EARLY HISTORY OF SEISMIC DESIGN AND CODES IN AUSTRALIA

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ABSTRACT: *This paper discusses the early history of earthquake codes, standards and seismic design in Australia including the publication of AS 2121 in 1979 and the first edition of AS 1170.4 in 1993 and how it has impacted on the design community. When AS 2121 was first introduced, it was limited to projects designed by the Commonwealth Government throughout Australia through the Department of Housing and Construction, for buildings and houses in the Meckering area in WA. It was then introduced into SA in 1983 for buildings over 12 m in height.*

The Newcastle earthquake in 1989 showed that seismic design for buildings in Australia was urgently required and indeed hastened the work of the subcommittee for the new earthquake loading code AS 1170.4. However, it was not until the publication of AS 1170.4 in 1993 and its adoption in 1994 in the BCA, that structural engineers started to become familiar with the design principles for seismic loads although it was still to take another 10 to 15 years to be fully accepted by the design community. Unfortunately, there is a new generation of owners, designers, and contractors some of whom still believe that earthquake design is not required in Australia.

KEYWORDS: Seismic Codes, Earthquakes, AS 2121, Newcastle earthquake, AS 1170.4.

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INTRODUCTION

History is not only about looking backwards, but it is also used when looking to the future see what we did in the past. The reason for writing a history of seismic design and Codes and Standards in Australia is that in the future when we are looking at recycling buildings and reusing them, we need to understand when the building was designed and what sort of seismic resistance the structure may have. This resistance, in turn, will depend on when the structure was built and the material used.

Just because the structure was built before seismic design was carried out does not necessarily mean that it will not resist some seismic loads, but its robustness and seismic resistance will depend on many factors. Also, those people involved in the early days of seismic design are rapidly disappearing, and if this history is not recorded now, then it is lost forever.

In the early days of structural engineering in Australia, Australian Standards were known as Codes of Practice or simply Codes to engineers. When the Building Code of Australia (BCA) was introduced in 1996, and to avoid confusing the word, Standards Australia replaced the word Code with the word Standard for all their publications. Therefore, we have used the word Code before 1996 and the word Standard from 1996.

John Woodside first became involved in seismic engineering in the early 1980s with the adoption of AS 2121 in South Australia. He worked for the firm of John Connell Associates (JCA) at that time. They were leading structural engineering consultant in Australia and they designed number of reinforced concrete multi-storey buildings in that era in Adelaide. Therefore, he had to learn very quickly how to design reinforced concrete buildings for seismic loads.

Structural engineers struggled in the early days using the new earthquake code with the new concepts and indeed the design principles required, as it was something they had never considered before. Structural engineers had to try and understand how the structure of the building might fail and then design it not to fail. It also was in an era when computations were prepared by hand with only computers with limited capacity, often using Basic or Fortran programs written by structural engineers, compared to the sophisticated structural software and computing power available today. Designers can now model buildings in three dimensions and see how they perform under various lateral loads and even remove selected members.

HISTORY OF EARTHQUAKES IN AUSTRALIA

We are lucky in Australia that some very dedicated seismologists have been studying earthquakes for many years and have provided wise advice, often at no or limited cost to structural engineers such as Kevin McCue [1], who began work at the BMR's Geophysical Observatory at Mundaring WA in 1968. He departed for Canberra just 4 days before the Meckering earthquake on 14 October 1968.

Thanks to Charles Bubb, he commenced a postgraduate degree in engineering seismology at Imperial College London under Professor Ambraseys in 1970, and his first project was to compile a history of Australian earthquakes, building on the work of many seismologists before him such as Doyle, Everingham, and Sutton [2]. The card deck of earthquakes so compiled became the basis for the Bureau of Mineral Resources' (now Geoscience Australia) first computerised earthquake data file.

Prominent geological faults testify that continental Australia has had earthquakes since its creation. The original aboriginal occupants had no written records. One, therefore, must use paleoseismology to determine when and where large earthquakes occurred before European settlement in 1788 and Geoscience Australia is currently actively engaged in such a project.

The first report of an earthquake in Australia was made by Governor Phillip in June 1788 in Sydney, and soon after the establishment of settlements in Tasmania, South Australia, and Western Australia local earthquakes were felt there. Since then earthquakes have been regularly reported in newspapers and elsewhere until the first modern seismograph was deployed at Riverview College, Sydney by the Jesuits in 1909. It was not until the 1950s that seismographs were distributed more widely throughout the Commonwealth by governments and universities.

Such was the public interest in natural phenomena including earthquakes around 1880 that a committee of the Australasian Association for the Advancement of Science was formed decades before the first seismometers were invented to study this phenomenon, their observations most important. It had taken another century before Australian engineers became interested.

Of course, there has been much written about Australian earthquakes over the last hundred years or so and a historical list of some of the most significant earthquakes from Geoscience Australia includes the following:

