THE HISTORIC DEVELOPMENT OF EARTHQUAKE ENGINEERING IN NEW ZEALAND

G.J. Beattie[1], L.M. Megget[2] and A.L. Andrews[3]

[1] *Principal Engineer, BRANZ Ltd, Wellington, New Zealand (President NZSEE)*
[2] *Fellow, New Zealand Society for Earthquake Engineering (Retired)*
[3] *Life Member, New Zealand Society for Earthquake Engineering (Retired)*
Email: graemebeattie@branz.co.nz

ABSTRACT :

This paper traces the development of earthquake engineering in New Zealand from the first European settlers to the present day, although focusing primarily on the period from 1931 Hawke's Bay earthquake. The development of building standards over the years will be reported, along with more specific detail on the development of innovative design principles and solutions, such as the employment of capacity design principles, the formulation of engineering-based design standards for house structures, and the development of base isolation systems for structures. The formation of the New Zealand Society for Earthquake Engineering and the role that it has played in the improvement of earthquake engineering practices in New Zealand will also be included.

KEYWORDS:

History, earthquake engineering, standards development

1. INTRODUCTION

While it can be said that opinion may be offered on any matter, historic fact remains fact that cannot be changed. It is therefore admitted at the outset of this paper that much of the information presented has been taken from the writings of our colleagues. Such references are appropriately acknowledged through the paper.

This paper traces the development of earthquake engineering in New Zealand from the first European settlers to the present day, although focusing primarily on the period from the 1931 Hawke's Bay earthquake. The development of building standards over the years is reported, along with more specific detail on the development of innovative design principles and solutions, such as the employment of capacity design principles, the formulation of engineering-based design standards for house structures, and the development of base isolation systems for structures. The formation of the New Zealand Society for Earthquake Engineering and its predecessor organisations and the role that the Society has played in the improvement of earthquake engineering practices in New Zealand is also included.

2. IN THE BEGINNING

New Zealand is a relatively young country with its first European settlers arriving around the 1800's. Prior to their arrival the country was inhabited by the native Maori people, who had lived in the country for many centuries. The buildings of the Maori were fabricated using adzed native New Zealand timbers as the skeletal frame and flaxes and other locally available materials for the cladding. These buildings were low, light and most probably quite good energy dissipaters because of their lashed joints.

The early settlers came mainly from the British Isles and their building techniques replicated the stone and unreinforced masonry structures that had stood so well for centuries in their motherland. There were significant numbers of timber frame houses built in the style of European houses of that time. However, it was the 1848 Marlborough earthquake, estimated magnitude 7.5, centred near Wellington, that severely tested these generally brittle unreinforced masonry structures. Many settlers learnt quickly that stone and unreinforced masonry buildings were not a suitable product for this hostile land.

Seven years later, Wellington was hit again by 1855 Wairarapa earthquake. This earthquake, of estimated magnitude 8.2, is the most powerful ever experienced in New Zealand since European settlement. While many structures destroyed in the 1948 event had been rebuilt in timber, some commercial premises had been replaced with new brick buildings because of the concern about the potential fire risk.

Figure 1 Government wooden Buildings completed in 1876

Unfortunately, the earthquake risk turned out to be greater and once again mass destruction of the masonry buildings occurred. From then on, the majority of new buildings were constructed with timber. An outstanding example of such construction, still standing today, was the four storey wooden Government Buildings, which were completed in 1876 (Figure 1). The exterior of the building imitates a classical European stone building.

As the years passed with little significant seismic activity, the memories of the earlier earthquakes dwindled and unreinforced masonry construction found its way back into vogue, mainly because the fear of the effects of fire associated with timber buildings.

3. THE FIRST CONSIDERATION OF EARTHQUAKES IN DESIGN

In the first quarter of the 20th century, consideration of earthquakes slowly began to emerge in the analysis and design of buildings in New Zealand. News of the 1906 San Francisco earthquake and the Great Kwanto earthquake of 1923 had raised an interest in designers, given that these events had led to the creation of regulations in the respective countries. Interestingly, the first notable New Zealand book on earthquake design was published by an architect, C. R. Ford (1926). In the book, Ford summarized earthquake damage in NZ and in Japan and the USA. Park (1987) suggests that this was probably the first book in the English language that dealt with earthquakes in their relation to building structures. Ford observed that in many New Zealand municipalities by-laws giving requirements for earthquake resistant building construction were commonly defective and he made a number of well reasoned recommendations for the design of building structures for earthquake resistance.

