EARTHQUAKE ENGINEERING IN AUSTRALIA – BEFORE MECKERING AND AFTER NEWCASTLE

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ABSTRACT

Earthquake Engineering in Australia, as elsewhere, has been formatted in the aftermath of damaging earthquakes. The first Australian Code AS2121-1979 was written and published after the 1968 Meckering WA earthquake. The second AS1170.4 1993 was published after the 1989 Newcastle NSW earthquake. Good quality Building Codes are a necessary basis for sound earthquake resistant designs. Both implementation and enforcement of the codes and sound robust construction in the field are essential for the protection of life and infrastructure. Also essential is the preservation and upgrading of the earthquake database. A study to assist the safer operation of emergency services immediately following damaging earthquakes is proposed.

1. INTRODUCTION

A learned doctor once said "For each man is ill in his own way". So it is with earthquakes. Each new earthquake shakes the ground in its own way, and each type of ground responds differently and every structure reacts differently. I also believe that each society formulates its own reaction to earthquakes and the threat of earthquakes. Here in Australia we have responded in our own way and I want to discuss the various formative events which happened to us in the past and then where we are now and what is yet to come. But when we talk about the past let us always remember this wise counsel:

"The past is another country; they do things differently there." L P Hartley

My own education as an engineer began here in the West. Natural disasters to us in the middle of this century meant flood, fire, drought and above all Cyclones. We all knew about those, and as structural engineers especially cyclones, but I do not recall anyone then mentioning earthquakes in the engineering or design context for Australia.

This is perhaps a little surprising because in the late 19th and early part of this century earthquakes were of great interest to the general public. There were often lengthy reports in the local papers of quite small events. This is in marked contrast to the New Zealand situation where in the 1850's it is claimed that local newspapers downplayed the effects of earthquakes, implying that the damage was due to poor building materials and techniques. Grapes and Downes in analysing the great 1855 event (magnitude 8+) [1] wrote:

> "The reasons were closely linked with important political issues, namely the concern about the effects of the earthquake on immigration, especially to Wellington ..."

However even in Australia emphasis is often placed on the very poor quality of construction. Let me offer one event picked at random just because it was mentioned in the *Canberra Times* while I was writing this, that of Dalton-Gunning 1949. I checked out the BMR Isoseismal Atlas and found this "... the walls were built of irregular granite and sandstone blocks the interstices between which had been filled with mortar, wood and even paper" [2].

So we had the early (Mechanics Institute) years of general public interest. Then after many years and two World Wars we had the early warning of Adelaide 1954, which largely went unheeded.

Then the wake-up call of Meckering 1968 which was heeded only by certain groups. Why was that?

2. PAST VIEWS AND ATTITUDES

The reasons different groups varied so widely in their reactions to these events were because of their widely varying views, attitudes and basic assumptions.

Put very simply they ranged from views that:

1) Earthquakes posed no threat to any major community in Australia and there was no need for any special precautions in construction.

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2) Earthquakes posed a limited and graduated threat, which could be dealt with by zoning.

3) Earthquakes were a threat to all communities in Australia and special precautions were necessary throughout Australia.

The first view has been slowly eroded by events such as Meckering and Newcastle 1989, but remember, that was then not now.
The second view introduces the concept of Zoning and is the one I espouse and I think is now accepted by most. That does not make it an easy one to deal with. Zoning was not easy then and I am sure it is not easy now. As one of our local newspaper pundits said recently "Drawing lines on maps, in social conduct, in religion, in law itself, has not proved one of humankind's greatest skills. Misery, expense and death are the usual outcomes." (Bill Mandle, *Canberra Times,* 15/8/98)

The third view is more commonly held by those educated in much more seismically active regions and in Australia is probably more common among seismologists.

These views were complicated by still other assumptions or attitudes. For example, some thought that earthquake resistant design and construction was simple and inexpensive, while others believed it was complex and costly. Some thought the undoubted lack of good instrumental data meant that Australia had few damaging earthquakes but others knew that the absence of evidence was not sufficient evidence of absence.

