THE IMPACT OF THE CANTERBURY EARTHQUAKE SEQUENCE ON THE EARTHQUAKE ENGINEERING PROFESSION IN NEW ZEALAND

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ABSTRACT

Professional engineers have provided a range of inputs into the responses to the Canterbury Earthquake Sequence and the recovery process that has followed. This earthquake sequence has been unique in many respects, including the intensity of shaking produced in the Christchurch CBD by each of the major aftershocks in February, June and December 2011. For engineers, the heavy workload has been continuous from the response to the original 4 September 2010 Darfield earthquake, and will extend for several years to come.

There have been many post-earthquake challenges for seismologists and geotechnical and structural engineers, commencing with urban search and rescue responses and rapid building evaluations, and extending through the more detailed assessments and repair specifications during the recovery phase. Engineers are required to interface with owners, regulatory authorities and insurers, and face many challenges in meeting the objectives of these different sectors, which are rarely aligned.

Adding to the technical demands has been the requirement for many scientists and engineers to provide input into the Canterbury Earthquakes Royal Commission of Inquiry and other investigations. The Royal Commission was set up to investigate the failure of buildings that led to the loss of 185 lives in the 22 February 2011 aftershock, and has placed close scrutiny on many aspects of engineering activities, particularly those undertaken following the 4 September 2010 earthquake. The prominent public reporting of the Royal Commission hearings has placed additional pressure on many engineers, including those who volunteered their services following the original earthquake into a role for which they had received only limited prior training. Interpreting and communicating ‘safety’ in relation to the re-occupancy (or continued occupancy) of commercial buildings continues to be a challenge in the face of liability concerns.

A more comprehensive understanding of the technical and process guidance required by engineers and authorities has resulted from the work undertaken in response to this earthquake sequence. Much of this guidance has now been produced, and will be of considerable benefit for future major earthquake events.

This paper reflects on the range of work undertaken by scientists and engineers during the response and recovery stages. The scope and implications of the various official inquiries are summarised, and the potential impacts on engineers involved in the response to and recovery from future major earthquakes are briefly discussed.

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1. INTRODUCTION

This paper gives a brief overview of the Canterbury earthquake sequence, principally by reference. The range of activities that scientists and engineers have been involved in during the response and recovery phases to date is summarised.

The main focus of the paper is on the key challenges faced during the recovery phase. In parallel with the recovery, there have been various forms of inquiry and investigation into aspects of the response, and into general design practice. The key matters raised in the Royal Commission of Inquiry in relation to engineering practice (pre-and post- event) are outlined, and the impact on earthquake engineering professionals, including those working in other regions of New Zealand, is described.

The paper concludes with some observations on the implications for scientists and engineers in New Zealand, both in relation to general practice and future post-earthquake involvement. A version of this paper was first presented at the 2012 Australian Earthquake Engineering Society annual conference.

2. THE EARTHQUAKE SEQUENCE

The Canterbury Earthquake Sequence commenced with the M_w7.1 Darfield Earthquake of 4 September 2010. No lives were lost in this mainshock. This was the first earthquake to significantly affect a large urban area across several local authorities in New Zealand since the Wairarapa and Wellington earthquakes of 1942.

There were various aftershocks in the days and weeks that followed, including a strongly felt aftershock of M_w 4.9 on the morning of Boxing Day, centred close to the city CBD.

The tragic M_w 6.2 Christchurch Earthquake occurred at 12.51 pm on 22 February 2011, resulting in the loss of 185 lives. This was the first earthquake in New Zealand to cause significant loss of life since the Hawke's Bay earthquake of 1931 in which 256 lives were lost.

Further significant aftershocks occurred on 13 June (M_w 5.5 and M_w 6.0) and 23 December 2011 (M_w 5.8 and M_w 5.9).

In total, more than 50 earthquakes of greater than M_w 5 have been recorded in this sequence, the most recent being on 25 May 2012. The overall plot of aftershocks up until December 2012 from GNS Science is shown in Figure 1, grouped in relation to the above principal aftershocks.

The general trend of the earthquake sequence has been from west to east, with the devastating earthquake of February 2011 and the strongly damaging 13 June 2011 events located in close proximity to the city. The December 2011 aftershock and following events have mostly been in the offshore area to east and northeast of Christchurch. While the majority of events have had this tendency to eastwards migration, Figure 1 shows that ongoing aftershocks continue to be widely distributed over the whole aftershock region, including near the eastern termination of the Greendale Fault.