It was most likely that the 256 lost lives in the February 1931 magnitude 7.8 Hawke’s Bay earthquake that spurred regulators into action. The central government set up a Building Regulations Committee comprising prominent engineers, architects and contractors, under the chairmanship of Professor J E L Cull of Canterbury College. Its mandate was to “prepare a report embodying such recommendations as it thought fit, with a view to improving the standard of building construction in the Dominion in relation to earthquake resistance”. This committee produced a report containing a “Draft General Earthquake Building By-law” which was presented to the House of Representatives in June 1931 (Cull 1931) and came into effect immediately. Important features of the by-law included recommendations (endorsing those of Ford) that 1) buildings be designed for a horizontal force equal to at least 0.08 (0.1 for public buildings) of the weight carried by the building, 2) vetting of designs and drawings was required and 3) supervision was necessary during construction. The by-laws required “Every building to be firmly bonded and have its parts tied together in such a manner that the structure will act as a unit.” Masonry walls were required to be tied together at each floor level and footings were required to be interconnected in two directions. Various restrictions on certain building types were detailed and the need for a wide distribution of bracing elements was recognized.

Following the introduction of the By-law, affected Hawke’s Bay towns were rebuilt under the control of Commissioners. The Public Works Department supplied engineers to oversee and approve recovery design and construction. One of these engineers was Charles Turner, who later held the position of Vice-President of the International Association of Earthquake Engineering (IAEE), elected in 1965.

The Government established the New Zealand Standards Institution in 1932 and it was this body that published

NZSS No. 95, New Zealand Standard Model Building By-Law in December 1935 (NZSI 1932). The Preface to the By-Law stated that its object was to "produce a building code applicable to the special conditions of New Zealand, in the form of a Model Building By-Law". The drafting committee restricted its terms of reference to (of?) structural requirements, leaving health and other issues to be dealt with later, and based it on the 1931 draft, including British and North American work. It is worth noting that the By-Law did not apply over the whole country and it was left to the local bodies to accept and use it as they wished. It is understood that designers in the four main cities and Napier made full use of the standard.

4. THE DEPRESSION, WAR AND AFTERMATH (1935 – 1960)

Recognition of the structural dynamics of buildings was expressed in a book titled "Structural Design of Earthquake Resistant Buildings", written by S Irwin Crookes, Jr in 1940, the first known New Zealand publication since that of Ford in the 1920s. Crookes was on the staff of the School of Architecture at the University of Auckland. Park (1987) notes that "His book was a milestone text for structural engineers involved in earthquake resistant design" particularly because it outlined procedures for multi-storey frames. The text drew significantly upon Californian practice at the time. Crookes maintained that the seismic design procedure proposed was a practical method for engineers to use because dynamic procedures available at the time could not be used with complete confidence. Interestingly, he remarked on the need for appropriately increased remuneration for designers of earthquake-resistant buildings – an issue still being debated today.

The depression years of the 1930s and the Second World War resulted in the construction of very few large buildings. Little documented work was done to advance the design of earthquake resistant buildings.

In 1940, a large earthquake in Southern California's Imperial Valley provided a clear representation of each of three components of strong ground motion at an intensely affected site. Known as the El Centro record, this became, for ensuing decades, a prime model, a distinction it maintained even as a library of good records subsequently accumulated. Even into the 1970's acceleration response spectra developed from these records were used by almost every seismic loadings code worldwide

The New Zealand Standard Model Building By-Law published in 1955, NZSS 95, superseded the 1939 edition (which had been a revision of the 1935 edition). A substantial change to the loading on a public building was recommended. It could be either that given by a uniform seismic coefficient of 0.1 up the height of the building (0.08 was recommended for private buildings), or that given by a seismic coefficient which varied linearly from zero at the base to 0.12 at the top of the building (same for private buildings). The second option recognized approximately the deflected shape of the building in its first mode of dynamic response.

The 1950s saw a significant development underway, although few engineers were aware of the progress. At the Dominion Physics Laboratory of the Department of Scientific and Industrial Research (DSIR), Dr Mike Murphy headed a newly formed Engineering Seismology Section. Its purpose was to investigate and inform Government and industry of everything relevant for defence against earthquakes. Field data needed collecting, so the Section set about designing strong motion accelerographs. Data had to be fed into a suitable analysing engine that could apply it to descriptions of buildings held in the engine and thus discover how the buildings would behave. The Section set about building an ingenious electronic analogue computer for that purpose. Outputs from this work, using the El Centro record and other international records allowed Dr Ivan Skinner (NZSEE Life Member) to develop the seismic coefficient inputs against the period of free first mode vibration in structures in a draft loadings code about to be developed (Skinner 1964).