Also the concept of intraplate earthquakes (i.e. all Australian earthquakes) was not fully appreciated and the highly variable recurrence intervals we have are hard to handle for normal building lifetimes. Buildings, nowadays, can be designed, built, used and then demolished in as short a space as 30 years. But whatever the reason, earthquakes to Australians were something exotic like tornadoes. Exotic events that happened in other countries and were not a concern for us. The Shaky Isles (*New Zealand, Ed.*), Yes, California and Japan Yes but not to us in Australia. We have popular books about cyclones but not earthquakes.

Even the Adelaide earthquake in 1954 did not produce much of a reaction. It was an early warning which largely went unheeded. It was quite a respectable event, magnitude 5.4 ML, but there were no injuries as a result of the earthquake. However, "the southern suburbs of Adelaide experienced the strongest shaking in their short history. Widespread damage occurred, mainly to old domestic dwellings (30,000 insurance claims were filed)" [3]. The actual loss was then about $100M in 1995 money but there would be much greater damage if the event was repeated today.

The first time I recall the Adelaide 1954 event raised as a threat or warning in Australia in a professional context was by Prof. Francis at an engineering conference in Melbourne. I made reassuring remarks and, speaking on behalf of the Comworks Head Office then in Melbourne, said I would look into it.

By that time I had worked for a period in PNG using earthquake resistant design techniques and earthquakes had taken on a new meaning for me but still, of course, not in the Australian context. Perhaps the first Australian document to deal with earthquakes was a Comworks Technical Instruction 5-A-21 issued in December 1961. It was amended in 1964 and again in 1965. I do not have a copy of any of those TI's but I do have one of the new series S3 which was issued in July 1969. It was called "The Design of Buildings in Areas Subject to Earthquake". The "Areas Subject" did not include Australia.

The introduction to S3 recognises the difficulty of earthquake engineering design in normal practice and suggests the best way is "the adoption of a code which will embody the practical experience of a number of engineers, which has been tested in a number of earthquakes and which will express in a useable form a range of view-points." The code selected since that first issue in 1961 was always the current issue of the SEAOC Code, the earthquake engineering design code of California. In the S3 1969 version it was SEAOC 1968, slightly modified, mainly for simplicity and to recognise vertical accelerations. However it goes on to introduce the concept of different seismic Zones using the American model building code, the Uniform Building Code (UBC), equating the then most severe zone of UBC, Zone 3 to SEAOC. The next step was to stress the very real limitations of all such codes as follows:

> "All codes, including this TI, which assume that a satisfactory approximation to the dynamic nature of the building response to earthquake loading can be obtained by means of the equivalent static load concept, must have some limitations in their application."

Then it went on to ask structural designers to modify their views of what was normal building practice and accept limitations. Stating plainly that these limitations generally "...will stem from complexities of building design which, although *normal* in areas not subject to significant seismic risk (UBC Zone Zero), cannot be regarded as *normal* in areas of severe seismic risk (USB Zone 3) such as New Guinea. The complexities which are particularly dangerous are torsional eccentricities in plan and sudden changes of stiffness or mass particularly with height". This was then *a big ask* and I suspect that it still is.

So right through the 1960's the concepts of seismic zoning from Zones Zero through to Zone 3 were known. But even looked at in the light of the New Guinea risk, that brief review of the Adelaide event did not cause any of us to take up the task of revising the current structural engineering thinking. That is, to Australian engineers the whole of Australia was Zone Zero. In fact, I was having enough trouble then convincing the skeptics in Commonwealth Government circles about the full power of tropical cyclones on the Northern Australian coastline without taking on the task of earthquakes as well.

All that changed for me when Meckering struck in 1968. A near M7 event with extensive surface faulting. Not just

Australia but Western Australia. That was different. A bit too close to home. Even my own home as it turned out.

3. INTRAPLATE EARTHQUAKES

At this point, let us remind ourselves that our earthquakes in Australia are intraplate earthquakes which do have some special features, of fundamental interest to seismologists, but which have also some practical consequences.