- 2015 - Queensland - Fraser Is M5.4
- 2012 - Victoria – Moe M5.4
- 2011 - Queensland – Bowen M5.4
- 2010 - Western Australia – Kalgoorlie M5.0
- 2000 - Victoria - Boolarra South M5.0
- 1997 - Western Australia - Collier Bay M6.3
- 1992 - Northern Territory - Arnhem Land M5.4
- 1989 - New South Wales – Newcastle M5.6
- 1988 - Northern Territory - Tennant Creek M6.3, 6.4 & 6.7
- 1986 - South Australia - Marryat Ck M5.8
- 1979 - Western Australia – Cadoux M6.2
- 1979 - Western Australia – Broome M6.5
- 1973 - New South Wales – Picton M5.6
- 1970 - Western Australia – L McKay M6.0
- 1968 - Western Australia – Meckering M6.8
- 1961 - New South Wales – Bowral M5.6
- 1954 - South Australia – Adelaide M5.6
- 1949 - New South Wales – Dalton/Gunning M5.6
- 1946 - Tasmania - West Tasman Sea (Flinders Island) M5.7
- 1941 - South Australia – Simpson Desert M6.5
- 1941 - Western Australia – Meeberrie M6.9
- 1934 - New South Wales - Dalton/Gunning M5.6
- 1929 - Western Australia - Offshore Broome M6.5
- 1920 - Western Australia – off the SW coast M6.0
- 1918 - Queensland – Bundaberg M6.0
- 1906 - WA - Central Coast M7.2
- 1902 - South Australia – Warooka M6.0
- 1897 - South Australia – Beachport M6.5
- 1883-1892 - Tasmania - West Tasman Sea Earthquake Swarm largest M6.8

The following should also be noted about Australian earthquakes.

- The largest known Australian earthquake had a magnitude of about 7.2 (equal in size to the largest earthquake in 2010 in the Canterbury NZ sequence of 2010-2015).
- The return period of a magnitude 6.2 earthquake (the size of the most destructive earthquake in 2011 of the Canterbury NZ sequence of 2010 - 2015) is about 10 years.

A magnitude 7 earthquake has a fault slip area about 100 times and released seismic energy about 1000 times that of a magnitude 5 earthquake. A shallow thrust-type magnitude 6 earthquake in Australia is the same as a shallow thrust-type magnitude 6 earthquake in New Zealand; only the foundations may be different.

HISTORY OF EARTHQUAKE ENGINEERING BEFORE AS 2121

We are fortunate that Charles Bubb, discussed later in this paper, has written about earthquake engineering in Australia before Meckering and after Newcastle [3].

The design of structures for seismic loads started in Australia after the Second World War, as engineers from the Commonwealth Department of Works had to design buildings, dams, roads, airports and bridges in the Territory of Papua New Guinea, which was subject to frequent earthquakes, tsunamis, and volcanoes.

On 1 March 1954, a magnitude 5.6 earthquake occurred south of Adelaide, the second strong earthquake to shake that city in 52 years. It caused three serious injuries and damage to about 3,000 buildings, including collapsed and cracked walls, smashed windows and collapsed chimneys. Some 30,000 insurance claims to total more than $100m in today's costs were made. However, that earthquake was still not enough to get structural engineers thinking about seismic design.

Figure 1: *Failure of masonry to housing, Adelaide. Photograph courtesy AEES.*

Possibly the first Australian document on seismic design was *The Design of Buildings in Areas Subject to Earthquakes,* titled Comworks Technical Instruction 5-A-21. It was published by the Commonwealth Department of Works in 1961 and subsequently revised in 1964 and 1965. A new series S3 was issued in July 1969. However, it did not apply to Australia.

CHARLES BUBB 1928 - 2015

Australian structural engineering in general and seismic design, in particular in Australia, owes an enormous debt to Charles Bubb [4] B.E., D.I.C. (Eng.Seis), F.I.E.Aust.

He was heavily involved in advancing the structural engineering profession in many areas from the 1960s through to the late 1980s including the adoption of limit state design, wind design and there is no doubt Australia has led the world in wind engineering as the results of his efforts. He was also responsible for leading Australia in seismic design in an era when it was not fashionable or even well understood by most structural engineers.

Charles Thomas James Bubb was born and educated in Perth, Western Australia. He graduated with a civil engineering degree from the University of Western Australia in 1950 and was later awarded a postgraduate diploma in engineering seismology from Imperial College in 1970. He has had an outstanding professional career most of it in Melbourne with the Commonwealth Department of Works which later morphed into the Department of Housing and Construction but with stints in between at the HEC Tasmania and in Port Moresby Papua New Guinea. His career was cut short when the Government scrapped the Department in 1987.

He was appointed Chief Structural Engineer in 1977, and then Director of Engineering at the Commonwealth Department of Works in 1979, the position he held until his retirement in August 1987.

After his retirement, Charles continued to serve on various high-level committees of Standards Australia and Engineers Australia.

Charles was one of the primary drivers of Australian earthquake engineering research following the 1968 Meckering earthquake in his role as Chairman of the Australian National Committee for Earthquake Engineering from 1971 to 1976, and then inaugural president of the Australian Earthquake Engineering Society (AEES) from 1990 to 1995, Figure 2. Charles led the development of the first Australian Earthquake Code AS 2121 in 1979 and was a significant contributor to the Australian Wind Loading Standard AS 1170.2.

It was in the then Territory of Papua New Guinea that Charles learned about earthquakes and wrote the first Technical Notes there to guide seismic design, little realising that soon after his return he would be shocked by the Meckering earthquake in his home state, a major earthquake that destroyed the town of Meckering and did considerable damage in Perth, about 120 km to the west. It was the first earthquake known, at the time, to rupture the ground surface in Australia causing a 35 km long fault scarp up to 2m high which cut the main east-west railway and highway and the Mundaring – Kalgoorlie water pipe as shown in Figure 3.

***Figure 2:** Charles Bubb and his wife, Vicki. Photograph courtesy Kevin McCue.*

This led him well into earthquake engineering although his other area of interest of cyclones was to engage him after Cyclone Tracy wrecked Darwin in December 1974 as the Commonwealth Department of Works was responsible for the reconstruction of Darwin.

