risk. Recent events have invoked a change of attitude. The current revision of the Australian Earthquake Load Code based on the Cornell-McGuire method for hazard mapping has many inherent shortcomings and uncertainties when translating the resulting "bulls-eye" maps into practical applications. An alternative methodology in preparing for such a Code, based on seismic zonation mapping using a multidisciplinary approach and taking account of all factors necessary to design for earthquake load, is considered a more realistic and reliable approach for continental tectonic situations.

INTRODUCTION

Recent events in Australia, including the earthquake hazard maps of Gaull et al (1990) and the 1989 ML 5.6 Newcastle earthquake (Rynn et al, 1992), have demonstrated the vulnerability of the building stock in virtually all Australian cities, particularly those in highly urbanised and coastal areas. Thus, there is a need to seriously consider earthquake mitigation for Australia, a continent previously considered as having a "low" seismic risk. This has led to concerted efforts in a much-needed and realistic revision of the Australian Earthquake Code AS2121-1979 (Standards Association of Australia, 1979; Woodside, 1990) and earthquake zonation mapping of Australia's urbanised areas (Rynn, This Volume).

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Although aseismic design of structures in Australia has been used for critical facilities in Australia since 1979 (Hutchinson and Wilson, 1987), it has not been a major criteria in normal structural design. Response spectra methods were employed, based on the codes and practices in the Western USA and New Zealand and the original Australian Earthquake Code AS2121-1979 (based on the deterministic method of McEwin et al, (1976). AS2121, still in use today, is **not** a loading code. A major reassessment is currently in progress to produce the draft edition of the Earthquake Load Code AS1170.4 (Standards Australia, 1991-1992). The basis of this is a modified version of the Gaull et al (1990) hazard maps of Australia which were produced using the Cornell-McGuire method (Cornell, 1968; McGuire, 1976: the current basis for seismic risk analyses; EERI, 1989).

Earthquake load codes are different from other engineering codes since seismic loads relate to interaction of the ground with the structures. The preparation of such a code based on Cornell-McGuire maps using historic earthquake data alone has inherent problems for large continental regions like Australia. Questions on the suitability of earthquake loads and design standards using acceleration coefficients derived from such maps for Australian conditions have been raised. Of specific note are the resulting "bulls-eyes", rather than streamline contour maps. With usually no observed surface fault rupture and the difficulty in delineating potential earthquake sources (Rynn, This Volume), what does each "bulls-eye" and its contours mean to the structural engineer or urban planner?

In today's society, it is mandatory that there **must** be a balance between the academic assessments of hazard and risk and the practical applications in land-use planning and building design and construction, particularly for urbanised areas (Kockelman, 1990). Methods relating to seismic zonation planning, which considers the social and economic environment of the community, produces a more realistic approach to the assessment of potential earthquake loadings for structures in continental or intraplate tectonic regimes. This paper discusses the current methodology commonly used and the effect of alternative methodology based on the seismic zonation approach in preparing a future Australian Earthquake Loading Code.

PROCEDURES FOR ASEISMIC DESIGN FOR ENGINEERED STRUCTURES AND URBAN PLANNING REQUIREMENTS

Codes are required to provide engineers with an acceptable level of design parameters for a specific region, such that a structure will not collapse when the maximum probable combination of loads is applied. Loads may be dead, live, snow, wind, earthquake, etc. or any combination of these. These loads relate to the weight of structure and continuity of strength throughout the structure and also apply to the bearing capacity and capability parameters of the foundation materials on which it bears. However, they do not provide for the site specific interaction between the near-surface geology and the structure. Thus, for any earthquake load code formulation, local geological and site specific soil conditions and energy absorbing characteristics of the deeper geological structure (attenuation) have to be included. To allow for sustainable development at **any** location, geographical (demography, topography, slope stability) and socio-economic (life-style, transportation, emergency management) constraints have to be considered for both engineering and urban planning uses.

Vulnerability to the seismic hazard (indeed to any natural hazard) therefore falls into the ambit of engineering and urban planning considerations and requirements. These requirements, through a Load Code, provide the constraints necessary to fulfil a community's desire for sustainable development. The priority is to ensure minimum potential risk for the causing of damage to property and personal injury, as indicated in the Foreword to the Draft Australian Standard AS1170.4.

