Reflections on Thirty Years of Significant Earthquakes in Australasia and Beyond: Earthquake Engineering into the Future

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Abstract

The Newcastle earthquake led to a broader appreciation in New Zealand of the range of impacts of damaging earthquakes on the community, as well as in Australia. This event highlighted the important roles of engineers in earthquake response and recovery, and in turn the areas where engineers needed to be both more involved in and better prepared before future events.

The involvement by New Zealand engineers in the Newcastle earthquake response and recovery also prompted a closer look at New Zealand's earthquake preparedness, particularly through the professional engineering lens. In conjunction with the preceding Loma Prieta earthquake and subsequent Northridge and Kobe earthquakes, the Newcastle earthquake strongly influenced subsequent work in New Zealand, notably the development of capabilities in post-earthquake assessment and placarding, and urban search and rescue. As a result, New Zealand was much better prepared to deal with the many challenges presented by the Canterbury Earthquake Sequence of 2010/11, including the production of residential repair and rebuilding guidance following the Canterbury Earthquakes drew upon the challenges experienced in Newcastle, where there was a lack of a technical reference point for engineers.

Nine years on from the Canterbury earthquakes, with the additional learnings from the November 2016 Kaikoura earthquake, there are different drivers and challenges in both assessing existing building stock and designing new buildings. This paper provides perspectives on the current trends and challenges for earthquake engineering professionals, particularly in relation to structural design practice. Aspects covered will include the community's perspective on seismic risk, issues with relatively modern buildings, the understanding of seismic hazard and enhancements to the earthquake loadings standard NZS1170.5, and the realisation of the importance of designing buildings with due consideration to damage and future usability rather than just life safety.

Keywords: earthquakes, recovery, response, risk, usability

1. Introduction

The Newcastle earthquake led to a broader appreciation in New Zealand as well as Australia of the range of impacts of damaging earthquakes on the community. This event highlighted the important roles of engineers in earthquake response and recovery, and the areas where engineers needed to be both more involved in and better prepared before future events.

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Nine years on from the Canterbury earthquakes, with the additional learnings from the November 2016 Kaikoura earthquake, there are different drivers and challenges in both assessing the existing building stock and designing new buildings. This paper provides perspectives on the current trends and challenges for earthquake engineering professionals, particularly in relation to structural design practice and emergency management. Aspects covered include the community's perspective on seismic risk, issues with relatively modern buildings, the understanding of seismic hazard and enhancements to the earthquake loadings standard NZS1170.5, and the realisation of the importance of designing buildings with due consideration to damage and future usability rather than just life safety.

2. The Newcastle Earthquake: New Zealand Involvement and Learnings

Immediately following the Newcastle earthquake, the New Zealand Government offered the New South Wales State Government assistance in the form of the services of experienced earthquake engineers for advice during the post-event recovery process. The NZSEE president, Bruce Shephard, another Society member, Brian Wood, arrived in Newcastle on 30 December for a period of two weeks. A number of other NZSEE members were active in Newcastle during this and subsequent periods, working for the Public Works Department, Newcastle City Council and the private sector, including insurers (Brunsdon, 1990 and 1991). The first author was involved in both the response and recovery phases from 29 December 1989 through until the end of 1991.

Some of the lessons that New Zealand took from this event included the following:

- The need for the methods and systems to be used for immediate post-earthquake engineering inspections to be established and understood by all beforehand
- New Zealand has an important role in supporting responses to earthquakes in Australia
- The importance of mitigating highly vulnerable façade elements of URM buildings
- The many challenges for the engineering community in developing consistent approaches to repairing damaged residential and commercial buildings in the absence of industry guidance, and the importance of forensic engineering skills

- The complexity of dealing with insurance claims (particularly residential) affecting older buildings

3. Learnings from Other Earthquakes 1994 to 2009

Commencing with the Loma Prieta and Newcastle earthquakes in 1989, the following decade featured a number of significant earthquakes around the world, most notably Northridge 1994, Kobe 1995 and Turkey and Taiwan in 1999.