5. THE RECOGNITION OF DUCTILITY

Early in the 1960s decade the draft of a new loadings code was in circulation. The draft introduced zonation of the country in an attempt to match prescribed levels of lateral load in simulation of earthquake responses for each zone with intensities of earthquake shaking expected to occur there (Figure 2). The delineation of the zones was guided by tectonic studies undertaken be the Geological Survey and possibly additional information from a study by I.D. Dick, using extreme-value theory. But there was a lack of supporting data, which caused concern for some seismologists. Nevertheless, Dick's work was the first to give a reasoned time-and-place distribution of earthquake magnitudes in NZ and remained the sole source of this information for 15 years. The draft also changed the vertical distribution of lateral loading to be used in structural design to one only of increasing linearly from zero at the base.

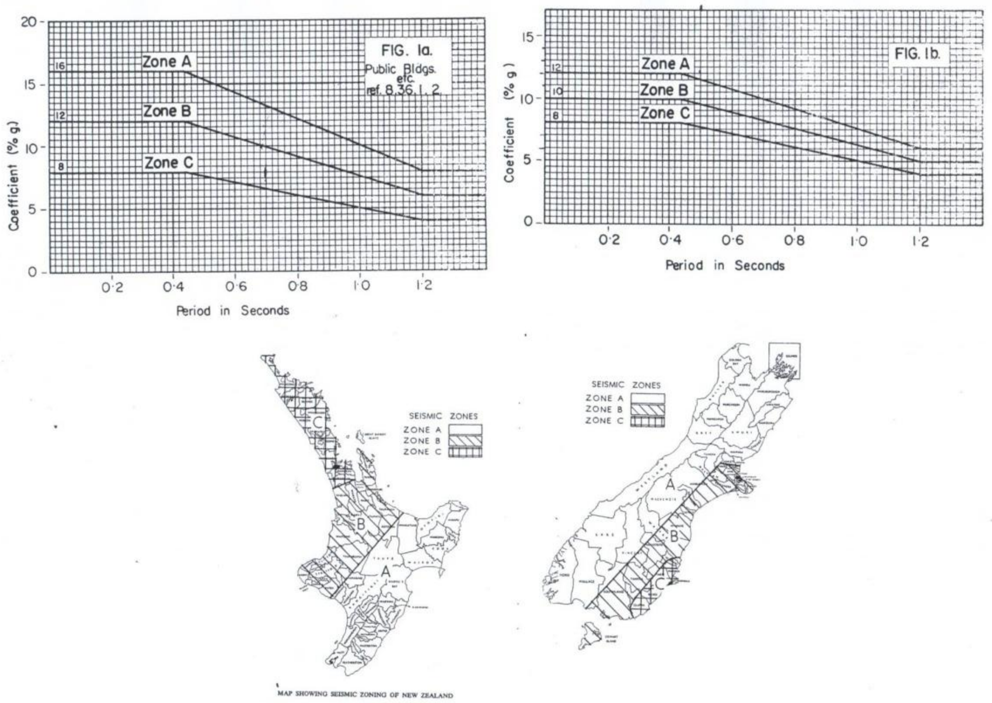

Figure 2 Map of Seismic Zones and Graph for Seismic Coefficient (from NZS 1900, chapter 8)

