THE STATE OF EARTHQUAKE ENGINEERING IN NEW ZEALAND - ONE ENGINEER'S VIEW

John Hare[1]

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ABSTRACT

The Canterbury earthquakes have afforded the author a unique opportunity to view the state of engineering from a different perspective. The development of the Detailed Engineering Evaluation (DEE) procedure and the related activities of the Engineering Advisory Group have required thorough consideration of structural engineering practice. This has extended to an overview of the outputs from the DEEs completed by a wide range of engineers, over a wide range of buildings. From these and more general observations of engineering practice in contrast with that of other countries, a view on the state of earthquake engineering in New Zealand is offered with some thoughts on future direction and development needs.

1 INTRODUCTION

This paper draws heavily from the author's experience over the last two years, in a role as both participant and observer through the post-earthquake engineering activities:

- As Principal Engineering adviser to CERA, assisting with matters relating to the post-earthquake assessment of buildings.
- As Chair of the Engineering Advisory Group commercial workstream, advising MBIE on methods of evaluation and post-earthquake building safety.
- As President of the Structural Engineering Society, a role accepted after the September 4th 2010 earthquake but before the devastating February 22nd 2011 event.
- As a Technical Director of Holmes Consulting Group, involved with building evaluation and restoration; as well as with the development of new building designs.

These roles have afforded a great opportunity to look not only at the performance of buildings, but also at the performance of our profession. This paper is a subjective view of our profession, with reflection on where we find ourselves now and where we may be headed.

2 IMPLICATIONS FOR WIDER NEW ZEALAND (AND BEYOND) OF THE CANTERBURY EARTHQUAKES

The significance of the Canterbury earthquake sequence would be difficult to overstate. Although there have been other notable earthquakes around the world over the last 40 years or so (since the advent of capacity design), there were a number of almost unique aspects to this sequence:

1. The incidence of shaking intensity so far in excess of the local design standard, in an area with both older seismically strengthened and modern buildings, has created a potential internationally significant database of building performance – assuming it can all be captured.
2. The unusual nature of the earthquake sequence, with the most significant earthquake in the sequence (February 22nd, 2011) following the first major event (September 4th 2010) by nearly six months.
3. The performance of modern reinforced concrete buildings has come under the spotlight, with concerns expressed in many quarters that the actual performance of these buildings did not match the expectations generated by previous laboratory testing.
4. The extremely high level of insurance coverage (by international standards).

2.1 The Earthquake Series

The first two points above address the earthquakes, the circumstances of which are unusual but not unique. The implications for future building design and management are considerable. One of the most significant has been the stark reminder that there is no cap on shaking at the design level earthquake. The recent likening of the earthquakes to "an unruly boxer" (Hopkins, 2012) was particularly apt. Earthquakes hunt out the vulnerabilities in buildings and hammer them mercilessly.

[1] *Holmes Consulting Group, Christchurch, New Zealand (Fellow).*

There was no surprise in the reminder that irregular or poorly configured buildings do not perform as well as regular ones. The challenge for the profession is in finding ways to 'regularise' building performance without imposing too many constraints on overall building design. This is no easy task – it must extend beyond the simple balancing of torsional response and adjacent storey stiffnesses in a linear elastic building analysis. However, cutting straight to the post-elastic response ignores the fact that there must be a path to arriving there.

The implications for earthquake risk buildings are even greater. The recent MBIE consultation on earthquake prone buildings followed the CERC recommendations and received over 500 submissions. How that process will be concluded remains to be seen. One of the most difficult issues to work through, that is not likely to be included in the immediate outcomes from the consultation, is the consideration of earthquake risk buildings with collapse potential, that is, buildings with capacities in excess of the earthquake prone building threshold of (33%NBS[1]), but which have vulnerabilities that may lead to sudden and brittle collapse.

Of the 185 deaths in the Christchurch earthquakes, 133 were lost in two buildings (PGC and CTV), neither of which may have been considered likely to be earthquake prone. Although the death toll may have been artificially lowered by the prior closure of many (likely) earthquake prone buildings after the September 4th earthquake, the indication is that this category of building (earthquake risk buildings with collapse potential) is likely to be our most deadly in the event of future large earthquakes.

2.2 Concrete Buildings

New Zealand is a concrete country, with the majority of our modern commercial structures being constructed almost entirely of reinforced concrete. Structural steel buildings have made inroads over recent years, as have timber buildings since the earthquake; but the majority of our building stock will consist of concrete buildings for the foreseeable future.