Charles encouraged and promoted research into wind engineering at Melbourne University and developed an interest in tornadoes and tornado risk in Australia, not a popular topic at that time. He introduced computer-aided design into the Department when computers were massive and basic and well ahead of its adoption by the private sector.

Charles, picking his time, initiated the formation of AEES in 1990 immediately after the Newcastle earthquake of December 1989 with Kevin McCue, and he handpicked David Rossiter to form a committee which then applied to become a technical society of IEAust. Charles was very much a strategic thinker; the merger into IEAust was a prelude to seeking affiliation with the world body IAEE. He prided himself on being able to pick trends and to make lasting relationships which would serve him well.

Figure 3: *The fault scarp at Meckering. Photograph courtesy of AEES.*

MECKERING EARTHQUAKE 1968

At 10.59 am WST on 14 October 1968, on a public holiday, the small agricultural town of Meckering about 120 km east of Perth was largely destroyed by an earthquake. The magnitude 6.8 earthquake was felt throughout south-west WA and caused damage to the surrounding towns including York and Northam, and in the Perth metropolitan area.

Unfortunately, a lot of this damage in Perth was not fully recorded although a cross fell from St Mary's Cathedral and St Georges Cathedral suffered some cracked windows, some damage to brickwork and the roof, which leaked over the crossing, leading to the fleche being removed. [5]

Before the earthquake, Meckering had about 78 buildings, and only 18 survived, and the badly damaged hotel is shown in Figure 4. Approximately 20 people were injured. The earthquake produced 35 km of ground rupturing shown in Figure 2 and where the fault crossed the highway, the road had an approximately 1.5 m high step in it. Railway lines were buckled, and a water main was folded in upon itself.

The Insurance Council of Australia estimated the damage at $1.5 million.

This was the first earthquake to make perceptive structural engineers including Charles Bubb consider what was needed to be done about designing structures for earthquake loads in Australia.

Figure 4: *The damage to the Meckering hotel. Photograph courtesy of AEES.*

AS 2121 - 1979

The Meckering earthquake provided the impetus to commence earthquake engineering in Australia with collaboration between various parties to try and understand what was required. A National Committee for Earthquake Engineering was assembled. Professor Stan Shaw from the UNSW School of Civil and Environmental Engineering with his skills in the area of structural engineering was appointed the chair of the Australian National Committee for Earthquake Engineering (ANCEE). He was also the first Australian National Delegate to the IAEE.

At its first meeting, the ANCEE set up two working sub-committees, ANCEE/1 on Code requirements chaired by Charles Bubb, and ANCEE/2 on seismicity chaired by Dr. David Sutton from Adelaide University initially and then Dr. David Denham from BMR.

Two seminars on earthquake engineering were organised by Standards Association of Australia on the 1st April in Adelaide, and the 2nd of April in Perth in 1974, to discuss the need for a Code for seismic design. At these meetings, Charles Bubb presented *"An Introduction to the Draft Code for the Design of Earthquake-Resistant Buildings*. The seismologists Denham, Underwood, and McEwin distributed the so-called *'pink pages,'* a set of preliminary earthquake intensity zones later published in the BMR Journal, as the first earthquake zone maps for Australia [6] but quite different from those eventually to be included in AS 2121 shown in Figure 4.

There is no doubt that the structural engineering consulting fraternity was not all that interested in the subject at that time, as it added cost and complexity to projects, and it was new.

Because of these seminars, and the persistence of those involved and, in particular, the efforts of Charles Bubb, this finally led to the publication of Australia's first earthquake code. This project included many meetings of the Committee BD/12, and Standards Association of Australia published the first Australian Earthquake Standard AS 2121 [7] in 1979. Charles was the chairman of the code committee responsible for AS 2121.

Those parties involved in the code included the following:

- Association of Consulting Engineers, Australia
- Australian Atomic Energy Commission
- Australian National Committee on Large Dams
- Australian Road Research Board
- Bureau of Mineral Resources, Geology and Geophysics
- Bureau of Steel Manufacturers of Australia
- Brick Development Research Institute
- Concrete Institute of Australia
- Concrete Masonry Association of Australia Co-op Limited
- CSIRO, Division of Building Research
- Department of Housing and Construction
- Department of Public Works, Western Australia
- Electricity Supply Association of Australia
- Experimental Building Station
- Geological Society of Australia Incorporated
- Hydro Electric Commission, Tasmania
- Insurance Council of Australia
- Public Buildings Department, South Australia
- University of Adelaide

The Code was based on following documents:

- Seismology Committee, Structural Engineers Association of California (SEAOC) - 'Recommended lateral force requirements and commentary,' 1977 edition [8].
- International Conference of Building Officials, California, U.S.A. - 'Uniform building code,' 1976 edition. [9]

AS 2121 was both a loading and design code. It included a commentary and was applicable for most common general-purpose types of structures. It did not include bridges, housing or special structures. It was written as a self-sufficient code including loadings, foundations, structural response, material behaviour, seismic zoning and commentary in a single volume

A series of seismic zones were introduced into Australia varying from seismic Zone Zero, Seismic Zone A, 1 and 2 with seismic Zone Zero being the lowest as shown in Figure 5. There were no requirements for earthquake resistant design for buildings in Zone Zero and with the other zones increasing requirements. These were shown on the seismic zone map for Australia below.

