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Australian Earthquake Engineering: Achievements, Challenges and Obstacles

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ABSTRACT: The Australian Earthquake Engineering Society was established in 1990 with its main objective to promote and advance the practice of earthquake engineering and engineering seismology in Australia. In the decade or so since its establishment the Society has had some successes in this regard as well as some disappointments. In this paper, the author will highlight these along with research and other important professional developments during this period. The perceived obstacles to getting a better take-up of earthquake engineering amongst Australian practitioners and the role of the Society in furthering the cause of earthquake engineering in Australia will then be discussed. The paper will conclude with an outline of possible strategies for overcoming these obstacles.

1 INTRODUCTION

The Australian Earthquake Engineering Society (AEES) was established in 1990 following the December 1989 Newcastle Earthquake. The move to establish the Society came out of a perceived need for an official national forum for professionals to discuss earthquake engineering and seismology issues. The New Zealand National Society for Earthquake Engineering was identified as a model for our own organisation.

It is of historical interest to note that the Australian Earthquake Loading Code was under development at the time of the Newcastle earthquake. To clarify, the first committee meeting was held in Adelaide in November 1989, 1 month before the Newcastle earthquake occurred. It must be stated that the general tone of discussion at this meeting was that the committee should not put too much effort into it – perhaps simply requiring all structures to be designed for 0.1g horizontal acceleration would suffice. Needless to say, the tone of the second and subsequent meetings was more serious, reflecting a desire to develop a standard that fit in the mould of a “loading” standard but also included domestic construction within its scope and provided some guidance on detailing. The resulting standard, published in 1993 (SA) and subsequently called up by the Building Code of Australia in 1995 (BCA), was perceived to be a reasonably “user friendly” document that practitioners previously unfamiliar with earthquake design could cope with.

With this in mind, it is important to state the original aim of the AEES, as approved upon its inception, which is:

- the promotion and advancement of the practice of earthquake engineering and engineering seismology in Australia.

Two additional Society objectives were added recently. These are:

- improving understanding of the impact of earthquakes on the physical, social, economic, political and cultural environment; and
- advocating comprehensive and realistic measures for reducing the harmful effects of earthquakes.

With this background, the following sections of this paper consider how well, or in some cases poorly, the Society has succeeded in achieving its aims and what are the main impediments for the Society. The paper concludes with some suggestions for how the Society might better achieve its aims.

2 SUCCESSES

The Society has been successful in establishing a national forum for the discussion of issues important to the earthquake engineering community. Its membership of approximately 240 members is drawn from all states and is comprised of a healthy mix of predominately engineers and seismologists. Perhaps, the large number of seismologists is indicative of the fact that this group has no other national forum for discussion or publication of results. This "mixing" is also responsible for one of the Society's greatest successes – the greatly improved interaction and mutual understanding of earthquake seismologists and engineers.

While the Society was not officially involved or responsible for the new Australian Earthquake Loading Standard, AS1170.4, the committee that produced it was largely comprised of Society members. Certainly, to the extent that its use has impacted on the wider engineering profession and the community it must be discussed in any analysis of how earthquake engineering has been embraced across Australia. In my view, two of the major successes of AS1170.4 are that earthquake loads are now considered in all parts of Australia and that domestic construction is included in its scope. Given the likelihood that much of the damage and potential loss of life in a future earthquake could occur in domestic construction, it was very important that this was done. The response of the profession to the new standard (as it was in 1993 when it was published) was generally favourable. Its ease-of-use was judged to be a "success" and helped in getting it approved for use quickly by the profession. This was in stark contrast to the difficult path travelled by the revised steel code at about the same time.

It is of interest to note here the reaction of some sectors of the construction/building industry to the "1993" earthquake loading standard. In particular, those involved predominately with the design and construction of small commercial and domestic construction, including two and three-storey apartment buildings, developed "deemed-to-comply" construction details. In a very practical way, this sector has avoided the need to design every house, apartment and small commercial building individually for earthquake loading. Some may argue that this is not in fact a success but, on balance, the author believes it is.

