THE EFFECTIVENESS OF POST-EARTHQUAKE BUILDING SAFETY EVALUATIONS CARRIED OUT IN THE CANTERBURY EARTHQUAKE SEQUENCE AND PROPOSALS FOR FUTURE DEVELOPMENT

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Abstract

The New Zealand Society for Earthquake Engineering (NZSEE) building safety evaluation process was implemented in several earthquakes occurring as part of the 2010-2011 Canterbury Earthquake sequence, providing an opportunity to evaluate the effectiveness of the current processes across a range of issues. In addition to the established rapid assessment process, guidelines were developed for the detailed engineering evaluation of damaged buildings.

A number of lessons have been drawn from these experiences relating to the effectiveness of placards and the rapid visual assessment of damage, requirements for a full spectrum of assessment processes, and training needs. From these lessons, improvements to the current building safety evaluation processes are proposed and further considerations for reoccupation of buildings are outlined. A number of alternative concepts are also explored for further discussion and development.

This paper summarizes the building safety evaluations carried out in Christchurch, lessons that have been taken from this experience, and modifications proposed to building evaluation processes where they may apply in a wider context.

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.

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 severe ground shaking in the CBD, causing significant damage, injury and loss of life.

Post-earthquake response activities and 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 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.

An associated paper (The 2010-2011 Canterbury New Zealand Earthquakes and the Emergency Management of Buildings and Infrastructure, Wood et. al) provides a wider background to the Canterbury earthquake sequence and describes the overall management of the emergency response and recovery.

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Post-Earthquake Building Evaluations in New Zealand

Rapid Building Safety Evaluation Process. Post-earthquake building safety evaluations in New Zealand are essentially based on the Applied Technology Council ATC-20 procedures (ATC-20, 1989). The process is described in guidelines (NZSEE 2009) developed by the New Zealand Society for Earthquake Engineering (NZSEE) and endorsed by the Ministry of Business, Innovation and Employment (MBIE), formerly the Department of Building and Housing.

The primary objectives of the rapid building safety evaluation process include allowing for the safe use of streets adjacent to damaged buildings, and the safe occupation of buildings for continued use. The focus is on public safety, rather than the provision of an engineering assessment service to building owners.

As such, the New Zealand 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.
- A level 2 rapid assessment is still relatively brief but importantly, requires access to the interior of the building for more extensive observations.

For benchmarking with international guidelines, the level 1 rapid assessment is generally similar to the 'Rapid Evaluation' technique defined in ATC-20, with the level 2 rapid assessment being roughly equivalent to the ATC-20 'Detailed Evaluation' procedure.

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.

The rapid assessments are based on the visual assessment of damage and are generally non-intrusive, with Level 2 assessments taking in the order of between one and four hours to carry out for a particular building depending on the complexity and size of the building being assessed. Depending on the size of the area impacted by the earthquake, the overall local authority-led process during the declared emergency period is expected to take in the order of a week to complete.

Regardless of the outcome of a level 1 or level 2 rapid assessment, further detailed assessment of the building should be carried out in due course by the building owner with a view to assessing and effecting the repairs required and confirming suitability for continued occupancy. ATC-20 refers to this final detailed assessment as an 'Engineering Evaluation' while the NZSEE guidelines refer to this as a 'Detailed Engineering Evaluation'.

Detailed Engineering Evaluation Process. The primary objective of a detailed assessment is to identify structural damage and define the scope of repairs required, in order to inform the building's suitability for occupation. However, at the time of the 2011 Christchurch Earthquakes, no specific guidelines existed in relation to what a detailed engineering evaluation should comprise.

Recommendations for the scope of such detailed assessments were initially proposed following the 2010 Darfield Earthquake (Hare & Galloway, 2011) and have been developed following the 2011 Christchurch Earthquake into guidelines for the detailed evaluation of earthquake affected buildings recently published by the Engineering Advisory Group of the Ministry of Business Innovation and Employment (EAG 2011).

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.