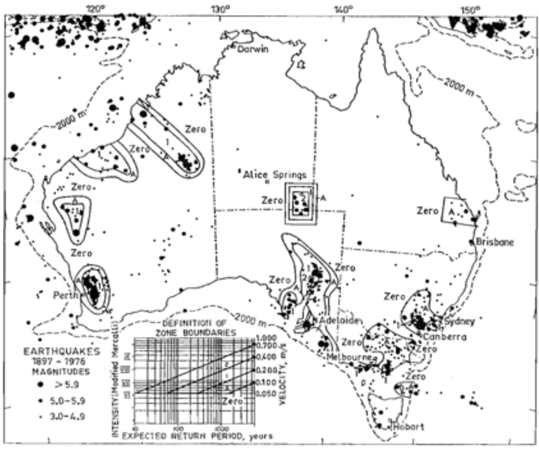


Figure 5*: Zone Map from AS2121.*

These zone numbers (apart from A) were deliberately chosen to be similar to those in use in the US Uniform Building Code with a doubling of the minimum design forces between 2 and 1. There was no zone 3 in Australia as was used in California.

Zone Category A was introduced to restrict loadbearing brick construction (with very low damping) for multi-storey apartment buildings in Perth where several buildings up to 10 stories had been erected on Mill Point Road. The construction of such buildings was possible under the new Code, but the forces were so large that they were thought to be technically economically unfeasible. Unfortunately, that trend has still continued, particularly in Perth.

In AS 2121, the principles of seismic design were introduced, and designers were required to determine the characteristic site period which involves consideration of geotechnical profiles before calculating the static forces.

The code also introduced various structural forms including ductile and non-ductile structures and different forms of structures including space frames which could be moment resisting or vertical load carrying with horizontal force resisting systems, dual bracing systems, shear walls, etc.

The Code included the following matters:

- The parts of buildings to be designed for minimum forces.
- The detailing of reinforced concrete and steel in the commentary.
- A considerable number of references to assist designers in understanding the principles of seismic design.

One of the main references in the Code was the book by Blume, Newmark and Corning titled *"Design of Multi-Storey Reinforced Concrete Buildings for Earthquake Motion"* [10] which became our bible in trying to understand what the new Earthquake Standard was about.

JCA also bought the SEAOC *"Blue Book."* From its first edition in 1959 through the 1970s, the Blue Book was the de facto precursor of UBC earthquake provisions used throughout the western United States and in many places overseas. Also, the technology for design including dynamic analysis and frame programmes were only coming into being and analysis was generally by hand, was time consuming and complicated.

AS 2121 was adopted by the Department of Housing and Construction in March 1984 for all of their projects and as they did most of their engineering in-house outside engineers would have had limited experience in seismic design.

The *"Australian Model Uniform Building Code"* (AMUBC), was first released by BCA in the early 1970's and used by the states and territories with local variations. The ABCB released the performance based BCA (BCA96) in October 1996. BCA96 was adopted by the Commonwealth and most states and territories on 1 July 1997, with the remainder states and territories adopting it by early 1998.

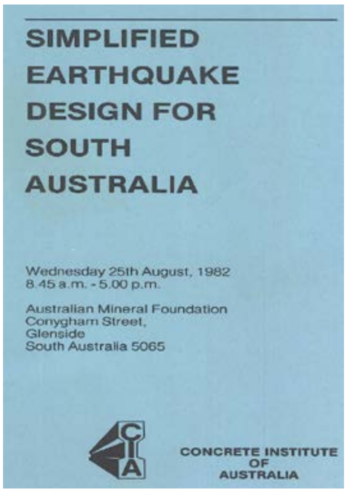
The WA government required earthquake design to AS 2121 in the Meckering area only and in South Australia. AS 2121 was incorporated into the SA Building Act on the 22 December 1982. However, buildings under 12 m in height were not required to be designed for seismic loads except where they had a post-disaster function. It is also understood that some local government councils such as Wollongong Council adopted the Code because of their experience with earthquakes (in 1961 and 1973).

AS 2121, unfortunately, was largely ignored by the design and building community including structural engineers and the building regulators. It was only brought back into focus as a consequence of the Newcastle earthquake in 1989.

In Canberra in 1972, the Black Mountain telecommunications tower was designed by CommWorks to resist earthquakes using a computer program DYFRAM. The tower was modelled as a lumped mass system using modal superposition with viscous damping and earthquake return periods of 250-1000 years.

The first commercial building in Adelaide thought to be designed to AS 2121 was the SGIC Building shown in Figure 6 in Victoria Square which was designed to a draft of AS 2121 by JCA. It was completed in 1981.

Figure 6: *SGIC Building Adelaide. Photograph courtesy John Woodside.*



SIMPLIFIED
EARTHQUAKE
DESIGN FOR
SOUTH
AUSTRALIA

Wednesday 25th August, 1982
8.45 a.m. - 5.00 p.m.

Australian Mineral Foundation
Conygham Street,
Glenside
South Australia 5065

CONCRETE INSTITUTE
OF
AUSTRALIA

Figure 7: *Getting prepared for earthquake design 1982 in SA. Photograph courtesy John Woodside.*

Other multi-storey buildings designed in Adelaide in that era to AS 2121 by JCA, included the Mail Exchange Building, Grenfell Street (18 Storeys), Chesser House, Grenfell Street (12 Storeys), Australis building Grenfell Street (21 Storeys), STA House, North Terrace (12 Storeys), Rivers Building, Currie Street (12 Storeys) and the Flinders Major Communications Building, Flinders (5 Storeys).

AS 1170.4 (1993)

In 1987, there was a discussion with Standards Association of Australia regarding the Seismic Zone Map of Australia and reconstituting the committee BD/12.

