A REVIEW OF POST-EARTHQUAKE BUILDING CONTROL POLICIES WITH RESPECT TO THE RECOVERY OF THE CHRISTCHURCH CBD

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This paper was presented at the 2012 Annual NZSEE Conference held in Christchurch, NZ.

ABSTRACT

The Canterbury earthquake sequence was particularly disruptive for building owners and businesses located within the CBD. The initial damage to buildings in the relatively moderate September 2010 earthquake was surpassed by the significantly more damaging February 2011 event, challenging the way in which engineers have traditionally considered earthquake recovery.

Internationally, re-occupation of buildings following an earthquake has been based on the need to get businesses operating from buildings that are rapidly identified as having suffered minor structural damage. However, following the February 2011 earthquake, the shift in risk profile was reflected by limiting re-occupation unless it could be shown that the building also had a minimum capacity to resist earthquakes. This challenges the balance between continuing function and safety in the traditional post-earthquake evaluation process.

The timeframe for commencement of repairs has a significant impact on the speed of recovery. The importance of well defined regulations was highlighted in the well insured Christchurch building market, where legal arguments halted repairs in many instances. There is also a clear need for a modified, streamlined building consent process for the repair of earthquake damaged buildings.

This paper looks at the various building control policies enacted during the Canterbury earthquakes, and their effectiveness in aiding the recovery of the Christchurch CBD.

1 INTRODUCTION

1.1 Background

While the Darfield Earthquake of 4th September, 2010 was the first major earthquake to test current New Zealand design standards, the occurrence of the subsequent Christchurch Earthquake of 22nd February, 2011 tested the effectiveness of post-earthquake building control policies.

Post-earthquake building evaluation processes were examined following the Darfield Earthquake and a number of recommendations were made with respect to the initial rapid building safety evaluation process, the scope of further detailed post-earthquake evaluations required, and the legislative and policy changes required to facilitate the recovery process (Hare & Galloway, 2011).

The occurrence of the 22nd February, 2011 Christchurch Earthquake prior to publication of that paper amongst others (e.g. CCC 2011; NZSEE 2011) precluded the adoption of recommendations for efficiencies in the post-earthquake rapid building safety evaluation process. The recent publication of guidelines (EAG 2011) has addressed many of the recommendations raised in relation to the detailed evaluation of buildings following an earthquake. However, substantial gaps remain in current building control policies to facilitate the recovery of a substantial urban area. This paper revisits aspects of the previous paper, and considers additional learnings from the 2011 Christchurch earthquake and subsequent events.

1.2 Unique Characteristics of the Canterbury Earthquake Sequence

The M7.1 Darfield Earthquake resulted in only moderate ground shaking in the Christchurch CBD due to its location some 37 km away. However, while the subsequent M6.3 Christchurch Earthquake had a smaller magnitude, its close proximity to the CBD produced the strongest ground shaking recorded worldwide at the time.

Post-earthquake recovery policies have been developed internationally on the assumption of a primary main shock followed by a series of lesser shocks, based on observations of typical aftershock sequences. In comparison, the characteristics of the Canterbury earthquake sequence are considered to be unique, and caution should therefore be exercised in focussing changes to recovery policies on this event when the traditional aftershock model is far more likely.

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Another possibly unique aspect is the high level of insurance cover that was carried prior to the sequence commencing. This has had a huge impact on the building assessment process. Whereas in areas with less insurance cover, building owners would be chaining themselves to their buildings to avoid demolition, many in Christchurch are actively pursuing demolition of buildings, some of which appear readily repairable.

1.3 Need for Publically Accepted Regulations and Guidelines

In the absence of formal New Zealand regulations dealing with post-disaster recovery, structural engineers responding to the Canterbury earthquakes followed what is generally considered to be international best practice for rapid building safety evaluations (ATC-20 & NZSEE 2009). Regardless of this, their actions have been criticised in the media and significant costs have been incurred by engineers defending their actions in the court of public opinion.

Perhaps partly as a result of this, one major firm is believed to have declined to carry out building safety evaluations following the recent 23rd December 2012 aftershock. In the event of a future earthquake occurring elsewhere in New Zealand, will structural engineers turn up to carry out building safety evaluations?

A substantial gap exists between an individual's expectations of life safety and the government's expectations for economic building improvement programmes and speed of post-earthquake recovery. Historical political decisions have resulted in the current building regulations which do not limit occupation of buildings based on their currently expected (or suspected) seismic performance. To significantly change these expectations in the aftermath of a significant earthquake is not feasible when considered in the context of facilitating a timely recovery process.

There is a clear need for formal New Zealand regulations and guidelines outlining the minimum standards for general occupation of buildings, expectations of post-earthquake building safety evaluations, and requirements for recovery. Without the development of formally accepted processes, the recovery from any future significant urban earthquakes will continue to be at least as disjointed, inefficient and frustrating as this one is proving to be. Furthermore, it is possible that engineering turnout in a future event will be severely limited, resulting in even more substantial delays to the recovery process.

2 POST-EARTHQUAKE RAPID BUILDING SAFETY EVALUATIONS

2.1 Post-Earthquake Building Evaluation Process

The process of carrying out post-earthquake building safety evaluations in New Zealand is described in guidelines developed from similar international procedures by the New Zealand Society for Earthquake Engineering (NZSEE) and endorsed by the Department of Building and Housing (DBH) (NZSEE 2009). This rapid building safety evaluation process was developed for use only during a state of emergency declared under the Civil Defence Emergency Management Act 2002 and follows a two stage process.

A level 1 rapid assessment involves a brief external visual inspection of a building. These level 1 assessments are a useful tool for Civil Defence co-ordinators in gaining a broad understanding of the scale of the event. However, they are of little use in determining the relative safety of individual buildings for public access, due to the extent of possible internal damage typically being unobservable from the exterior of a building.