As expressed by Jonnie Johnson (Ministry of Works Chief Structural Engineer) in a NZ Engineering Leading Article in September 1963: "Owing to the paucity of building since the inception of seismic provisions in the by-laws these clauses (of 1935) have remained largely unchanged despite considerable advances in the more active overseas countries. The concern of various professional groups in New Zealand at the lack of progress is shown by a number of recent developments. A demand for by-law revision stimulated by a request from the Otago Branch of the NZ Institution of Engineers for consideration of regional seismic zoning, and Auckland's interest in taller buildings, have resulted in a complete redrafting of the seismic provisions in the Model Building By-Laws by the loading committee of the Standards Institute". (Johnson 1963). His concluding comments make interesting reading today, "All the committees concerned with earthquakes found that their work was hampered by a deplorable lack of essential data. Although the Dominion Physical Laboratory (DSIR) has shown the way in the design and installation of strong-motion instruments and in the development of an electrical analogue to indicate the responses of a wide range of buildings to known earthquake ground motions, much local research work remains to be done. Until designers are able to predict with reasonable certainty the intensities and nature of the ground motions in all regions of importance to the community, and until they know more of the properties of NZ buildings, earthquake resistant design is unlikely to reach a high standard." The same issue contained 2 very topical papers on the subject, "Dynamic Response of Multi-story Buildings by R. O'Driscoll and Robin Shepherd (Life Member NZSEE) and the second by Ivan Skinner entitled "Earthquake–resistant Design of Buildings Research Problems" (Skinner 1963). In 1963 there were only six accelerometers installed throughout the country each able to record 2 horizontal components of the ground acceleration along with about 36 "unsatisfactory" peak-reading accelerometers. Only one 30 m high block of flats in Wellington was instrumented with 7 accelerometers and 7 strain-measuring cells.

The code was ratified by the Standards Institute and issued as a model building by-law in 1965 (NZSI 1965). While the inverted triangle static loading method was the primary method of simulating seismic response, the code did allow a more precise dynamic response analysis to be carried out for special structures. Eccentricity of the structure was discouraged and there was a requirement that structural elements intended to resist seismic forces should be designed for adequate "ductility".

With regard to this new term "ductility" the commentary to the standard stated "When a large recorded earthquake is applied to a building and the resultant forces calculated on the assumption that the building deforms elastically with 5 or 10% damping, very large forces are obtained. These calculated forces are usually several times larger than the static forces, which are applied during design under existing building codes. Despite the size of the calculated forces, well constructed buildings have performed surprisingly well during past earthquakes. This reserve of earthquake resistance has been attributed to the ductility of the buildings – the plastic deformation of the structural components and foundations, which absorb energy from the building motion. Hence, buildings in which such plastic deformation is acceptable have a considerable reserve or earthquake resistance beyond their capacity when stressed only to the elastic limit". For reinforced concrete buildings, a structural ductility of 4 with a damping of 10% of critical was assumed. No guidance on how ductility might be achieved was provided in the standard. Furthermore, the Concrete Code (NZSS 1900: Chapter 6.3) contained little detail on how a designer could comply with this requirement.

Otto Glogau had succeeded Jonnie Johnson as the Ministry of Works (now known as the Ministry of Works and Development) Chief Structural Engineer. He, assisted by his deputy, Gordon McKenzie (NZSEE Life Member), prepared a "supplement", which contained extra provisions for the design of Public Buildings (PW81/10/1).

The 3rd World Conference on Earthquake Engineering (3WCEE) was held in New Zealand in 1965. By all accounts, the conference was a rousing success, being held in the two main centres of Auckland and Wellington with a two day tour between the two to give delegates a break. It also served to stimulate an interest in earthquake engineering in the country.

It was also in 1965 that an Earthquake Group for the Consulting Engineers' Division (CED) of the New Zealand Institution of Engineers (NZIE) was convened by Latham Andrews. The Group, later strengthened by additional membership from centres outside Wellington, was the base from which the New Zealand Society for Earthquake Engineering (NZSEE) was formed. A couple of months after an extremely successful Earthquake Symposium at the 1968 NZIE Conference, an inaugural meeting of the NZSEE was held in April 1968 and a management committee was elected. Publication of early Bulletins of the Society was made easy (setting aside the tragedy of the event) by the magnitude 7.1 Inangahua earthquake. A prime objective of the Society was to create a climate of cooperation between disciplines and between academia and practice.

6. STRENGTH AND CAPACITY DESIGN

Some consider that the "father of ductile design" in New Zealand was John Hollings (NZSEE Life Member - deceased) of consulting engineers Beca Carter Hollings & Ferner. Hollings published two inspirational papers in 1969 (Hollings 1969a and 1969b). The first paper described a ductile reinforced concrete structure as a "glass structure with lead like hinges". He proposed that beam-hinging mechanisms were far better than column hinges and he suggested a step by step design method for ductile multi-storey structures, which was a fore runner of the now accepted capacity design procedure, developed in New Zealand. Figure 3 shows a sketch of one of the first beam-hinging mechanisms published. The notion that a plastic hinge zone "must sustain imposed rotations through several reversals (during an earthquake) without loss of structural integrity" was indeed enlightening. Detailing of beam ends so that they would act as lead-like plastic hinges was explained.