Two major successes in the area of engineering seismology in Australia must be said to be the "Cities" project and the joint urban monitoring programme. For those who are not familiar with these projects, AGSO's "Cities" project involves the development of GIS earthquake risk assessment methods for the major cities in Australia. All of the capital cities and major regional centres will be covered by this project when completed, providing an important tool for the management of earthquake risk in Australia. Also of significance for structural engineers (designers and analysts alike) is the urban monitoring programme. This programme saw two seismographs, one free-field and one located in the basement of a major building structure, installed in each of the capital cities of Australia. The project has greatly increased the number of strong ground motion recorders in Australia and, provided that funding for the continued operation and maintenance continues, will provide important data on earthquake ground motion in a region where widespread structural damage is likely to occur in the event of a large earthquake near one of the major populated regions of Australia. Earthquake engineers will be able to use this data for back calibrating their structural models typically used in structural analysis and design. Seismologists will be able to use this data in developing improved ground motion models for intra-plate earthquake regions such as Australia.

Finally, since 1990 there has been some very important earthquake related research undertaken in Australia. While the amount of money put towards earthquake engineering and seismology research in Australia pales in significance to that spent by the US, it has been reasonably well targeted towards areas of local relevance. For example, excellent research has been undertaken on wide band beam construction, unreinforced masonry construction, non-seismic (gravity loading only) concrete frames and intra-plate earthquakes to mention but a few of the projects. A quick survey of the major research grants funded by the Australian Research Council (ARC) since 1990 (listed in Table 1) indicates that 14 projects have been supported on the engineering side. A greater number have been funded in the area of seismology, however, the majority of these are focussed towards minerals and/or petroleum exploration applications and are not especially relevant to earthquake engineering applications. Figure 1 indicates the level of research funding for earthquake engineering projects since 1990. As can be seen, the amounts are not large but surprisingly, the trend appears to be generally increasing from 1990 with a dramatic drop in the last two years. The recent drop may be due to the time lapsed since the Newcastle earthquake; with the fading memory the inclination to fund earthquake related research might be disappearing! However, there are a growing number of research academics taking an interest in earthquake engineering issues so hopefully this downward trend does not continue.

Table 1. ARC Earthquake Research Funding (1990 – present).

Year	Project Title
1991 – 93	Simplified earthquake analysis for masonry structure design
1992	Performance of light gauge steel frame bracing when subjected to earthquake loading
1993	The response of URM walls to earthquake and the development of cost-effective retrofitting measures to reduce their vulnerability
1992 – 93	Earthquake simulator testing of small-scale reinforced concrete structures
1993 – 95	Experimental and theoretical evaluation of the seismic ductility of shear wall structures
1994 – 96	Earthquake ground motions and structural ductility factors for Australian conditions
1996 – 98	Theoretical and experimental study of RC frames with wide band beams subjected to earthquake loading
1997 – 99	Nonlinear dynamic analysis and design of RC framed structures subjected to earthquake loads
1997 – 99	The seismic integrity of walls and connections in unreinforced brick masonry buildings
1998 – 00	Control of environmentally induced tall building vibrations by liquid column vibration absorber
1999 – 01	Pile design for seismically active areas
1999 – 01	Finite element model for seismic vibration control of structures using 'smart' elements
2000 – 02	Earthquake induced displacements for building structures in Australia
2000 – 02	Behaviour of partially restrained sway frames constructed with concrete filled steel columns and semi-rigid composite connections for multi-storey buildings

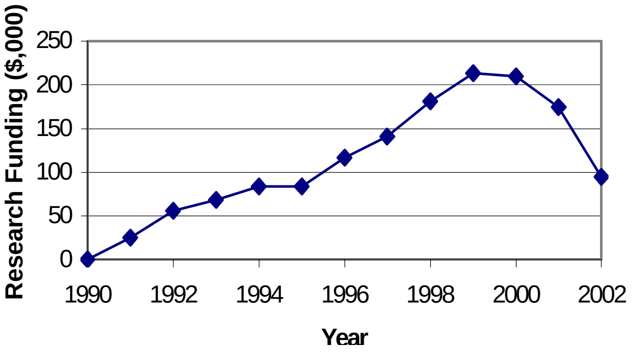


Figure 1. ARC earthquake engineering research funding from 1990 – present.