A level 2 rapid assessment is still relatively brief but importantly, requires access to the interior of the building for more extensive observations. However, these assessments typically do not involve the removal of wall linings, unless there is specific cause for concern. Level 2 rapid assessments are typically used to assign placards defining occupation restrictions prior to lifting the state of emergency.

Regardless of the outcome of a level 1 or level 2 rapid assessment, it must be understood that further detailed assessment of the building should be carried out in due course. The objective of a detailed assessment is generally to define the scope of structural repairs required, and to quantify the expected seismic performance of the building. Recommendations for the scope of such detailed assessments were initially proposed following the 2010 Darfield Earthquake (Hare & Galloway, 2011) and have been developed into guidelines for the detailed evaluation of earthquake affected buildings recently published by the DBH Engineering Advisory Group (EAG 2011). Although this series of documents is published for use in the Canterbury area, it is intended that it will ultimately be rewritten for wider application over the whole country.

A Detailed Engineering Evaluation (DEE) as defined by the EAG involves review of the existing documentation for the building, identification of likely areas for damage, detailed inspection of the damaged building (including removal of linings as considered necessary), assessment of foundation performance and critical structural weaknesses, evaluation of the pre- and post-earthquake capacity of the building, and an assessment of the level of damage sustained. As such a DEE is expected to take several days or weeks to complete, depending on the scale of the building.

The rapid assessment process states that it is only intended for use during a declared state of emergency, which is likely to last for only a few days or weeks. However, it may take months or years to carry out detailed assessments on every building in the affected area. As such, there is a need for an accepted interim process between the lifting of a state of emergency and the completion of a detailed engineering evaluation.

In the absence of any other suitable mechanism, the rapid visual assessment of damage was typically used in Christchurch for re-inspections of buildings following aftershocks occurring outside the declared state of emergency.

This level of assessment was generally equivalent to at least a level 2 rapid assessment and was used to assess continued occupation or re-occupation of earthquake affected buildings. As such, they were typically referred to as level 2 rapid assessments, regardless of the fact that they were being conducted outside of the state of emergency.

2.2 Effectiveness of Rapid Building Safety Evaluations

A fundamental assumption required to evaluate the effectiveness of building safety evaluations is whether a building should be considered safe until proven dangerous, or vice versa. The former is relatively quick to determine in that an assessment of the degree of damage sustained can be carried out with a reasonable level of confidence, assuming the structural system is clearly understood. However, the assumption that a building is considered dangerous until it can be proven to be safe requires a step change in the level of resources required, as well as a definition of what is considered acceptably safe. Therefore it is proposed that rapid building safety evaluations should continue to be based on the premise that a building is considered safe until proven dangerous.

Post-earthquake building safety evaluation processes have generally been developed on the expectation that aftershocks will reduce in severity from the main shock. In essence, if a building has survived the main shock without significant damage to the primary lateral or vertical load paths, it is considered likely to survive the aftershocks. The focus of a rapid building safety evaluation is therefore on identifying damage to the building with respect to any significant reduction in its capacity to resist further aftershocks.

A further enhancement of this process that has been promoted in California is to add consideration of 'disproportionate damage' (ATC 52-4). Essentially this is a comparison of observed versus predicted damage for certain building types, according to the level of shaking experienced. This would have served little use following the 2011 Christchurch Earthquake, where all shaking clearly exceeded the lower threshold level at which damage would be expected. But it may have had application following the 2010 Darfield Earthquake or one of the other lesser aftershocks, in the absence of the 22nd February earthquake. However, it is also noted that this approach would only be applicable in areas where there is sufficient instrumentation to establish the level of shaking experienced.

Experience from the Canterbury earthquakes showed that level 2 rapid assessments typically identified the majority of the critical structural damage, when carried out by a suitably experienced structural engineer. In particular, damage to buildings with exposed structural elements was readily identified. However, damage to the hidden structural elements typical of reinforced concrete or structural steel buildings was more difficult to identify in the early stages of assessment. In some cases this damage posed a significant safety hazard, such as the fracture of reinforcing steel in concrete walls which otherwise exhibited only minor cracking.

As outlined above, the primary focus of the post-earthquake building safety evaluation process is on identifying damage with respect to any significant reduction in a building's capacity to resist further aftershocks. On this basis, rapid building safety evaluations carried out following the 2010 Darfield Earthquake could be considered to have been reasonably effective, given that no lives were lost in the subsequent aftershocks including the relatively significant 2010 Boxing Day event.

However, while the Christchurch Earthquake on 22nd February, 2011 was a magnitude smaller than the original 2010 Darfield Earthquake, it produced substantially stronger ground shaking in the Christchurch CBD. The result was that buildings that survived the Darfield Earthquake and its aftershocks succumbed to what was essentially a new event with the highest ground accelerations ever recorded worldwide at the time.

Review of the buildings which claimed lives in the 2011 Christchurch Earthquake is currently underway in the Canterbury Earthquakes Royal Commission of Enquiry (CERC). In the vast majority of cases these investigations have concluded that the damage sustained by the building as a result of the Darfield Earthquake was not considered to be a significant factor in its subsequent collapse.

Therefore these buildings would have been expected to collapse in the 2011 Christchurch Earthquake regardless of whether or not the prior 2010 Darfield Earthquake had occurred. Furthermore, it has been suggested that if the 2010 Darfield Earthquake had not occurred, the casualties resulting from the 2011 Christchurch Earthquake would have been significantly higher, with estimation that an additional 294 deaths may have occurred due to unreinforced masonry buildings alone (Ingham 2011).