In his PCEE paper, Melbourne 1995, Bolt [4] gives a table of a sample of large intraplate earthquakes, from all parts of the world. There are 14 listed, starting from the year 1356, with magnitudes (M_s) ranging from 8.5 down to 6.4. One of those, in China in 1556, produced the greatest loss of life ever recorded. But, his list also includes Meeberrie, 1941, Meckering 1968 and Tennant Creek 1988, which certainly makes interesting reading and food for thought?

There is another way of viewing our earthquakes as being commonly associated with new or unknown fault sources. For instance, Bolt states that throughout the world: "... five of the ten historic earthquakes in stable continental regions that have been associated with new surface fault offsets have occurred in Australia, and all since 1968." (The five are Meckering WA 1968, Calingiri WA 1970, Cadoux WA 1979, Marryat Creek SA 1986 and Tennant Creek NT 1988).

And again he points out that for intraplate earthquakes "there is a general ignorance, ... of where the main active fault sources are located." For these and other reasons given in his paper Bolt reminds us that the study of the Australian crust is "of global interest in relations to intraplate earthquakes."

So, we have a duty to the world as well as to ourselves to continue with these studies and with data collection.

4. THE EFFECT OF MECKERING ON EARTHQUAKE ENGINEERING

So, while Adelaide 1954 by itself produced hardly a ripple on the national scene, Meckering 1968 was a different matter. In fact for a small group in the professions it was a wake-up call.

But why was it heeded only by certain groups? As an earthquake it was big enough, real enough in its effects on infrastructure. There was a 32 km fault scarp. But the area was too lightly settled to produce significant damage, no serious injuries or deaths to attract major attention. Too remote and too far away from the Eastern States.

There were strong views within the structural engineering community that no special changes were necessary. For example, Lay 1968, reported after a site inspection that "There is no evidence in the behaviour of Perth – Meckering structures during the 14/10/68 and subsequent earth movements to indicate any need for a change in the approach to the engineering design of Australian structures. Good building practice would appear to be an adequate approach to adopt in general design" [5].

The strength and prevalence of those common sense views required special attention and treatment in the Australian context. Particularly in zoning and in application of special requirements. I say "common-sense" because there is fundamental sense behind them. They place the focus on good and robust construction which no one can gainsay. As Lay himself says "Sound construction is essential". This dictum is truer for earthquakes than for any other loading. If there is a weakness, the earthquake will seek it out and even cause collapse and therefore loss of life. The earthquake will also find the weakness that ignorance builds in. Hopkins [6] reports that "Many of the collapsed hotels in Baguio City (July 16 1990) suffered from the effects of soft storeys because "non-structural" walls affected the structural response." It is the earthquake and the principles of mechanics that determine which are structural and which are non-structural elements". Common-sense and "normal" practice would wrongly assume that the architect, the owner or the builder could determine "which are non-structural elements."

But being "common-sense" it overlooks the "uncommon" requirements of Earthquake Resistant design... the demand for ductility beyond the normal and the need for lateral resistance in all directions proportional to the mass, unlike normal wind loading. The major undamaged engineering structure in Meckering, the silo survived because of its good construction **and** its symmetry.

Common sense also overlooks the whole questions of non-ductile structures and fabrications and their special weaknesses. These views were reconciled by the zoning process. By the retention of the Zone Zero concept and the introduction of a new Zone A to regulate the design of non-ductile structures in areas considered to be of a low risk to ductile structures.

Nevertheless, in hindsight we can see that Meckering provided a firm foundation on which to commence building the practice of Earthquake Engineering in this country. Meckering enabled a small group, the Australian National Committee on Earthquake Engineering to write and introduce a modern Earthquake Code. It eventually became an Australian Standard AS2121. In some respects it was largely a WA and a SA standard because of Meckering and Adelaide (1954). It certainly became a Commonwealth standard, especially for major facilities.