A key consideration of a DEE is the assessment of the resilience provided by a building. While new buildings designed to current codes are expected to have a substantial margin between their design capacity and collapse, this may not be the case for older buildings. The DEE procedure considers the resilience provided by an existing building by requiring the specific assessment of brittle collapse mechanisms. This consideration of critical structural weaknesses builds on the concept previously outlined in the NZSEE guidelines for the Assessment and Improvement of the Structural Performance of Buildings in Earthquakes (NZSEE 2006).

Brittle collapse mechanisms are benchmarked against the expected performance of new buildings by adjusting their capacity for the expected margin against collapse;

$$\%NBS_{element} = \frac{capacity}{K_d \times demand} \tag{1}$$

Where: K_d is a factor between 1.0 and 2.0 reflecting the resilience of the assessed brittle mechanism;

%NBS is the equivalent percentage of new building standard, considered in relation to the capacity required for a new building constructed at the same location

The DEE guidelines provide both qualitative and quantitative procedures to be followed. While the qualitative assessment provides an estimate of the expected building performance and addresses the items outlined above, the quantitative procedure is intended to better assess the residual capacity of the building in its damaged state and to provide a focus for the proposed repairs and strengthening. It is intended that the qualitative process would be sufficient for buildings that do not have significant damage, although the use of the quantitative procedure is encouraged for all buildings achieving less than 33% of new building standard in the qualitative procedure.

As such a DEE for a particular building is expected to take several days or weeks to complete, depending on the scale of the building. When considered across a large region with the inevitable resource constraints, the detailed engineering evaluation process is expected to take several years.

Building Evaluations carried out in Christchurch. Rapid building safety evaluations were carried out under the direction of the Civil Defence Emergency Management Controller immediately following the 4th September 2010 Darfield Earthquake, a State of Local Emergency having been declared. 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 took several days to complete for the buildings contained within the Christchurch CBD, and along the main arterial routes from the suburbs into the CBD.

Private owners or tenants typically engaged their own structural engineers to carry out rapid assessments of their buildings prior to re-occupation. 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. These rapid assessments were carried out by engineers contracted by building owners many more times than the formal process conducted by Civil Defence, as many building owners requested re-inspections after each substantial aftershock.

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.

Observations and Lessons Learned

Placarding of Buildings. The placement of placards on buildings is intended to convey to the public their suitability for continued occupation. The placards used in New Zealand have been developed from international practice, principally from ATC-20, with minor modifications. Placards are deliberately titled 'Unsafe', 'Restricted Use' and 'Inspected' to avoid the use of the word 'Safe'. A clear description of the limitations of the assessment is also included on the placards. However, the majority of building users appear to have read the placards by only their colors; red, yellow or green. The subtlety is that many of these people appear to genuinely believe that a building with a green placard should therefore have been 'safe' in any size of earthquake.

Over time a number of different placards were placed on buildings. In many cases it was not possible to distinguish whether the placard had been placed on the basis of a level 1 or level 2 assessment as the same placards are used for both.

Some consulting engineers working for private clients also developed their own placards to leave on a building following their inspection, since only engineers under the direction of the local territorial authority could issue formal placards. As such, several placards may have been present on a single building at any one time, with the potential for confusion as to the formal status of the building.

Effectiveness of Rapid Building Safety Evaluations. The effectiveness of the rapid building safety evaluations carried out was found to vary significantly depending on the individuals carrying out the assessment. In particular, assessments carried out by non-engineers were found to identify only the most obvious damage, without the necessary judgment as to the implications of this damage.

On the whole, level 1 rapid assessments (in conjunction with windshield and helicopter surveys) were found to be a useful tool for Civil Defence coordinators in gaining a broad understanding of the scale of the event and for planning the re-opening of streets. However, they are considered 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.