2.3 Administration of Safety Notices

One of the most important outcomes from the rapid building safety evaluations is the placarding which acts as a public notification of the building status. Depending on the timing and the location, this may have happened under three separate pieces of legislation, administered by any one of three authorities:

- Civil Defence Emergency Management Act 2002 (s86), administered by Civil Defence, during the state of emergency
- Canterbury Earthquake Recovery Act 2011 (s45), administered by the Canterbury Earthquake Recovery Authority (CERA), after the state of emergency (within the CBD, or elsewhere for commercial buildings only)
- Building Act 2004 (s124) as modified by the Canterbury Earthquake (Building Act) Order 2010, administered by Christchurch City Council (CCC), after the state of emergency (for all other buildings and rockfall hazard)

This makes the updating and/or removal of placards a long-winded and inefficient process. A considerably simpler way of achieving this would be to have all placarding done under a single piece of legislation, even if it were to be administered by separate authorities over time.

2.4 Frequent Re-Inspection and Use of Indicators

Although the majority of aftershocks were relatively minor, there have also been many that have caused greater concern. Many building owners or tenants considered magnitude 5 or greater as a threshold requiring re-inspection, with prior evacuation in some cases. This has been both a distraction of engineering resource from the more important detailed evaluations, and a disruption for tenants.

Although re-inspection of properties is a necessary process, it could be made more efficient in a number of ways, including:

- Using the seismograph network to provide guidance based on actual ground accelerations (intensity), rather than focussing on magnitude. This would limit the area where re-inspections were required, but may require deployment of further equipment.
- Adopting an indictor approach to re-inspections which building owners or tenants could manage. With familiarity, it should be possible to identify points in buildings that could be treated as indicators. Over a reasonable range of indicators, absence of damage could be considered as sufficient evidence that the building remains undamaged as a whole and a formal engineering inspection is not required.

2.5 Communication of Risk

It has become apparent through the CERC hearings that there are serious inadequacies in the public understanding of risk, safety and building standards. Without seeking to assign blame for this, it is apparent that there is a need for clarity.

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 engineering 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 recognised that regardless of the word to be used, the public are not concerned with context, i.e. what size of earthquake may cause damage. Rather, they are concerned whether any earthquake may be a life safety hazard.

Engineers must therefore endeavour to convey to the public that buildings carry a level of inherent seismic risk. 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.

2.6 Recommendations for Rapid Building Safety Evaluation Process

The Canterbury earthquakes showed that structural engineering resources are tightly constrained following an earthquake. As such, any approach to recovery must use engineering resource wisely. The assessment of building damage can be completed relatively quickly and efficiently, with a reasonable degree of confidence. In contrast, detailed evaluation of building capacity is a complex process taking substantially longer to complete.

The level 1 rapid building safety evaluation process may be useful for Civil Defence coordinators in determining the overall scale of an event and the location of significant damage. However, it is not considered satisfactory to determine whether a building is suitable for occupation. Therefore, it is proposed that the objective of a level 1 rapid assessment should be to determine whether a building is immediately considered dangerous (receiving a red – unsafe placard), or should be considered for a further level 2 rapid assessment. Accordingly it is recommended that the outcome of a level 1 rapid assessment should comprise only a red (unsafe) placard, or alternatively a new (perhaps white) placard noting that the building has been visited, but that it requires a further level 2 assessment. Yellow or green placards should not be outcomes of a level 1 rapid assessment.

The current level 2 rapid building safety evaluation process, based on the visual assessment of damage, is considered to be suitable for assessing the significance of damage to earthquake affected buildings, provided that the structural system is readily identifiable. Without this understanding, it is impossible for the engineer to identify the critical elements for observation and understand the significance of damage observed. Should an engineer be unable to determine the lateral load resisting system, the building should receive a yellow placard, regardless of the absence of apparent structural damage.

A lesson taken from Christchurch is that local knowledge was not utilised as much as it could have been. Experienced local engineers have a historical knowledge of the building stock which should be utilised to provide an additional level of information. In particular this would apply to buildings for which the structural system cannot be readily identified by visual inspection. Better engagement with these key engineers in a consultative/review role is therefore encouraged.

Where structural elements are hidden by internal linings, identification of the lateral load resisting system may require intrusive investigations. A reasonable expectation is that these investigations should be able to be carried out with no more than a head torch and a claw hammer. In particular it is noted that access to building plans and specifications is considered to be outside the scope of a rapid building safety evaluation. Any further level of intrusive investigation would be considered to comprise a detailed assessment.

The expected level of assessment should be the same, regardless of who an engineer is engaged by. At present, an engineer may be engaged by the territorial authority (TA) to carry out a level 2 rapid assessment during a state of emergency. However, outside of the state of emergency, there is no defined process for an engineer engaged to carry out placarding for the TA, or for an engineer engaged by a building owner to carry out a rapid building safety evaluation. It is desirable to define a singular process for these assessments, particularly for aftershocks occurring outside of the state of emergency, in order to maintain a consistency of approach and to encourage sharing of assessments to avoid duplication between TAs and local engineers.

The scope of the rapid building safety evaluation process should therefore be extended beyond the period of a declared state of emergency to cover the substantial period until a full detailed engineering evaluation can be completed. This could be relatively simply accomplished if the placarding were to be implemented under a single piece of legislation.

Given the time taken to complete a full DEE, the TA may desire an intermediate level of review for substantial buildings which pose a potential hazard across a larger area of the city. For these buildings a further level of intrusive investigations could be required for a pre-determined list of critical forms of damage. The aim of this process would be to investigate known forms of hidden damage which may have severe consequences but require intrusive investigations and/or materials testing.

3 RE-OCCUPATION OF EARTHQUAKE DAMAGED BUILDINGS

3.1 Historical Requirements for Re-Occupation of Buildings

Historically the re-occupation of earthquake damaged buildings has been based on an assessment of the damage sustained by the building (ATC-20 & NZSEE 2009). If the building has not suffered significant damage then it is considered suitable for re-occupation.