CONSIDERATIONS OF THE CORNELL-MCGUIRE METHOD FOR AUSTRALIA

Normally, the initial step in deriving design codes for the aseismic design of structures is to assess probabilistic estimates of peak ground accelerations from earthquake hazard maps (EERI, 1989). The Cornell-McGuire approach is the most widely accepted by seismologists, engineers and planners. Despite this, many inherent limitations and uncertainties in the initial assumptions and input data exist which have a profound influence on the resulting hazard maps, particularly for continental regions of relatively "low" seismicity and short historic records like Australia (Rynn and Boyce, 1987). These shortcomings are rarely considered by the practitioners when using these maps. Serious concern has been raised in the use of the Gaull et al (1990) hazard maps with "ad-hoc" modifications to produce acceleration coefficients for the Draft Earthquake Code AS1170.4 (Boyce, 1990; Melchers, 1992).

Some **limitations** of the Cornell-McGuire method include:
(a) Delineation of an earthquake source area with little (known) seismicity and poor geological information - this area has a profound effect on ground motion estimates (smaller area gives larger risk and vice versa) and the sharp boundaries are unworkable for planning purposes. While the original definition is suitable in plate margin areas, with the "smoothing" approach of Bender and Perkins (1987) included, its applicability in Australia is questioned;
(b) Interaction of structural foundations with surface geology, typified by geological controls (Holocene sediments), amplification and liquefaction on damage in the 1989 Newcastle and other continental earthquakes (Brennan, This Volume) is not considered.

An example of the effect of seismologically reasonable variations in selected parameters and resulting uncertainties in peak ground accelerations (pga) derived from the method are given in Table 1 (Rynn, 1989). Resulting pga estimates vary by 300% or more, an unsuitable situation for implementing reliable values into design criteria.

Consideration of the earthquake return interval on which to base probability estimates is a vital issue to practitioners. Confusion may result if standardisation is not applied, particularly in continental situations where earthquake loading is the least applied in design criteria of all natural phenomena effects. Consider Figure 1 in Northeastern Australia for the 1 in 500 year event with ML(max) 6.8 (Rynn, 1988; Gaull et al, 1990) and the 1 in 1000 year event with ML(max) 7.5 (Brennan and Jepson, 1991), both using the same data set with slight variations in attenuation. The differences are most evident. Selection of the correct interval is critical when legal ramifications of engineering designs incorporating earthquake loading are to be considered.

TABLE 1. Uncertainties in seismic risk estimates for 1 in 500 year earthquake for Northeastern Australia
(Example for City of Bundaberg in Source Area Q1, Figure 1)

Parameter	Uncertainty	Effect on risk estimates Source zone Q1	 pga Bundaberg
SEISMOLOGY:			
Epicentral location	± 10-50 km		
Focal depth	± 5-10 km		
Richter magnitude ML	± 0-5		
Intensity MM	± 1		
Isoseismal radii	± 20%		
CORNELL-MCGUIRE METHOD FOR (1 IN 500 YEAR EARTHQUAKE)			
ML (max)	6.8-8.0	increase to 50%	0.12g
magnitude-frequency a	increase 20%	increase < 10%	0.08g
b	decrease 20%	increase to 50%	0.12g
attenuation relations			
σ	0.28-1.0	increase to 200%	0.20g
c_1, c_2, c_3 [with σ=0.64, ML(max)6.8]	Esteva and Villaverde (1974)	increase to 150%	0.20g
Current standards (pga) for Bundaberg			
AS2121-1979			0.05g
Gaull et al (1990): Cornell-McGuire method with ML(max) 6.8; a,b,c_1, c_2, c_3 from Rynn (1988); σ = 0.28			0.10g