The performance of our concrete buildings was mixed. Concerns had been raised over precast flooring systems since the middle of the 1990s. Although there were not large areas of floor lost, there was considerable damage observed in forms consistent with the research predictions. Support rotations, web shear failures, beam elongation and fractured floor mesh all validated those prior concerns. However, these systems remain in use with no further constraints, yet.

More surprising to most was the lack of correlation of previous observed laboratory testing with actual behaviour, especially in reinforced concrete wall structures. The incidence of a few wide cracks (as opposed to many well-distributed narrow cracks) with (in some cases) badly damaged reinforcement, may lead us to reconsider our understanding of minimum steel content, the strength of aged concrete and our assumptions on strain penetration at cracks.

[1] % New Building Standard

2.3 Insurance

As has been well publicised, levels of insurance cover in New Zealand are the highest in the world. With over 80% of properties covered, we have approximately four times the levels of earthquake cover of most areas of equivalent seismic hazard. Aside from our apparent risk aversion, it is likely that availability and low cost have contributed, with premiums and deductibles both significantly lower than other similarly risky areas.

Insurance has played a disproportionately large part in the post-earthquake activities of engineers. Some have struggled to reconcile their role as objective technical advisers against pressure to act as insurance advocates, as noted above.

An obvious impact of insurance is in the demolition of many buildings that may have been repaired if there were no insurance. An owner faced with the decision between repairing a building that may thereafter have a stigma attached of being under strength and damage-prone (not to mention perhaps uninsurable) and having a full settlement, was always going to take the settlement. Engineers that support owners through this process needed to be careful to remain objective, reporting only the technical matters.

In some cases, it could be considered that the insurance has created almost as many issues as it has solved. On viewing a series of light industrial properties, it was apparent that the industrial processes remained relatively unaffected in some cases, but had to contract to work around damage that could have easily been repaired quickly, simply and cheaply, if not for protracted insurance negotiations. The insurance negotiations were primarily related to perceived loss of capital value that has little bearing on the higher value operational value of the contents.

It is highly unlikely that future insurance cover will be as readily available for all buildings, that the terms and conditions will be as open, and that the deductable levels will be as low. These factors may limit the value of the conclusions we can draw from this aspect of the Canterbury earthquakes. For example, the low proportion of buildings being repaired, as opposed to replaced, may not be considered representative of future outcomes for a similar scale of event.

3 THE PRE-EARTHQUAKE CONTEXT

New Zealand has had a significant role in the development of earthquake engineering as practised over much of the developed world. University researchers in New Zealand were among the pioneers of capacity design in reinforced concrete. Capacity design was embodied in our Standards from the mid-70s, and the subsequent development of our Building Code has reflected our continued interest in the advancement of seismic design. All of the materials Standards were progressively updated to include aspects of capacity design, with steel arguably being the last major material to do so, in the late 80s.

As a young country, our built heritage has been relatively modest, but still with some remarkable buildings spread through the country. Rampant redevelopment of our major city centres in the mid-80s (Auckland, Wellington and Christchurch to a much lesser degree) contributed to significant changes in the streetscape, with a consequent reduction in the number of character buildings (i.e. those which may contribute to the overall streetscape but not necessarily with specific historic interest). Nevertheless, there was a significant remaining stock of older buildings, dating back to the late 1800s. Many of these buildings would be considered earthquake prone in today's terminology, but the general hazard has been understood for a long time – at least since 1968 (Municipal Corporations Act). Legislation since 1968 has progressively increased both the scope of buildings (and building elements) under consideration and the assessment criteria, culminating in the current 2004 Building Act definition of earthquake prone buildings.

Implementation of strengthening requirements for buildings has been mixed. Earthquake risk has been sparingly understood outside the profession, and technical requirements have often given way to political pressures. As recently as June 2010 (only 3 months before the first earthquake of the Canterbury sequence) a hearing on the proposed new Christchurch City Council earthquake prone building policy heard from a sequence of owners, that imposition of a more active policy would cause deep financial hardship. By my count, only one engineer spoke at that public hearing, in favour of a more active approach.

Although the design of new structures since the mid 70s had generally included capacity design procedures, there remained questions. With hindsight, the most significant of these is probably the non-ductile column condition highlighted by the Canterbury Earthquakes Royal Commission inquiry into the failure of the CTV building (CERC [6] 2013). However, other potentially serious issues include:

- The performance of precast floor diaphragms under actions including frame elongation and support rotation.
- The performance of structures reinforced with cold-drawn hard wire mesh.
- The detailing of collector and drag elements in diaphragms.

Liquefaction in Christchurch had been a recognised risk for some time, but as the assessment methodologies became progressively more sophisticated, it appeared that the calculated return periods for damaging motions were decreasing steadily. Notwithstanding this, an earlier report (Elder *at al,* 1991) had clearly outlined shaking and liquefaction damage scenarios that were remarkably close to what was to come approximately 20 years later.