Level 2 rapid assessments were typically found to identify 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 of similar magnitude. 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, it was partly due to good fortune that localized fall hazards didn't result in serious injury in this event. Following the Darfield Earthquake, a restrained approach was generally taken to removing fall hazards. If unsecured parapets were not observed to be damaged, they were typically left in place without cordons. This was in part due to the success of this approach in the 2007 Gisborne Earthquake where the earthquake and aftershocks were strongly directional. However, the Boxing Day event was on a new fault with dominant east-west shaking in contrast to the north-south shaking of the Darfield event. As a result, a number of previously undamaged masonry parapets and walls collapsed in the Boxing Day event.

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 Christchurch Earthquake has been the subject of the Canterbury Earthquakes Royal Commission of inquiry (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 Darfield Earthquake had not occurred, the casualties resulting from the 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).

Re-occupation of Damaged Buildings. In Christchurch, the large scale construction generally provides commercial and retail space, with most of the population residing in single storey, timber framed houses. As a result, the majority of the affected population was able to shelter in place. However, this would not necessarily be the case in larger centers such as Auckland, the US or Japan where a large proportion of the population live in multi-storey residential buildings.

Historically the re-occupation of earthquake damaged buildings has been based on a rapid 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. However, the New Zealand rapid building safety evaluation 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, while it may take months or years to carry out detailed assessments on every building in the affected area.

In the absence of any other defined process, 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. 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 visual assessment is not feasible given the resources available.

The completion of level 2 rapid assessments for the majority of the buildings within the Christchurch CBD following the 2010 Darfield Earthquake took approximately two weeks. These rapid assessments were subsequently repeated following the 22nd February and 13th June 2012 aftershocks. However, detailed evaluation of the capacity of the same buildings has been ongoing for 18 months and counting since the start of the recovery phase in April 2012. 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.

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 Christchurch 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.

Frequent Re-inspection and use of Indicators. Although the majority of aftershocks in the Canterbury Earthquake sequence were relatively minor, there were also 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 was 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 a seismograph network to provide guidance based on actual ground accelerations (intensity), rather than focusing on magnitude. This would limit the area where re-inspections were required, but does require deployment of further equipment, including ideally, in buildings themselves.
- Adopting an indicator 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.

Training in the Evaluation of Damaged Buildings. Prior to the Canterbury Earthquakes relatively few engineers or building officials had undergone training in the evaluation of damaged buildings. Widespread training should be provided to a large pool of experienced engineers prior to an event occurring in order to build a general understanding of the process involved.

A technical clearinghouse forum was established in Christchurch following the 2010 Darfield Earthquake to share information and openly debate issues. Discussions initially occurred weekly, but the frequency has diminished with time and the increasingly common understandings. These meetings were found to be a valuable means of briefing engineers on the rapidly evolving response, sharing technical information, highlighting new forms of damage discovered, and maintaining some consistency across the profession.

The implementation of the DEE process has showed that engineers, while generally well trained in design, can be poor at forensics and reporting. For example, there have been instances of DEE reporting capacities of less than 5-10% of current code for single storey timber framed buildings. The basis for these evaluations is not always clear and in some instances, the evaluation has used the Initial Evaluation Procedure (IEP), which is not typically very robust for such buildings. Similarly, labeling of liquefaction as a critical structural weakness is inappropriate for such buildings, which are extremely unlikely to cause loss of life through foundation failure. This problem, of engineers failing to step back from the detail to consider global performance, has been the cause of considerable consternation, prompting the observation that nowhere in the DEE guidelines does it say 'disengage engineering judgment'!

Proposed Modifications to the Building Evaluation Process

Rapid Building Safety Evaluation Process. Keeping in mind the need to provide shelter and economic stability for the residents of an affected community, it is important not to be unduly conservative when assessing damaged buildings.

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 suitable for occupation provided it has not suffered significant structural damage causing a reduction in capacity.

Following an earthquake the initial briefing process is particularly important to ensure both the safety of the evaluation teams, and the consistency of assessments. The assessment of damaged buildings is a complex problem requiring good engineering judgment and experience. As such, it is proposed that only suitably experienced structural engineers should be permitted to issue placards (although they may be teamed up with building control officials, etc). Our experience has shown that it is worth sacrificing the speed at which the assessments are completed in the interests of quality. Furthermore, a roaming auditor is recommended to ensure consistency between assessments carried out by different teams, and to identify teams that may not display the required engineering judgment.

