THE 2010-2011 CANTERBURY NEW ZEALAND EARTHQUAKES AND THE EMERGENCY MANAGEMENT OF BUILDINGS AND INFRASTRUCTURE

Peter R Wood[1], Dave Brunsdon[2], John Hare[3], Mike Stannard[4], Bruce Galloway[3]

Abstract

The 2010-2011 Canterbury sequence occurred in an area of New Zealand with a low probabilistic seismic hazard. The sequence commenced with the M7.1 Darfield earthquake of 4 September 2010 that caused unprecedented urban liquefaction and lateral spreading, severely damaged unreinforced masonry buildings, caused significant non-structural damage, and disrupted infrastructure. Aftershocks included the damaging events of: December 2010; February 2011; June 2011; and December 2011. The 22 February 2011 M6.3 event caused significant shaking of Christchurch, New Zealand's second largest City, with even more unprecedented urban liquefaction, lateral spreading, additional severe damage to and collapse of unreinforced masonry buildings causing fatalities and injuries, further non-structural damage and disruption to infrastructure, and damage to modern buildings. Two multi-storey, reinforced concrete buildings collapsed with fatalities and injuries. Rock fall and cliff collapse caused additional fatalities and injuries. A total of 185 lives were lost. A state of National Emergency was in place for just over two months.

Prior to the Canterbury earthquake sequence, ATC-20 Procedures for Postearthquake Safety Evaluation of Buildings was adapted to the New Zealand statutory environment and published by the New Zealand Society for Earthquake Engineering as Building Safety Evaluations during a State of Emergency Guidelines for Territorial Authorities 2009. Adaptations incorporated experiences from earthquakes in Gisborne New Zealand, L'Aquila Italy, and Padang Indonesia, and included recognizing that a building may be compromised by the state of its neighboring surrounds. The Guideline was followed, with amendments, to manage the impacted buildings during the states of emergency that followed the earthquakes of 4 September 2010 and 22 February 2011. This paper outlines the building evaluation process as part of management of the emergency and some key lessons identified. An associated paper (The Effectiveness of Post-Earthquake Building Safety Evaluations Carried out in the Canterbury Earthquake Sequence and Proposals for Future Development, Galloway et. al) adds further detail.

Introduction

The 2010-2011 Canterbury Earthquake sequence occurred in an area of New Zealand with a low probabilistic seismic hazard. The earthquake sequence comprised a series of ruptures on previously unknown faults located on the eastern margin of the Pacific/Australian Tectonic Plate Boundary (Figure 1).

The sequence commenced with the M7.1 Darfield earthquake of 4th September 2010 that damaged unreinforced masonry buildings, caused significant non-structural damage, and disrupted infrastructure. The 2010 Darfield earthquake also caused unprecedented urban liquefaction and lateral spreading in the coastal city of Christchurch which is situated on the margins of the Canterbury alluvial Plains and the basaltic flanks of the Port Hills of Banks Peninsula. The strong ground shaking also induced liquefaction and lateral spreading in the parts of Waimakariri District Council and Selwyn District Council adjacent to the area of Christchurch City Council; the area impacted is now referred to as Greater Christchurch.

[1] *Ministry of Civil Defence & Emergency Management, Wellington, New Zealand*
[2] *Kestrel Group, Wellington, New Zealand*
[3] *Holmes Consulting Group, Christchurch, New Zealand*
[4] *Building & Housing Group, Ministry of Business, Innovation & Employment, Wellington, New Zealand*

The sequence was characterized by a large number of aftershocks including the damaging events of: 26th December 2010; 22nd February 2011; 13th June 2011; and 23rd December 2011 (Figure 2).