3 FAILURES AND IMPEDIMENTS

In spite of the best efforts of AEES members and the wider earthquake engineering community, the profession has been slow if not downright reluctant to adopt many of the modern earthquake engineering design practices (e.g. capacity design). Furthermore, the ongoing maintenance of existing seismic monitoring networks is being threatened through lack of financial support. The reasons for this are somewhat confused but appear to first and foremost the perception that the earthquake hazard in Australia is insignificant and that Newcastle was a "one-off" event. It is difficult to counter this "argument" without some hard data. However, it has always been the author's position to weigh this against the potential impact of a similar or potentially larger seismic event in Sydney or Melbourne. The concentration of Australia's population (and economic production) into these two major metropolitan areas means that from a Total Disaster Management perspective, the economic impact of a major earthquake occurring in Sydney or Melbourne would be severe for the entire country. The question remains, however – in dollar terms how severe? Is the risk acceptable?

Results from a number of research projects listed in Table 1 give some insight as to how this could be answered. Shake table tests on a 1/5-scale reinforced concrete frame at the University of Adelaide indicated that a "code-compatible" concrete frame would respond "elastically" under the design magnitude (500 year return period) earthquake. For Adelaide, that corresponds roughly to an effective peak ground acceleration of 0.10g. Figure 2, which shows the maximum base shear versus the peak shake table acceleration recorded during the series of tests, suggests that the structure only began to respond inelastically at base shear levels in excess of 25% of the weight of the structure. Of concern also is the fact that at the design magnitude earthquake "loading" of 0.10g, the maximum base shear recorded was approximately 27% of the weight of the structure. This was confirmed with an experimental static push-over test that was conducted on the frame after all dynamic testing was completed. The data, plotted in Figure 3, shows again that the structural response does not become significantly non-linear until quite large base shear is reached – well in excess of the 4% - 6% normally used in design checks by assuming an R-factor of 4 (for non-seismic concrete frames). The lateral drift at 18 mm of the displacement (when collapse was imminent) was only 0.9%, although most of the deformation occurred in the bottom storey where the effective storey drift was roughly 2.5%.

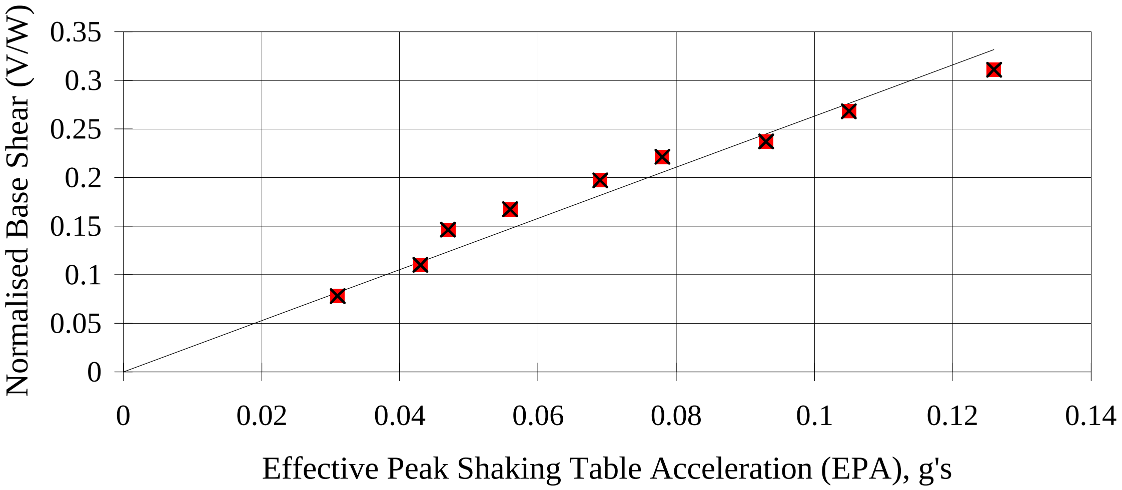


Figure 2. Shake table test results for 1/5-scale 3-storey r/c frame (Griffith and Heneker, 1995).