5. THE NATIONAL COMMITTEE ON EARTHQUAKE ENGINEERING

By good fortune, it so happened that before the Meckering event the late Professor Stan Shaw had spent some time in Japan. Japan was then and is still the Headquarters of The International Association for Earthquake Engineering (IAEE). Also, then as now, IAEE had established a system of National Committees throughout the world. The rules to set up such an affiliated body, although simple and inclusive, were formally monitored and had worked well in a number of different countries. Meckering provided the necessary trigger for affiliation and the significant arcuate fault scarp 33 km long and 2 m high at the centre convinced the IAEE that Australia had at least some real earthquakes.

This event resulted in formal contact with IAEE and Stan Shaw became chair of the Australian National Committee for Earthquake Engineering (ANCEE) and therefore our first National Delegate to the IAEE. This meant we were then working within the framework of the international community of earthquake engineers and could utilise their status and standing. This international status made it possible to form a group of interested professionals from the quite different disciplines and to gain recognition from Commonwealth and State Governments. Also to work with bodies such as the Institution of Engineers and other professional groups to represent all the Earthquake Engineering professions... Seismology, Geology, Geotechnical, Geophysics, Disaster Mitigation and Relief, Risk Analysis and Risk Engineering and Insurance, Structural Engineering and Architecture.

At the very first meeting of the ANCEE it was decided that some degree of earthquake resistance should be provided in the design of buildings and other structures in certain parts of Australia. The problem was divided into two parts namely the engineering problem of providing various degrees of earthquake resistance and the general problem of identifying those areas in which earthquake resistant design is required [7].

A series of Seminars on Earthquake Engineering was organised by the then Standards Association of Australia (SAA) in 1974 in Adelaide and Perth. These Seminars were just the first step, nevertheless it was as a result of Meckering and the work of Professor Shaw, the later Dr David Sutton and others, some 10 years later and after many meetings and discussions, Standards Australia published our first Australian Earthquake Code... AS2121-1979. Despite the Code being an Australian Standard there was still no general concern in the building and engineering professions outside WA and SA either! Indeed one of our leading structural engineers in the Eastern States could say to me, even in 1990, that in all his career he had never designed a building or structure in Australia for earthquake resistance.

The next step on the way was not an earthquake but another kind of natural disaster. The devastation of Darwin in 1974 by tropical cyclone Tracey brought a new realisation to the general public and to Governments of the potential for major community damage from Natural Hazards.

Also it introduced the concepts of post disaster facilities, of different design standards for different purposes. The realisation that some things, and some infrastructure had to survive even very severe challenges and still function. That means that the designer must really examine every element of the facility. I wrote at the time: "These items (*of survival*) are neglected either because they are currently no one professional's concern or are not conventionally within the practice of engineering" [8]. Mere Code compliance is not enough. The standard of construction and construction supervision must fit the purpose.

In those days, such matters were often a Commonwealth responsibility. I do not know, where all these various responsibilities lie now and I am not sure that anyone else does. As far as I can tell, if such items are a requirement of an Australian Standard they may be incorporated. If they are not spelt out in any Standard then there is little chance now (1998) that they would be built in. The exercise of judgement of an overview for the public good seems now to be more difficult to provide. To provide the money would be even more difficult.

6. A NATURAL DISASTER INSURANCE SCHEME

After the extensive flooding in the Brisbane area in February 1974 the then Federal Government created a National Disasters Organisation to work with the various State emergency services. The usual problem of flood insurance had arisen, many people finding themselves without any insurance cover for the damage. The insurance industry put forward a scheme mainly to provide universal Australia wide insurance against flooding, landslips and earthquake. The scheme was to be financed by a compulsory levy on fire insurance policies. Later, after cyclone Tracey, a further levy for high risk tropical cyclone areas was added.

Discussion continued over the next five years but there were major disagreements over many aspects including the necessity for any such scheme to be compulsory. However, in the end, a Natural Disasters Insurance Scheme was proposed to the government of the day. In 1979 the then Treasurer, the Hon. John Howard, M.P., issued a Policy Information Paper on Natural Disaster Insurance. This stated that the Commonwealth Government, for various reasons given in the Paper, decided not to proceed with the proposed scheme [9].