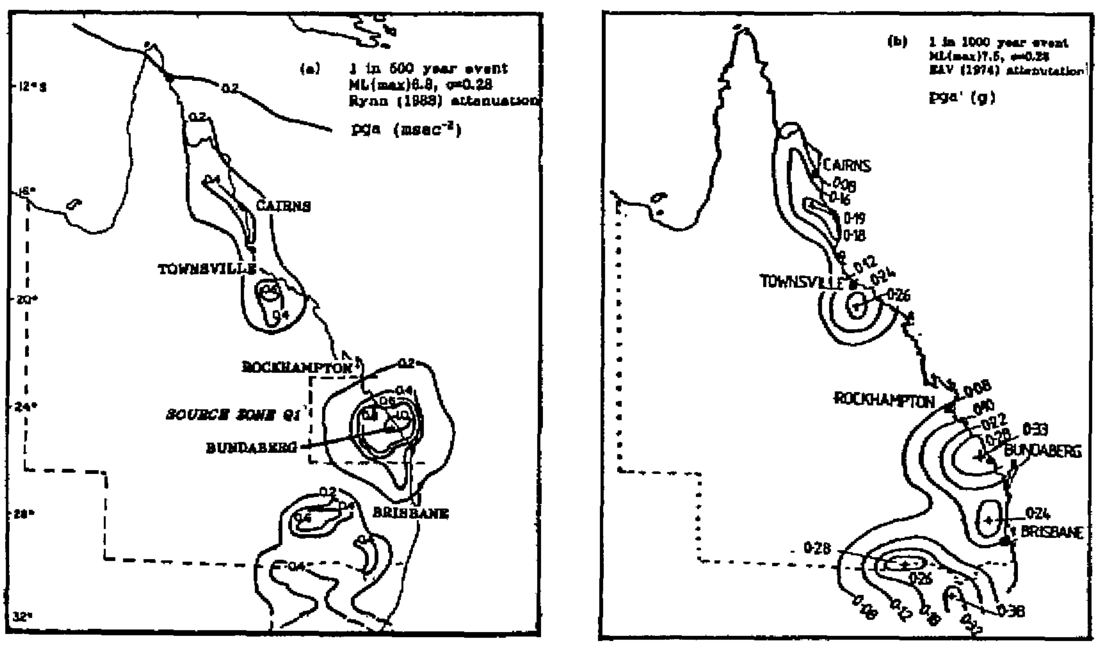

FIGURE 1. Comparison of different earthquake return intervals

The assessment of acceleration coefficients for Draft Code AS1170.4 is considered inadequate based on the above. A responsible case for questioning the method as currently applied is thus valid.

SEISMIC HAZARD MAPS: "BULLS-EYES" VERSES "STREAMLINED"

The limitations to the Cornell-McGuire method in relation to the definitions of earthquake source area and probabilistic analysis are reflected in the outcomes, namely "bulls-eye" patterns of peak ground motion contours. In terms of practical suitability for design criteria, particularly for Australia, are these, as stated in EERI (1989) *"the best means of handling random (earthquake) phenomena and uncertainties in characteristics of structures in a logical and consistent manner"*? Previous experiences with other codes suggest not. The need is for realistic contours to be both "streamlined" and at a scale of adequate size to be useful in urban area assessments.

Australia's earthquake data consists mostly of single events of varying magnitude scattered over the continent. The effect of such limited data on the Cornell-McGuire method for a large continent is the necessity to change continually the design parameters from one location to another - the legacy of "bulls-eye" contours. This is vividly illustrated for the peak ground acceleration maps in Figures 2 (Gaull et al, 1990) and 3 (Draft Code AS1170.4, 1992). Consider the "single" 1988 Tennant Creek (ML6.5) earthquake (X on Figure 2) - the former map prepared prior to the event, the latter as a modification of Figure 2 including it. The pga contours for this event alone extend their influence over 1,000,000 km^2 of northern Australia wherein no other significant earthquake is known and little urbanisation (possibly two major, but small centres) exists in the region. It could have been expected that rather than introducing significant complexity with more "bulls-eyes", a streamlined version, removing all "bulls-eyes" was warranted as basis for Draft Code AS1170.4. Boyce (1990) indicates that, for such a case as this, a sensitivity analysis by varying source zone boundaries and calculating their effect is necessary. This has the required smoothing effect for resultant pga's.

Comparisons of Australia and USA hazard maps further highlight the problem. Their hazard maps, Figures 2 and 4 respectively, show the effects of the amount of available earthquake data - less for Australia and so more "bulls-eyes". For the USA, streamlining of Figure 4 to obtain the ATC map Figure 5 is clearly evident. Selection of design parameters for earthquake load is thus quite reliable. Comparison of the Australian (Figure 3) and USA (Figure 5) pga maps for the respective codes - "bulls-eye" verses "streamlining" - is again unquestionable evidence for a reassessment of Figure 3 currently adopted in Draft Code AS1170.4.