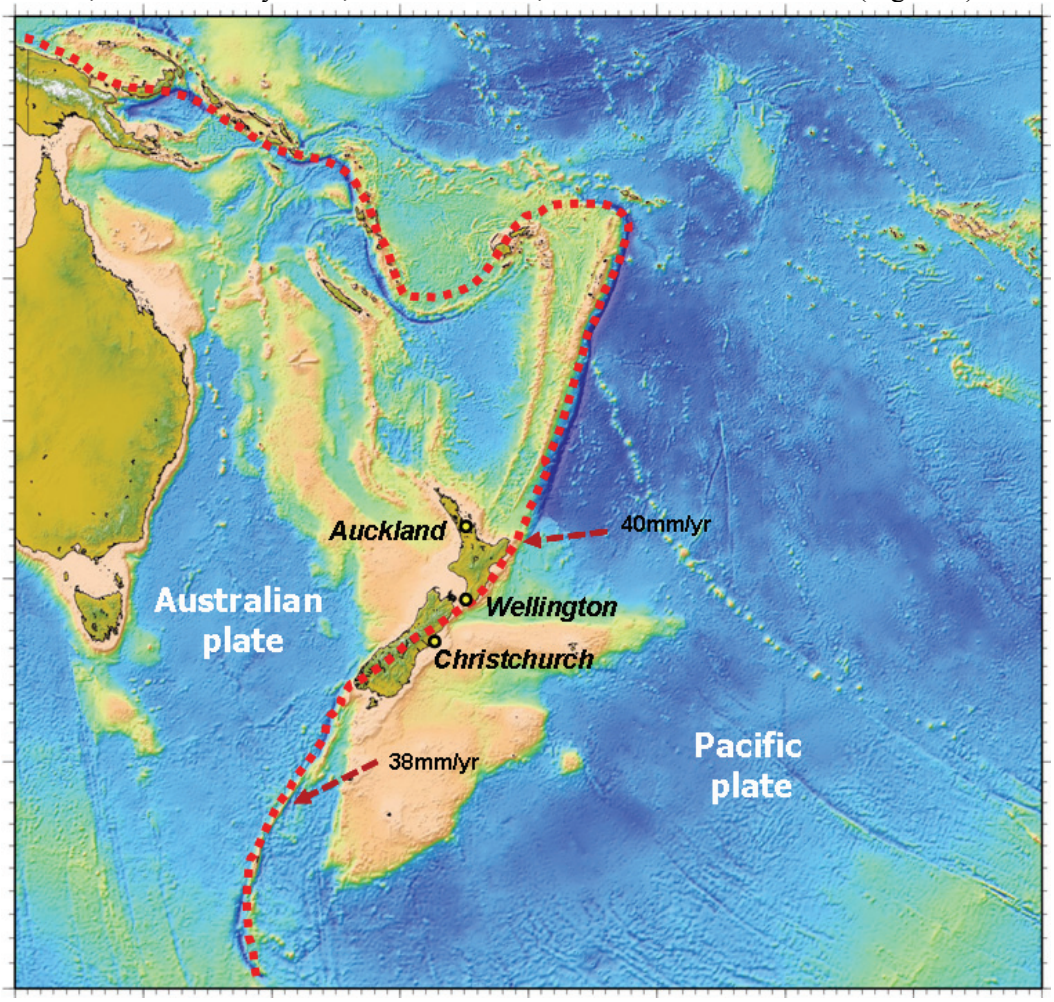

Figure 1. New Zealand on the Pacific/Australian Plate Boundary

The 22nd February 2011 M6.3 Christchurch earthquake caused significant shaking of Christchurch, New Zealand's second largest city, with even more unprecedented urban liquefaction, lateral spreading, additional severe damage to and collapse of unreinforced masonry buildings causing fatalities and injuries, further non-structural damage and disruption to infrastructure, and significant damage to modern buildings. Two multi-storied reinforced concrete buildings collapsed with additional fatalities and injuries. Rock fall and cliff collapse also resulted in additional fatalities and injuries. A total of 185 lives were lost. New Zealand's first ever State of National Emergency was declared on 23 February and was in place for just over two months.