In the second paper Hollings described in detail the proposed method for ductile design of concrete frames as applied to a 16-storey block of flats. The seismic coefficient was twice that of the SEAOC Code. The paper describes how to proportion the seismic forces between frames, checking the elastic period from the deformations, allowing for torsion and how to find the design actions. The columns were designed with a minimum margin of 1.25 above the beam overstrengths being 1.81 times stronger than the code strength levels. This was certainly the beginnings of capacity design as we know it. Generous amounts of confining steel were provided in hinge zones.

For column shear ties he used the only good source of detailing recommendations at that time (Blume Newmark & Corning 1961) to find the proportion of column ties specified.

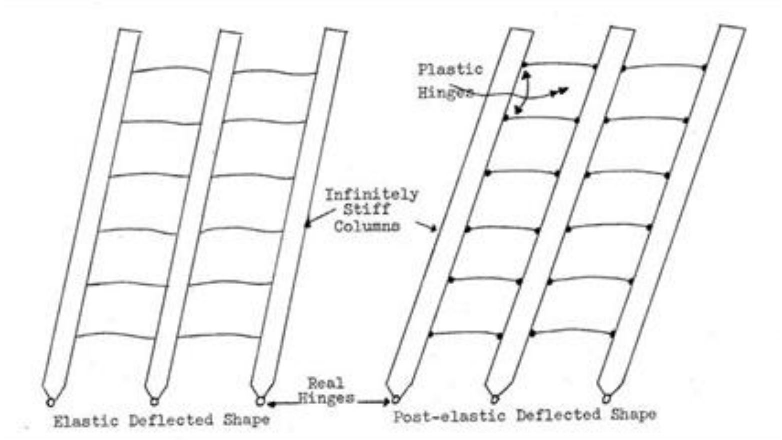

Figure 3. Elastic deflected shape & Plastic hinge positions in a ductile frame. From Hollings 1968a.

The Park and Paulay era began in the latter half of the 1960s as Bob Park (NZSEE Life Member - deceased) returned to the University of Canterbury from Bristol University and Tom Paulay (NZSEE Life Member) taking up a teaching position at Canterbury. Together they spent the rest of their research careers (almost 40 years each) working on the behaviour, design and detailing of reinforced concrete structures to resist earthquake loading. Many of the unknowns described by Skinner, Hollings and others were given the full research treatment, both experimentally and theoretically.

These included the performance of plastic hinge zones in beams, columns and walls. Park wrote a leading paper for the NZIE Journal, *NZ Engineering* in 1968 where he clearly described the differences between the structural ductility factor and the required curvature ductilities at each plastic hinge for both beam-sway and column sway mechanisms. Usefully, how to estimate these curvatures was described in detail. Park & Paulay's pivotal work "Reinforced Concrete Structures" was published in 1975, and has been used internationally by designers and students for decades since.

A new loadings standard for buildings, NZS 4203, was first published in 1976, formulated under the visionary chairmanship of Mr Otto Glogau. This standard codified the strength method of design but included the allowable stress method as an "alternative". The requirements for specific soil types were made specific with higher coefficients for softer soils. It included for the first time a structural type factor and a material factor, both to be incorporated into the estimation of the base shear coefficient to provide recognition of available ductility. The inverted triangular distribution of seismic forces was continued with the proviso that 10% of the base shear should be added to the top floor for buildings with a height/width ratio greater than 3. This was to include some contribution of possible higher mode behaviour in slender buildings. A disincentive for structures that were not designed to dissipate seismic energy by flexural yielding was that they were required to be designed for higher loads.

Material standards were lagging the development of the loadings standard and urgently required updating from working stress design principles to strength design principles. Designers needed to use their own judgement until they were updated. Nigel Priestley (NZSEE Fellow) took up a teaching position at the University of Canterbury in 1976, joining Bob Park and Tom Paulay in the development of provisions for the concrete material standard and the masonry standard. Priestley developed methods for confining the compression zones of slender masonry wall elements using steel plates in the mortar joints (Priestley & Elder 1982), although this never really gained popularity in the profession. Paulay and Priestley published a popular book on the seismic design of reinforced concrete and masonry buildings in 1992 (Paulay & Priestley 1992).