Similar inadequacies were apparent in the early development of other Australian Codes of Practice related to potential effects of natural phenonema (Australian Rainfall and Runoff Code and Wind Loading Code) - small data bases and probabilistic analyses which also led to "bulls-eye"-type maps. Subsequent improvements in these aspects led to streamlining of the performance curves which only then become truly characteristic of the particular effect and so suitable for emergency design criteria.

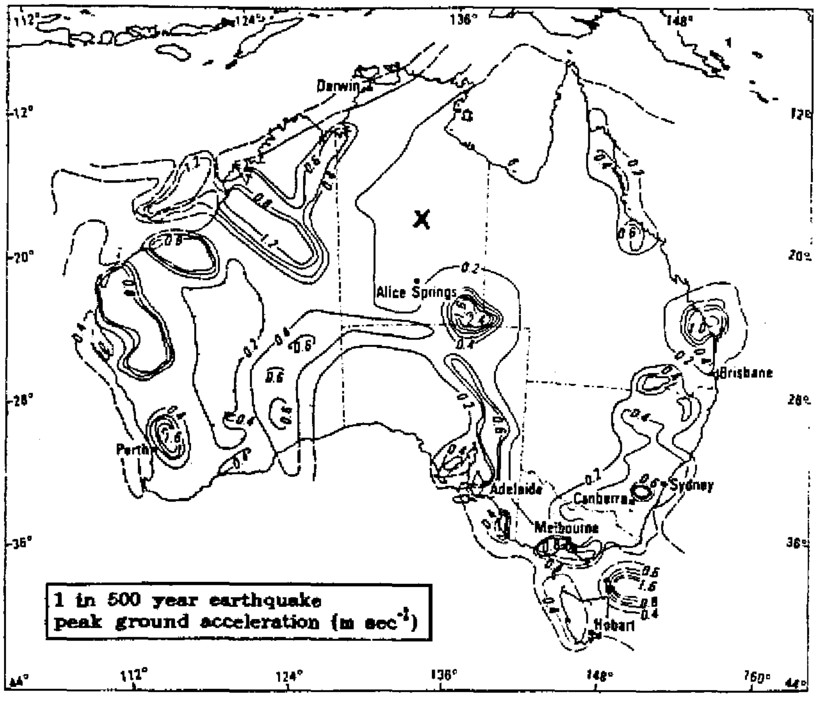

FIGURE 2. Australia : Earthquake Hazard Map (Gaull et al, 1990)

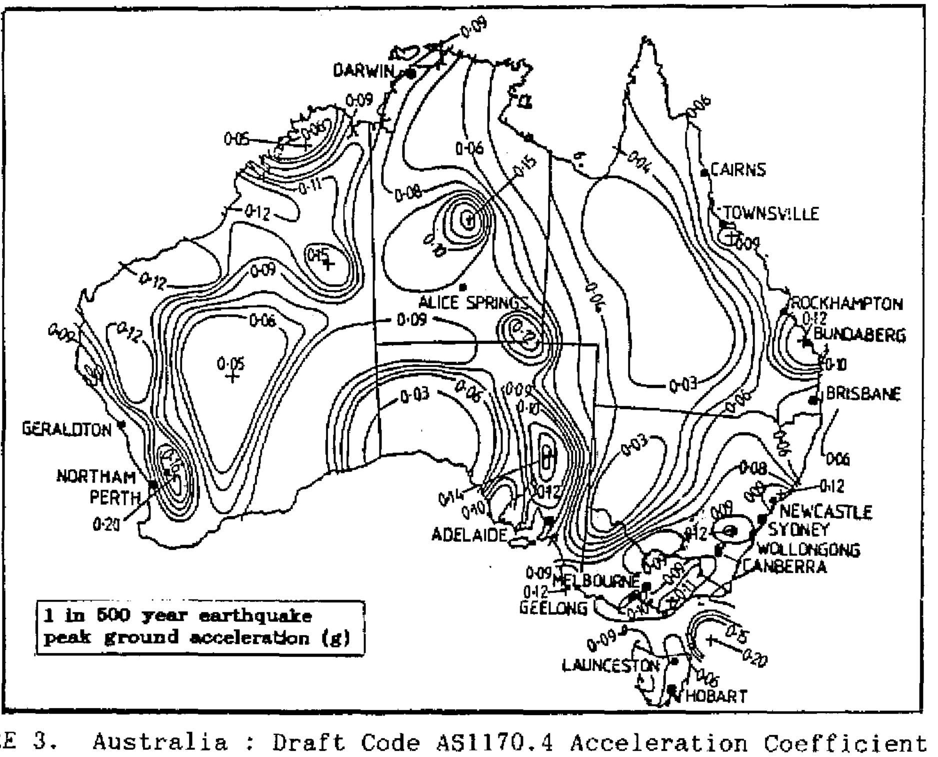

FIGURE 3. Australia : Draft Code AS1170.4 Acceleration Coefficient Map (Standards Australia, 1991-1992)