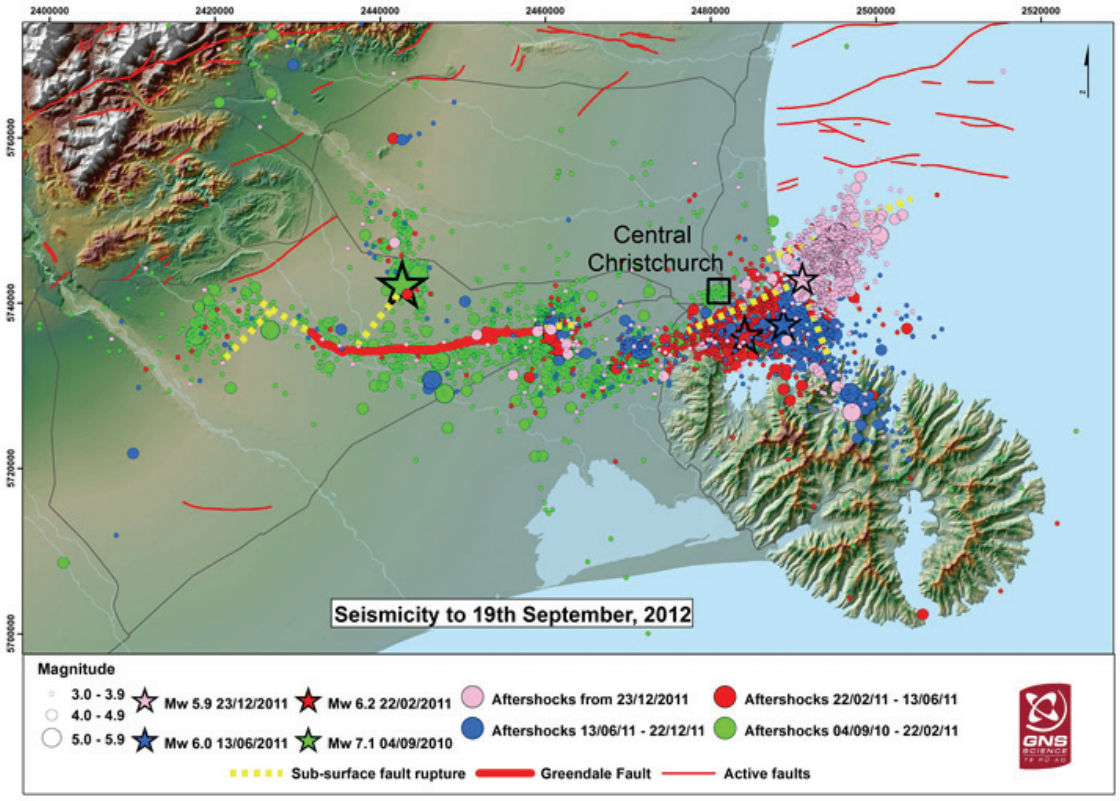

Figure 2. The Canterbury earthquake sequence (4th September 2010 to 19th September 2011)

While the initial M7.1 Darfield Earthquake of 4th September 2010 generated moderate shaking in the nearby city of Christchurch some 37 km away, the M6.3 Christchurch Earthquake of 22nd February 2011 was centered just 8 km from the central business district (CBD) and resulted in record ground shaking in the CBD (Figure 3).

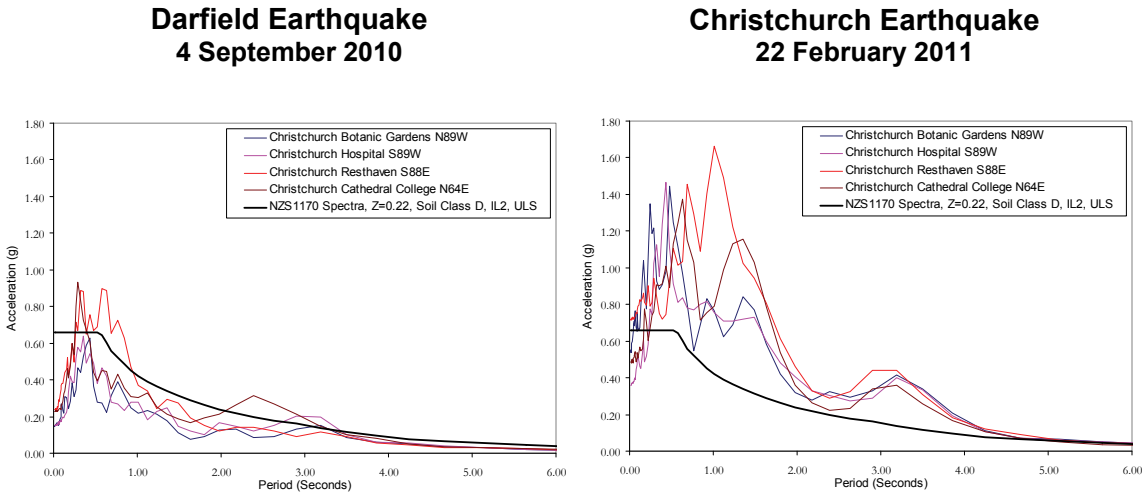

Figure 3. Acceleration spectra in the Christchurch CBD from the M7.1 Darfield and Christchurch M6.2 earthquakes compared to the NZS1170.5:2004 design spectra

While the Darfield Earthquake was the first major earthquake to test current New Zealand design standards, the occurrence of the subsequent Christchurch Earthquake tested these even further, and for some buildings, to their Ultimate Limit State. These two earthquakes and other damaging aftershocks tested the effectiveness of New Zealand's post-earthquake building management arrangements.