These events were closely studied by the New Zealand and Australian earthquake engineering fraternities via Earthquake Commission-funded earthquake reconnaissance (Learning from Earthquakes) missions. The following themes from these earthquakes were prominent in relation to the assessment and design of structures:

- The vulnerability of non-ductile concrete and steel buildings, and the need to include them within the scope of seismic assessments (which up until the early 2000s in New Zealand had been limited to URM buildings)
- The significance of global configurational weaknesses (e.g. vertical and horizontal irregularities) in the seismic performance of buildings, in addition to connection detailing
- The impacts of "liquefaction" on building performance (the loss of strength and stiffness in saturated or partially saturated low density or uncompacted sandy soils)

Many learnings were also obtained in relation to response preparedness. The NZSEE reconnaissance team to Northridge prompted the establishment of an Urban Search and Rescue (USAR) capability in New Zealand (Norton et al, 1995). This capability was built upon and extended as a direct consequence of the recommendations of the NZSEE reconnaissance teams to Turkey and Taiwan in 1999 (Sharpe 2000, Brunsdon 2000 and Angus et al, 2003). In turn, the Australian Earthquake Engineering Society facilitated the training of Australian engineers in USAR in Melbourne and Adelaide in 2004 and 2005.

The Northridge earthquake also provided the first evidence of the life safety issues associated with precast flooring systems (Norton et al, 1995).

While the 2000s featured fewer large impact earthquakes internationally, the devastating Indian Ocean tsunami in December 2005 brought tsunami to the forefront as a hazard with the potential for immense consequences.

Indonesia was also impacted by the September 2009 Padang, West Sumatra earthquake. Considerable support was given to the affected region by the Australian and New Zealand governments, including the enablement of engineering support. The NZ Government-funded NZSEE team spent two weeks assisting with the assessment of government buildings, applying the principles of the US ATC 20-based New Zealand rapid building assessment processes (Brunsdon et al, 2010). This experience, along with key observations from the procedures used following the 2008 L'Aquila, Italy earthquake led to a further enhancement of the New Zealand procedures. Their update was partially complete by the beginning of September 2010.

4. The Canterbury and Kaikoura Earthquakes: Continuing to Learn

4.1 Canterbury Earthquake Sequence

4.1.1 Overview

Professional engineers provided a range of inputs into the responses to the Canterbury Earthquake Sequence and the recovery process that followed. This earthquake sequence was been unique in many respects, including the intensity of shaking produced in the Christchurch CBD by each of the major aftershocks in December 2010, February, June and December 2011.

There have been many post-earthquake challenges from this sequence 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 – aspects of which are still continuing nine years after the first earthquake. For engineers from Christchurch in particular, the heavy workload has been continuous. The insurance claims process has been demanding for those involved for both homeowners and insurers. Engineers are required to interface with owners, insurers and regulatory authorities, and face many challenges in meeting the objectives of these different sectors, which are rarely aligned (Brunsdon et al, 2013).

The Canterbury Earthquakes Royal Commission of Inquiry and other investigations added to this pressure. 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 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 (CERC, 2013). Interpreting and communicating ‘safety’ in relation to the re-occupancy (or continued occupancy) of commercial buildings was a challenge in the face of liability concerns.

4.1.2 Response – USAR and Placarding

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 (Brunsdon et al, 2013).

The Canterbury earthquakes also presented the first opportunity to deploy the NZ rapid building safety evaluation guidelines. Many lessons have been learned from this experience, which was extensively investigated by the Royal Commission, and an updated system is now in place, based on a three-tier capability approach (refer Figure 1).