Before the September 4th 2010 earthquake, it would be fair to say that there was an air of complacency with regard to seismic risk in Christchurch. To the extent that the seismic hazard was considered, it was generally assumed that the main issue would be the Alpine Fault, with less understanding of the immediate local hazard. In fact, in the year prior to the earthquakes, a noted local architect announced in public that there was only a perceived earthquake problem in Christchurch because the university needed something to study.

4 THE EARTHQUAKES

Building performance through the earthquakes has been well documented and will be the subject of much further review to come; that is not the purpose of this paper. The performance of engineers invites more scrutiny than perhaps it has received, although there has been at least one comprehensive account of the subsequent engineering activities (Brunsdon *et al*, 2013).

In the immediate aftermath of the earthquakes, many engineers were involved in the immediate recovery. It is of note that 593 engineers shared the IPENZ Fulton Downer award of 2012 for their participation. Activities included safety evaluation, damage assessment and propping and shoring of buildings and structures.

Although there had been little training in any of these activities, the national philosophy of "just get on with it" generally stood the profession in good stead. Innovation was rife, particularly in the shoring of damaged buildings. There must now be at least 101 uses for shipping containers over and above what their designers envisaged. Truck strops have proven to be versatile for tying back gables and shoring piers, and salvaged structural steel building elements have been quickly reinvented in a variety of configurations to achieve different purposes.

The commitment shown by engineers in meeting the challenges thrown at them in the immediate post-earthquake environment was impressive. For many the immediate aftermath of the earthquakes was a curious mix of adrenalin, despair (at the destruction) and professional exhilaration. Despite many local engineers being under stress through their own personal circumstances, they spent long hours completing rapid safety evaluations and helping to restore their clients' homes and businesses. Others from further afield selflessly abandoned their families, homes and businesses to assist. Quite possibly, there may never have been a prouder time to be a member of the engineering profession.

Along with the professional challenge, it was also a time for answering the questions that had been in the back of engineers minds for many years – how would our buildings perform when a major earthquake struck? Observations from earthquakes in other parts of the world had provided much useful data, but this was the first major urban earthquake in New Zealand since 1931, and certainly since the advent of capacity design.

5 THE OUTCOMES

The obvious question is "how did we do?" However the answer is not so obvious.

On one hand, given that the earthquake produced ground shaking well in excess of the design level, the immediately observable building damage was probably less than many expected. While it is not a view that may be shared by many lay people, the overall building performance in engineering terms could be considered satisfactory if life safety was the main measure.

- In one line: **With one exception, all modern (post-76) buildings in Christchurch met the basic life safety objective of the NZ Building Code**.

But this view neglects the influence of duration and the sequence itself. Had the February 22nd earthquake gone on much longer, there may have been considerably more collapse. It is also clear that if the February 22nd earthquake had been the first in the series there would have been many more deaths and injuries (owing to the closure of a significant number of buildings after the September 4th 2010 earthquake).

With deeper investigation, there are some less favourable conclusions that can be drawn and that should be addressed in the future. These matters relate less to technical matters and more to engineering design practice and to standards of verification and validation of design. Some of the most significant are as follows:

- The number of buildings that performed poorly and which, on closer inspection, should possibly not have received building consent was higher than expected. While this may have been expected with older buildings, this extended right through to buildings that were designed and constructed relatively recently. It is rumoured that the insurance industry is currently gathering data for lawsuits with the intention of recouping insurance losses.
- The poor performance of some building systems or elements that had been accepted into general use without adequate testing and review.
- The clear evidence of poor construction even in recently constructed buildings, with key details not executed properly.

All of these are discussed in more detail below, but an immediate conclusion that could be drawn is that wholesale change to the Building Code would not be nearly as effective as properly applying the one that we already have.

6 POST-EARTHQUAKE BUILDING ASSESSMENTS

The need for a more systematic approach to post-earthquake evaluation was somewhat apparent immediately after the September 4th 2010 earthquake. The Canterbury Technical Clearinghouse (CTC) meetings that commenced shortly after the earthquake offered the opportunity to share observations and lessons learnt.

The Engineering Advisory Group (EAG) was established in October 2010, initiated by the Earthquake Commission, but then formally appointed by the Ministry of Business, Innovation and Employment (formerly the Department of Building and Housing). The EAG's role at this time was focussed on the development of assessment and repair standards for residential structures, with emphasis on foundation assessment.