Post-earthquake response and recovery policies have been developed internationally on the assumption of a primary main shock followed by an aftershock sequence that can be some what predicted, as by the modified version of Omori's empirical law (Utsu et. al. 1995). In comparison, the characteristics of the Canterbury earthquake sequence of repeated damaging earthquakes are considered to be relatively unique, and caution should therefore be exercised in focusing changes to recovery policies on this event when the traditional aftershock model should be given due consideration.

The impacts of the Christchurch earthquakes, including the associated loss of life, have been subject to the Royal Commission of Inquiry into Building Failure caused by Canterbury Earthquakes (The Canterbury Earthquakes Royal Commission). The Commission's process has been open to the public; the evidence, submissions, and records of hearings are available in the Commissions on-line Document Library at - http://canterbury.royalcommission.govt.nz/.

A companion paper (*The Effectiveness of Post-Earthquake Building Safety Evaluations Carried Out In the Canterbury Earthquake Sequence and Proposals for Future Development*, Galloway et.al) provides more detail on the management of buildings following the earthquakes of the Canterbury sequence and proposes improvements in approach based on the experiences.

Emergency Management and Building Evaluations following Canterbury Earthquakes

General Civil Defence Emergency Management planning arrangements are outlined in the Guide to the National Civil Defence Emergency Management Plan and in the Regional Civil Defence Emergency Management Group Plans.

Immediately an earthquake was felt significantly in Christchurch, impact assessments commenced, initially based on but limited reports and first-hand accounts, often communicated by short SMS 'text' messages.

GeoNet[5] typically provided, within 30 minutes, the first instrumentally informed report of the location, depth, magnitude, time, and the estimated Maximum Mercalli Intensity of the earthquake; GeoNet Rapid now provides such information in about five minutes (see www.geonet.org.nz). GeoNet also provides acceleration and displacement data from broadband seismometers.

The core Emergency Services (Police, NZ Fire Service, and Ambulance) accumulate intelligence of where emergency (111) phone calls are coming from and the nature of each incident. These 111 calls come to any one of three Communication Centers in Christchurch, Wellington, or Auckland (see Figure 1) which utilize an integrated information management system that includes reports from officers in the field or on-the-beat. Summaries and updates are communicated to National and Local Civil Defence Emergency Management Authorities.

Territorial Authorities, such as Christchurch City, Waimakariri, and Selwyn District Councils are alerted to infrastructure changes and outages from their SCADA systems, they and other agencies will also use 'windscreen' surveys to assess impacts. Media and social media reports also add to the emerging picture of the nature and extent of the impacts of the event.

[5] www.geonet.org.nz

All available information, including the state of buildings, is compiled by the responding authorities and typically escalates to civil defence emergency operation centers (EOCs). On the basis of the emerging situational awareness of responders and the developing common operating picture, decisions are made on what actions to take. Judgment calls are required as to whether normal arrangements are able to manage the event. When normal resources and arrangements may be overwhelmed, then a State of Emergency may be declared, under the Civil Defence Emergency Management Act 2002.

4 September 2010 Darfield Earthquake. Immediately following the 4 September 2010 M7.1 Darfield Earthquake, a State of Local Emergency was declared. Rapid building evaluations were then carried out under the direction of the Civil Defence Emergency Management Controller (CCC, 2011). Half hour briefings were typically provided to engineers and building officials before sending them out in teams to carry out the rapid assessments across the city. This assessment process for the buildings contained within the Christchurch CBD, along the main arterial routes from the suburbs into the CBD, and for the eastern suburbs took days to complete. By 14 September 2010 the CCC building evaluation teams had posted placards on 1,236 commercial buildings and 6,686 residential buildings. Additional postings were completed by Waimakariri and Selwyn District Councils.

26 December 2010 Boxing Day earthquake. Following the damaging M4.9 Boxing Day aftershock on 26 December 2010, centered almost under the Christchurch CBD, a state of emergency was not declared, and the formal building evaluation process could not therefore be carried out under the direction, and with liability protection, of the Civil Defence Emergency Management Controller. As a result, there was no formalized command structure and a haphazard approach to building evaluation resulted. Noting that this event occurred at the beginning of what is New Zealand's major national summer holiday, engineers were not available in large numbers and buildings in a dangerous condition continued to be occupied for some time. A further consequence was that people untrained in building evaluation (such as police, fire) felt the need to protect the public and in some cases unnecessarily restricted access to buildings that, although damaged, had not suffered significantly.