Standards Australia in 1988 decided to revise AS 2121, and the committee BD/12 for AS 2121 was formally disbanded although it had been inactive for some years. A new sub-committee was assembled during that year prior to the Newcastle earthquake, consisting of representatives of Government Departments, both State and Federal, seismologists and engineers and other interested parties including;

- Australian Uniform Building Regulation Consultative Committee
- Australian Construction Services, Department of Administrative Services
- Bureau of Mineral Resources, Geology and Geophysics
- Cement and Concrete Association of Australia
- Department of Housing and Construction (SA)
- Department of Mines and Energy (SA)
- Department of Resource Industries {QLD)
- Division of Building, Construction and Engineering, CSIRO
- Institution of Engineers Australia
- Insurance Council of Australia
- Phillip Institute of Technology (VIC)
- Public Works Department (NSW)
- Steel Reinforcement Institute of Australia
- University of Adelaide (SA)
- University of Queensland (QLD)

In May 1987 at an informal meeting of Dr. J Nutt, Mr. E Go and Mr. H Isaacs, Dr. John Nutt who was chairman of BD/6, suggested that the chairman was a practising engineer, preferably from South Australia or Western Australia.` [11]

John Woodside was approached to be chairman of the new subcommittee in August 1989 by Mr. Eddy Go which he accepted.

The committee was to be made up of 11 persons including practising engineers, statutory representatives, engineers and seismologists from government departments geotechnical experts, specialists, and the resource and insurance industries. John Woodside was chosen to be chairman because he was one of the few structural engineers in Australia who had had experience in designing of buildings for seismic loads other than the Australian Construction Services, the remnants of the former Department of Housing and Construction.

The subcommittee known as BD6/4 was part of the SA Committee BD6, which is responsible for all the loading Standards for buildings in Australia.

The terms of reference were that the subcommittee was to prepare and maintain an Australian Standard on load effects due to earthquakes (to become Part 4 of AS 1170) and give guidance on design rules earthquake-resistant structures

The new Earthquake Standard was to be a Loading Standard, part of the AS 1170 Series of Loading Standards. The use of specific materials such as timber, masonry, concrete, and steel was not to be included as in AS 2121 but were to be part of the various material standards. Nor was the commentary included in the Standard. The new standard was to be titled 'AS 1170.4 - Minimum Design Loads on Structures, Part 4 – Earthquake Loads' [12].

The final list of the Standards Committee members was:

- Dr. Lam Pham - Division of Building, CSIRO, Melbourne
- Prof Graham Hutchison - Department of Civil & Agricultural Engineering, University of Melbourne
- Mr. Kevin McCue - Australian Geological Survey Organisation, Canberra
- Mr. Gary Gibson - Seismology Research Centre, Royal Melbourne Institute of Technology, Bundoora, Melbourne
- Mr. Bill Boyce - Cameron McNamara (Qld), Brisbane
- Mr. Gerhard Horoschun - Australian Construction Services (ACT), Canberra
- Mr. Bob Potter - Technical Manager, Cement and Concrete Association of Australia, Sydney
- Dr. Mike Griffith - Department of Civil Engineering, University of Adelaide
- Mr. Rob McPharlan - Kinhill, Melbourne
- Dr. Steve Lawrence - Division of Building, CSIRO, West Ryde, Sydney

- Dr. Jim Loke - Public Works Department, Sydney
- Mr. Norm Gilchrist - Australian Uniform Building Regulations Coordinating Council (AUBRCC), Perth
- Mr. George Capentanaksis - AUBRCC, Adelaide
- Mr. Jim Wilson - SACON, Adelaide
- Mr. Norm Griffiths - Australian Insurance Council, Melbourne
- Mr. David Love - Department of Mines and Energy, Adelaide
- Mr. John Woodside - Connell Wagner (SA) Pty Ltd (Chairman), Adelaide
- Mr. Eddy Go - Standards Australia (Secretary), Sydney

The subcommittee, BD/6/4 first met on Tuesday the 12th of December 1989 in Adelaide, about the two weeks before the Newcastle earthquake on the 28 December 1989.

There is no doubt the Newcastle earthquake changed the attitude of those in the building industry, including regulators, to the risk of earthquakes and the damage that could occur in Australia. To misquote a former Australian Prime Minister, it was *“the earthquake we had to have.”*

The Newcastle earthquake also resulted in considerable discussion and more interest in research for half a decade. It also confirmed that many of the lessons learnt from overseas earthquakes such as the failure of un-reinforced masonry, the amplification of forces in soft soils and the impact of such a disaster on a community, that occurred in Newcastle.

At the first meeting of the earthquake loading code subcommittee, one of the crucial decisions made was whether they were to write a specific standard for Australian conditions or take the previous path of adopting an overseas code. After considerable discussion and because Australia only carried out limited research in earthquake engineering principally at Adelaide and Melbourne universities and through the research arms of organisations such as the Australian Geological Survey Organisation, the latter course was adopted.

The subcommittee based the new Code on *“Tentative Provisions for Development of Seismic Regulations in Buildings, ATC–3–06” (Second Edition)*[13], prepared by the Applied Technology Council of the USA. Information was also taken from the National Earthquake Hazard Reduction Program (NEHRP) Document *“Recommended Provisions for the Development of Seismic Regulations for New Buildings”* 1985.

Standards Australia advised had to be written in limit state format to suit other loading and material standards that had changed to this format.

The Australian Uniform Building Regulations Consultative Committee (AUBRCC) advised they would not accept the Standard as a loading code for the BCA without domestic housing being included, and this objective was met by ensuring that housing was designed for a minimal lateral force and was tied together.