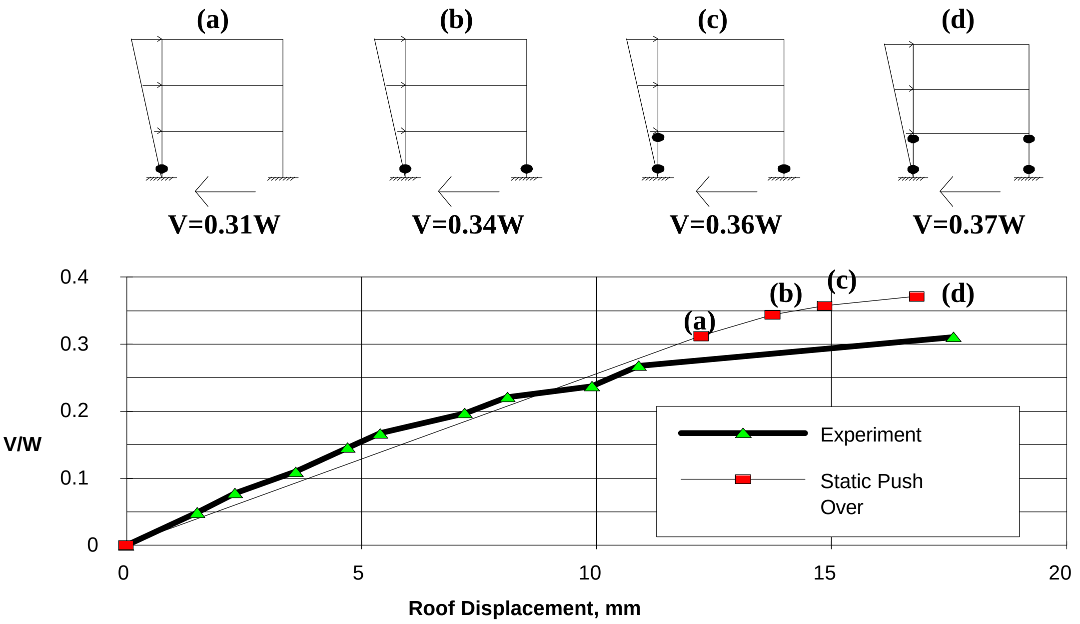
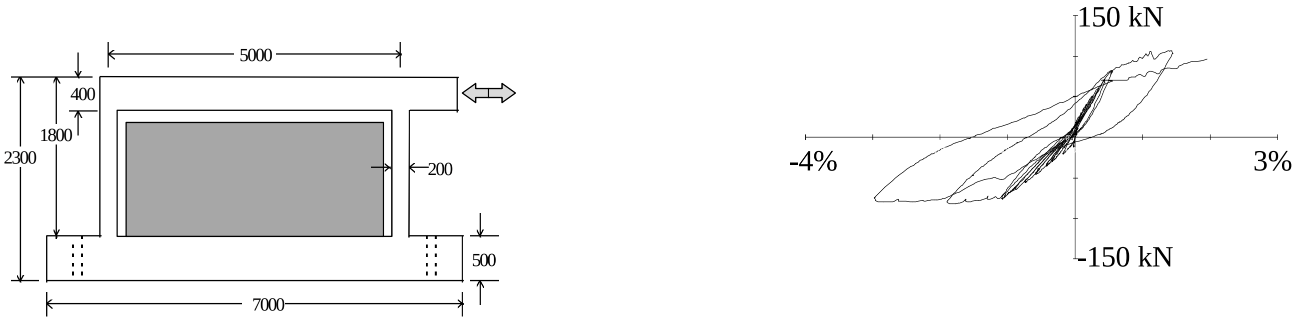


Figure 3. Static push-over test of 1/5-scale 3-storey r/c frame (experiment and analysis) (Griffith and Heneker, 1995).