With the reasonably limited scope of damage to most commercial structures after the September 4th 2010 earthquake, this may have been enough if there had been no further significant earthquakes. However, December 26th 2010 gave further cause for concern and then February 22nd 2011 confirmed it – if public confidence in engineers was to be restored, much greater guidance and consistency were needed. There were a number of issues that contributed to this situation:

- The public's perception that a failure of engineering review had contributed to the loss of life on February 22nd.
- The complexity that was emerging in the evaluation of the consequences of damage for reinforced concrete buildings, including widespread observations of performance that was contrary to expectations.
- The extreme intensity of shaking resulting in so much damage that the CBD was completely shut down.

A second (commercial) workstream of the EAG was established, with the immediate goal of providing guidance for detailed evaluation of earthquake damaged buildings in Canterbury. This was followed shortly later by the Canterbury Earthquakes Recovery Agency (CERA) putting in place a policy requiring owners to provide detailed evaluation reports for all non-residential buildings, to be staged over a suitable period of time according to significance and location.

Guidance was issued progressively, commencing with a first draft of the Detailed Engineering Evaluation (DEE) procedures in May 2011. With the CERA policy requiring all owners to provide reports on their buildings, engineers were required to adopt the procedures, including a spreadsheet based short-form reporting template.

Given the demands on both the EAG and the engineers, there was little time for specific training to be offered. However, there were frequent presentations to the CTC meetings. These were generally well attended, but not by all engineers. A constant concern has been the lack of uptake of the engineers that seldom or never come to the CTC meetings.

Reports are reviewed by engineers working under contract for CERA. A core group of engineers has been working there since CERA was established, having mostly come across from Civil Defence (pre-CERA). These engineers had already developed a close familiarity with the damage to the Christchurch building stock and were therefore well equiped to review submitted reports.

6.1 Quality of Assessments

The CERA engineers have been in an ideal position to observe the standards of evaluation and reporting. While few generalisations apply across the board, there are some observations that can be made:

- A significant proportion of assessments have been grossly over-conservative. One suggestion has been that some engineers' assessments of building capacity owe more to their sense of their potential liability than to their clients' needs (and those of the broader society). The questionable aspect of this is that although there is a slim chance of being proven unconservative in the event of future damaging earthquakes, this attitude seems to completely neglect the likelihood of future legal action relating to unwarranted insurance claims.

- Associated with this is the broader impact of grossly conservative evaluations. Serviceable buildings have been vacated due to concerns over seismic safety even when there has been no significant damage. While this is partly a reflection of the public's current lack of appetite to accept seismic risk, engineers should consider whether this is really serving society well, and what their role could be in assisting progress. Given the passage of time and the need for warm, dry housing and buildings in which to continue our business, we could consider that there are worse things in life than learning to live with earthquake risk.
- Many engineers have only a limited understanding of the term 'critical structural weakness' and the influence of vulnerabilities on building performance. Although clarifications have been issued frequently, this has taken on a life of its own, as engineers seemingly compete to find more and more 'critical' issues with buildings. However, many of the issues identified will not satisfy the most important test – does a life safety hazard result?
- Some engineers now undertaking review and assessment of buildings have little or no experience with seismic assessment and retrofit. The result is that they may be undertaking work that arguably, they are not competent to do. Where such engineers are able and willing to link with others of appropriate experience to provide guidance and review, this is readily overcome, but many of them are not in this position, whether by choice or by circumstance.
- A more concerning issue has been the desire of some engineers to go straight into detailed analysis without necessarily taking the time to understand the building first. It is generally well understood that in the design of new buildings, an engineer can 'force' the building to behave as we want it to by capacity design techniques and appropriate detailing. However an existing building cannot have behaviour imposed on it – the role of the engineer is reversed in this case, to understanding what the original designer may have intended and then to determine if that is in fact what will happen. This requires acute observation and an enquiring mind, neither of which are generally to be found in those who jump straight into the computer.

6.2 Antagonism towards the Assessment Process

Although the need for a consistent assessment procedure seemed obvious, it has met some resistance. There are a few engineers who have been reluctant to comply with reasonable requests to complete the process, citing overwork or simply not considering it necessary. Often this is associated with parallel application for Building Consent, where the suggestion has been made that award of a Building Consent indicates a satisfactory review has been completed. This is a confusion of the identification of damage (achieved by the DEE) and the apparent compliance of proposed new work (achieved ultimately through Code Compliance Certificate). The two are complementary, not overlapping.

Further issues have arisen where a small minority of engineers have seized on the statement that gathering of information on building performance was a part of the purpose of the reporting procedures put in place. They have stated that this should not be their and their clients' responsibility and initially refused to comply with some of the reporting requirements. The lack of vision that this attitude displays is disappointing and calls into question our collective approach to our profession. We are part of the wider communities that we work in and it is our obligation as a profession to learn from events such as this, and apply those lessons to the betterment of all.