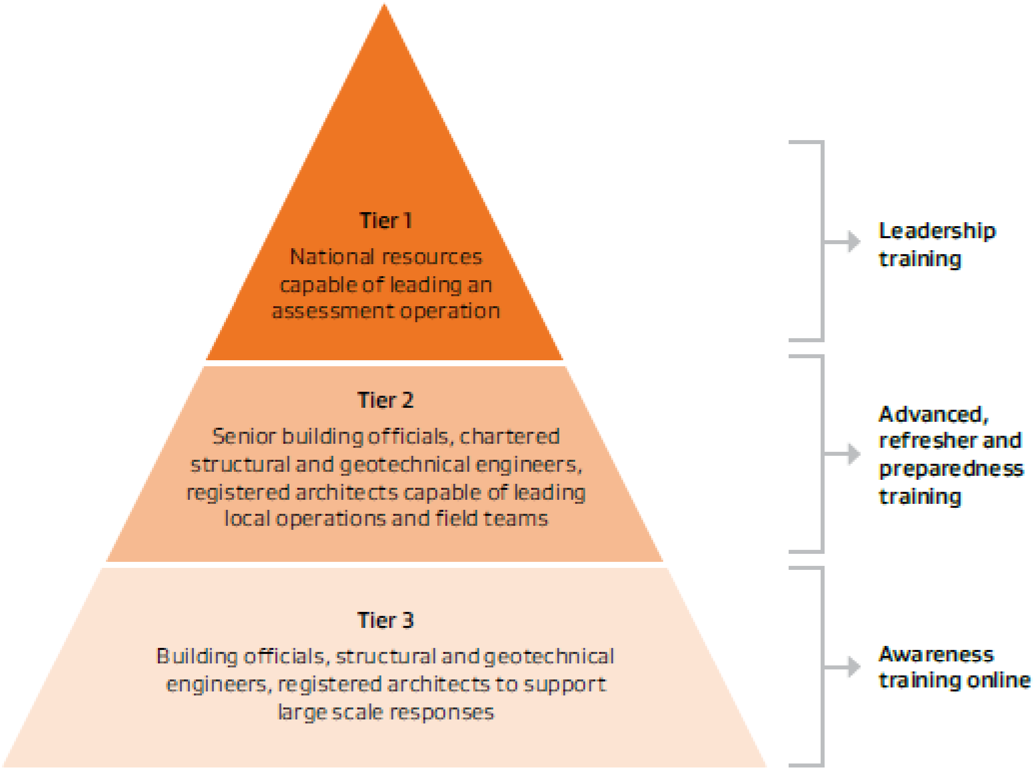

Figure 1: Building Assessor Capabilities (MBIE 2018)

There are approximately 500 engineers and building officials trained in rapid building assessment at the Tier 2 level. Earthquake, flooding and geotechnical Field Guides have also been developed for assessors. The placards have been reworded in plain English and a decision was made, following CERC recommendations, to change the green placard to white, somewhat contrary to international practice (MBIE 2018).

Overall, a better understanding of the scope of managing buildings in emergencies has emerged, as covered in section 6.

4.1.3 Recovery – residential rebuild guidance

The production of residential repair and rebuilding guidance following the Canterbury Earthquakes (MBIE, 2012) drew upon the challenges experienced in Newcastle, where there was a lack of a technical reference point for engineers. The challenges of understanding the damage to older buildings, particularly those that had experienced different degrees of historical settlement over the years, have definite similarities across both events. The importance of careful forensic analysis and reporting, based on an understanding of earthquake effects, and the associated need for training were highlighted in both earthquakes.

Forensic and material engineering skills are essential to navigate the complexities of earthquake damage, particularly for insurance settlement purposes, where there is a need to carefully distinguish pre-existing damage from that caused by the earthquake. These skills do not however simply become acquired during the course of a career in general engineering practice – training is required as well as experience.

As is often the case, there have been many cases of differences of opinion between engineers engaged by property owners and engineers engaged by insurers. There have also been many cases of inadequately scoped and/ or poorly executed repairs to residential properties that have required revisitation. In 2017 the government set up the Greater Christchurch Claims Resolution Service to provide homeowners with a mechanism to assist with such disputes with the government insurance agencies (Earthquake Commission and Southern Response). Engineering New Zealand have provided the engineering component of this resolution service, establishing an expert panel to provide independent reporting, peer review and facilitation services as required.

4.2 Kaikoura Earthquake

The 16 November 2016 M7.8 Kaikōura Earthquake was a complex event, with 21 faults rupturing throughout the North Canterbury and Marlborough landscape, generating a localised seven metre tsunami and triggering thousands of landslides.

The earthquake resulted in long duration shaking in excess of the code demand for many buildings with fundamental periods between 1 and 2 seconds in Wellington, particularly in those parts of the city where shaking has been amplified due to basin effects and deeper deposits, notably in the port area or Thorndon basin. Damage was concentrated in 6 to 15 storey concrete moment frame buildings with precast flooring systems. The duration of the earthquake has also meant that these structures were likely to have been subjected to multiple cycles of inelastic action.