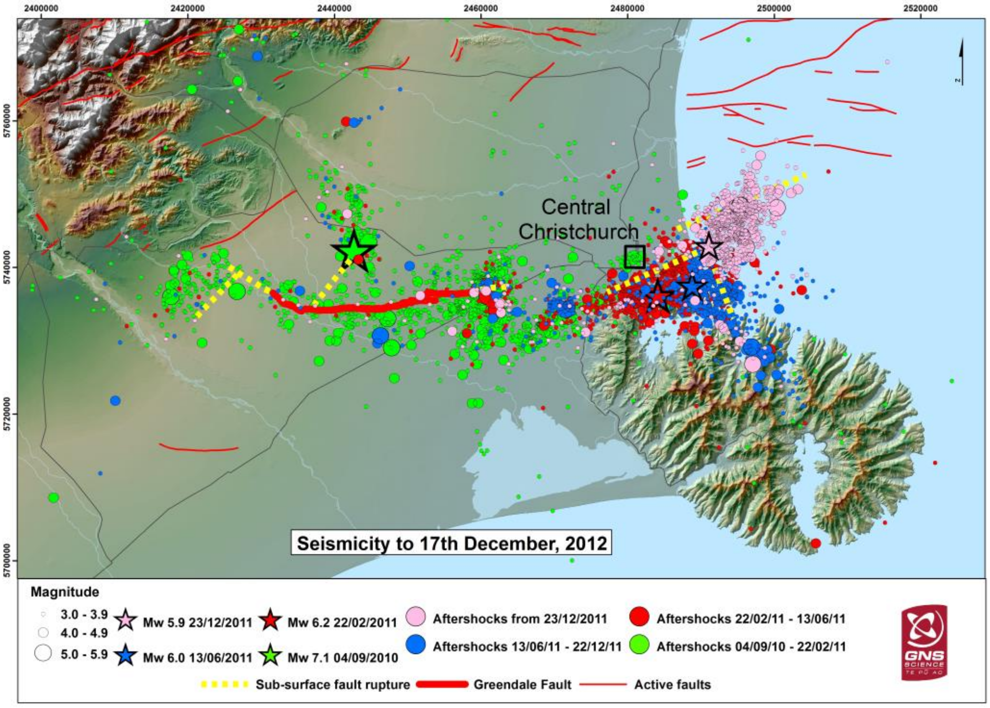

Figure 1: Seismicity Plot to December 2012.
(Acknowledgement to Robert Langridge and William Reis (GNS Science)).

Prior to the 22 February 2011 earthquake, advice was widely circulated that the magnitude 6 earthquake that would typically follow a magnitude 7 earthquake had not occurred. This advice noted that there was approximately a 25% chance of such an event in the coming year, with approximate estimates of a possible 5% chance of such an event occurring in close proximity of the city. Only Orion Energy reacted to this advice, but at these low probabilities there was no formal response or consideration of evacuation or more than standard preparation measures.

The Canterbury Earthquake sequence is described more fully in the special editions of the NZSEE Bulletin (NZSEE, 2011) and the NZ Journal of Geology and Geophysics (Townend, *et al*, 2012).

3. CONTEXT AND BACKGROUND TO THE RESPONSE AND RECOVERY

In order to provide the context to the involvement of earthquake engineers in the response and recovery process, a series of 'situation statements' are given in this section, along with observations on their post-earthquake implications. These cover both the key pre-event and post-event influencing factors which are shaping the recovery and the role of scientists and engineers within.

3.1 Pre-event

1. The NZ Building Act doesn't address post-disaster aspects. For example, the provisions which address dangerous buildings actually exclude earthquake.
   - This has led to the need for considerable interpretation as to how the Building Act, Building Code and regulations apply in an environment involving large numbers of residential and commercial buildings with differing levels of damage.
2. There is a very limited technical (engineering) capability within central and local government in New Zealand.
   - Central technical leadership and capability has arguably been lacking since the Ministry of Works and Development was dis-established in 1988.
3. The Canterbury Earthquake sequence has followed more than a decade of dealing with leaky buildings, which has seen the failure of the weatherproofing envelope in many residential and other buildings. This has cost owners, local authorities, contractors and some building professionals dearly.
   - This has led to a highly risk averse environment in terms of regulatory processes followed by local authorities, and on the part of building professionals. Both of these sectors have experienced financial exposures that are arguably disproportionate to their roles in the design, specification, consenting and construction process.
4. New Zealand has high levels of insurance cover across both the residential and commercial sectors. In particular, the government's residential cover for natural hazards provided by the Earthquake Commission, which includes land, is regarded as being unique internationally.
   - This high level of cover has generated a sense of expectation on the part of many owners. In some commercial cases, the provisions of the individual building owners' policies have contributed to the demolition of buildings (with or without reconstruction) that may have been physically repairable. The costs of new fit-out etc. associated with a repaired building are also a factor in such decisions.
5. The CBD of Christchurch and surrounding suburban centres had a very high proportion of unstrengthened unreinforced masonry (URM) buildings compared to other New Zealand centres, due to a combination of the historical development of the city's building stock and the passive approaches by the Christchurch City Council towards addressing earthquake prone buildings.
   - This meant that the city was highly vulnerable to earthquake, and that even modern buildings that had survived the earthquakes well may have been compromised by critical damage to neighbouring URM buildings.
6. The CBD of Christchurch had also been in somewhat of a decline prior to the earthquakes, struggling to adapt to the changing retail environment and as a result having a wider footprint than was commercially sustainable.
   - This has been both a challenge and an opportunity following the earthquakes, requiring planners for the reconstruction to review completely the future requirements and needs of the city.
7. For liquefaction the (much lower) design seismicity prior to the earthquake sequence was such that residential developments in Christchurch over recent decades were generally considered to comply with the provisions of the Building Act, with respect to the known liquefaction hazards at the time.
   - Also, while the threat of rockfall to public assets in the Port Hills was being systematically considered, on private properties it was being carried out on a more piecemeal basis. The Port Hills for a number of years had been subject to a generalised large-scale risk zoning intended to guide appropriate levels of investigation at building consent stage. Prior to the earthquake series, nobody would have perceived a design triggering event with the levels

of energy that were generated by some of those events.