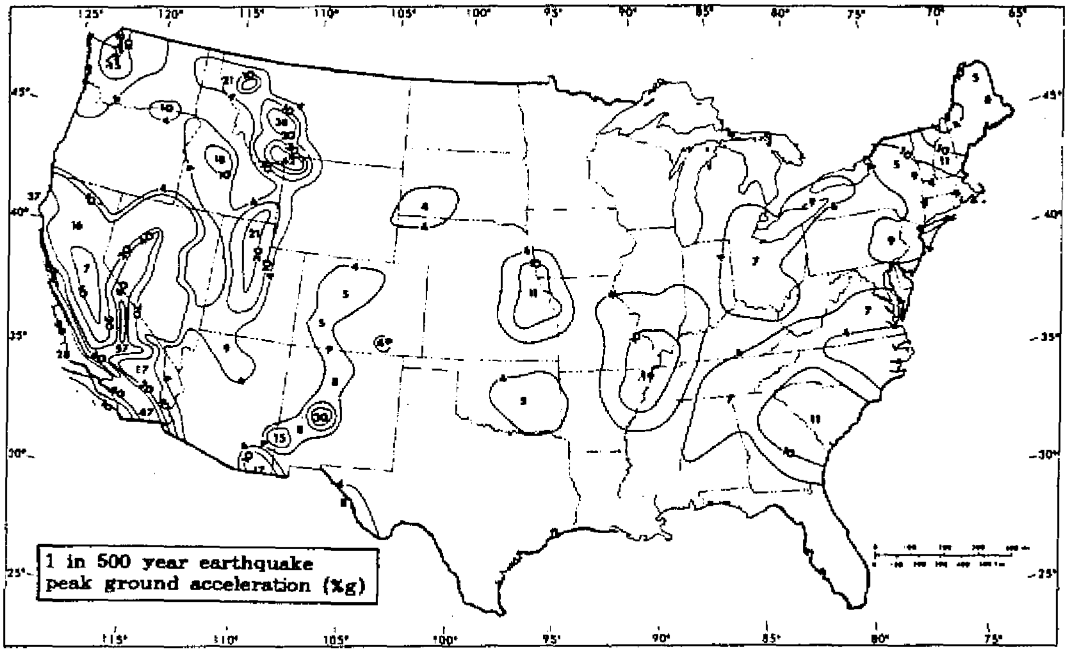

FIGURE 4. USA : Earthquake Hazard Map (Algermissen and Perkins, 1976)