The level 1 rapid building safety evaluation process may be useful for Civil Defence Emergency Management 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, or should be considered for a further level 2 rapid assessment.

The current level 2 rapid building safety evaluation procedure, 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.

While a large number of engineers will volunteer to carry out building evaluations for the authorities, it is inevitable that a similar number will be engaged privately to carry out assessments for building owners or tenants in parallel. In developing a system for managing the post-earthquake evaluation of buildings, it is important to integrate these engineers within the formal evaluation process to avoid duplication of effort as much as possible and to assist forming a 'common operating picture' of the impacted areas.

Placards. A minor change to the placard colors is proposed to ensure the public read the detail of the placards. Using red, yellow, and white would remove the visual correlation between green and go/safe.

The placards should include a clear distinction as to whether they are based on a level 1 or 2 assessment. It is recommended that the outcome of a level 1 rapid assessment should comprise only a red (unsafe) placard, or 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.

While engineers working for private clients may be tempted to post their own placards to indicate the outcome of their assessment, this practice should be strongly discouraged as it can lead to confusion in the case that the formal placard placed by the territorial authority is different. It is preferable to develop a management process that allows these engineers to submit the relevant paperwork for action by the authority if a change of formal placard status is required.

While the placards already include an area to note the observed hazards, it was noted that this was generally poorly utilized. The importance of communicating known hazards to future assessors must be highlighted to ensure that external hazards such as rockfall, or slope stability are not forgotten by engineers subsequently carrying out building assessments. Assessors must also be aware that a placard may have been placed as a result of the first critical piece of damage observed. Therefore, in order to change a placard to allow re-occupation, a full re-evaluation of the building should be carried out without reliance on the original assessment.

Interim Use Evaluation for Re-occupation. 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, under New Zealand law, level 1 and level 2 rapid assessments would be carried out at the direction of the Civil Defence Controller, to protect the engineers and building officials from liability (except in cases of gross negligence) and to identify potentially dangerous buildings requiring public cordons.

However, it is also proposed that a new Interim Use Evaluation (IUE) be defined, which would be carried out by the owner's engineer to establish suitability for re-occupation. It is recommended that this would be essentially 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. Guidance on this process has been developed and published for the Greater Christchurch region by the Department of Building and Housing (DBH, 2012).

The IUE could also be developed to specifically address unreinforced masonry buildings. Where substantial securing works (such as effective parapet securing and wall to floor ties) cannot be observed and the seismicity is such that stronger or different faulting mechanisms are considered likely, unreinforced masonry buildings could be declared unsuitable for occupation and cordoned off until securing works can be carried out.

Concepts for Further Discussion and Development

Form of Seismicity. 'Active' faults typically generate earthquakes according to their characteristic earthquake model, having a characteristic magnitude and frequency of occurrence. Active faults are judged to be 'weak' with an aftershock sequence that can be predicted such as by the modified version of Omori's empirical law (Utsu et. al. 1995). Active faults and their earthquake directivity are largely controlled in New Zealand on the Pacific/Australian tectonic plate boundary by the relative plate motions. As a result, an earthquake occurring on a major active fault is likely to cause significant damage in the large triggering event, while the damage caused by subsequent aftershocks should decay in a relatively predictable manner.

In contrast, ‘intra-plate’ earthquakes on ‘strong faults’ (such as the Canterbury sequence) occur relatively rarely, and may trigger other nearby faults with different characteristics. The variability of these smaller ‘intra-plate’ events can have a significant impact on the shaking experienced at a particular site. Because the energy released is small, the shaking intensity quickly drops off with distance. A small shallow aftershock a few tens of kilometers away can therefore generate significantly greater ground shaking intensity locally than may have been experienced at that site as a result of the more distant triggering ‘mainshock’ event.