3.2 Post-event

1. The highly unusual situation of having no loss of life in the main shock followed by considerable loss of life in a significant aftershock has created a very difficult context for all involved. The trauma and uncertainty for the community was heightened by this sequence of events.
   - As a consequence, the question of 'what is safe?', and the role of engineers in establishing relative safety, has assumed many challenging dimensions.
   - Conversely, the fact that a significant number of damaged buildings (principally URM) had been closed following the main shock significantly reduced the potential loss of life in the 22 February 2011 earthquake.
2. The continued series of damaging aftershocks further sapped the confidence of those living in the affected area and heightened risk perceptions.
3. The principal inquiry to investigate the causes of the building collapses that caused the loss of life commenced in May of 2011 and concluded in September 2012. The hearings of the Canterbury Earthquakes Royal Commission were very widely reported, with the scrutiny of the actions of engineers prominent.
4. Insurance premiums have risen appreciably throughout NZ, with availability not being guaranteed.
   - It is interesting to consider that notwithstanding a likely period of greater seismic activity, Christchurch could now be seen as a better risk than many seismically active zones, as the hazard has been thoroughly studied, the most high-risk commercial buildings demolished or strengthened, and the new buildings will have been built in an environment of greater awareness of seismic risk.

The net result of the above occurrences was that the rest of New Zealand became very aware of the seismic risk of the built environment – in many cases for the first time. Collectively these factors have contributed to a most challenging environment for engineers – arguably uniquely so when compared to other major international earthquakes. In the time when the greatest need for engineering resource is in the Canterbury region, there is also considerable competition for that resource from the other centres. Significant numbers of professional engineers have been brought into New Zealand from overseas offices to assist with assessment and repair/ reconstruction design work. If it were not for the lingering effects of the Global Financial Crisis reducing 'business as usual' demand for engineering services both nationally and internationally, the situation may well have been even more difficult to manage.

4. INVOLVEMENT OF ENGINEERS IN RESPONSE

Engineers were heavily involved in the response to the September 2010 and February 2011 earthquakes, and in each of the significant aftershocks.

The principal involvement was in relation to the evaluation of buildings and structures, and as part of the urban search and rescue (USAR) response. Many engineers were also involved in assessing infrastructure networks and assisting with their emergency service provision and restoration.

Building Evaluation

Rapid Building Safety Evaluation was undertaken using the NZSEE Guidelines (NZSEE, 2009). The procedures in these Guidelines were adapted from the Californian procedures developed in the late 1980s by the Applied Technology Council and subsequently modified (ATC, 1995). The 2009 version of the NZSEE Guidelines was endorsed by the Department of Building and Housing, and supported by the Ministry of Civil Defence and Emergency Management. The procedures were further developed in an unpublished format following the NZSEE involvement in the response to the 30 September 2009 Padang, Indonesia earthquake, working with Australian engineers. The background to and application of the NZ building evaluation procedures in the Canterbury events is described in the NZSEE report commissioned by the Canterbury Earthquakes Royal Commission (NZSEE, 2011).

At the time of the September 2010 Darfield earthquake, only a limited number of NZ engineers had undertaken training in building safety evaluation. However during the state of emergency period following the September 2010 and February 2011 earthquakes, a total of 94 and 352 professional engineers respectively were involved as volunteers in the rapid building evaluation process. Many of these had only received on-the-day induction, as opposed to systematic training. Significant process improvements were identified during the September 2010 response, and were implemented in the February 2011 response. Many other engineers undertook building evaluations working directly for building owners or managers. In the days following the February 2011 earthquake, a number of NZ's most experienced structural engineers also worked together as part of Christchurch City Council's *Critical Buildings* operation, which focused on assessing the stability and immediate stabilisation measures for approximately 40 significantly damaged multi-storey buildings. A small group of a dozen engineers was also formed to support the building control officers in their placarding of residential houses during this response phase.

The NZSEE rapid building evaluation arrangements focused on the immediate assessment and placarding processes. The associated technical procedures for undertaking subsequent detailed engineering evaluation had not yet been given specific attention. It had been broadly envisaged that engineers would have access to sufficient guidance using NZ engineering documents and knowledge, as well as drawing upon established international documentation such as available via United States agencies. However the need for more specific guidance for detailed evaluations became particularly apparent following the February 2011 earthquake, where some unique patterns of damage were observed.

Urban Search and Rescue

Following the September 2010 earthquake, 13 engineers deployed as part of NZ's USAR capability. In this early morning event, as people were not trapped within buildings, much of the efforts of the USAR engineers focused on the CBD building safety evaluation operation. The February 2011 earthquake however posed an altogether different challenge, with all available NZ USAR engineering resources (a total of 22 engineers) deployed with the national USAR task force, with the majority working in this capacity for the ensuing four weeks.

These were the first large scale operational deployments of NZ's USAR engineers, and indeed of the national task force as a unit. NZ was very grateful for the assistance of international task forces from Australia, United States of America, the United Kingdom, Japan, China, Singapore and Taiwan, each bringing their own specialist engineering resources.

5. INVOLVEMENT OF ENGINEERS IN RECOVERY

Although it was not fully appreciated at the time, the wide-ranging inputs during the response to these main earthquakes simply represented the first phase of the engineering and scientific involvement. The engineers and scientists that worked tirelessly in response were then required to continue on directly to spearhead the technical aspects of recovery. Overall this has been and continues to be a very intense period of involvement over more than two years since the Darfield Earthquake.