6.3 The Impact of Insurance on Building Assessments

The remarkably high levels of insurance cover and the loose terms and conditions that have been adopted have resulted in unprecedented levels of insurance claims. It remains to be seen whether this will ever be repeated, but common sense dictates it should not. However it has placed engineers in the hot seat when it comes to potential impact of their reports. Simple observations of damage are a relatively objective activity, but the selection of testing and measurement procedures and the interpretation of the outcomes required more careful consideration that is not always being given. Engineers in this position would do well to consider the possible future consequences if insurers seek to recoup any of their losses.

7 FUTURE ENGINEERING DESIGN STANDARDS

The immediate future of earthquake engineering is challenging. The huge volume of data that is being gathered will require years of processing, but the rebuilding process in Christchurch is already underway. The lessons that have emerged through general observations, the detailed evaluations and through the Royal Commission need time to be absorbed and carried through into the Building Code and into standard design office practice.

In an attempt to spread at least some of the lessons learnt, the Management Committee of SESOC quickly issued some guidance in November 2011. Timing of this was dictated in part by a Royal Commission request for a copy of this guidance at the soonest possible date, but after some initial criticism, the document was amended and reissued for formal comment (SESOC, 2012). This is a live document, intended to fill the gap until the more slow-moving Standards and Code updates can take place.

The mixed reception of this document illustrates some issues for structural engineering in New Zealand that merit further discussion.

7.1 In or out of the room?

It has been observed above that there was difficulty communicating with all engineers in Christchurch after the earthquakes, as some seldom or never attend the CTC meetings that were so effective in disseminating information. However this observation applies equally across the whole country.

Membership of the professional organisation (IPENZ), or technical societies, is not compulsory for practising engineers; although continued professional development is a requirement for Chartered Professional Engineers. However, the significant minority of engineers (and other building professionals) that sits 'outside the room' in respect of professional activities is a problem that will ultimately reflect poorly on all. While many engineers over the years have expressed frustration with their professional body, it could be said that we get the professional organisation that we deserve. The corollary is that if we wish it to be better, we must get involved.

By definition, the functions of a professional body may include "to define, promote, oversee, support and regulate the affairs of its members". In the eyes of the public, the responsibility should extend to all members of the profession, not just those that join the professional body. However, the professional body has no jurisdiction over engineers that do not join or take part in wider professional activities.

IPENZ and the technical societies must work hard to maintain their relevance. IPENZ in particular, because it must include all branches of engineering, struggles at times to be all things to all members. But professional apathy is a problem for us all.

7.2 Professional Duty of Care

Although the Building Code (NZBC) represents the minimum standard with which all new building work must comply, there is also a less clear 'duty of care' with respect to professional practice, that requires engineers to keep abreast of new developments and issues that are identified. If an engineer becomes aware of aspects of the Building Code that are inadequate, that engineer is obliged to follow the test of what a reasonable engineer might do under the circumstances. A significant difficulty in this is in the question of what lengths a reasonable engineer must go to keep informed.

By publishing the Interim Design Guidance, SESOC has effectively notified engineers that there are issues with the Building Code or its application that should not be ignored. As one of the main technical societies (in fact the largest collaborating technical society within IPENZ), it would be difficult for an engineer to argue that he or she was not aware of the advice. However it is not clear whether engineers are generally following this guidance.

The guidance offers a three tier approach. The base level (Verification method compliance) offers clarification of aspects of the Standards that have been misinterpreted or neglected. These are matters that should have been done, irrespective of the earthquakes, to satisfy code requirements. The second level (SESOC recommendation) offers further guidance on measures that may be added to the base level in order to satisfy the intent of the Standards, incorporating lessons learned from the earthquakes. The third level (Damage Reduction Recommendation) offers guidance on design or detailing measures that may result in improved performance over and above code minimum level.

Some Building Control Authorities have picked up the Interim Design Guidance, but have not necessarily understood the implications of the three tier approach. There is no legal obligation to comply with any but the first tier recommendations, but clearly the second tier could be considered good practice and so should be considered carefully, at the least. The real need however, is for engineers to communicate these issues to their clients with the purpose of informing them of their options and helping them reach sound decisions about their buildings.

8 INNOVATION

Sometimes, our 'kiwi innovation' is an asset, sometimes a liability. Innovation is a necessary aspect of engineering, required to advance the profession and the wider industry. To be termed innovative is the greatest of accolades for an engineer. Almost all engineers claim to be innovative and conversely, the engineer regarded as not being innovative may struggle to win work.