Based on this, it is worth considering whether we should treat the response to earthquakes generated along major fault zones differently to earthquakes generated in an area of moderate seismicity. The assumption that aftershocks will produce shaking of decreasing intensity appears to be less applicable for areas of moderate intra-plate seismicity, and a more conservative approach to cordoning and re-occupation could therefore be adopted in these regions.

In essence, reoccupation of buildings in major fault zones could continue to be based on the current damage focused assessments, while the more time consuming vulnerability focused assessments may be more appropriate in the regions of moderate seismicity.

Consideration of Vulnerabilities and Disproportionate Damage. The Christchurch CBD comprised primarily low to medium rise structures. Even though these buildings were subjected to significantly stronger shaking than the design spectra, local vulnerabilities rather than capacity were typically the cause of collapse.

Based on this, assessments focused on identifying and addressing local vulnerabilities are considered to be most effective at mitigating seismic risk. While identification and evaluation of vulnerabilities is relatively achievable when carrying out a qualitative or detailed evaluation with access to building plans, it can be particularly difficult to identify critical deficiencies when carrying out a rapid visual assessment of a building where structural elements may be hidden or detailing may not be visible. Because of this, these vulnerabilities should ideally be proactively addressed prior to an earthquake occurring.

However, the concept of ‘disproportionate damage’ that has been promoted in California as an enhancement of the building safety evaluation process (ATC-52-4, 2010) can help in identifying buildings with vulnerabilities. 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 2011 Christchurch 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.

Development of a Building Database. The current approach to building safety evaluation is based on the premise that the public accepted the risk posed by buildings 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 make more informed decisions as to whether to resume occupancy.

Galloway and Hare (2012) outline a proposed system of data collection that would require national implementation over a period expected to be in the order of 5-10 years. The system would involve for each building the collection of information such as a description of the primary structural systems, foundations and soil conditions, typical floor plans, expected building performance and potential vulnerabilities.

The primary objective of the approach is to gather data on the expected earthquake performance of existing buildings. Summary information for each building could then be provided to assessment teams to inform the rapid building safety evaluations being carried out. In particular, identification of the expected vulnerabilities is considered to be of great benefit when carrying out a rapid visual assessment of damage as these vulnerabilities may not be identifiable without reference to building plans and details.

Following an earthquake, the data on expected seismic performance of buildings could be used to set minimum capacities for re-occupation, if the current regulatory minimums were not considered to be acceptable. Furthermore, if this information was publically available, it would likely result in ongoing improvements to the existing building stock, driven by increased tenant demand for improvement in earthquake performance. The implementation of a nationwide earthquake safety rating to formalize this process has been discussed widely in California and New Zealand. Related to these matters is the review of current 'Earthquake Prone Building' policies in New Zealand.

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. However, such a concept could be integrated as part of 'GeoBuild'- a National digital building consenting model being developed by MBIE.

Summary of Recommendations

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. 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.

It is recommended that the objective of a level 1 rapid assessment should be limited to determining whether a building is immediately considered dangerous, or should be considered for a further level 2 assessment. A level 2 rapid assessment is considered to be suitable for use by Civil Defence Emergency Management in identifying potentially dangerous buildings requiring public cordons. Minor changes are proposed to the current placards.

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 Interim Use Evaluation 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.

The expectations of post-earthquake building safety evaluations should be defined in regulations and the scope of the rapid building safety evaluation process extended beyond the period of a declared state of emergency to cover the substantial period until a full detailed engineering evaluation can be completed.

It is proposed that a detailed engineering evaluation should involve review of existing documentation to identify potential vulnerabilities in order to inform the identification and assessment of damage. Assessment of the pre- and post- earthquake capacity of the building is also required in order to evaluate the significance of the damage observed.

Concepts relating to different forms of seismicity, consideration of vulnerabilities, and development of a building database are discussed in relation to the post-earthquake building safety evaluation process with a view to future development.

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