The extent of damage sustained by a building would typically be assessed by carrying out a rapid building safety evaluation. At the engineer's discretion, removal of internal linings may be required to identify likely hidden damage.

Where part of a building suffered significant damage, temporary securing works may be required. Provided that these securing works restored the capacity of the building to its pre-earthquake condition, the building should also be considered suitable for re-occupation.

3.2 Re-Occupation Policies Used in Christchurch

Level 2 rapid assessments were carried out during the declared state of emergency to determine whether buildings were suitable for re-occupation after both the 2010 Darfield and 2011 Christchurch earthquakes. However, as highlighted previously, there is no defined process for building safety evaluations conducted outside of the declared state of emergency.

Following the lifting of the declared state of emergency on 16 September, 2010, CCC continued to accept a completed level 2 rapid assessment form for the re-occupation of buildings.

However, the Canterbury Earthquake (Building Act) Order 2010 passed on 16 September 2010 amended the definition of a Dangerous Building to include Earthquake-Prone buildings, and provided the TA with powers to restrict entry to such buildings. Around early October, 2010, CCC published the following policy for re-occupation of earthquake damaged buildings;

> *Before Council will accept that a building can be reoccupied, building owners must obtain certification at their cost from a Chartered Professional Engineer practicing in structural engineering. The certification must state that:-*
>
> - *the building is not dangerous in terms of Section 121(1) of the Building Act, as amended by the Canterbury Earthquake (Building Act) Order 2010…*

This policy essentially required the verification that a building is not considered to be Earthquake-prone prior to allowing re-occupation. However, a period of months or years would have been required to carry out detailed analyses and calculations to determine the capacity of every building in Christchurch. The impracticality of this was quickly appreciated and a revised CCC policy was issued on 18 October, 2010 which provided the following options for removal of red and yellow safety notices to permit re-occupation;

Option 1:

a. Interim securing to bring the building back to pre-earthquake condition, followed by:

b. Strengthening (or other improvement in structural performance) to at least the standard required by the CCC Earthquake-prone, Dangerous and Insanitary Buildings Policy 2010 (CCC EPB Policy) by 4th September 2013.

Note: Interim securing work is not regarded as an alteration in terms of s112 of the Building Act 2004 and will not require a building consent.

Option 2:

a. Strengthening (or other improvement in structural performance) to at least the standard required by the CCC EPB Policy.

The revised policy allowed a building to be re-occupied, provided its capacity was no less than before the earthquakes. In effect, this requires an assessment of the damage sustained and is similar to a level 2 rapid assessment, although on identifying damage an engineer would then have to go further in order to document temporary repairs and/or establish the significance of the damage. However, it should not be assumed at this stage that quantitative analysis would be performed. Instead, 'back of the envelope' estimation of conservative repairs would be appropriate in many cases, to restore capacity to at least its pre-earthquake condition or to remove specific hazards.

Following the subsequent 2011 Christchurch Earthquake, the declared state of emergency lasted for almost 10 weeks, being lifted on 30 April, 2011 with a cordon remaining in place around the CBD. This substantial length of time allowed most buildings outside the cordon to be re-occupied under the Civil Defence placard system, which is based on level 2 rapid assessments.

From 30 April, 2011 to the time of writing this paper there has been no official policy in place for re-occupation of buildings. In some instances a minimum capacity of 33% current code was enforced for re-occupation, while in some isolated cases a minimum capacity of 67% was requested. These levels were commonly applied regardless of the damage sustained, leading to buildings which had sustained only minor damage being unable to be re-occupied until detailed evaluation and strengthening could be carried out. The authors note though, that CERA has a draft occupancy policy that would allow occupancy of undamaged earthquake-prone buildings. At time of writing, this had still not been formally ratified.

3.3 Temporary Securing Works

In a number of cases, temporary securing works were required to restore the capacity of badly damaged elements to enable re-occupation of a building. However, design loads for such temporary securing works are not defined in current regulations.

Where damage resulted in a reduction in strength of an element, temporary securing works were typically designed to at least reinstate the capacity of the undamaged element. However, in some cases alternative load paths were also required (e.g. shoring for URM walls which had sustained out of plane movement). In these circumstances the design loads for the temporary securing works are less well defined.

Immediately following the 2010 Darfield Earthquake, reference was occasionally made to the New Zealand USAR Level 2 Engineers Manual (NZUSAR 2009) which provides design loads for temporary shoring as a factor of initial earthquake magnitude and time elapsed since the main event. However, the close proximity of smaller aftershocks in the Canterbury earthquake sequence meant that these design loads were exceeded on several occasions.

It is recommended that design loads for temporary securing of damaged elements, required for public safety or re-occupation, should be equivalent to the greater of 33% current code, or the capacity of the undamaged element. However, consideration should also be given to the cause of the damage with reasonable steps taken to mitigate this in the securing works. These minimum requirements for temporary securing works should be specified in the building regulations.

3.4 Effectiveness of Re-Occupation Policies

Re-occupation of buildings following the 2010 Darfield Earthquake was typically based on a visual assessment of damage determined by carrying out a level 2 rapid assessment. As highlighted above, the CERC review of building collapses resulting in casualties has indicated that these buildings would generally have been expected to collapse in the 2011 Christchurch Earthquake regardless of whether or not the prior 2010 Darfield Earthquake had occurred.

The capacities of existing buildings started to become available as the first detailed evaluations were completed some months after the initial 2010 Darfield Earthquake. However, prior to the 2011 Christchurch Earthquake, these building capacities were typically of little interest to building owners, other than informing them in relation to their insurance obligations and long term requirements for strengthening.