A formal placarding process was not undertaken, as no emergency was declared in Wellington City. However, prompted by the failure of three precast flooring units in a six storey 2005 building on the waterfront (MBIE, 2017) and other early damage reports, a specifically developed assessment approach was adopted in Wellington for these buildings (Brunsdon et al 2017). A Targeted Damage Evaluation (TDE) procedure was developed by leading researchers and practitioners to support the Wellington City Council requirement under legislation passed following the earthquake. This legislation required the owners of 72 specifically identified buildings undertake a more detailed inspection. This process was a refinement of the Detailed Damage Evaluation developed following the February 2011 earthquake, and was able to be put in place within five weeks of the Kaikōura earthquake.

Critical damage states (Henry, et al 2017) were identified in several of the identified buildings. The results demonstrated its value by identifying damage unseen during the initial response whilst optimising the use of scarce engineering resources (Kestrel Group, 2017).

One of the key points from this work is the need be prepared to customise post-earthquake assessment processes to an earthquake and its specific impacts.

Along with the original and subsequent research into precast flooring systems (Matthews, 2004; MacPherson, 2005; Jensen, 2006; Woods, 2008; Corney et al, 2014), the damage observations from the Canterbury and Kaikoura earthquakes have increased the focus by government, territorial authorities, design engineers and owners on better understanding and systematically assessing the life safety risk posed by existing precast concrete floor systems.

5. Structural Design for Earthquakes in New Zealand: Current Thinking

5.1 Seismic Hazard and Risk

There is possibly a need to consider a more deterministic methodology for determining seismic hazard as an alternative to the long-established use of probabilistic seismic hazard analysis (PSHA). Concerns are being discussed within primarily the structural engineering field that we may be underestimating the seismic risk to our communities using the current suite of “tools”: PSHA and seismic design and assessment methods.

Hare (2019) proposed that seismic demand should be estimated using a deterministic approach. Within engineering reason and knowledge, characteristics of a major/severe earthquake (size, energy release, duration, frequency content, directivity) could be estimated for a specific site, given the known faults, and reasonable inferences (engineering seismology, and geology) for unknown faults that could influence that site. This means of determining likely severe shaking at a site could be applied to regional planning, such as land use and municipal infrastructure (roads, water and power reticulation), and geotechnical aspects such as slope stability and liquefaction. The associated point was made that PSHA should be kept for insurance purposes such as loss estimation.

There is currently a much greater awareness of the importance of engineers understanding the technical dimensions of risk – including that the *consequence* (of failure, loss of function, or financial loss) is more important than the bare statistical likelihood of an earthquake, as can often be the more dominant consideration. A clearer view is also emerging that engineers shouldn’t be assuming responsibility for setting societal thresholds – that responsibility belongs to Society, and the politicians who act on their behalf (Hare, 2019).

5.2 Assessing and Strengthening Existing Buildings

The updating of the 2006 NZSEE seismic assessment guidelines was a major undertaking during the period 2013 to 2017, set against the unfolding learnings from the Canterbury and Kaikoura earthquakes. The new guidelines (MBIE, EQC, NZSEE, SESOC and NZGS, 2017) represent the latest knowledge for assessing existing buildings.

The 2016 amendments to the Building Act updated the earthquake prone buildings provisions to address the recommendations of the Canterbury Earthquakes Royal Commission. While the definition of an earthquake prone building still focuses on a moderate earthquake (one-third as strong as the 500-year design shaking for the same building on the same site), heavier parts of buildings are now included within the scope of assessments in addition to the primary structure. In a further significant development, the new assessment guidelines now form part of the regulatory framework for earthquake prone buildings, and as such it is a mandatory requirement that they be used for all assessments. An overview observation is that assessing the expected seismic behaviour of an existing building is in many cases more complex than designing a new structure. Furthermore, making it a regulatory requirement just adds to the challenges.

5.3 New Building Design

The current legal focus in NZ for performance of buildings in major earthquakes is on “life safety”. This has come to mean that if the occupants can safely evacuate a building, then the legal requirements are met; equally, that the structure may not be able to be repaired, and hence it would be demolished. The objective of property (and hence investment) protection is not currently required by law (in terms of the Building Act 2004 and the Building Regulations 1992).