However good the then Treasure's reasons were for not proceeding, the problems with flood insurance continue to this day. For example with the Katherine floods early this year (1998). We still have the situation in August 1998 after the Wollongong deluge where the *Canberra Times* reported that "... the Governor General, Sir William Deane appealed to insurance companies to pay out victims even if their policies did not cover flood damage". (*CT* 22/8/98; Wollongong braces for more landslips). Will we ever learn?

I raise the matter here, even though earthquake insurance in Australia is easily obtained and seems to be virtually free, albeit with a $300 excess, with a standard household policy. It may not always be that way. I was astonished to be told many years ago by senior office bearers of IAEE that they had no earthquake insurance on their own houses. Of course, as they explained, in seismically active areas, earthquake insurance is like flood insurance in flood prone areas. If you really need it, you can't get it or if you can get it you can't afford it. When our situation here in Australia becomes like that, we will know we have joined the ranks of the seismically active.

One of the strongest arguments against the National Scheme was the necessity for any such scheme to be compulsory.

This objection to compulsion seems to have diminished over the years. Several State and Territory Governments now have a compulsory levy on household insurance policies to help pay for the operation of emergency services. The latest is the ACT Government 1998 budget proposal to place a $10 million levy upon insurance companies. In the absence of a National Insurance Scheme, we must expect the payouts to victims not covered by their insurance will continue to be on an ad-hoc basis.

7. THE EFFECT OF NEWCASTLE ON EARTHQUAKE ENGINEERING

The perceptions of earthquake risk in Australia were permanently changed by the tragic loss of life which took place in Newcastle on the morning of December 28th 1989. This time the earthquake struck a well populated and built-up area. Tragically, the Workers Club, an older building extended several times in its life, collapsed and took nine lives. This was the first loss of life from a building collapse during an earthquake in Australia. A total of 13 lives lost and, in addition, about 100 to 120 people were seriously injured.

Now, awareness of the risk reached a new level in the community not only in the building professions. Briefly, the engineers were the heroes of Newcastle. With that awareness it was possible to modify the Australian Earthquake Code to apply everywhere and to have it incorporated in the Building Code of Australia, which made its application mandatory throughout Australia. All this could be done in just a few years. In my opinion, that would not have been possible before the Newcastle earthquake. In that same climate it was possible to form a fully fledged National Earthquake Engineering Society (the AEES) and this in turn enables us to consider other possibilities in Earthquake Engineering.

I do have a proposal to put forward later but first a comment on code development. The most promising new development is in the writing of a new joint Code with New Zealand. This is the first real chance Australian earthquake engineers have had to develop a code for our specific conditions. That is for intraplate earthquakes. Although many other countries have the same type of problem at least in part, no one has done this before from first principles.

These principles though will be restricted to matters of earthquake resistant design and construction. Remember that we still have no fundamental theory for the causation of the intraplate earthquakes that we have here in Australia. With no theory there can be no basis of prediction and therefore no forewarning of the mainshock. As Bruce Bolt says "... the occurrence of the Newcastle earthquake was unexpected (although the region has had a few historical earthquakes); the causative fault is still a matter of speculation" [4].

The lessons of the vulnerability of unreinforced masonry and the damage arising from the soft soil (alluvium) contribution were again repeated. There is another lesson from the Newcastle experience and the Newcastle Earthquake Study. The lack of maintenance was found to be a major factor in the resulting damage in Newcastle and the Study proposed that continuing safety of buildings be positively assured by a formal maintenance programme. While there are no known actual building codes, regulations or legislation which would enforce or require upgrading, evaluation or even maintenance of existing buildings and facilities, current and future prudent actions must now take full account of the Newcastle experience.

8. THE DOMINANCE OF PEAK GROUND ACCELERATION

Let me now introduce another conflict with "common-sense", which is well worth highlighting. One of the most common problems in discussing earthquakes and their effects and the necessary precautions is the dominance that Peak Ground Acceleration (PGA) assumes. This dominance and the problems it leads to is fully discussed by Heidebrecht in a recent paper [10].