A 1977 issue of the steel standard was considered to be an interim measure to allow steel structures to meet the ductility and capacity design considerations of the new loadings standard and an NZSEE Study Group was set up to consider the state of the art of the seismic design of steel structures. The Study Group reported its findings in 1985 (- 1985), noting that there was still research to be done in a number of areas. The 1981 timber design standard, NZS 3603, contained no detailed seismic provisions. An NZSEE Study Group was set up in 1982 and its findings were published in 1986 (- 1986), followed by an update of the standard in 1990. A re-issue of the standard occurred in 1993 when a soft conversion of the working stress format to limit states format was undertaken. Capacity design provisions were included in a new section of the standard.

The publication of NZS 3604 (SANZ 1978) in 1978 was a major step forward in the design of timber framed houses for earthquake resistance as it was based on sound engineering principles and calculations. For the first time, the standard for light timber framed construction was based on the loadings standard, NZS 4203, but with account taken of redundancies, additional strength and other favourable factors known to be present in such structures. The standard aimed at minimising damage to houses in major earthquakes to ensure they were still habitable after the design earthquake event, an important quality given that limited temporary shelter is expected to be available.

7. BASE ISOLATION AND MECHANICAL ENERGY DISSIPATION

While not completely new, New Zealand patents for a crude system having been obtained in 1929, commercially available base isolation techniques for structures were not developed until the 1970s. The concept is that the structure is supported on flexible bearings so that the period of vibration of the structure is longer than the predominant ground motion and that mechanical energy dissipating devices provide sufficient extra damping to reduce the response.

Notable for the invention of the lead-rubber isolation bearing (LRB) was Bill Robinson (Life Member of NZSEE)(Skinner et al 1980). This bearing had layers of elastomeric rubber sandwiched between steel plates, to provide stability to the rubber and a lead plug in the centre to absorb energy as it deformed. The first use of the LRB in a building was under the 4-storey William Clayton Building (Figure 4), designed by the Ministry of Works and Development, and built within shouting distance of the Wellington Fault. The designers covered themselves against the possible failure of this design approach by detailing the superstructure to behave in a ductile fashion. A 150 mm wide isolation gap was included around the perimeter of the building. However, more recent studies on the nearby fault have suggested that a gap of three times this amount may have been more appropriate. Just as well the designers took a cautious approach to the new technology.

Base isolation of new buildings has been less popular in New Zealand than overseas, but currently two major hospital buildings are under construction with base isolators in place, indicating that they are being seen as essential in the design of structures required to be function following major earthquakes. One deserving recipient of a base isolated retrofit has been the New Zealand Parliament Buildings.

8. DISPLACEMENT-BASED DESIGN

From the early 1990’s Nigel Priestley began challenging the accepted design philosophies of emphasis on strength-based design and ductility, suggesting that we are led in directions that are not always rational (Priestley 1993). Instead he proposed a pure displacement-based design approach, providing a relatively simple example of its application to bridge piers, and suggested that the method could also be applied to multi-storey frame or shearwall structures. Priestley’s argument was not so much that the current force-based method was unsafe as that the increased analysis complexity may not be justified given the sometimes coarse assumptions made. Further, he suggested that if it was accepted that displacements were more important than forces, then perhaps our designs should be based on displacement, rather than acceleration spectra. Over the following 10 or so years Nigel further developed the procedure as experimental work filled in the missing information and the culmination of the work has been co-authorship of a comprehensive book on the subject (Priestley et al 2007).

Figure 4 New Zealand's first base isolated building – the William Clayton building

9. ENGINEERING SEISMOLOGY

In parallel with developments above the ground, a greater understanding of the engineering seismology of the country has been developing over the last two decades, due largely to the efforts of engineering seismologist, Dr Graeme McVerry of Geological and Nuclear Science (GNS). He has been responsible for developing the section in the new seismic loadings standard, NZS1170.5 (SNZ 2004) on site hazard spectra, including the hazard factor maps.

10. CONCLUSIONS

For a relatively young country, New Zealand has managed in a short time to develop world class standards for the construction of its buildings and bridges to resist the seismic loads to which they may be expected to be exposed, particularly in the last 50 years. This has been thanks to the dedicated efforts of both academics and practising engineers, often working in a voluntary capacity while serving on standards development committees. Highly significant research work has been completed on many aspects of structural performance in earthquakes (both analytical and experimental), leading to the development of these standards, but we are still waiting for the "big one" in New Zealand to confirm that we have done it correctly with our capacity design approach, ductility and detailing requirements in plastic hinge zones, and with our base isolation techniques. Here's hoping that we have got it right!