Within the wider building industry of NZ (investors, government departments, engineers, architects, and increasingly, the insurers), there is a developing discussion regarding “maintenance of function” of a structure, going well beyond “life safety” performance. An Act of Parliament would be required to make maintenance of function a compulsory performance requirement. Sectors of the end-users of the “building infrastructure” are however starting to request maintenance of function – such as hospital campus, critical to the recovery of a region after a catastrophic event.

“Maintenance of Function” is more than a building structure with low damage. It is coming to mean:

- That people can reoccupy the building in a reasonable time period (in hours or days - not months or even years)
- The key functions of the building are maintained to an acceptable level
    - Weathertightness
    - Security
    - Electrical power
    - Telecommunications
    - Water supply and sanitation
    - Interior fit-out
    - Vertical and horizontal movement of people and property
    - Structural soundness (for anticipated aftershocks or the abatement of the storm front, and for the next major event some time in the future).

Some damage may have occurred to fit-out and cladding, but to an acceptably low degree, and without compromising the main functions of the building, including what the occupants are undertaking.

Designers and researchers are expanding the options for “maintenance of function” structures both in New Zealand and globally. Alternative structural configurations in steel, reinforced concrete and timber are being developed. In parallel, fit-out, mechanical services, cladding and systems to protect the structures from ground motion (the well-established base isolation) and absorb of seismic energy (dissipation systems: lead dampers, viscous dampers, hysteretic dampers) are now reasonably well understood.

5.4 ‘Telling the Story’ about a Design

One of the most important aspects of a completed design or assessment of an existing building is the ‘Executive Summary’ that tells the story of the structure and process followed. This is particularly valuable given the opaqueness of many structural modelling processes.

For a new building, a *Design Features Report* should summarise in narrative format the basis and underpinning philosophy for the design. For the assessment of an existing building for earthquake prone purposes, an *Assessment Summary Report* is now required to capture all relevant information about the building and the assessment process followed. A template in tabular form is provided (www.EQ-Assess.org.nz), along with all the relevant technical guidance for assessing buildings.

The purpose of the respective summaries is two-fold – for peer review and regulatory compliance in the first instance, and for the benefit of the next engineer who works on the building in the future. Bearing in mind that this may be in a few decades' time, there is considerable value in having a 'time capsule' of information.

6. Some Thoughts on Earthquake Engineering into the Future

6.1 New Building Design

New building designs should be reasonably expected to perform well in earthquake shaking that exceeds the levels used in design. This is an important principle given the inherent uncertainty in design levels.

The associated question therefore is 'What actually comprises good structural design for earthquake? Table 1 following proposes key themes and associated considerations that should be addressed in order to produce a 'good' structure, set against the different phases of design.

Table 1: Key Considerations in producing 'Good' Building Designs for Earthquake

Phase	Theme	Considerations
Overview	Clarity of performance objectives	• Owner expectations – do they understand what 'just meeting code requirements' actually mean?
	Understand the ground and its implications	• Informs the level and nature of the seismic loads • The appropriateness of the selected structural form for the ground flexibility
	Be clear on deformation targets for different levels of shaking	• *Moderate*, *significant* and *extreme* levels of earthquake shaking
Concept design	Ensure there is a regular layout with a complete load path	• A full and effective load path with all elements tied together (including if/ when elements of the structure go post-elastic)
	Clearly identify the critical elements	• Assuming any degree of ductility in selecting overall design levels must be backed up with detailing of critical elements
	Appropriate selection of overall ductility	
Design detailing	Appropriate detailing critical elements and connections	• Focus on the critical elements that will (or may) be required to yield
Quality Assurance	Robust reviews	• At the concept design stage and upon completion of the design
	Identify the critical elements	• Elements that need to be carefully checked on site (consequence of incorrect construction)

A key question in relation to performance objectives is 'When is going beyond code minima appropriate?'. This talks to the need to consider the survivability of the structure (not just the occupants).

The table also suggests that robust reviews at the concept design stage is essential, and that Quality Assurance should not just be regarded as a process step to follow the completion of a design.