He begins by stating that "... Peak Ground Acceleration (PGA) continues to be given an inappropriate level of importance in earthquake engineering". He then explains why the practice continues... It (PGA) is easy to determine from a strong motion accelerogram and "engineers feel comfortable with acceleration as a parameter", (p.229). I myself believe that, while engineers feel comfortable with the concept of using acceleration as a parameter within the context of calculations, codes and risk assessments, they feel most *uncomfortable* with the very large accelerations which are now frequently measured, even in Australia. They are going to feel more and more uncomfortable as time goes on and more strong motion measurements are made. The peak accelerations will continue to increase with time. But this does not mean that damage must increase or that design loadings must get larger to match. Heidebrecht explains the problem...

> "The primary problem with using PGA as a measure of damage potential is that it only represents that potential for very low period structures, usually those with periods of about 0.2 sec or shorter. Since most engineered structures have periods of 0.5 sec or higher, it is inappropriate to use PGA as the single measure of damage potential."

At times high accelerations have little practical effect. He gives a very good example of an aftershock, magnitude 5.0 (mainstruck was 5.7) in a remote area of New Brunswick, Canada 31/3/1982 which generated several strong motion records with fairly high PGA including one of 0.4g BUT

> "... the crockery in a hunter's cabin very near the epicentre was undisturbed and the earthquake caused no discernible damage anywhere."

The reason for this is that the peaks of the response spectra are at very short periods below 0.04 sec as shown in Figure 1 below.

This phenomenon partly explains why the Code forces specified have not risen to meet the larger and larger accelerations being recorded. As Heidebrecht points out ... "While the historical trend (for NBCC and NZS) (*and Australia also*) has been to move towards a more explicit and more rational use of ground motion parameters in determining seismic design forces, the actual levels of those design forces have remained more or less constant during a period of about 40 years, independent of changes in parameter (PGA to PGV), changes in methodology and changes in probability level".

This still leaves the matter of the changes in the probability level adopted in the various codes to a common standard, the 10% in 50 year probability of exceedance is becoming an internationally accepted reference level which is now being used by a number of countries. This is only a problem because as he says "...many engineers still believe in a direct linkage between the levels of motion and design forces".

On this point Heidebrecht says, and I agree, that it does not matter much what probability level you use to determine the level of ground motions. You just adjust the results anyway so you might as well use the 10% in 50 year one. But I disagree when you use it (because it is such a short time scale) to determine the hazard for Zoning if you are using a Zone Zero or a Zone A. That is why we used the long period of 6000 years in the zoning criteria of AS2121 (see p12 and 13 of AS2121-1979).

And maybe it is worse when you do not think you are using Zone Zero when in fact you are, as may happen in the current Australian Code. The end result in some cases is to do nothing extra, because you are not required to do anything specific by the Code. Perhaps you might think you have designed for some earthquake resistance, i.e. for significant lateral forces, when you have not really designed for any at all. The concept of Zone Zero seems more transparent to me in such cases. Similar results might also ensue for non-ductile fabrications in a Zone A type situation and no additional resistance provided. Your client may not understand your explanations if your code design fails the test