The broad areas of involvement of engineers and scientists in the recovery following the Canterbury earthquakes are as follows:

1. Specific advice with respect to damage assessments and repair and reconstruction solution for buildings and infrastructure.
2. Overarching technical and regulatory advice and interpretation for and on behalf of Government agencies to assist specific solutions.
3. Research and analysis of performance in the earthquakes.
4. Contributing to reviews and inquiries.

Such is the relatively small earthquake engineering community in New Zealand, many of the country's more experienced scientists and engineers have been directly involved across several (and in many cases all) of these areas.

Involvement in the first of these areas has included working for owners and tenants or insurers. There are many different legal facets at play depending on the focus of the client, which in turn can give rise to different interpretations and the inevitable tensions between parties.

With respect to the second area above, an Engineering Advisory Group (EAG) was established in October 2010 to support engineers undertaking damage assessment and repair formulations by providing overarching technical and regulatory advice. Initiated by the Earthquake Commission, the EAG was formalised as a committee appointed by the Chief Executive of the Ministry of Business, Innovation and Employment (formerly the Department of Building and Housing). As noted earlier, NZ government agencies have a very limited technical capability, hence the need for this form of support.

The focus of the EAG has been to:

- Promote consistent approaches to assessing land and buildings, and for specifying repairs and reconstruction methods; and
- Enable consistent interpretation of relevant regulations between engineers and building consent authorities (councils).

While the initial focus of the EAG was on residential repairs, following the far more damaging 22 February 2011 earthquake there was an even greater need for co-ordinated technical information in relation to the assessment and repair/ reconstruction specification of buildings. The EAG has subsequently operated via two functional workstreams – *Residential* and *Commercial*, with cross-cutting subgroups addressing seismicity and geotechnical matters.

The EAG comprises a small group of leading engineers and remediation specialists, including representatives from the following organisations:

- Ministry of Business, Innovation and Employment
- Earthquake Commission (EQC)
- Building Research Association of NZ (BRANZ)
- GNS Science
- Structural Engineering Society (SESOC)
- NZ Society for Earthquake Engineering
- NZ Geotechnical Society

One of the first regulatory actions undertaken following the 22 February 2011 earthquake was to increase the seismic hazard factor for Christchurch. After intensive consultation with GNS Science and the EAG, the seismic zone (Z) factor for the greater Christchurch area was increased from 0.22 to 0.30 on 19 May 2011. This was considered necessary because of the increased levels of seismicity in the region, triggered by the first earthquake. GNS Science currently considers that the seismicity levels may drop to the pre-earthquake levels over a period of up to 50 years. This provision was accompanied by a requirement for stronger foundations for residential buildings in areas where liquefaction could occur, and a national requirement for residential floor slabs to be tied together with ductile reinforcing bars or mesh.

The residential workstream of the EAG has prepared guidance for assessing, repairing and rebuilding residential dwellings, focusing on foundations in liquefaction-affected areas (Department of Building and Housing, 2011; Department of Building and Housing, 2012; MBIE, 2012). Following the establishment of Red, Green and Orange residential zones by the Canterbury Earthquake Recovery Authority (CERA) in June 2011, this work included the establishment of Foundation Technical Categories within the Green Zone. These were created as a mechanism to triage engineering resources, create consistency in the assessment of land and provide guidance to engineers. Land classified as Technical Category 1 (TC1) or Technical Category 2 (TC2) was generally at lower risk of liquefaction damage in future earthquakes. Land classified as Technical Category 3 (TC3) was considered to be at a higher risk of damage from liquefaction in future earthquakes, requiring a more thorough level of damage assessment and (particularly for re-building) soils data from deep geotechnical investigations.

This work has drawn upon an extensive effort led by EQC's consulting engineers Tonkin & Taylor Ltd. to gather and analyse land damage data from various sources, including area-wide land and building damage surveys, and the use of LiDAR (EQC and Tonkin & Taylor, 2012). An intensive deep geotechnical investigation programme is also underway, involving the combined efforts of government-sponsored drilling programmes and private insurance sponsored investigations. This will result in probably the largest known dataset of soils information and land damage information worldwide. The information in this dataset has been made available by CERA for use by scientists, engineers and building control officials involved in recovery and research work via the Canterbury Geotechnical Database (CGD) (https://canterburygeotechnicaldatabase.projectorbit.com).
The CGD gives a good technical description of all the different information layers available and comprehensively describes the survey and mapping processes. The CGD is an important element of the consenting framework for Christchurch, Waimakariri District and Selwyn District councils, as it enables ready access to subsurface information for reference purposes.

In addition to the development, monitoring and updating of guidance, the residential workstream members have been making presentations to and holding workshops for the various sector groups to ensure maximum uptake of the guidance and a consistent understanding of the philosophies in the document. Workshop and seminar sessions have been held with insurers' Project Management Office (PMO) staff, building control officials, architects, engineers and other sectors. Regular meetings are also held with building control officers to assist with the processing of building consent applications. The ability to share experiences with these groups has provided a valuable feedback loop to the EAG and MBIE.

Consideration is now being given to what form liquefaction hazard categorisation should take for the rest of the country. The recent publication by Environment Canterbury and GNS Science of updated liquefaction hazard information areas of Christchurch and neighbouring districts indicate current practice for regional-scale liquefaction hazard assessment and representation (ECan and GNS Science, 2013).