This is consistent with historical approaches to seismic risk, where building owners or tenants have very rarely evacuated an occupied building on becoming aware that it is likely to be Earthquake-prone (having a capacity of less than 33% current code). However, this approach changed significantly in the aftermath of the devastating 2011 Christchurch Earthquake, which changed the public's perception of seismic risk. The result is that buildings found to have a capacity of less than 33% current code are currently being evacuated by owners and tenants in Canterbury and throughout the rest of the country.

It is now being widely suggested in both the media and the CERC that a minimum capacity to resist earthquakes should apply to re-occupation of buildings following an earthquake, regardless of the damage sustained. However, having deployed the rapid building safety evaluation process formally in two declared emergencies and informally in many smaller aftershocks, it is clear that a level of review far in excess of a level 2 rapid assessment is not feasible given the resources available.

The completion of level 2 rapid assessments for buildings within the Christchurch CBD following the 2011 Christchurch Earthquake took approximately 3 weeks, while detailed evaluation of the capacity of the same buildings has been ongoing for 19 months and counting. To cordon off the fall zones of buildings for which the capacity was not known would have essentially resulted in a cordon around the CBD. To carry out detailed evaluations prior to re-occupation of buildings would therefore require the closure of a major city for periods in excess of a year.

Consider also that a more typical aftershock sequence would not have included an event such as the February 22nd earthquake. In other words, in a more typical aftershock sequence it is unlikely that undamaged or lightly damaged buildings would collapse, compared to what eventuated in February.

The economy of the Christchurch CBD is worth approximately $4.85 billion per year (BERL, *pers. comm.*). Had the Christchurch CBD been closed pending detailed evaluations of every building, and assuming that 50% of the CBD business activities could be temporarily relocated elsewhere, the cost to the economy over the period from 4th September 2010 to 22nd February 2011 equates to approximately $1 billion. Furthermore, had the unlikely 22nd February event not happened, a further 6-12 months may have been required to complete a full quantitative evaluation of the buildings, resulting in total losses to the regional economy of in excess of $2.5 billion.

In comparison, the 2009 valuation of a statistical life (VOSL) used for road safety purposes in New Zealand was $3.5 million. Using this as a means to establish a statistical economic cost of the 169 lives lost in the Christchurch CBD as a result of the 22nd February 2011 earthquake gives a total of $592 million. Noting that this figure does not include the additional cost of injuries (estimated by ACC to be $200 million), it still remains well short of the cost of closing the CBD. As such, it is difficult to economically justify even a short closure of a city for public safety reasons. Although this is only one measure, which cannot outweigh the human tragedy, it is an important consideration for future earthquake scenarios, where the prospect of a much larger aftershock is remote.

It is also worth considering the likely outcome of closing the CBD pending quantitative evaluations. Given the public perception of earthquake risk prior to the devastating 22nd February earthquake and the overall perceptions of good building performance in the 4th September earthquake, it is relatively unlikely that tenants or owners would have evacuated buildings found to have poor seismic performance (as evidenced by the lack of action on earthquake prone buildings over the past decades). Furthermore, had buildings been evacuated due to poor seismic performance, it is questionable whether business interruption policies could have been invoked, leaving many businesses badly out of pocket. Coupled with this, leases may not have been able to be terminated, meaning businesses would not have the option of finding alternative premises.

3.5 Recommendations for Re-Occupation of Earthquake Damaged Buildings

Re-occupation of buildings in Christchurch was typically based on a level 2 rapid assessment of the damage sustained. The CERC review of building failures causing loss of life has shown that the damage sustained in the 2010 Darfield Earthquake was generally not considered to be a significant factor in the subsequent collapse.

Prior to these earthquakes, society has accepted the level of seismic risk posed by buildings with poor seismic performance, through the requirements of the Building Act and the TA's Earthquake-Prone Building Policy. While it is acknowledged that public consciousness of earthquake risk and regional seismicity are increased following an earthquake, the likelihood of more extensive damage is reduced in a typical earthquake sequence, where more severe damage is expected in the main event than in aftershocks. Therefore the minimum acceptable seismic capacity for occupation of buildings should be of more general concern prior to a period of earthquake activity.

Given the assumption that the accepted level of risk to the public before, during and after a state of emergency should be comparable, it is therefore considered that the suitability for re-occupation of earthquake damaged buildings should be based on the significance of the damage sustained.

Provided that the vertical and lateral load resisting systems can be identified, it is considered that the level 2 rapid assessment process is suitable for identifying the significance of damage sustained by earthquake affected buildings. During a state of emergency it is anticipated that level 1 and level 2 rapid assessments would be carried out under the auspices of Civil Defence to identify potentially dangerous buildings requiring public cordons.

However, it is also proposed that a new Rapid Occupancy Assessment be defined, which would be carried out by the owner's engineer to establish suitability for re-occupation. It is recommended that this assessment would be the same as a level 2 rapid assessment, unless the primary vertical or lateral load resisting systems cannot be identified. In this case, further research would be required to identify the primary structural systems in order to establish the extent and significance of damage observed.

4 ALTERNATIVE LONG TERM APPROACH TO BUILDING EVALUATION

The current approach to building safety evaluation is based on the premise that the public accepted the risk posed by the building prior to an earthquake and should therefore accept a similar level of risk afterwards. The recommendations provided above for rapid building safety evaluations and for re-occupation of earthquake damaged buildings also assume that information is not readily available with respect to the expected performance of existing buildings. However, if detailed information was available in a concise manner, then minimum performance requirements could be set for re-occupation and tenants could be better informed in making their decision as to whether to resume occupancy.

The following section outlines a proposed system of data collection that would require national implementation over a period expected to be in the order of 5-10 years. It is acknowledged that the proposed system is fairly ambitious and its implementation would require due consideration of the additional compliance burden in relation to the increased effectiveness of post-earthquake building safety evaluations.