22nd February 2011 Christchurch Earthquake. The 22nd February 2011 M6.2 Christchurch Earthquake caused extensive damage, injuries, and loss of life. A State of National Emergency was declared (for the first time ever, after an initial period of local management for the first 24 hours). Given the intensity of building damage in the CBD, it (the 'Red Zone') was cordoned and closed to all but emergency personnel including Urban Search and Rescue Teams (USAR).

The Christchurch City building evaluation and placarding operation was planned on Wednesday 23rd and Thursday 24th, with field inspections in the CBD commencing on Friday 25th. This planning work was led by Council building control officials supported by engineers who had been closely involved in the leadership group in the 4 September operation. Other volunteer Building evaluators (engineers and building officials from outside the Canterbury region were swiftly mobilized by the Institution of Professional Engineers (IPENZ) and members of the Building Officials Institute (BOINZ).

With the benefit of the experience from September, a planned operation was launched. As the whole CBD was locked down while USAR operations were underway, there was not the same urgency to commence rapid building evaluation operations there as there had been in September. Due to the significantly heightened risk within the CBD, only experienced Chartered Professional Engineers were used for assessments within the Red Zone.

An important aspect of the operation was the early inclusion and warranting of consulting engineers who had been working on buildings following September and who had a detailed understanding of the likely response of those buildings to major aftershocks, as well as other privately engaged engineers acting for clients to assess commercial buildings newly damaged.

As part of the overall building evaluation process, specific plans were established and implemented for the evaluation of:

- the Central Business District, where the Urban Search and Rescue (USAR) resources, including International teams, were initially deployed;
- arterial routes into and out of the central city to facilitate safer travel;
- *Operation Critical Buildings* - for high rise, particularly those giving stability concerns and threatening thoroughfares and other buildings. A team of experienced structural engineers were dedicated to setting up monitoring and assessing arrangements that led in some instances to emergency stabilization or demolition. Most of the subject buildings were demolished over a period of months to over a year.
- A rapid response team of engineers to respond to urgent incoming requests for building inspections was also established, and included geotechnical engineers as well as structural engineers.

In addition, a limited pool of specialist engineers was provided to two building control operations:

- *Operation Suburb* - deploying up to 1,000 building control officials, welfare representatives and EQC[6] personnel per day for areas of residential housing (by far the majority of which are one to two storey single dwellings); and
- *Operation Shop* - covering key suburban shops and other community services that could provide critical services and goods including pharmacies, supermarkets, medical centers, hardware stores, and libraries.

Detailed engineering evaluations started in earnest at the end of the Response phase and the beginning of the Recovery phase, when the State of National Emergency was lifted on 30 April 2011, over two months after the 22nd February earthquake. Progress continues to be made on the detailed engineering evaluations of damaged buildings. At the time of writing, approximately 1,100 DEE's had been formally submitted to the Canterbury Earthquake Recovery Authority (CERA), with 7,000 more yet to be completed, over an estimated period of three years. These numbers are slightly deceptive in that four property owning organizations (Christchurch City Council, Ministry of Education, Canterbury District Health Board and the University of Canterbury) account for approximately 4,500 of these buildings and their assessments are advancing in parallel with the private sector effort.

Information Management

Territorial authority records were based on property addresses (actually "rateable units"). This created difficulties for campus's containing several buildings (e.g. schools, universities, hospitals), where in some instances a single representative 'placard' was recorded for the site, with a variety of approaches used to describe the hazard posed by each individual building to users.

It is recommended that Territorial Authorities maintain digital records of unique building identifiers in addition to the sometimes independent street addresses (and rating units).. Building assessments and placard status should be recorded against the building identifier. This is particularly critical when recording meaningful information in relation to the assessment of large campuses and sites with multiple buildings.

[6] EQC – the Earthquake Commission, a government agency that provides prescribed catastrophic insurance cover to only residential properties that have fire insurance, and has been managing, on behalf of government, the residential repair process; see – www.eqc.govt.nz

In Christchurch, placards were placed on buildings because of structural damage, hazard posed by land stability, or sanitary reasons. Each of these placards may have been placed under different legislation, leading to significant difficulties in updating and monitoring placards. Furthermore, a subsequent review of one hazard (eg the structural safety of the building) may have resulted in the placard being changed when the original hazard (eg rockfall) may still be present. Although this was not common in the CBD, it became a significant issue in some of the hillside suburbs.

Another issue which became apparent under *Operation Suburb* was an operational decision for residential houses to be posted only with either the 'Unsafe - Red' or a 'Black and White" notice - that indicated the house had been inspected and was either 'Yellow' or 'Green' and gave contact details for further information. This lead to uncertainty, confusion, and consternation when owners in some cases were effectively shut out of their homes without explanations, when a lesser restriction on use of parts of the house may have been appropriate.