The commercial workstream has focused on the production of guidelines for undertaking detailed engineering evaluations of commercial buildings post-earthquake (EAG, 2011). The purpose of the detailed engineering evaluation (DEE) process can be summarised as:

- inform decisions by owners about the continued use of their buildings,
- provide a starting point for decisions on any repair work to be carried out; and
- ascertain the state of buildings generally following the emergency phase.

The DEE procedures feature both qualitative and quantitative assessment procedures. The process typically commences with a qualitative assessment, which begins with a review of the original documentation to identify potential areas of vulnerability, followed by an inspection of the building. This focuses on overall collapse mechanisms as well as direct life safety hazards, with the objective of being sure that all or any damage to the primary load paths is systematically determined. The initial requirement was that where either significant damage is apparent **or** little damage but an estimated capacity of less than 33% of New Building Standard (ie. potentially earthquake prone) is determined from the qualitative assessment, then a quantitative assessment should be undertaken. This was relaxed toward the end of 2012 so that for undamaged buildings only a qualitative assessment was required, with the earthquake prone building provisions of the Building Act taking effect for low scoring buildings.

Enacted in April 2011, the Canterbury Earthquake Recovery (CER) Act gave the CERA Chief Executive significant powers to require assessments of buildings to be undertaken. Over the next three years CERA will be asking owners of non-residential and multi-unit residential buildings in greater Christchurch to have a detailed engineering evaluation prepared for their buildings using the approach developed by the EAG, and the results reported back to CERA.

A secondary purpose of this process is to gather data in a consistent format that allows the creation of a database of key information relating to building performance in the earthquakes. This may form the basis of a national buildings database that will allow better planning in the event of future earthquakes in other centres.

6. THE CANTERBURY EARTHQUAKES ROYAL COMMISSION OF INQUIRY

6.1 Establishment, Scope and Operation

The Canterbury Earthquakes Royal Commission was set up in April 2011 to report on the causes of building failure as a result of the earthquakes, as well as the legal and best-practice requirements for buildings in New Zealand Central Business Districts. The Royal Commission was chaired by Justice Mark Cooper, with Sir Ron Carter, Distinguished Fellow of IPENZ and Emeritus Professor Richard Fenwick, Life Member of NZSEE, as members.

While the main focus of the Royal Commission was on the Canterbury Television (CTV) and Pyne Gould Corporation (PGC) buildings, where 115 and 18 lives were lost respectively, all buildings where people perished were investigated and individual hearings held. The hearings were held between October 2011 and September 2012. All hearings were open to the public, and received extensive media coverage on a daily basis, in addition to the live streaming of proceedings.

A wide range of reports were requested or commissioned by the Royal Commission to assist them in their deliberations - refer http://canterbury.royalcommission.govt.nz . The Department of Building and Housing established an expert panel and appointed consultants to examine the performance of the CTV, PGC, Hotel Grand Chancellor and Forsyth Barr buildings. The resulting reports were an important component of information supplied to the Royal Commission (DBH Expert Panel, 2012), as were the international peer reviews of those reports.

6.2 Issues Arising from the Reports and Hearings

One of the outcomes of the investigations carried out on behalf of the Department of Building and Housing was the decision to follow up on issues relating to the detailing of stair landings and non-ductile gravity dominated reinforced concrete columns. These were columns from the period of approximately 1984 through 1995 when the concrete standard allowed 'protected' columns to have less ductility than the current standard requires. The Department notified local authorities and practitioners throughout New Zealand of the need to re-evaluate certain forms of stair and column details from the mid-1980 to mid-1990 period, noting however that there is currently are no mechanism to require that such vulnerabilities are addressed.

A significant finding from the analysis of the 42 lives lost in relation to URM buildings was that only 5 people died within the buildings that failed. The lives lost were principally due to people either running outside or being directly outside (several in vehicles), and being crushed by falling masonry parapets and facades – refer to the analysis in Figure 2. There were very few instances of URM buildings completely collapsing, except those with no internal wood-framed structure (Ingham and Griffith, 2011).

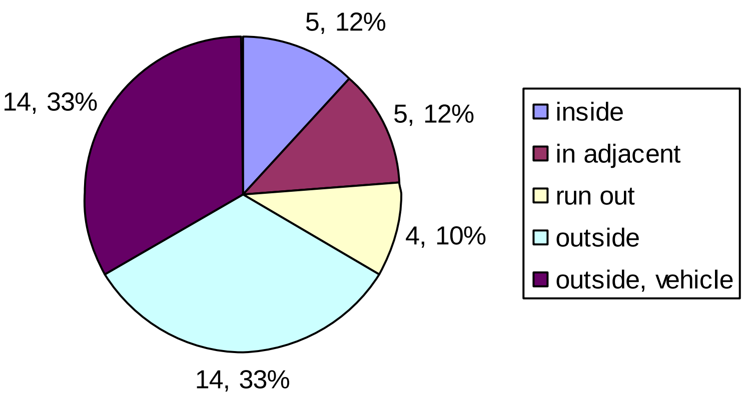

Figure 2: Deaths from building failure (excluding CTV and PGC) (EAG, 2012).

The significant loss of life in public areas has led to a refocusing on public safety aspects. The corollary of this is that public safety has not received adequate attention over the past two decades in the various debates on how to mitigate seismic risk in the built environment.