4.1 Objective of Proposed Approach

The primary objective of the proposed approach is to gather data on the expected earthquake performance of existing buildings throughout New Zealand.

If this information was publically available, it would likely result in ongoing improvements to New Zealand's existing building stock, driven by increased tenant demand for earthquake performance. The implementation of a nationwide earthquake safety rating to formalise this process has been discussed widely. Following an earthquake, the data on expected seismic performance of buildings could also be used to set minimum capacities for re-occupation, if the TA considered that current regulatory minimums are not acceptable.

4.2 Standardised Database of Expected Seismic Performance of Buildings

Given the current engagement of building owners, tenants, and TAs with respect to earthquake risk, it is anticipated that evaluation of the expected seismic performance of a significant number of existing buildings will be carried out nationwide over the next few years. A unique opportunity exists during this period to gather key information about New Zealand's building stock.

It is therefore proposed that a nationwide database is developed containing the following information for every building in the country;

- expected seismic performance (expressed as % current code)
- standardised A4 sheet summarising the building's characteristics and expected performance
- standardised spreadsheet recording key data
- brief supporting report

The intention of the standardised A4 sheet is that it could be used by engineers carrying out rapid building safety evaluations following an earthquake. By referring to the summary sheet, an additional level of information can be used to provide a more holistic assessment of the relative safety afforded by a building. The A4 sheet would ideally include information such as: address; building description; photograph; typical floor plan; year of design; description of structural system, foundations and soil conditions; expected seismic performance; and identification of critical elements to inspect following an earthquake. An example document is appended to this paper for reference.

During the process of collecting this information, it would be of little additional effort to require a standardised spreadsheet recording key data. Similarly to the current CERA Standardised Report Form, this information could be used in the post-earthquake evaluation process to identify buildings with particular features, or in the future for research, cost-benefit analysis, or the identification of buildings with key deficiencies. It could also form the basis of a publically notified building safety rating system, satisfying the public desire to understand the nature of the buildings that they are using.

It is expected that a brief supporting report would also be required, outlining the assumptions made in the evaluation of the seismic capacity as well as the method of evaluation carried out. It is anticipated that this report may be peer reviewed by the TA (or other independent reviewer) on submission to ensure consistency of approach.

Collection of the data required to assemble this database could be carried out in several ways;

- mandatory provision of documentation within a defined period
- mandatory provision of documentation with any building consent application (this includes change of use and alterations to existing buildings, as well as for new buildings)
- voluntary provision of documentation with the proviso that following an earthquake, early re-occupation will only be permitted for buildings having the required documentation

4.3 Matrix Approach to Re-Occupation

If building capacities were known at the time of carrying out rapid building safety evaluations, an approach considering both seismic performance and damage sustained could be used for the building placarding system. Acknowledging the tight constraints on structural engineering resources following an earthquake, the existence of a database as outlined above would provide the necessary information regarding seismic performance, while the rapid assessment process would identify the significance of damage sustained.

It is assumed that the TA would be capable of printing off the A4 summary sheets for a whole city block to give to volunteers carrying out the initial rapid assessments, while engineers carrying out subsequent assessments for private clients would also have access to a web-based database.

Depending on the degree of damage sustained by a building, and the expected seismic performance of the undamaged building, placards could be assigned based on a matrix as shown in Figure 1.

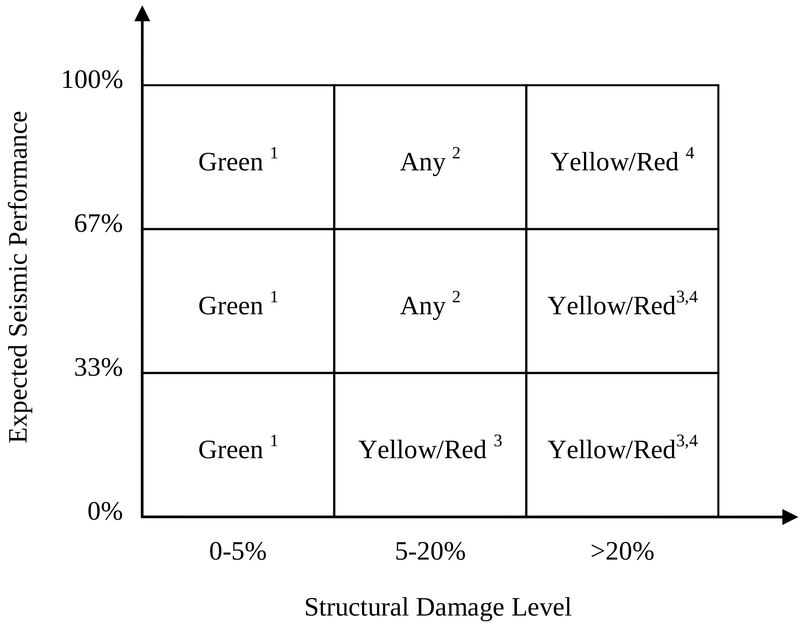

Figure 1: Indicative matrix for assigning placard

Notes:

1. No significant structural damage observed
2. Assign placard (green/yellow/red) based on damage observed
3. Occupation not permitted due to poor expected seismic performance
4. Green placard unlikely due to extent of damage

A benefit of this approach is that it easily allows for the placard status to be updated in accordance with the matrix if the damage is repaired, or if the building capacity is improved by strengthening.

However, it is likely that a field manual would also be required in order to determine the severity of damage sustained. Various forms of damage could be described along with the level of damage expected for a range of observations. For example, while a series of small diagonal shear cracks in a reinforced concrete wall may be of little concern, the recent discovery that singular horizontal cracks can be associated with significant strain hardening or fracture of the reinforcing has shown that simple assessment of crack widths may be inadequate in some situations.