However, the part of 'innovative' that seems to be frequently forgotten is the need to be more rigorous in establishing that the innovative system or detail being adopted actually delivers the performance that is being sought. In respect of seismic design, a standard 'code' approach to design carries with it the implicit performance that a fully compliant design should achieve, not just at the design (ULS) level, but also in the event of a greater level of shaking. Because the material Standards satisfy this implicitly through deemed to comply design and detailing that does not require explicit consideration, there is little in the Building Code that clearly states this objective, although this is a gap that may be reviewed soon.

However in the case of innovative systems that step outside the umbrella of the Standards, the onus must fall back onto the engineers to ensure they can meet this level of performance. Critical thinking is an essential ability in this circumstance, that is, the ability to question the underlying assumptions and requirements and follow through with appropriate rigour of analysis and design. Too often, 'judgement' is cited as reason enough to accept something, where the truth is that the engineer has not the ability or the energy to deliver an appropriately robust analysis.

All levels of the engineering profession need to consider their part in this. An academically based guideline that has not been through an appropriate review and that is based on incomplete research must be used with caution. There may or may not be a liability chain back to the institution that produces the guidance, but the engineers applying proposed new techniques surely have responsibility. Once again, critical analysis is required to ensure that all aspects are fully addressed. Typical failings to address matters such as diaphragm actions and the third dimension (concurrent actions) are easily missed; but this should not be an excuse, particularly from those that are taking the responsibility for advancing professional practice beyond their own doors.

9 COMPLIANCE AND DESIGN OFFICE PRACTICE

Those that were in practice in the development and construction boom of the 80's may remember the environment of the time. Wellington and Auckland in particular were blighted with rampant development. In those days, cheap was king and the industry default was in many cases to exploit every available loophole in order to reduce cost and improve ease of construction. Christchurch had suffered less of this sort of development, but nevertheless, this was the time of the CTV building, so the obvious parallels may be drawn.

Since the 80's, the passing of successive Building Acts has seen some changes in approach to building consents. This is mainly addressing compliance issues, that is, how the Building Consent Authorities (BCAs) deliver their regulatory functions. Producer Statements (and now the Certificate of Design Work for residential projects) have replaced Design Certificates. Although a consistency of approach may have been an intended outcome, it has yet to happen, with different BCAs having different approaches to processing of building consents.

It must be stressed that strict compliance with the Standards is only one path to achieving compliance. However as noted above under Innovation above, those who wish to work outside the Standards have obligations to verify performance that meets the intent of the Standards.

Simply increasing the scope (and thickness) of the Standards is also counter-productive. A checklist mentality breeds checklist thinking and that is one of our problems. Arguably, a better outcome may be achieved at the top end, if there was no prescription in the Standards but instead, a clearly articulated set of performance requirements.

It is clear that there is still some of the 80's attitude in evidence. 'Design by loophole' is alive and well, with at least one observer having said that it appears as if some designers (not just structural engineers) are playing a game of seeing how far they can get with too little (or poor) documentation. Mutual peer review[2] has been alleged in some local jurisdictions, where there is too little subsequent auditing by the BCA to ensure that rigour has been applied.

The societies have been active in trying to correct this with initiatives by IPENZ, ACENZ, the Construction Industry Council and SESOC in recent years directed towards improving standards of documentation, applying quality assurance procedures and ensuring adequate review. And yet the outcomes remain mixed. Those who take their responsibilities seriously are following good practice procedures and guidelines, but others either do not know or do not care that they are lowering the standards of the industry as a whole. In some cases, engineers who flout good design practice are in fact hailed as 'innovative'.

Competence is clearly part of the issue, but ethics is integral. There are clearly engineers actively in practice who are perhaps not aware of their own limitations (the so-called Dunning-Kruger effect). This has been characterised as a cognitive deficiency as opposed to an ethical deficiency (Schmidt, 2011) and can be used to support an examination based professional assessment but that would not be enough to eliminate the problem completely. When this proposal was put to a meeting of engineers in Wellington recently, the majority opinion seemed to be instead that a more consistent and rigorous application of regulatory review is required to ensure an appropriate level of compliance.

As distressing as it must be for the profession to admit it, there are however engineers that are not meeting their ethical obligations. As a problem facing the profession as a whole, it would be ideal if this could be rectified internally, but it has proven difficult - firstly to detect the issues, and then secondly to deal effectively with them.

This is hard for the majority who are living up to their obligations. It is clear in looking at some buildings more closely, that those who bend the rules are gaining a competitive advantage that effectively rewards them for doing so. In the current environment, it sometimes seems that the only true problem is getting caught.