6.3 Building Safety Evaluation

One aspect that came under particular scrutiny during the Royal Commission for each building was the placarding undertaken following the September 2010 earthquake, and the subsequent actions by owners, tenants, engineers and council prior to 22 February 2011. This saw individual engineers who had undertaken rapid building safety evaluations questioned very closely in relation to their actions and decisions. As noted previously, in many cases these engineers had provided their inputs on a voluntary basis to assist the Christchurch City Council and with a brief process induction only, rather than systematic training. The close public scrutiny of their initial actions often lacked the context of the highly unusual nature of the February earthquake as an aftershock, which produced the strongest ground shaking recorded worldwide at the time, greatly exceeding the aftershock assumptions of international building evaluation procedures such as the Applied

Technology Council (ATC, 1999) which anticipate aftershocks of lesser magnitude and intensity.

This process has questioned the basis of the New Zealand and international arrangements for rapid post-earthquake assessments of simply establishing 'no diminished capacity' rather than determining the actual capacity. In the vast majority of cases, the building investigations have concluded that the damage sustained by the building as a result of the September 2010 earthquake was not considered to be a significant factor in its subsequent collapse. These buildings would have been expected to collapse in the 2011 Christchurch Earthquake, whether or not the September 2010 earthquake had occurred. Furthermore, it has been suggested that if the Darfield Earthquake had not occurred, the casualties resulting from the February 2011 earthquake would have been significantly higher, with estimation that an additional 294 deaths may have occurred due to unreinforced masonry buildings alone (Ingham and Griffith, 2011). Accordingly, it is generally accepted that rapid building evaluations should continue to be based on the premise that a building is considered occupiable provided there is no significant structural damage (ie. no diminished capacity).

Some difficulties were also experienced by engineers involved in the application of the placard system for houses. The placard wording was found to be not particularly applicable to dwellings, where the aim was to try to keep occupants in the dwellings if it was considered safe to do so, even if this was only a part of the house.

A number of lessons are being drawn from these experiences relating to the public communication of seismic risk, effectiveness of building evaluations, requirements for a full spectrum of assessment processes, and associated training needs. A reasonably clear view has been formulated on the improvements required to make rapid building evaluation systems and processes more robust. The principal or overarching recommendations from NZSEE to the Royal Commission are to establish:

1. Appropriate legal mandate.
2. Central government agency providing a focal point, guidance and support for preparedness activities.
3. Criteria and process for building re-occupancy.
4. Local authorities appropriately prepared to set up and manage a building evaluation operation.
5. Appropriate numbers of trained and warranted building professionals.
6. Effective mobilisation arrangements for warranted building professionals (locally and nationally).

With likely changes to the earthquake-prone building legislation following the Canterbury earthquake sequence requiring much more pro-active assessment and disclosure, assessors in future should have better information on the existing capacity of buildings that can assist in making placarding decisions. Alternative arrangements involving a standardised database of expected seismic performance that could more directly link with the outcomes of day to day engineering assessments have also been suggested (Galloway and Hare, 2012).

There has been strong international interest from other countries in how best practice internationally for post-disaster building evaluation can be improved from the experiences of the Canterbury earthquakes. Interaction with ATC personnel and state officials in California and engineers from Japan has led to further alignment of thinking ahead of specific work on the Royal Commission recommendations (Galloway, *et al.*, 2013).

6.4 Royal Commission Reports

The Royal Commission has reported its findings progressively (CERC, 2012). Part One (Volumes 1, 2 and 3) of the report was delivered to the Governor-General on 29 June 2012 and released by the Government on 23 August 2012. It contains recommendations to inform early decision-making about the central city's recovery from the Canterbury earthquakes and includes a range of recommendations aimed at improving design and construction practice Part Two (Volume 4) of the report containing recommendations about earthquake-prone buildings was delivered on 10 October 2012, and was released by Government on 7 December. The third and final part of the report (Volumes 5, 6 and 7) covering results of the investigation into the collapse of the CTV building and other aspects of the Terms of Reference which had not already been addressed was released by Government on 10 December.

The reports contain a total of 189 recommendations covering a range of engineering practice and regulatory areas. The first 70 recommendations were accepted by Government in 2012; the remaining recommendations are under consideration at the time of writing.

6.5 Other Reviews and Inquiries

There have been other reviews and inquiries undertaken separately to the Royal Commission. These include a review commissioned by the Ministry of Civil Defence and Emergency Management into the response to the February 2011 earthquake (McLean *et al.*, 2012), and the Coroner's inquiry into the cause of the deaths of eight people from the CTV building. These people were thought to have survived the initial collapse of the building but were not able to be rescued. The focus of this inquiry was on the response of the emergency services, including USAR operations. Three engineers were required to supply briefs of evidence to the inquiry, with two appearing in front of the Coroner.

7. THE IMPACT ON THE ENGINEERING PROFESSION

The unique features of the Canterbury Earthquake sequence as outlined in the previous sections, along with the intensive nature of the various investigations and inquiries, has put a spotlight on scientists and engineers in relation to determining seismic risk. For example, key government agencies, building owners and the general public alike are wanting to know the earthquake status of the buildings they own or occupy. While this obviously has a particular focus in Canterbury, this demand for earthquake risk information is high throughout New Zealand.

This section makes observations on some of the key issues that are having the greatest impact on the engineering profession. Comments are also made on the possible implications for engineering involvement in the response to future earthquakes.