Public Understanding and Communication of Seismic Risk

It has become apparent, particularly through the Canterbury Earthquakes Royal Commission hearings, that there are serious inadequacies in the public understanding of risk, safety and building standards. While not seeking to assign blame for this, it is apparent that there is a need for clarity (Galloway & Hare 2012).

The most obvious issue is in the use of the term 'safe'. The subtlety that there is no such thing as absolute safety is of little concern to most lay people, for whom 'safe' conveys an absolute expectation and is without limitation. In comparison, 'safe' in 'building safety evaluation' terms was intended to convey the relative risk being no greater than it was previously.

Although it has been commonly agreed that the use of the word 'safe' should be avoided, there is a semantic aspect to this. It must be recognized that regardless of the word to be used, the public are not concerned with context, i.e. what size of earthquake or shaking intensity may cause damage. Rather, they are concerned whether any earthquake may be a life safety hazard.

Engineers must therefore endeavor to convey to the public that buildings carry a level of inherent seismic risk, and that they can not be guaranteed to be 'earthquake proof'. There needs to be a concerted effort to educate the public as to the nature of risk and risk mitigation, if we are to avoid this situation repeating itself.

Role of the Media

Public information management during an emergency involves collecting, analysing, and disseminating information to the public: to create strong public confidence in the emergency management response; to support public safety with public information; to positively influence public behaviour with public information; to manage public expectations. Public information management is critical for emergency response and recovery and can be a significant operation.

By way of example, following the Christchurch earthquake of 22 February 2011, 1,269 journalists were accredited in the response with 177 media staff in the Christchurch Response Centre providing 24/7 liaison. International interest was immediate - following reports of trapped or missing foreign nationals, including Japanese students.

The Independent Review of the Response to the Christchurch earthquake of 22 February 2011 (McLean et. al 2012) notes that "the media did an excellent job in informing the country and the world about the

tragic disaster that had befallen Christchurch. Within the limitations of their technical capacity and reach into the community, the media also make considerable efforts to tell the people of Christchurch what they needed to know about the Response to the earthquake. However, technical limitations and loss of services (such as electricity) made this effort insufficient.

Communication from the Response organizations to the media was also good."

Building Regulations

Through the Canterbury Earthquakes it has become apparent that there is a significant gap in the current New Zealand regulatory policy for managing buildings in a disaster. Building regulations have been developed to prepare for a natural disaster by addressing the design and construction of new buildings and the assessment of existing buildings, while emergency management legislation has been developed to address emergency management at a high level without attention to the details of managing buildings in the immediate response to a significant disaster.

A related matter is the lack of policy when it comes to the recovery phase that follows. Following the Darfield earthquake of 4 September 2010 and the Christchurch earthquake of 22 February 2011, a number of pieces of legislation (Canterbury Earthquake (Building Act) Order 2010; Canterbury Earthquake Recovery Act 2011) were passed under urgency to provide the powers anticipated to be required to enable a timely and effective recovery. These requirements for recovery now need review and development into a broader context in readiness for future application.

Both response and recovery policy needs to consider the cordoning, securing and repair of damaged buildings. It should also provide a process for re-occupation of damaged buildings with associated criteria. The communication of structural, geotechnical, or other hazards by placarding should be able to be implemented under a single process that can be applied both within and outside of a declared state of emergency. This process should consider other hazards such as flood, or cyclone events in addition to the current focus on earthquakes.

The Canterbury Earthquakes Royal Commission has heard submissions on these matters, including that the emergency provisions of the Building Act should be strengthened so that buildings can be managed fully under that act alone, rather than, for an emergency, being managed under the *Building Act*, then the *Civil Defence Emergency Management Act*, and in the case of Greater Christchurch then under the *Canterbury Earthquakes Authority Act*, before reverting back to the *Building Act* (see Figure 4, and Figure 5).