Regardless of whether the deficiency is in engineers' competence or their ethics, a common solution presents itself, of applying greater levels of scrutiny at a regulatory level. This is not where current trends in regulation appear to be heading. Risk based assessment is being promoted as a means of streamlining consenting and reducing costs. However the assessment of risk based on the complexity and scale of the project fails to take into account some of the most significant variables – the competence and ethics of the designers.

Associated with this is the sometimes loose behaviour of designers in applying sensible quality assurance procedures. A frequent complaint on the part of regulators is that they are being used as a checking service instead of simply getting on with their statutory duty of reviewing compliance. This is reflected also in the marginal oversight and training being provided to recent graduates in some cases.

Lack of time due to high current workload is a poor excuse – we are all responsible for balancing our own work pressures. If a similar earthquake event were to happen in twenty years time, to suggest to a commission that workload got in the way of delivering a good outcome is unlikely to carry much weight with the public. Equally, to suggest that the need to serve the public justifies taking on more work than can be safely or reasonably delivered, offers little protection.

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[2] That is, the practice of having 'friendly' reviewers completing peer reviews, possibly in the expectation that the favour will be returned one day.

Put simply, the time it takes to mentor and train inexperienced staff and to check and review work product should not be negotiable. Those that seek to reduce cost (and take a competitive advantage by doing so) by sliding over these activities should reconsider their position; and the rest of the profession should take a greater role in ensuring that the message gets through.

9.1 Examples of non-compliance

There are plenty of examples that have been thrown up through the assessment and review process, but it would be foolhardy to assume that the problem is limited to Christchurch. For obvious reasons, individual cases cannot be discussed here, but a range of generic issues from recent practice include:

- Use of non-ductile HRC mesh in both floor diaphragms and tilt panels, some of which have significant flexural demand.
- Unreinforced concrete ledges supporting precast floor systems, often with no bearing strip
- Short or even negative seatings for precast floor systems
- Over-reinforced hollowcore ends at supports, in cases where potential support rotation could lead to failure remote from the support
- Substantial roof areas with no bracing in portal framed warehouses with heavy cladding panels
- Shallow embedded anchors used in locations where ductility demand may develop, either in the primary load path, or where displacement compatibility may drive failure.
- Complex precast systems with poorly defined load paths and inadequate connections
- Use of post fixed expansion anchors in masonry

10 COMPARISONS WITH INTERNATIONAL PRACTICE

This comparison is limited to the West Coast of the USA, where the author has direct experience as a licensed Professional Engineer in California. There are many similarities between earthquake engineering practice in New Zealand and California with respect to materials used and the design and construction practices employed, but there are also definite differences. Some of the most significant are discussed below.

10.1 Professional Design Office Practice

There are a number of differences in approach with respect to professional practice development. One of the most striking differences is in the area of code development.

Although the California Building Code is administered by a section of the state government, it relies heavily on supporting documents produced by organisation such as the American Society of Civil Engineers (ASCE), American Concrete Institute (ACI) and American Institution of Steel Construction (AISC). Typically these organisations rely on the input of volunteer engineers to develop and update Standards. An exhaustive process of review and balloting is typically endured before a Standard is adopted.

There are inherent issues with this process. Because of the balloting process, the introduction of a new standard can take years. There is an averaging effect of having so many people involved that can reduce the impact of new ideas and make it harder to adopt innovative procedures and technology. In practice however, this does not prevent innovation, but it may make it harder to push through underdeveloped ideas.

Peer review, when required, is considerably more robust than is often the case in New Zealand. This may be because of the implicit threat of ‘name and shame’ that happens under their licensing regime, but it is also a cultural thing. All in all, it feels more collegial, in the best sense of the word.

Much of this may be an outcome of increased accountability, although this may be a perception rather than a reality. In the author’s experience, dealing with lawyers and insurers in NZ is no more pleasurable than in the US!

One of the most encouraging aspects of practice in the US is the sense of ownership of the profession that appears to be comparatively under-developed in New Zealand. Attending an event such as the Structural Engineers Association of California (SEAOC) conference, it is notable that the speakers presenting new developments in structural engineering and code updates tend to be business leaders of the consulting engineering practices. That is, the leadership of the profession recognises the importance of technical and practice development, not simply commercial imperatives.

10.2 Engineering Licensure

California (along with the rest of the US) operates a two tier licensing system. The first tier of Professional Engineer (PE) is at a level approximately equivalent to New Zealand’s Chartered Professional Engineer (CPEng) and is attained by passing a series of four exams over two days, the prequalification for which varies according to qualifications and experience (six years minimum). The second tier of Structural Engineer (SE) requires a further 3 years experience post-PE, and the passing of a further four four-hour exams. All structural work for public hospitals, public schools and in some jurisdictions, for complex structures, must be completed under the seal of an SE.