7.1 Lack of appreciation of likelihood as a component of risk

Putting the annual probability of a major earthquake occurring in context is one of the challenges in communicating earthquake risk to owners. Prior to the Canterbury earthquakes, annual probabilities of 1 in 100 or less were considered by building owners and occupiers as sufficiently low as to act as a deterrent for taking positive mitigation action, irrespective of the vulnerability. However following the 22 February 2011 earthquake, the dominant personal perspective became one of conditionality – ie. given that "another major earthquake may well occur in the foreseeable future, I don't want to have a collapse or loss situation occur".

This is an understandable perspective for those that have been through the Canterbury earthquakes to have. However this new perspective of risk, which essentially removes likelihood of occurrence from consideration, is currently driving commercial building occupancy decision-making across New Zealand.

Even if a building is deemed to be earthquake-prone it does not necessarily mean that the building is unsafe in the short-term and should not be occupied. Prior to the Canterbury earthquakes, under local authority earthquake prone building policies required by the Building Act, owners were typically given between five and thirty years to demolish or strengthen buildings found to be earthquake prone.

It is also considered that the provisions of the Health and Safety in Employment Act, which put the onus on employers to eliminate, isolate or minimise workplace hazards, are unduly influencing decision-making in the aftermath of the February 2011 earthquake.

7.2 The limitations of engineering assessment tools

The demand from owners and tenants is to have a 'number' that characterises earthquake risk. The expression '% of New Building Standard' or %NBS is typically that number for commercial buildings, although some engineers are preferring to use the NZSEE letter rating scale which relates to %NBS ranges, as implying a lesser of a degree of accuracy.

The engineering calculation 'tools' used to derive that number are however not necessarily that robust, particularly the 'Initial Evaluation Procedure' (IEP) which is typically used for a rapid screening assessment for commercial buildings. The IEP is a conservatively oriented seismic coefficient-based methodology (NZSEE, 2006), which makes broad discounts on capacity where 'critical structural weaknesses' such as vertical or horizontal irregularity are found to be present. The underlying assumption is that IEP assessments are undertaken by experienced earthquake engineers.

These critical structural weaknesses have their origins in heavier multi-storey buildings, where their presence can lead to an early failure. However their presence is much less influential in low-rise, lighter weight structures, where failure is only likely to occur under strong ground shaking and will be influenced more by heavy mass elements. A general lack of appreciation of this is leading to unduly conservative assessments for a range of buildings that are dominant in the outskirts of cities and smaller towns, and in institutions such as schools.

It is also of concern that decisions are being made to vacate some buildings within days or weeks of only an IEP outcome which indicates a capacity of less than 33%NBS. Again, while this is an understandable reaction, it is based on a lack of appreciation of both risk and the coarseness of the engineering process on which the assessment is based.

There is a need to move more towards an approach which focuses on identifying and addressing the structural vulnerabilities of buildings. It should be considered that neither the CTV or PGC buildings that contributed most to the loss of life were earthquake prone as currently defined (ie. having <u>both</u> an assessed strength of less than 33% NBS <u>and</u> being likely to collapse in a moderate earthquake), but each of them clearly had recognisable vulnerabilities.

Similar limitations have been encountered in terms of liquefaction settlement calculation methods in relation to both residential and light commercial/ industrial foundations. Internationally, settlement calculation methods have been developed from a limited number of soil types and profile characteristics (not necessarily the same as Christchurch soils), and typically from small datasets. Theoretical calculations of settlements do not often match site performance to a high degree of accuracy, and there are settlement or damage inducing mechanisms at play that are not amenable to current calculation techniques. The dataset on the CGD is being studied both locally and internationally, and will hopefully provide improved calculation methodologies over time.

As part of the triaging associated with the residential green zone technical categories, index criteria were set for liquefaction-induced settlements under serviceability limit state (SLS) and ultimate limit state (ULS) shaking. The use of a specific calculation methodology was established as a requirement in order to provide a consistent basis for comparison purposes (MBIE, 2012a). However given the many uncertainties and input parameters involved in liquefaction settlement calculations (including ground water level selection), this is not a ‘bright line test’, and considerable judgement is required in both determining and expressing the results. Similarly, judgement is required in the selection of appropriate foundation types, and the residential workstream of the EAG has provided advice on which may be suitable for a particular situation. Often this may involve a range of options, with the choice to be made by the engineer assessing the site conditions.

7.3 The effect of the marketplace

NZSEE has for many years recommended that where seismic strengthening of commercial buildings is required, then this should be carried out to two-thirds of current code (or 67% NBS).

In view of the risk perceptions noted above, this level is now being latched upon by the commercial property market as a minimum leasing requirement. Whilst laudable from a risk reduction perspective, it has rapidly created a large number of ‘less desirable’ properties in the main centres that are now difficult to lease. This is compounded by the performance issues identified in some modern multi-storey buildings in Christchurch, such as floor separation from perimeter frames that has led to a reduction in the effective capacity rating of a number of modern buildings in other centres.

A blanket requirement to strengthen buildings to this level would have significant cost implications for owners and the community, and would capture many buildings that do not pose a risk to occupants or the public. Consideration of the MBIE consultation document on earthquake prone building provisions (MBIE, 2012b), underway at the time of writing, is sharpening the focus on this issue and the wider understanding of risk.

7.4 ‘Safe’ is not an appropriate statement for engineers to make

Building owners need to make their own decisions about how to manage their buildings, with the benefit of expert engineering advice that takes into account the individual circumstances of each building and the risks in each case. It is important that engineers don’t get drawn into making absolute statements about the safety of buildings.