The subcommittee also made the decision they would not use the previous zones of AS2121 because of the large jumps between zone values but would develop a contour map of hazard for different return periods. This would avoid the argument of designers suggesting their project was on the lower side of the boundary resulting in the lower force conditions and is also in line with what is used in New Zealand and the US in their earthquakes codes.

For the first time, every Australian seismologist involved in the social problems caused by earthquakes, the observation of local earthquakes and media commentators as experts, or earthquake hazard assessment for particular projects, was part of the earthquake hazard assessment team. The process was a collegiate one, and in the end, a consensus map was compiled [14] in 1991 shown in Figure 7.

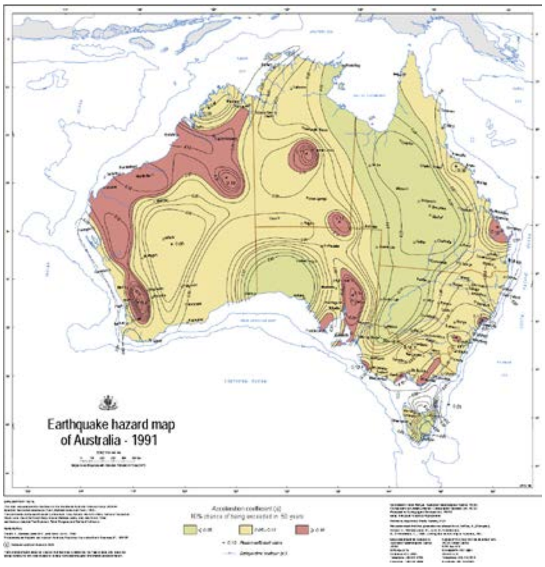


***Figure 7:** Earthquake Hazard Map 1991 courtesy AGSO.*

In his role as chairman of the subcommittee, John Woodside had certain views on the use and layout of the new Code as a practising structural engineer with seismic design experience [15]. The matters which he sought to have included were:

- It had to be a simple Code which was easy to follow and use and for users new to earthquake engineering, one they could readily use and which set minimum standards for earthquake design.
- Recognition that because of earthquake design that buildings and parts of buildings must consider lateral loads and stability. (There was an era in structural engineering up to the 70’s in Australia where lateral stability was largely ignored as wind loads were low, building were usually only a few stories in height and such building had an inherent lateral strength. This was also true of single storey masonry buildings)
- For small buildings typically no detailed earthquake design for lateral loads was required except for detailing, connection, and tying together.
- In most cases for larger buildings for lateral loads, only a static analysis was required and only for large, complex or unusual buildings a dynamic analysis would be necessary.
- A Code where one progressed from front to back of the code without having to find data or design information in following sections and return to earlier sections wherever possible.
- A separate section for domestic construction with only detailing required for most domestic construction. It was hoped at the time that the housing industry would have picked up the section and produced deemed to comply details, but this did not eventuate.
- A separate section for the design of non-structural components including building services and architectural elements. Again it was hoped at the time that the construction industry in Australia would pick up the section and produced deemed to comply details, but these did not eventuate.
- Recognition that masonry was not a suitable material for seismic design unless it was correctly designed for lateral loads and effectively anchored
- If the user reached a certain section of the Code that said that is all that had to be done, then there were no sleeper clauses later to catch designers out.
- A section on the upgrading of existing buildings was included although it was very general in nature.

In many ways, Australia is a lucky country when it comes to earthquakes. Because of its sparse population, most earthquakes occur in uninhabited areas far from our major population centres and those few potentially fatal ones in towns and cities have taken place on public holidays. The 1954 Adelaide earthquake took place when Adelaide was a city of approximately 300,000 people, and the main centre of the earthquake was about 20 km to the south of the city in what was then farming land. If the same earthquake occurred today in or near the CBD, significantly greater damage would result because the whole area now is occupied by housing and commercial buildings.

The 1968 Meckering earthquake occurred mid-morning on a public holiday when most people were out of doors. The 1989 Newcastle earthquake also occurred over the Christmas/New Year period, when many people were away from Newcastle, and the schools and public buildings were closed, and there was a bus strike. If it had occurred on a normal working day at the same time, the death toll would have been significantly higher, possibly 300-500 people or more.

As population and population density increase, the extent of damage caused by earthquakes in Australia will increase.

Standards Association of Australia was also under considerable pressure to have the Standard published because of the Newcastle earthquake and the need to rebuild there. It was unfortunate that after nearly three years of reviews and draughting since the subcommittee first met, there was no new Standard published due to the attempted harmonising with the New Zealand Earthquake Standard.

The first public review of the new standard was issued in about March 1991 with comments closing in July 1991. A considerable number of comments were received, indicating scrutiny by the design community, which was pleasing. The Code subcommittee met to consider the comments and to review and incorporate them as appropriate.

Two of the areas where considerable pressure was brought to bear on the subcommittee was from the AS 3700 code committee and the masonry industry and AUUBRC.

AUBRCC did not like the use of a site factor of 2 in soft soils, but this was rejected by the code subcommittee because overseas experience had shown that soft soils accentuate earthquake forces.

The masonry industry did not like the requirement that for irregular non-ductile unreinforced masonry buildings there was a height limitation of three stories in the new Code. Originally the subcommittee proposed that such buildings would be limited to two stories, but they raised it to three stories to be consistent with the traditional three-storey walk-up flats and units where no lift was provided.