REFERENCES

Ford, C.R. (1926). Earthquakes and Building Construction. Published by Whitcombe and Tombs Ltd, Auckland.

Park, Robert. (1987). Development of Structural Design Procedures for Earthquake Resistance in New Zealand. *IPENZ Transactions* **Vol. 14, No 1**, March 1987, 22-32.

Cull, J. E. L. (Chairman)(1931). Report of the Building Regulations Committee. Report to the New Zealand House of Representatives, H-21.

NZSI (1932). New Zealand Standard Model Building By-Law. New Zealand Standards Institute, Wellington, New Zealand.

Crookes. S. I. Structural Design of Earthquake-Resistant Buildings. Published by Leightons Ltd, Auckland, New Zealand.

Johnson, J.A.R. (1963). Earthquake Engineering in NZ. Leading Article, *New Zealand Engineering*, **18(9),** September 15, 305.

Skinner, R. I. (1964). Earthquake-generated Forces and Movements in Tall Buildings – A Handbook for Architects and Engineers. *New Zealand Department of Scientific and Industrial Research Bulletin 166*.

Skinner, R. I. (1963). Earthquake-resistant Design of Buildings: Research Problems. *New Zealand Engineering*, 18(9), 313-315.

NZSI (1965). NZSS 1900:1965. New Zealand Standard Model Building By-Law, Chapter 8 Basic Design Loads. New Zealand Standards Institute, Wellington, New Zealand.

NSI (1964). NZSS 1900:1965. New Zealand Standard Model Building By-Law, Chapter 9.3 Design and Construction, Concrete. New Zealand Standards Institute, Wellington, New Zealand.

Hollings, J.P. (1968a). Reinforced Concrete Seismic Design, *Bulletin of the New Zealand Society for Earthquake Engineering*, **2(3)**, 217-250.

Hollings, J.P. (1968b.) A reinforced concrete building in Wellington, *Bulletin of the New Zealand Society for Earthquake Engineering*, **2(4)**, 420-442.

Blume, J.A., Newmark, N.M. and Corning, L.H. (1961). Design of multi-storey reinforced concrete buildings for earthquake motions, Portland Cement Association, Illinois, USA.

Park, R. and Paulay, T. (1975). Reinforced Concrete Structures, Published by John Wiley & Sons, New York, 769p.

Priestley, M. J. N. & Elder, D. M. (1982). Cyclic Loading Tests of Slender Masonry Shear Walls. *Bulletin of the New Zealand National Society for Earthquake Engineering*, **12(1)**, 3-21.

Paulay, T. & Priestley, M. J. N. (1992). Seismic Design of Reinforced Concrete and Masonry Buildings. Published by John Wiley & Sons, USA, 744p

- (1985). Seismic Design of Steel Structures. *Bulletin of the New Zealand National Society for Earthquake Engineering*, **18(4)**, 323-405.

- (1986). Seismic Design of Steel Structures. *Bulletin of the New Zealand National Society for Earthquake Engineering*, **19(1)**, 40-63, and **19(2)**, 123-152.

SANZ (1978). NZS 3604:1978. Code of practice for Light Timber framed Buildings not requiring specific design. Standards Association of New Zealand, Wellington, New Zealand.

Skinner, R. I., Tyler, R. G., Heine, A. J. & Robinson, W. H. (1980) Hysteretic dampers for the protection of structures from earthquakes. *Bulletin of the New Zealand National Society for Earthquake Engineering*, **13(1)**, 22-36.

Priestley, M. J. N., Calvi, G. M. & Kowalski, M. J. Displacement Based Seismic Design of Structures. Published by IUSS Press, Pavia, Italy.

SNZ (2004). NZS 1170.5:2004. Structural Design Actions – Earthquake Actions – New Zealand. Standards New Zealand, Wellington, New Zealand.

Priestley, M. J. N. (1993). Myths and fallacies in earthquake engineering – conflicts between design and reality. *Bulletin of the New Zealand Society for Earthquake Engineering*, **26(3)**, 329-341.

Megget, L. M. (2006). From brittle to ductile: 75 years of seismic design in New Zealand. *Bulletin of the New Zealand Society for Earthquake Engineering*, **39(3)**, 158-169.

Davenport, P. N. (2004) Review of seismic provisions of historic New Zealand loading codes. 2004 NZSEE Conference, Rotorua, New Zealand.