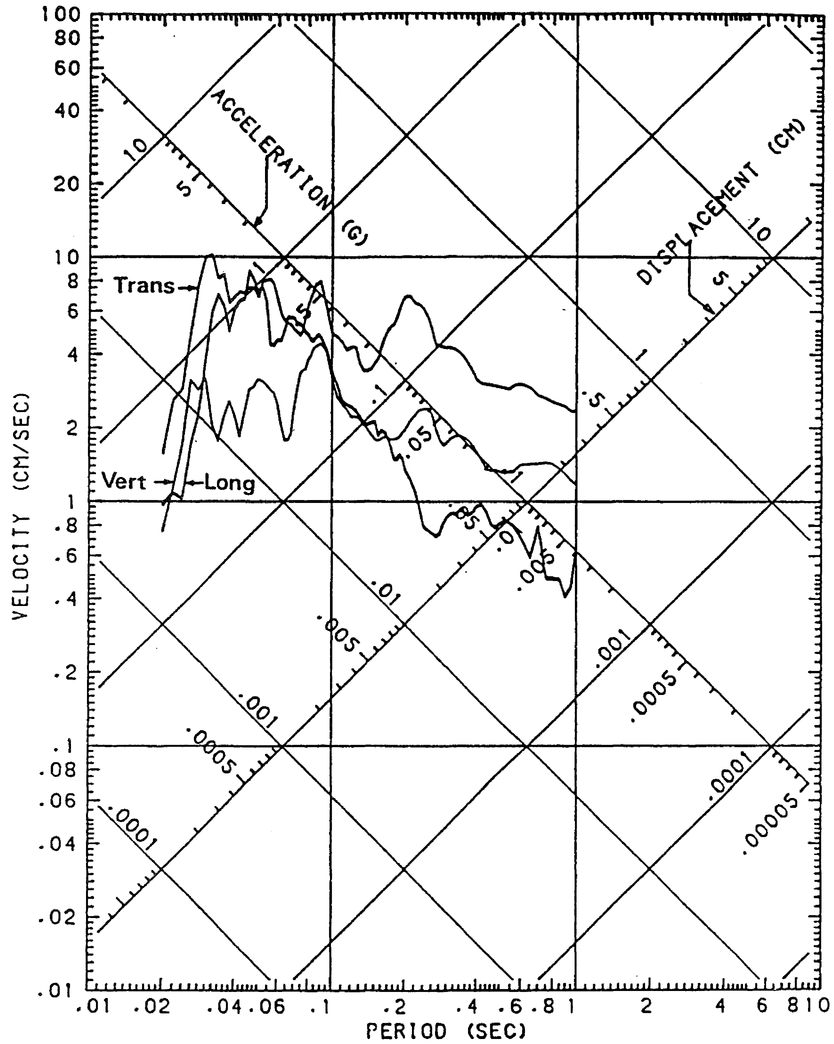

***Figure 1:** Response Spectra (2% damping) for Miramichi Region Canada. The transverse component is the one with the 0.4g PGA (from Heidebrecht (10)).*

of an earthquake. Remember Caracas 1967 where only trivial longitudinal force resistance was provided in many buildings and a moderate shock produced collapse!

For those interested in other codes Heidebrecht also gives in his Table 7 (p. 237) the history of the National Building Code of Canada. The Canadians adopted the American system also using Zones Zero, 1, 2, 3 and with Zone 3 equal to the California level of seismic hazard [10].

9. PROTECT THE EARTHQUAKE DATA BASE

I want first to pay tribute here to the work of the seismologists. Without their basic scientific work and data collection in Australia the work done in earthquake engineering would no have been possible. Even before Meckering enough basic work had been done by Doyle, Everingham and Sutton to set the overall seismicity in context. Their definitive work "Seismicity of the Australian Continent" was in press in 1968 when the Meckering earthquake happened. Some thirty years later we can say with some confidence that in the past 100 years there have been no more than 20 earthquakes of magnitude 6 or greater on our continent. Say about 1 every 5 years. Compare this with David Denham's 1976 statement "The rate of occurance of about on (mag. 6) every five years contrasts with a world average of about 140 per year" [11].

The earthquake data base and the instrumentation and the interpretation of the data has always been strongly supported at the national level by the seismologists of the former BMR and continued by them within AGSO. Similarly by others in the various State and University seismologists agencies. In the past such work seemed sacrosanct but times have changed.

One pressing need is the need to protect the database we have now. In other disciplines and other fields of engineering data collection has been tested against the use pays doctrine. A most valuable helpful and practical guide here is "At What Price Data". Even though it deals with the field of Coastal Engineering rather than engineering seismology, the principles are the same [12].

We must protect our ability to gather more data on a continuous basis. We must prevent the databases and the data collection from being stopped or compromised in the name of so called economic rationalism or other short term (short sighted?) economic principles. That is essential.