So, what is the problem? In Australia, frame details typically result in a strong-beam, weak-column design. Thus, a typical "code-compatible" concrete frame structure has a soft-storey collapse mechanism as was observed during the static push-over experiment. In the event of a bigger than expected earthquake there is little ductility that can be relied on if the seismic demand exceeds the elastic capacity.

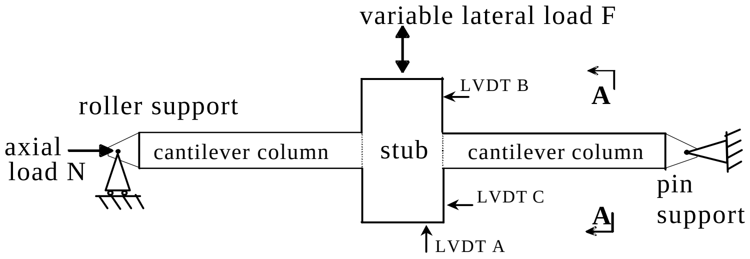
In other tests at Adelaide, the ductility of frames and columns has been shown to be extremely limited. Figure 4 shows the load-deflection curve for a ½-scale concrete frame subjected to quasi-static cyclic loading. The beam-column joint failed at about 1% drift without showing any significant signs of inelastic response beforehand. A similar result was observed in quasi-static tests conducted on concrete columns where the column strength was reached at drifts of about 1.5% with little usable ductility exhibited during the cyclic tests (Figure 5). The axial load during these tests was 22.5% of the ultimate column compressive load.



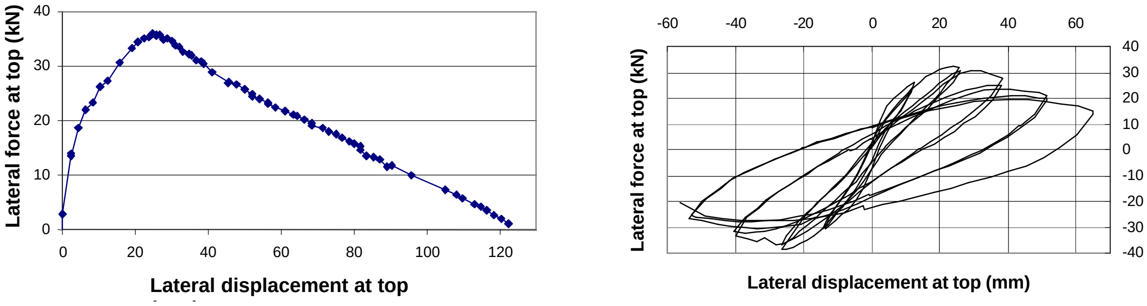
(a) Schematic of Infill RC frame test specimen

(b) Storey shear versus drift (no infill)

Figure 4. Test results for ½-scale r/c frame subject to cyclic loading (Griffith and Alaia, 1997).



(a) Schematic of column test configuration



(b) Monotonic static test of r/c column.

(c) Cyclic test of r/c column.

Figure 5. Test results for 200x200mm R/C column (Wu et al, 2001).