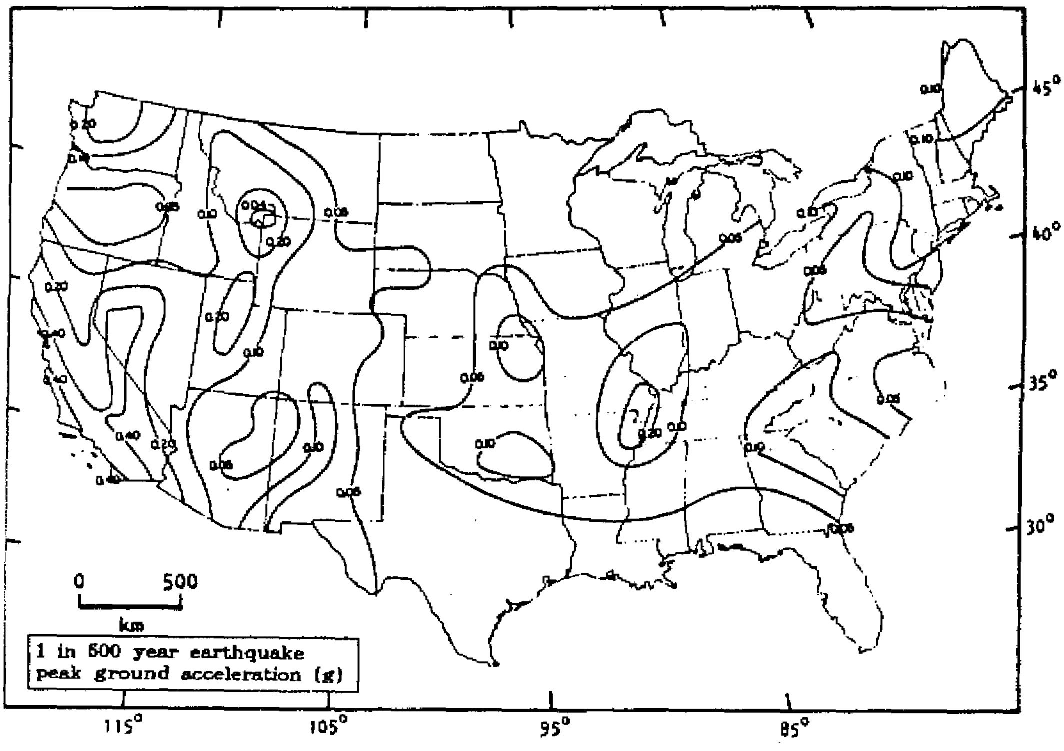

FIGURE 5. USA : ATC Effective Peak Acceleration Map
(Applied Technology Council), 1974)

Although earthquakes in Australia are of low frequency and scattered (by the apparent nature of continental seismicity), the same argument applies for an Earthquake Load Code in regard to the Cornell-McGuire method as the most appropriate choice. Although the Cornell-McGuire hazard maps for Australia are an important seismological process in establishing pga estimates on a continental scale, to implement reliable and realistic acceleration coefficients in the Earthquake Load Code, particularly for urban areas, an alternative method is required. This must incorporate seismological data and relations with additional pertinent information to provide streamlined maps of suitable scale.

ALTERNATIVE INPUT TO DESIGN CODES - ZONATION MAPPING

To overcome the inadequacies of probabilistic earthquake hazard mapping on a continental scale in providing engineering and planning practitioners with suitable design criteria for urbanised areas, an alternative method to the Cornell-McGuire procedure is that of earthquake zonation mapping. It is most suited as the basis for an Earthquake Load Code.

This method satisfies all conditions and minimises the limitations and uncertainties discussed above. The multidisciplinary analysis integrates earthquake, geological (surface sediment and deep source structure, amplification, liquefaction), geographical, demographic, engineering, built environment, and geotechnical data with emergency management, local government response, insurance and socio-economic aspects under both regional and site-specific conditions. Considerations can be reliable extended to: extrapolation to large magnitude events; any source area; any earthquake type (radiation pattern); response spectra to take account of natural frequencies of structures, ground surface and their interactions; ground motion simulation models. For rural areas in Australia, either adjacent to or remote from urbanised areas, reliable acceleration coefficients could be obtained by meshing urban-scale zonation maps and streamlined broad-scale Cornell-McGuire hazard maps, with suitable smoothing.

The success of this method from a practitioners viewpoint has already been proven in Utah (Kockelman, 1990), San Mateo County (USGS Map Series I 1257) and for the City of Sydney, Australia (Rynn, This Volume). Indeed, the method was used nearly 20 years ago for Wellington, New Zealand. Although this urban area study by Grant-Taylor et al (1974) preceded the Cornell-McGuire method, many of the "practical" inadequacies now present with probabilistic hazard mapping were clearly recognised:

> *"Seismologists and geologists can place broad macro-zones of frequency and intensity of earthquakes across New Zealand, but these are not of great assistance to the architect or engineer who is designing structures against these earthquakes, or at least against the moderate ones. He must take into account the nature of the foundation rock and soil, because we are becoming increasingly aware that the interplay between an earthquake's vibrations and foundation materials is as important as the earthquake itself, since it controls the pattern of damage arising."* (1974).

It has been shown that the probabilistic method of Cornell-McGuire in determining hazard maps and acceleration coefficients for the continent of Australia as the basis for the Earthquake Load Code is not appropriate. This would also apply to the consideration of the legal interpretation of its use in formulating Codes of Practice to which engineers and urban planners must comply. The more precise and understandable method that should be adopted to produce a realistic and more certain approach of earthquake loading in design criteria is that of earthquake zonation mapping.

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