To this could be added consideration of disproportionate damage, depending on the intensity of the shaking that has been experienced by the buildings. In the event of significant damage to buildings that have suffered relatively low intensity shaking, it could be assumed that such buildings may be more damage-prone and hence should not be occupied without strengthening or shoring.

However, given that minimum levels for occupation of buildings prior to an earthquake do not currently exist, it must be noted that this approach is based on the premise that the acceptable level of risk reduces after an earthquake. As noted previously this is counterintuitive, given that most earthquake sequences are likely to cause more severe damage in the main event than in subsequent aftershocks.

If a minimum level for occupation of buildings is desired, it is proposed that this should be defined in regulations, with the evaluation of building capacities carried out as part of a long term nationwide programme to address buildings with poor seismic performance.

5 REGULATIONS AFFECTING REPAIR OF EARTHQUAKE-DAMAGED BUILDINGS

5.1 Earthquake-Prone Building Regulations

The New Zealand Building Act (Building Act 2004) defines an Earthquake-prone Building (EPB) as having its ultimate capacity exceeded in a moderate earthquake (equivalent to 33% of current code). The Act permits TAs to issue a notice requiring work to be carried out on an EPB to reduce or remove the danger, or to restrict access to the building. The Building Act also requires TAs to develop their own policies with respect to identifying EPBs under their jurisdiction, but does not explicitly state whether the powers of TAs extend to setting strengthening targets beyond the definition of an EPB (33% of current code).

A significant delay in the repair process has been caused by arguments between building owners and insurance companies in relation to whether TAs have the power to require a level of strengthening above 33% of current code. The ongoing challenge to the legal status of the policy, as opposed to the Act, is likely to result in a formal legal challenge. Given the expense and delays caused by this lack of clarity, it would seem prudent to clarify the extent of a TA's powers in the Building Act.

EPB policies developed by TAs have typically included target strengthening levels but neither the Building Act nor the policies have considered the repair of earthquake damaged buildings. Acknowledging this, CCC passed under urgency an amendment to their EPB policy on 10 September, 2010 (CCC 2010). This amendment requires a building consent to be obtained for the repair of earthquake damaged buildings, with strengthening requirements to be determined by the Council in accordance with the recommendation of the NZSEE that 67% current code is a reasonable target.

However, the EPB policy does not go on to describe the types of circumstances that may be considered in accepting strengthening to a lesser level. It is generally understood that these circumstances may include reasons such as being unable to physically achieve 67% due to building constraints, or severely compromising the heritage fabric of a building to the extent that it outweighs the benefits of strengthening to this level. Incorporation of these reasons in either the Building Act or the EPB policies would provide a clear directive as to the negotiable exceptions to the strengthening target, reducing the uncertainty in the repair process and removing the need for lengthy arguments between building owners, insurers and the TA.

The lack of clarity in the wording of CCC's EPB policy has resulted in similar arguments between building owners and insurers as to whether the recommendation to strengthen buildings to 67% of current code is a requirement or a target. The delays are such that arguments between building owners, insurers and the TA are still ongoing 19 months after the first earthquake.

EPB policies adopted by TAs typically assume that under normal circumstances submission of a building consent for an alteration or change of use would trigger identification of a building as a potential EPB, with strengthening required accordingly. However, it is not clear whether the repair of earthquake damage should require a building consent or trigger the requirements of section 112 of the Building Act. While the Building Act definition of alter includes to repair a building, Schedule 1 also states that a building consent is not required for any lawful repair using comparable materials.

5.2 Consenting of Repairs

In the absence of any specific legislation for the repair of damaged buildings, the normal consenting process was typically applied in Christchurch. The approach taken by the CCC was to consider repair of earthquake damage as an alteration under section 112 of the Building Act. By treating it as an alteration requiring building consent, the assessment and upgrade of fire systems and accessibility features are also triggered. The result is that even minor repairs of earthquake damage may require installation of new fire systems and/or access ramps/lifts.

Where a building has been damaged by an event outside of the control of the building owner for which repairs are required, it does not seem reasonable to trigger further additional requirements for improvements to the building. It is therefore proposed that the repair of damaged buildings should not invoke upgrades of fire systems or accessible features as would be currently required for alterations under the Building Act.

Furthermore, a similar approach should be taken in the case of voluntary seismic upgrades where a change of use is not proposed. By triggering upgrades to fire systems and accessible features, building owners may be put off carrying out safety improvements to the seismic performance of their building because of the additional cost of the improvements to fire and accessibility.

It is also proposed that seismic strengthening requirements be triggered only if a building is considered Earthquake-prone under the Act, or has suffered substantial structural damage. A definition of substantial structural damage is proposed as the lateral load carrying capacity of the structure in any horizontal direction being reduced by more than 20% from its pre-damaged condition. This is drawn from US practice, which includes such a definition in local Building Code amendments in some jurisdictions. The concept of disproportionate damage introduced earlier could also be considered in the application of triggers for seismic strengthening requirements.

Requirements for the repair of earthquake damaged buildings should be adopted into the building regulations to give certainty to both building owners and insurers, and to provide TAs with a clearly defined process to follow in the event of an earthquake.

5.3 Temporary Buildings

The evacuation of damaged buildings to carry out repairs or to demolish and rebuild places a huge strain on the available lettable space. A significant number of temporary buildings are therefore required to allow continued operation of businesses, schools and community functions.

The majority of these temporary buildings are of lightweight construction and are mass-produced by pre-fabrication specialists. As such, they pose a very low risk in terms of safety. However, a full building consent was typically required since the Building Act does not allow for an alternative process to be used for temporary buildings.

It is proposed that provisions be included in the Act for temporary buildings erected following a state of emergency. These provisions could apply for buildings with a specified intended life of 5 years or less, and should waive the typical requirements for items such as: geotechnical reports for simple portable units; accessible ramps; amendment of title for spread of fire to boundary (where the adjacent section is empty and agreement is obtained).