The author was critical of the masonry industry for delaying their response to this matter well after the Code had been published. This height requirement was subsequently amended with a green slip amendment, No 1, to 4 stories for regular structures to soothe the masonry industry. Unreinforced masonry structures of 3 to 4 stories were a common form of construction in Sydney and Melbourne in that era. Indeed, it is understood that the seismic design requirements for many such structures were expediently ignored up until probably the late 1990s. Fortunately, those structures are largely no longer built.

As part of the Closer Economic Relations Agreement between Australia and New Zealand, Standards Australia and Standards New Zealand were moving to harmonise various standards. Meetings were held in Auckland in November 1991 and Wellington in February 1992. Standards Australia approved the finalising of the Australian Standard on the basis that it would adopt appropriate elements of the New Zealand Standard [16]. It was thought that the new Australian earthquake loading standard would have a finite life because New Zealand and Australia were moving towards common loading standards including a common earthquake standard.

AS1170.4 (2007) was also to be a joint harmonised Standard with New Zealand, however, severe difficulties developed during the drafting process in about 1997/1998. The challenge was how to combine the existing New Zealand Standard developed for a country straddling a plate boundary and with a long history of seismic design to that of Australia with a limited history of seismic design and in an intraplate environment. The design practice and philosophy were quite different between the two countries. In Australia our design reflected a lower seismicity and a country with no capacity design and static stress design [17]. For the academics teaching earthquake engineering to a few specialist postgraduate engineers, and the structural engineering practitioners, this was a road too far to travel in Australia and a simple approach was chosen for AS 1170.4 (1993).

A postal ballot for acceptance of the new Standard AS 1170.4 (1993) was held in 1992 with publication in 1993. After publication, the Standard was incorporated into the BCA as a Loading Code and was gazetted by each State when it became a legal requirement for the design of buildings for earthquake loads.

One of the concerns of the subcommittee was getting the Code accepted by industry and designers. John Woodside, in particular, spoke at number of conferences and other occasions to get across the message that Australia needed a Seismic Code to design buildings.

A seminar series was also presented to future users of the Code by Standards Association of Australia in all the capital cities and Newcastle in September and November 1993. The speakers included John Woodside, Kevin McCue, Prof Graham Hutchinson and Dr. Lam Pham from the code subcommittee.

Materials codes such as the Concrete Standard AS 3600, the Masonry Standard AS 3700 and the Steel Standard AS 4100 also had to be amended to bring them into line with the new Loading Code AS 1170.4 (1993).

With the publication of the first edition of AS 3600 in 1988, the rules for concrete structure subject to seismic action, previously given in various appendices through AS 2121 were gathered together in Appendix A.

John Woodside was also on the AS 3600 committee and assisted as a member of the working group for the first edition of AS 3600 in incorporating the seismic detailing from AS 2121 into the new concrete standard as Appendix A. This work was based on AS 2121 and the 1997 UBC and then current version of ACI 318 from the USA.

In 1997, a working group was re-established for the next edition of AS 3600 to comply with AS 1170.4 (1993). This work was incorporated as Appendix A in the second edition of AS 3600-1994. The third edition of AS 3600-2001 continued the Appendix A, again consistent with AS 1170.4 (1993).

The fourth edition of AS 3600 published in 2009 and Appendix C was rewritten for AS 1170.4 (2007) although this is not recorded in the preface. Unfortunately, it does not appear that any significant effort was made to bring this section of the current standard up to current practices and in line with the current version of ACI 318.

As Charles Bubb has pointed out, one of the unfortunate aspects of separation of the earthquake code AS 1170.4 (1993) into a loading code only and not including the materials is that the committee members of the materials standards may have little experience or interest in the response of structures to earthquakes loads [18]. As a result, the relevant clauses can be delegated to subcommittees with limited representation and understanding of the risk of earthquakes, remembering that detailing is often the most critical element in any design for seismic loads. The provisions developed may not be entirely appropriate for the level of risk assumed in the loading code.

As an example, a recent review of AS 3600-2009 [19] has shown some errors and omissions in the earthquake detailing requirements compared to the current version of ACI 318, which AS 3600 relies heavily on. These matters are currently being considered by the AS 3600 committee. It is therefore strongly recommended that each of the materials standards ensure that they have several representatives on their subcommittee who are specialists in earthquake research or design, and, at least, one member who is on the subcommittee for AS 1170.4.

NEWCASTLE EARTHQUAKE 1989

At 10:27 am on 28 December 1989 one of Australia's most serious natural disasters occurred when an earthquake shook Newcastle, NSW measuring magnitude 5.6 resulting in 13 deaths and more than 160 people injured. The damage was estimated at A$4 billion, including an insured loss of more than A$1 billion. The earthquake epicentre was about 15km south of the Newcastle central business district at an estimated focal depth of 11 to 12 km. That is a 2 or 3 km^2 area of rock in the Earth’s outer crust ruptured initiating at 11 to 12 km beneath the surface.

Figure 8: *Collapse of Workers Club. Photograph courtesy Newcastle Council Earthquake Collection, Newcastle Region Library Ref No. 046 000 544.*

The effects were felt over 200,000 square kilometres with isolated reports of movement in high-rise buildings up to 800 kilometres from Newcastle. Damage to buildings and facilities was reported over an area extending 9,000 square kilometres. The earthquake caused damage to more than 35,000 homes, 147 schools, and 3,000 commercial and other buildings and structures. At the height of the crisis, between 300 and 400 people were housed in temporary accommodation. In the month following the earthquake. Kevin McCue and others [20] have written much about the earthquake.