10. A NEW PROPOSAL TO ASSIST EMERGENCY SERVICES

Up to this point we have been looking back to past events, and our present position. That is how we got to be here, and what led us to our present situation. But we need to do more than that. So now I want to look at where we might go from here. What do we lack and what we might yet achieve.

One thing we lack is the ability to predict an earthquake disaster before it happens. From my reading of the literature this is not something we should expect to do in Australia. The precursors here will be more difficult to find because of our lower level of seismic activity. If prediction can be done at all, which seems very doubtful, then it will be done in more active regions first. Therefore I personally would not recommend giving any priority to work on prediction of earthquakes in Australia. By that I mean predicting individual earthquakes and issuing public warnings of damaging events.

Of course, I am all for predicting seismicity from past frequency of earthquakes, in a word Zoning for risk. And we need to always be careful to periodically review our basic assumptions in the light of new evidence and findings elsewhere in the world. For example, the basic assumption that the distribution of large earthquakes in time is random is always worth re-examining [13].

But, perhaps paradoxically, because or even in spite of our lower level of seismicity we might be able to make some progress in predicting damaging earthquakes AFTER a mainshock. That is in predicting aftershocks. This might be of more use to us than it is to other regions because we may have a different pattern of aftershocks. For example, we do not always have them. We do sometimes have foreshocks too, of course, and excluding that possibility could constitute the main problem.

Let me outline the current situation. As we approach the ninth anniversary of the tragic Newcastle Earthquake knowledge of the likelihood of a damaging aftershock following a damaging Australian earthquake is no better now than it was then. Still, emergency personnel especially, must decide what precautions they should place on normal business and personal access. Parts of Newcastle were severely restricted in use and general access was limited by the expectation of at least one damaging aftershock, which did not eventuate.

Some of us were primarily involved in assigning a high probability to a damaging aftershock and so we have first-hand knowledge of the data available then. The decision had to be made on general background information without the benefit of any specific Australian study or review of even the general type of earthquake. The decision, made some considerable time later to resume normal operations was made on generalities also. If those decisions had to be made now, as I write, they would have to be made on the same basis, namely on generalities not based, as they should be, on a study of the specific Australian conditions of shallow intraplate earthquakes and their usual aftershock sequence.

My proposal is therefore that a preliminary study be made of available data to determine if any defining parameters can be found which could be used to guide such important decisions. Guidance, if achievable, would be in terms of probabilities within a timeframe, not in deterministic format. A forecast rather than a prediction. Whatever the result of the study it would enable such decisions to be better founded that they are now and also to guide the direction of future data collection.

Perhaps a warning would be in order here, or at least a counsel of prudence. Any individual giving a warning would need either legislative protection, a large insurance policy, a very deep pocket or a lot of courage. If a damaging aftershock occurred when assurances had been given or even if one did not occur when forecast, massive compensation might be sought. In California, I believe, the USGS has undertaken such forecasts for some years. But they have been very careful to act only under the protection of State laws and procedures which indemnify them. We would need such procedures in place here before going much further but we should begin studies and data collection now.

11. CONCLUSION

So we and our predecessors have put in place earthquake engineering measures intended to be the best for Australian circumstances. We have not solved the matter of existing facilities but where our measures have been adopted in full then we believe life protection has been provided. That protection began with the primary aim to save lives. Then we began to consider reducing the loss from damage also. Next perhaps we might try and produce special individual facilities which would survive almost unscathed. To enable communities to recover much more swiftly than they can now.

We can and should try for such noble goals.

But perhaps we should also end on a note of caution. "It is drawn as a lesson from major global disasters that it is total collapse of structures that cause massive life loss. In the absence of total collapse, lives are reasonably secure" [7].

Finally it is essential to remind ourselves again of the need for the standard of construction and construction supervision to fit the purpose design intent – if this is not provided the additional cost built into the design will be wasted" [7]. Aim high by all means, but for now do not promise too much until our work has been tested in significant earthquake events. I suspect that our clients already expect more of our skills than we can deliver in the real world.

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