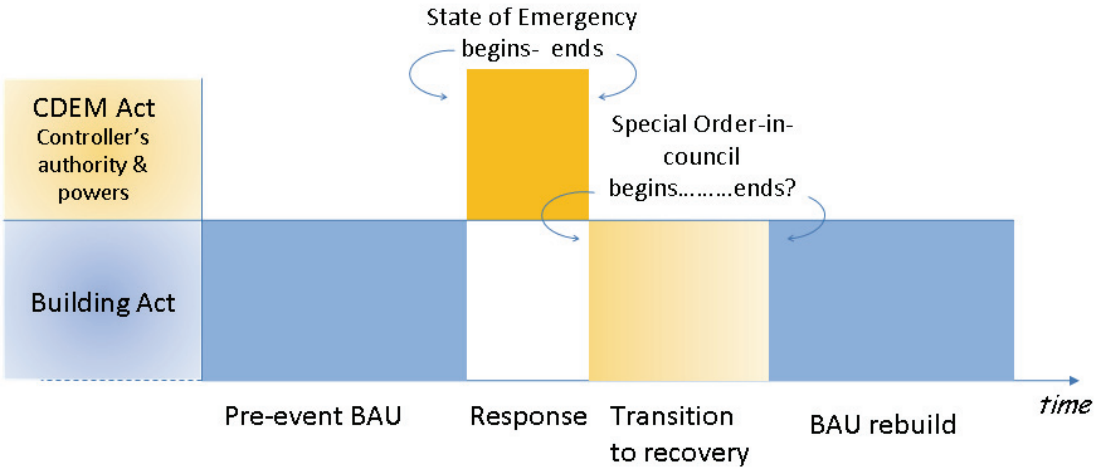

Figure 4. Current building emergency evaluation arrangements without transitions and underpinning business-as-usual (BAU) support

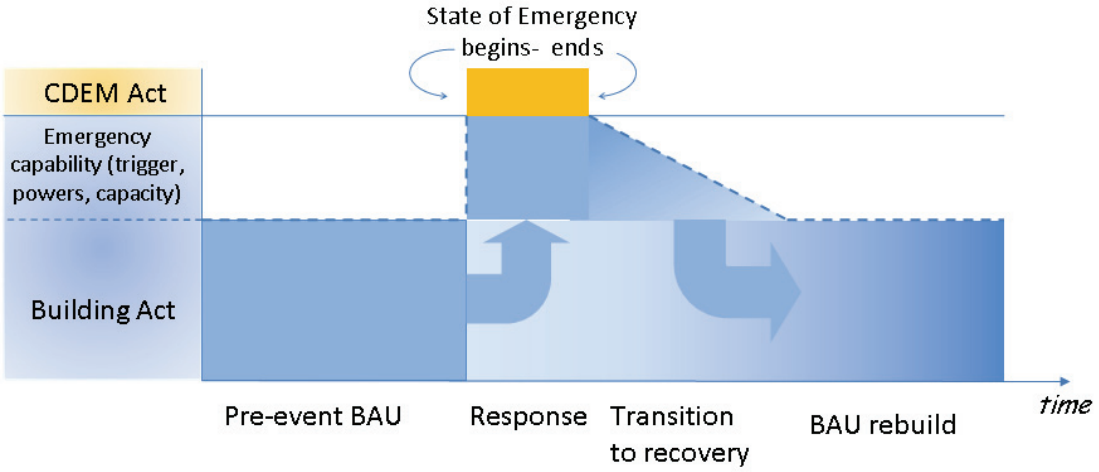

Figure 5. Proposal for Building Act emergency building evaluation arrangements integrated with business-as-usual (BAU) arrangements

The Greater Christchurch experience, since 4 Sep 2010, has shown that improvements to the rapid emergency building evaluation process are required to address the needs and understandings of building owners, occupiers, territorial authorities, building consenting authorities, engineers, building officials, the emergency services (with respect to allowing access or not to "Red" or "Yellow" placarded buildings), the media, and the public. The process warrants revision and further development to better cater for all stakeholders, particular attention to the communication process is needed.

Training Development and Maintenance

The repeatedly exercised Canterbury building evaluations have shown that experienced, capable and competent, building evaluators are more efficient and effective than less experienced evaluators. This was particularly seen in response to the earthquake of 13 June. Therefore, it is recommended that a cadre of capable and competent Lead Building Evaluators, of both engineers and building officials, be established and maintained. This capability objective model is illustrated in Figure 6. The arrangements now proposed for New Zealand are similar to those of the U.S. CalEMA Safety Assessment Program.