This event showed doubters once and for all that earthquakes are a risk that cannot be ignored in Australia and that although the probability of an earthquake is low, the consequences can be significant. The loss of life in Newcastle was very low compared to what would have occurred in a normal working day. Unfortunately, with the old building stock in Australia, it will only take a large earthquake in one of the major city such as Sydney or Melbourne for the loss of life to easily be several thousand people.

At the time of the 1989 Newcastle earthquake, the design of buildings to resist earthquakes with some exceptions noted previously, was not required in Australia. The Newcastle Workers Club was designed and built in the early 1970s and indeed talking to one of the designers afterwards, he said they knew nothing about earthquake design at that time, and it was never considered even though Newcastle had had previous earthquakes.

The Workers Club building collapsed during the earthquake, Figure 8, and it frequently held major events at which hundreds of people were present. Failure was attributed to the progressive collapse of the concrete columns on the western side of the building due to the incorrect detailing of the reinforcement, incorrectly designed and a lack of understanding of the effect of earthquakes on the design of such buildings [21] [22]. The building was subsequently demolished and rebuilt.

The New Royal Newcastle Hospital suffered extensive damage, and two wings were partially closed, and the hospital initially evacuated. It was subsequently demolished in 2007. The new John Hunter Hospital was under construction at the time, and the earthquake caused about $6 million damage and delayed its opening until 1991.

The emergency management of the earthquake in Newcastle was chaotic, and there were no disaster plans for such an event [23]. As a result, a natural disaster was not declared, leaving the Newcastle City Council to cope on their own.

Following the earthquake, AS 2121 Zone A was adopted for Newcastle for the design of new buildings and Zone 1 for post-disaster buildings.

Much of Australia’s building stock would perform in a similar fashion to a Newcastle sized earthquake and many buildings including unreinforced masonry buildings (URM) are the most vulnerable to seismic action.

Consequently, Australia is considered a *'low-hazard'* but *'high-consequence'* country regarding damage due to earthquakes, i.e., the probability of an earthquake occurring in a major city is low, but the consequences, should one occur, are likely to be dramatic. Furthermore, on average, Australia experiences earthquakes of moment magnitude 6 or greater every 10 years on average, releasing at least 4 times as much energy as that of the Newcastle earthquake (magnitude 5.6). At the same distance, the amplitudes of ground motion would be about 2½ times that at Newcastle.

There have been many reports, conferences, and papers on this earthquake [24] [25]. Nine people were killed in the collapse of the Workers Club as shown in Figure 6, another 3 died under collapsed awnings, and the coroner declared that a 13th died of a heart attack as a result of the earthquake.

During the magnitude 6 (Warooka) earthquake in 1902 in South Australia, two people in Adelaide died from a heart attack triggered by the earthquake. Underground miners have also died in Australia as a result of rock bursts or mining-induced seismic events. So Newcastle 1989 was not the first time people have been killed in seismic events in Australia.

The Newcastle earthquake once again demonstrated all the basic principles of earthquake engineering design applied to Australia, and damage occurred due to:

- Failure of unreinforced masonry and, in particular, the failure of galvanised brick ties due to corrosion from the lime mortar.
- The failure of non-structural elements such as ceilings, chimneys, and building services.
- The effects of eccentricity and soft storeys on the performance of buildings.
- Inadequate seismic design including tying together of the structure.

The Australian Earthquake Engineering Society (AEES) was established as a professional society of the Institution of Engineers, Australia, in 1990 following the Newcastle Earthquake.

FUTURE EARTHQUAKE STANDARDS

From research and our understanding of the effects of earthquakes, there is no doubt we will continue to improve our understanding of design for seismic loads. However, we have to have the real evidence from real earthquakes to give us this feedback which can lead to unfortunate damage and loss of life. There is always a continuing need to educate the younger engineers, builders, and owners that earthquake risk is a real danger that cannot be ignored in Australia.

There is a need to install more monitoring equipment on the ground to measure the ground shaking and in buildings to measure their response to earthquakes throughout Australia where earthquakes are undoubtedly different to those in California (mechanisms are different) and probably different from one side of Australia to the other (different foundations leading to different ground motion prediction equations).

After all, how can we design a building to withstand an earthquake when we do not know how the ground shakes; what amplitude of shaking, over what period range and for how long?

CONCLUSIONS

Before 1995, there were only a limited number of buildings, some in Adelaide and some Commonwealth Government buildings that have been designed in accordance with AS 2121 with recognized earthquake design.

Buildings designed after the adoption of AS 1170.4 in the BCA in 1995 should have a reasonable structural resistance for seismic loads. It is likely however that many of the buildings will not have good earthquake resistance for non-structural elements, as the design community has largely ignored this component of seismic design. This is despite the efforts of many to get the design community to recognise their statutory requirements.

Importantly, although not included in AS 1170.4 but set out in the foreword to the Commentary on the Standard is the statement that *"the design of structures to the Standard does not necessarily prevent structural or non-structural damage in the event of an earthquake."* The Standard simply provides the minimum criteria considered to be prudent for the protection of life by minimising the probability of collapse of the structure or parts of it, i.e., Life Safety.

This means the structures will be damaged in a strong earthquake, some of them more seriously than their replacement value, but hopefully, they will not collapse. Both prevention of collapse and sustaining minimal damage may be requirements of future earthquake standards. In addition to the structural design of buildings, we need to include the design of non-structural parts and components to complete the design of buildings.

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To all those who have been involved in the Codes and Standards relating to seismic design, they are to be congratulated on being involved in the early days of seismic engineering in Australia. They have generously given their time and usually at no cost.

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