6.2 Post-earthquake Arrangements for Engineers

Successive earthquake events in New Zealand and internationally continue to highlight the importance of having effective arrangements for the management of buildings in the response and recovery phases in place before an earthquake. These arrangements need to include the following elements:

1. Operational arrangements for Response and Recovery that clarify how engineers will work together with emergency managers and building control managers, with appropriate preparedness and prior engagement; and
2. Resource capability and capacity to deliver on these arrangements. This includes designated leaders to prepare for and co-ordinate operations, and suitable numbers of trained and experienced engineers and building officers to provide necessary technical inputs

In New Zealand there is now a clearer understanding about the scope of *building management in emergencies*, and how in particular it is much broader than just rapid building assessments and placarding of buildings (MBIE, 2018).

The training and development of the individuals that have the knowledge and experience to lead building management operations is a crucial element of the overall national capability, but one that still requires greater attention in New Zealand. An associated need is for the establishment of specific standing arrangements between metropolitan territorial authorities and engineers to enable early leadership of response processes, and maximising the use of information from instrumented buildings (Brunsdon et al, 2017).

A further consideration is that '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, rather than the significantly different event that occurred in February 2011 – and often without an appropriately comprehensive assessment of the functioning load paths (Hare, 2014).

7. Key Considerations for Australia

7.1 New Building Design

Although most of Australia may be considered to be of low seismicity, there remains the possibility that an earthquake of similar scale to that experienced by Christchurch in February 2011 could affect a major urban area.

Given the low probability of a direct hit on a populated area, it would be uneconomic to require specific seismic design to a level that is reflected even in the lowest seismic zones of New Zealand. However, the introduction of specific design and detailing provisions for buildings that fail to satisfy prescribed configuration requirements, together with more widespread non-specific robustness provisions, may be considered. This could suppress the worst of the behaviour observed in buildings in Christchurch (Hare, 2014).

7.2 Post-earthquake Considerations

Key points of relevance to the Australian earthquake engineering community in relation to the response phase include:

1. Establish mechanisms for post-earthquake technical leadership and co-ordination (Brunsdon, 2019).
2. Continue to train experienced structural and geotechnical engineers in collapse rescue, and have them integrated within USAR arrangements.
3. Training is required for engineers who may be expected to carry out post-earthquake rapid building evaluations. It is likely that the best approach for Australia may be to be concentrating on building a relatively small core of well-trained engineers, rather than try and spread it far and wide (Hare, 2014).
4. It is important to have a consistent basis of evaluating buildings in order to ensure that critical and sometimes hidden damage is identified, and that its impact is considered. This may inform whether continued occupation prior to repair is appropriate.

For recovery, there is a need to have technical guidance for assessing and repairing damage to commons forms of construction, particularly masonry. There is also a need for engineers to be trained in forensic engineering, insurance basics and report writing, all with earthquakes firmly in mind.

8. Concluding Observations

The Newcastle earthquake led to a broader appreciation in New Zealand of the range of impacts of damaging earthquakes on the community, as well as in Australia. This event highlighted the important roles of engineers in earthquake response and recovery, and in turn the areas where engineers needed to be both more involved in and better prepared before future events. Along with the learnings from the other significant earthquakes during the 1990s and 2000s, this event laid the foundations for some key aspects of the technical response to the Canterbury earthquakes.

However as well as causing largely predictable damage to older structures, the Canterbury earthquakes, along with the Kaikoura earthquake, have highlighted a number of aspects associated with relatively modern multi-storey buildings that need specific consideration. In New Zealand, an area of concern is how precast techniques have been applied.

As a consequence, these events collectively have led to a change in the community's perception of seismic risk in New Zealand. As well as concerns about the potential for buildings to collapse, the economic implications of having code-complying buildings that are only able to withstand one significant earthquake before requiring replacement are becoming increasingly unpalatable.

All of the major earthquakes over the past thirty years have underlined the importance of good building design for earthquakes – that is, ensuring attention is paid to basic aspects such as regularity of layout (particularly vertical, to avoid soft storey vulnerability), complete load paths, careful detailing of critical elements and effective quality assurance.

There is still a need for renewed attention and efforts to put more effective post-earthquake building management arrangements in place – an aspect of earthquake preparedness that still requires much work on both sides of the Tasman.

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