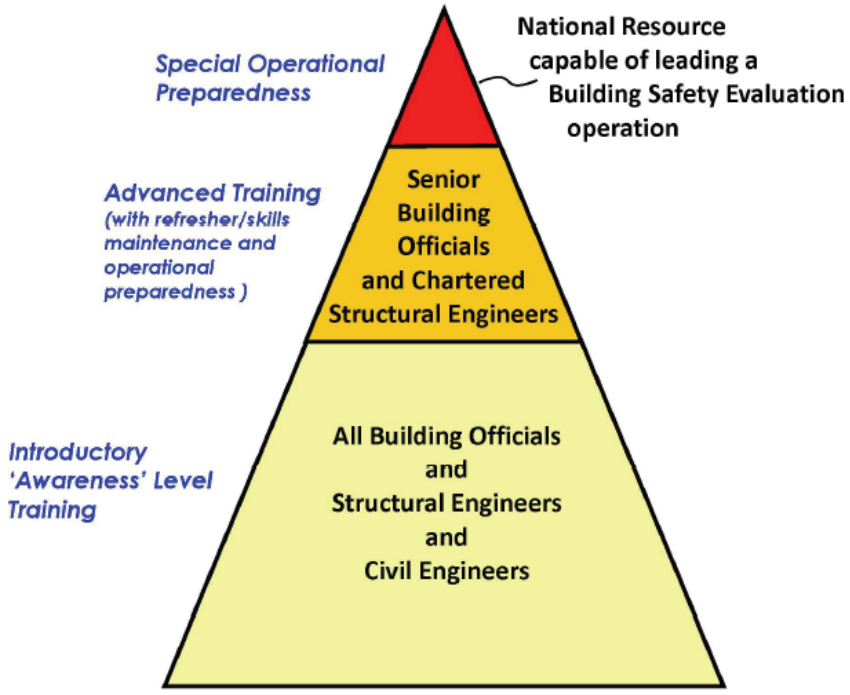

Figure 6. Building Evaluation Resource and Training Capability Objectives

One of the features of this capability objective is having a national resource capable and ready to either lead or support a building safety evaluation operation.

The development of an appropriate capacity and capability for building evaluation involves two key elements, namely:

- the development and maintenance of materials and arrangements for training; and
- the mechanisms for registering the status of those who have undergone training as part of their professional development.

Both elements require appropriate resourcing. Registration mechanisms should link directly to deployment arrangements.

It is considered that many aspects of the current Californian arrangements represent a good model for New Zealand to consider further.

Components of Building Evaluation Best Practice

Following from experiences in managing buildings following earthquakes (and floods and landslides), in New Zealand and overseas, the key components of best practice for the establishment and management of an effective building evaluation operation are:

1. Appropriate legal mandate;
2. An established criteria and process for building re-occupancy;
3. Central government agency providing a focal point, guidance and support for preparedness activities;
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 mobilization arrangements for warranted building professionals (locally and nationally).

The components and indicators are considered broadly relevant to any country or set of jurisdictions. They are also applicable to any hazard or cause that may have given rise to large numbers of impaired buildings and structures, not just earthquake. A robust building safety evaluation framework needs to be consequence-based rather than hazard based, noting that aspects of the skill-sets and processes may differ depending on the causative event.

Recommendations

There is a difficult balance that must be struck in the emergency management of buildings and infrastructure. While there is a need to clearly identify buildings suitable for provision of shelter and economic continuity, it is also important to communicate to the public the inherent risk associated with earthquakes.

1. The scope of the building evaluation process should be extended beyond the period of a state of emergency to cover the substantial period until a full detailed engineering evaluation can be completed, and the resulting repair or demolition.
2. Territorial Authorities need to maintain digital records of unique building identifiers in addition to the sometimes independent street addresses (and rating units). Building assessments and placard status should be recorded against the building identifier.
3. The public must be educated that buildings carry a level of inherent seismic risk, and that they can not be guaranteed to be ‘earthquake proof’. There needs to be a concerted effort to educate the public as to the nature of risk and the benefits and costs of risk mitigation, aligned with similar education programs to mitigate traffic accidents and drowning.
4. It is evident from the Canterbury experience that communication of the intent, process and status of building management to all stakeholders is critical, while noting that rapid changes in status can occur, as following aftershocks.
5. There is a clear need for formal regulations and guidelines to facilitate the recovery of a major urban centre following an earthquake. These should define the minimum acceptable seismic capacity for occupation of buildings and must specifically address the assessment and repair of damaged buildings.
6. Evaluation of building capacities should be carried out as part of a long term nationwide program to address buildings with poor seismic performance.

7. In the New Zealand legislative context, changes to the Building Act are desirable so that buildings are managed under the one legislation, before, during, and after the emergency, regardless if the event warrants a State of Emergency or not.
8. Finally, experienced, capable and competent building evaluators have been seen to be efficient and effective. Therefore, it is recommended that a cadre of capable and competent Lead Building Evaluators, of both engineers and building officials, is established and maintained. The model envisaged is similar to that of the U.S. CalEMA Safety Assessment Program.

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