From this work, it can be concluded that the behaviour of code-compliant concrete frames during the "design magnitude" earthquake should be acceptable (if foundation failures do not occur due to the large elastic base shears). However, to get a feel for the magnitude of an earthquake required to generate significant inelastic demand, a series of non-linear time history analyses was performed on a number of concrete frames. The results for a 2-bay, 5-storey concrete frame are presented in Figure 6 where the elastic base shear and the inelastic base shear are plotted versus peak ground acceleration. As was seen previously, the response is essentially elastic for the design magnitude (500 year return period) earthquake (0.10g). However, substantial ductility demands begin to be placed on the structure for larger inputs. This begs the question as to what is the chance of a bigger earthquake, say in excess of 0.3g. Figure 7, taken from Paulay and Priestley (1992) suggests that for low seismicity regions there is a big increase in acceleration for small increases in return period in the 500 to 2000 year return period range. It is unlikely that much ductility exists to save these structures in an overload situation. This raises an important question at this stage – should we be designing for longer return period earthquakes in Australia? Say, for example, a 1000-year or 2000-year event.

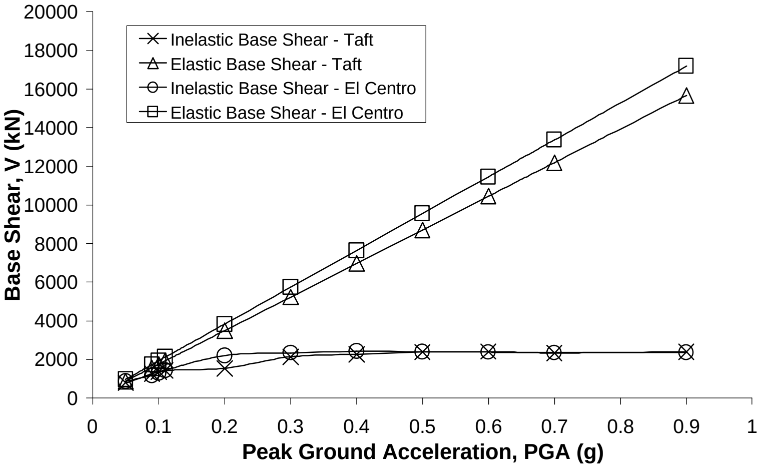


Figure 6. Variation of elastic and inelastic base shear with peak ground acceleration for 2-bay, 5-storey frame (Potger and Griffith, 2002).

Another area of research activity concerns the seismic response and design of unreinforced brick masonry construction in Australia. It appears that URM construction can be made to "work" under the design earthquake with an R-factor of 1.5 (all over-strength, no ductility) but little or no capacity exists to cope with a larger seismic event. Work is in progress to attempt to more accurately estimate the seismic demands, in terms of displacements, that are likely during Australian earthquakes. This information, when used in conjunction with a displacement-based method of assessing the seismic capacity of URM walls subject to out-of-plane motion (Doherty et al, 2002) will enable engineers to make better judgements as to just how much (or little) reserve seismic capacity exists in typical URM construction.

Clearly, these issues are of great concern. However, as a Society and a profession the question of what is a suitable return period for Australian design needs to be addressed. If the 500-year return period magnitude is correct, then perhaps there is nothing to worry about. On the other hand, a 2000-year return period event would make significant inelastic "demand" on r/c frames and most likely cause significant damage to most URM structures in the immediate area. Are we willing (or able) to live with the consequences of the bigger event when it eventually does occur? At the moment, there seems to be complacency that the 500-year event is sufficient and appropriate for design and the larger "what if" scenario is not a justifiable design consideration. However, there is a significant difference in the distribution of peak ground acceleration as a function of average return period between high seismicity regions and low seismicity regions. The basic design philosophy embodied in the Australian earthquake code is a "copy" of the US counterpart where it is recognised that the 2000-year earthquake is roughly only 25% greater than the 500-year ultimate strength design earthquake. In low seismicity regions, the difference between the 2000-year and 500-year earthquakes (in terms of PGA) could be of the order of 300%. In this context, the consequence of the bigger than expected earthquake in Australia will clearly be much more catastrophic.