The question of whether some form of higher qualification should be a pre-requisite for the design or certification of complex buildings in New Zealand was discussed by the Royal Commission (CERC [7] 2013). The Commission recommended that a Recognised Structural Engineer title should be introduced by the Ministry of Building Innovation and Employment in consultation with IPENZ, the Registration Authority and the technical societies.

At the recent SESOC annual meeting, a discussion paper on the topic was presented to an audience of engineers. A possible examination based higher qualification based on the system in use in British Columbia was discussed, to mixed reception. One conclusion reached was that more rigorous imposition of building controls would be of more benefit in delivering better building outcomes.

10.3 Product Selection and Acceptance

Proprietary product selection is approached quite differently in California. There is great reluctance to incorporate any proprietary product, detail or system that does not have International Code Council Evaluation Service (ICC-ES) or equivalent certification. This certification clearly notes any limits on application and gives design guidance to specifiers and installers as to the appropriate use of the product. In order to achieve this certification, products have to pass an audited testing and reporting regime that ensures a level of independent review is achieved. Contrast this to New Zealand, where the standard of verification of products is poor and/or uneven.

Testing of products in New Zealand is often not undertaken in a statistically admissible form. More critically, boundary conditions and testing protocols often do not adequately account for the range of actions that may occur in service. It should not be the role of the designer to determine limits of application of a product based on the presentation of testing outcomes. Rather, it should be the responsibility of the manufacturers and suppliers to ensure that their products are used appropriately with clearly defined limits on application. Again, as noted above, engineers need to apply critical thinking in the consideration of what products and materials they specify and use. Seduction by marketing is not a substitute for clear analysis.

A valid concern with this may be the cost of compliance in such a small market as the New Zealand construction industry. However, we may like to consider whether that should be a reason to accept a lesser standard than may be expected elsewhere in the developed world.

This issue is further exacerbated by the increasing volume of counterfeit or substandard material that is entering our marketplace. The poor performance of eccentric brace links in one building at least was in part attributed to non-compliant structural steel being used. However the spread of such materials is much broader than just steel grades.

10.4 Quality Assurance in Construction.

Site verification of completed work is another issue that was highlighted by the earthquakes. The demise of the clerk of works (due to concerns with cost) has never been totally resolved. Consistency of construction monitoring activities with the supervision requirements stated in the material standards has never quite been achieved. It is also questionable whether the check-box QA procedures that are employed across the industry actually deliver any positive outcome, when the industry is heading more and more towards construction management-style contracts with less and less self-performed work.

In California, a separate regime of mandated ‘special inspections’ is required for most construction work. Key elements of building work are identified (either by code default, or as added to by the designer) that must be verified by the special inspector, an independent certifier usually operating at technician level. This effectively fills at least part of the void left in the absence of a clerk of works in a way that construction monitoring has never achieved. As the special inspector is engaged separately, the helpful engineer scenario is avoided, that is the cases where the engineer can be persuaded to accept work of a lesser quality on the basis of knowing what the design may have up its sleeve.

11 CONCLUSIONS

It may be too early (or melodramatic) to say, but there is a sense that earthquake engineering in New Zealand could be at a cross-roads. Although we could state that our buildings performed to an acceptable level in the Canterbury earthquake sequence, there is too much evidence of poor practice and attitudes to ignore. The Royal Commission has provided 189 recommendations in varying forms, but beyond that, there are many more issues that demand attention.

The following in particular require attention:

1. The engineering profession needs considerably more training in assessment of existing and/or damaged buildings and probably more comprehensive guidelines to go with it.
2. There is a need to ensure that the majority of the profession is engaged with professional development and training initiatives, not simply as a grudge purchase, but with genuine commitment.
3. Structural engineers need to reconsider their approach to design. The question should not be “Have we done the minimum necessary to (just about) comply?” Instead there should be a focus on design to achieve specific performance objectives, which should be arrived at in clear consultation with clients and stakeholders.
4. The notion of innovation needs to be reconsidered. New methods of design and construction should be encouraged, but researchers and developers of new technology must recognise and act on their responsibility to ensure that when the technology is to be applied, it is complete, comprehensive and clear; and that its limitations are also clearly understood.
5. The industry as a whole needs to review its approach to quality assurance, at all levels. In the design office, sufficient QA should be applied to produce acceptable documents for building consent and construction; and during construction, to ensure that all critical work is of an acceptable standard. Use of the Special Inspector approach that is employed in the US may be considered.

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