5.4 Recommendations to Facilitate the Recovery Process

The extent of a TA's powers needs to be clarified in the Building Act to reduce the uncertainty and delays caused by arguments between owners, insurers and TAs. Local TAs should be required to develop policies outlining how they intend to identify potential EPBs with the resources they have available. However, they should not be required to develop individual policies in relation to acceptable levels of public safety which should be defined at a national level.

It is recommended that regulations such as a minimum acceptable earthquake capacity for occupation, trigger levels for full seismic upgrades, minimum levels for strengthening and timeframes in which to carry this out should be defined at a national level by incorporation into the Building Act.

Greater clarity is needed as to the nature of structural repairs that require consents. Furthermore it is proposed that the repair of damaged buildings should not invoke upgrades of fire systems or accessible features as would be currently required for alterations under the Building Act. A similar approach should also be taken in the case of voluntary seismic upgrades where a change of use is not proposed. A streamlined consent process should be developed for the erection of temporary buildings following a disaster.

6 SUMMARY OF RECOMMENDATIONS FOR CHANGES TO POST-EARTHQUAKE BUILDING CONTROL POLICIES

There is a clear need for formal New Zealand regulations and guidelines to facilitate the recovery of a major urban centre following an earthquake.

The Building Act should define the minimum acceptable seismic capacity for occupation of buildings, trigger levels for full seismic upgrades, minimum levels for strengthening and timeframes in which to carry this out. TAs' individual policies should be limited to outlining how they will enforce the national standards.

The Building Act must specifically address the repair of damaged buildings. Furthermore, the repair of damaged buildings, or the voluntary seismic upgrade of existing buildings should not invoke upgrades of fire systems or accessible features. Streamlined provisions should also be included for the erection of temporary buildings following a disaster.

The expectations of post-earthquake building safety evaluations should be defined in formal regulations and the scope of the rapid building safety evaluation process should be extended beyond the period of a declared state of emergency to cover the substantial period until a full detailed engineering evaluation can be completed. Furthermore, all placarding should be carried out under a single piece of legislation, even if it were to be administered by separate authorities over time.

It is recommended that the objective of a level 1 rapid assessment should be limited to determining whether a building is immediately considered dangerous (receiving a red – unsafe placard), or should be considered for a further level 2 rapid assessment. A level 2 rapid assessment is considered to be suitable for use by Civil Defence in identifying potentially dangerous buildings requiring public cordons.

Provided that the primary vertical and lateral load resisting systems can be identified, assessment of the significance of the visually observable damage sustained is also considered to be satisfactory for assessing re-occupation of earthquake affected buildings. A new Rapid Occupancy Assessment is proposed, being essentially identical to the level 2 rapid assessment process but requiring further research to establish the primary structural systems if these cannot be readily identified from visual observation.

A concerted effort must be made to educate the public as to the nature of seismic risk and the benefits of risk mitigation. Evaluation of building capacities should be carried out as part of a long term nationwide programme to address buildings with poor seismic performance.

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Building Data Sheet

Building:	Engineering House
Address:	123 Quake Street
Year of design:	1982
Number of stories:	18
Occupancy:	Commercial/Office
Assessed by:	An Engineer

Structural System

The building consists of 18 floors above ground level, including a 3 storey podium. Parking is provided in a 3 level basement.

The gravity load resisting system comprises a reinforced concrete frame supporting precast double tee flooring spanning in an east-west direction. The tees are flange hung with an in-situ topping reinforced with hard drawn wire mesh that forms the structural diaphragm.

Lateral loads are resisted by the perimeter ductile reinforced concrete moment resisting frames, constructed of in-situ concrete columns and precast beams.

The east and west frames use conventional ductile frame detailing, with diagonal reinforcement provided on the north and south frames. The internal gravity frames do not have ductile detailing.

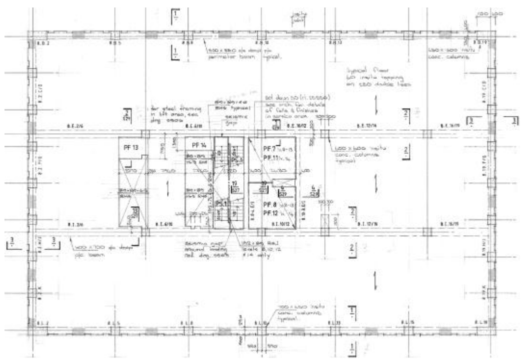
The stairs are not fixed at the landings and seating lengths of 75mm are provided. The rear of the tower is clad with precast concrete panels. The panels are fixed from floor to floor with a sliding detail at the top of the panels.

Foundations and Soil Conditions

The site comprises 5-10 m of medium dense to dense sands and silts overlying dense gravels. Ground water level is at 3.5 m bgl.

The building is founded on driven concrete piles, founded at 8 m – 12 m depth.

Typical Floor Plan



Photograph

Seismic Evaluation

Overall capacity:	70% NBS
CSW capacity:	30% NBS
Date of assessment:	2012
Evaluated against:	NZS1170.5:2004
Zone factor:	0.3
Importance level:	2
Ductility, μ :	4 (both directions)

Expected Building Performance

A linear response spectrum analysis was carried out to establish the capacity of the building.

The perimeter concrete MRF's were found to have sufficient capacity and detailing to resist loads in excess of 100% NBS.

The overall performance of the building is limited by the deformation capacity of the internal gravity frames which are expected to sustain column shear failures at 70% NBS.

The stair detailing was found to comprise a critical structural weakness with collapse possible at loads exceeding 60% current code (equivalent to 30% NBS as a CSW).

Critical Elements to Inspect

Stair seatings

Flange hung double tees

Internal gravity columns

North and south perimeter frames