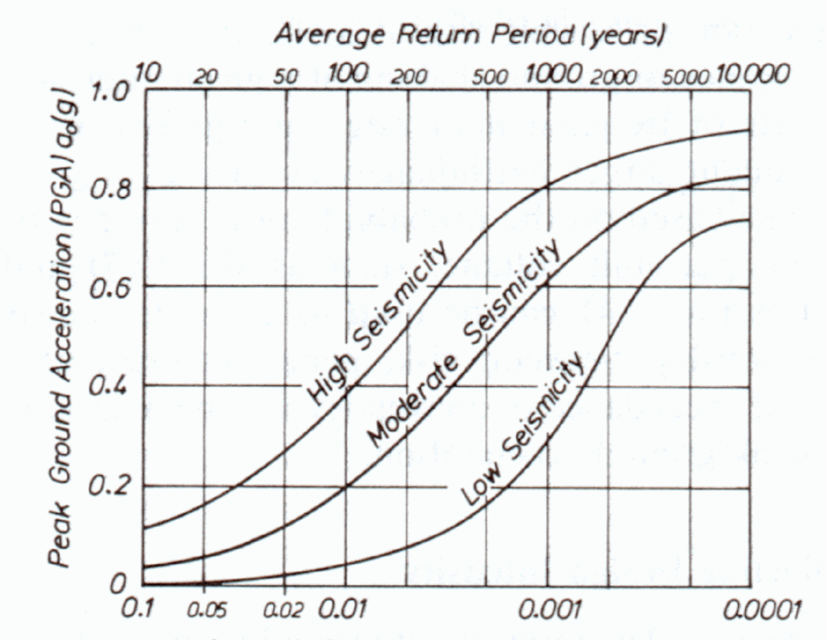


Figure 7. Relationship between PGA and annual probability of exceedance for different seismic regions (from Paulay and Priestley, 1992).

Another major reason for the reluctance to adopt rigorous (i.e. New Zealand) earthquake resistant design practices in Australia is that it cannot be justified by a cost/benefit analysis. However, on a building-by-building basis, it is even hard to justify in California (EERI, 1998). Of course, calculating this ratio is hugely problematic. While it is comparatively easy to calculate the differential cost of design and construction to a more stringent standard, it is extremely difficult to calculate the corresponding benefit. From a financial perspective, there seems to be little benefit to a building owner to have their building meet or exceed the minimum standards if "they" are covered by insurance in the event of disaster. This is even more the case if a business is also covered for "business interruption" costs. Of course, we all pay in the end so that only by taking a "big picture" perspective to calculate benefits is it likely that a cost/benefit ratio less than one will result. Methods used by the insurance industry for making loss estimates could be used to estimate the difference in damages corresponding to different standards of seismic design. For example, the probable maximum loss estimates (by Greig Fester Pty. Ltd.) for magnitude 5.6 and 6.6 earthquakes in Sydney are $4.7 and $11-15 billion in domestic construction alone. A large percentage, over 80%, of this damage would be in unreinforced masonry construction. Alternatively, a displacement-based method for the vulnerability assessment of classes of buildings may also be suitable (Calvi, 1999). Of course, it is my view that this is just the perspective we should be taking as a Society and indeed the charter of the Institution of Engineers states that as a profession, we are to put "the needs of the community first", ahead even of our client's.

Other related and complicating issues such as a lack of understanding of structural dynamics/seismic engineering fundamentals by the broad structural engineering profession and the largely "de-engineered" public sector that we are now operating with make it difficult to convince government bodies, the profession and the community that modern earthquake engineering design procedures warrant taking up in earnest. To complicate matters, the very real economic pressure on consultants to "make a buck" does not create an environment conducive to "change". Enormous effort is required to implement change on a large scale. An approach that invokes a sequence of incremental changes may be more palatable and, in the end, take less time and effort.

Last but not least, it appears that we have failed (to-date) in getting sound earthquake engineering knowledge integrated into the various state-based disaster management planning processes. The reason for this seems to be a misunderstanding by the AEES of how state disaster management planning operates and perhaps also a lack of understanding, and certainly experience, in how local earthquake engineering expertise can be utilised by disaster management planners.