There were many instances following the September 2010 earthquake of engineers verbally and in writing advising clients that buildings were safe to occupy. This advice was generally given with aftershocks of lesser intensity in mind – and often without an appropriately comprehensive assessment of the functioning load paths.

This in turn highlights the need for care and clarity in post-earthquake reporting by engineers – something which is always challenging given the number of buildings being investigated and reported on, and the general lack of experience of engineers in post-earthquake assessments.

7.5 The recovery is being undertaken within ‘business as usual’ legal frameworks

Following the lifting of the national declaration of emergency at the end of April 2011, normal legal frameworks have applied, apart from the CER Act provisions. In essence this means that usual liability arrangements apply.

This is particularly challenging for geotechnical and structural engineers working for insurers or their project managers on residential properties and light commercial and industrial buildings, given the volume of relatively small but technically challenging cases. A further complication is that the objective in the residential rebuild is for repairs and rebuilds to receive standard building consents. The area of greatest difficulty lies with assessing future foundation performance at SLS, given both the uncertainty of ground performance and the lack of clarity surrounding SLS criteria, particularly in relation to liquefaction as noted previously.

There are additional challenges for engineers working in the residential sector. The Consumer Guarantees Act (CGA) applies for services provided to private owners and cannot be contracted out of. In normal situations, liability concerns arising from the CGA can be mitigated by working with the owner, either directly or via the architect or designer. As well as enabling a clearer understanding of the owner’s requirements and expectations, the engineer is better placed to discuss risks associated with the project with them to ensure a good understanding by all parties of both the likely and possible outcomes. However the opportunity to have a direct dialogue with owners does not always exist for engineers working for insurers or their PMO. The potential for miscommunication of possible risks is therefore heightened.

Particular concerns relate to having a case to defend in situations where there may in fact be no ultimate liability incurred by the engineer.

The consequence of heightened liability concerns is that some engineers are tending towards more conservative solutions in order to reduce their perceived risk exposure. In many situations this is increasing the cost of design solutions beyond what is required for adequate performance when viewed from a strictly technical perspective.

It is noted that this approach could have the opposite effect in some cases, particularly in the commercial arena, where insurers may seek to recover costs from solutions (eg. demolition) that are found upon further review to be unjustifiably conservative.

Engineers therefore need to ensure that appropriate contractual arrangements are put in place, good communications are maintained with owners and that processes that take account of potential liabilities are followed.

7.6 Response to Future Earthquakes

As noted earlier, a number of engineers who made themselves available to assist following the 4 September 2010 earthquake found themselves facing very detailed and public questioning in regard to their actions and decisions.

A key question therefore going forward is: *Will structural engineers turn up to carry out rapid building evaluations following future earthquakes?*

As was the case in the response to the major events in this sequence, it is considered that the engineering equivalent of "Is there a doctor in the house?" is always likely to draw a favourable response. But it is imperative that a better operating platform be provided by structuring the arrangements appropriately, including the systematic delivery of training. This should form part of a more structured approach overall to embed competent engineering within emergency management (Brunsdon, 2012).

8. CONCLUDING OBSERVATIONS

The Canterbury Earthquake sequence has had a significant impact on the earthquake engineering profession in New Zealand. The tragic outcomes of the February 2011 'aftershock' have contributed towards a more conservative outlook towards seismic risk generally. It shouldn't be overlooked that the extreme accelerations in that earthquake and the significant trailing aftershock events mean that this sequence is highly unusual in comparison with other international earthquake events.

For many engineers and scientists, this has been a period of intense involvement. Particularly for those living in Christchurch, there is little respite in prospect given the scope, intensity and likely time period of the recovery. Damaged houses and the difficulties of living in a significantly different city continue to add to the personal challenges for many.

Conversely, many engineers and scientists have commented that this is the most professionally exciting, challenging and satisfying phase of their careers. Many engineers have found themselves in circumstances where they have needed to adapt into new or expanded roles. It is clear that the level of professional maturity that many in this situation have attained has significantly progressed as a consequence.

The relentless nature of the engineering workload creates other professional challenges. Considerable judgement is required in carrying out both assessments and the design of repairs and reconstruction, irrespective of whether they are smaller residential or larger commercial buildings. Allocating sufficient 'thinking' and analysis time to each and every project is in itself a key judgement call in the face of the sheer volume of cases. Post-earthquake investigation also involves a significant element of forensic engineering and careful reporting, skillsets that are quite different from routine design tasks, and that usually require considerable experience.

Engineers are finding themselves in something of a difficult situation in relation to advising on seismic risk. Their services are in demand as never before, but many of the commonly used engineering assessment tools are not proving sharp enough to distinguish true vulnerabilities in commercial buildings, or guide selection of foundation repair and rebuild situations in residential and low-rise commercial and industrial buildings. And for the design of new structures, while there is considerable interest in low damage structures, some of the new systems may still feature the same design questions as established forms of construction in relation to aspects such as floor diaphragm performance.

The high levels of insurance cover by international standards have created particularly unusual demands, with engineers being asked to assist in the determination of damage, apportionment between events (sometimes with the added pressure of having different insurance or reinsurance carriers for each) and considerations of entitlement. While the engineers' role should generally be to provide the technical support to loss adjusters and lawyers, they are often requested to consider the terms of the insurance agreements and make judgement calls beyond the limits of their professional training.

As a profession, the key challenge is in maintaining a balanced perspective on the question of the risk to occupants posed by buildings of lower seismic capacity – both in Christchurch and throughout New Zealand.

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