4 STRATEGIES FOR OVERCOMING THE ABOVE MENTIONED PROBLEMS

In order to improve the up-take of modern earthquake engineering design principles by the profession and to increase the quality and quantity of earthquake engineering input into the total disaster management process in this country, it is proposed that the Society consider a three-pronged attack in the following areas:

1. Education
2. Advocacy
3. Coordination

4.1 *Education*

Within the domain of education, it is recognised that this will require some long-term effort at the grass roots level in parallel with short-term effort at the professional level. This could take the form of:

- Undergraduate training. This means that we must get earthquake engineering into the undergraduate civil engineering curriculum across the country. This might also require some training of academics since not all civil engineering departments in Australia have the necessary expertise to offer such a course.

- Professional training – the AEES could coordinate and sponsor workshops to raise the understanding of fundamental earthquake engineering principles and design issues amongst practising engineers. This might consist of "refresher" courses (half-day) for those with previous experience and more substantial (3-4 day) courses for "first-timers".

4.2 *Advocacy*

Within the domain of advocacy, the society should work to raise the awareness amongst the wider community of the benefits of improved seismic resistance in all construction (new and existing) but especially to major building owners/managers. This could take the form of:

- AEES to promote seminar/workshops for building owners and insurers to make them aware of key issues.
- AEES to promote the concept of earthquake rating for buildings (a.k.a. “performance-based engineering). This would aim to encourage building owners and insurers to embrace the concept of earthquake design for new construction and seismic rehabilitation of existing structures. At present, it is mainly only large corporations and government entities that “self-insure” that are undertaking seismic rehabilitation – often at the behest of their “re-insurers”.
- AEES to communicate the need for strong ground motion data to the federal and state authorities – perhaps even encourage legislation to have large building projects incorporate strong ground motion recorders and their maintenance into the project.

4.3 *Coordination*

Finally, within the domain of coordination, the society should work to establish effective engagement of the membership with key disaster management organisations at both the national and state levels and to increase the efficiency in the way the very limited national research funding is spent on earthquake-related research. This could take the form of:

- AEES membership to become actively involved in the Total Disaster Management process at national, state and local levels.
- AEES body to workshop all parties involved in the design, construction, and management of the built infrastructure to identify and prioritise research needs. The Society should then communicate this information to the research community, industry and importantly, the funding bodies.

In addition, the Society should take the lead in discussions of what is the most sensible “return period” for earthquake design in Australia. This could involve holding a number of public workshops but would need to involve a wide cross-section of the relevant engineering community.

5 **CLOSING REMARKS**

In closing, from an earthquake engineering perspective it appears that as a nation Australia has seen some substantial accomplishments over the last decade. Earthquake design, using an equivalent static force calculated using a simple period dependent formula and strength reduction factor to account for perceived ductility, is now required for virtually all buildings in the country. However, there is much we could improve on with (perhaps arguably) little additional expenditure. The impediments to further escalation in the sophistication of the method we use for aseismic design include:

- the low perceived earthquake hazard in Australia;
- the notion that the 500-year return period earthquake is appropriate for Australia;
- the perception that the benefits of more rigorous seismic design do not justify the extra costs;
- lack of understanding of seismic design issues and underlying theory among wider profession;
- economic pressure in the workplace not an environment sympathetic to change;
- no financial incentive for building owners since covered by earthquake insurance and no recognition in individual rates for reduction of risk;
- de-engineered public sector limits the ability of traditional government sector to take up the

cause.

A 3-pronged approach has been outlined in this paper to encourage the further up-take of modern earthquake resistant design principles in Australia. Advocacy and Education are intended to create an environment where the market place better understands the benefits and need for seismic resistance and so that the engineering community can properly service the communities needs. The Australian Earthquake Engineering Society seems to be the logical group to coordinate these activities as well as serving as a conduit for providing technical expertise to national and state-based disaster management groups.

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