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Post-Earthquake Assessment and Repairability of RC Buildings: Lessons from Canterbury and Emerging Challenges

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ABSTRACT: The Canterbury Earthquakes have provided many lessons related to concrete buildings, and continue to influence codes and standards internationally, but perhaps the most striking lesson is the potential for widespread demolition of generally good-performing buildings. With a transformation of the urban environment resulting from demolition of approximately 60% of concrete buildings in the CBD, questions have been raised about the acceptability of this outcome and the reasons for demolition. While the assessed level of damage generally controlled the demolition/repair decision, there is strong evidence that, in the absence of reparability guidelines, other variables, such as insurance and changes to building regulations, have significantly influenced the decision on a number of buildings. This paper summarises factors influencing demolition/repair decisions on concrete buildings, challenges faced by engineers engaged in detailed post-earthquake assessments, and offers suggestions for future research toward the development of reparability guidelines aligned with insurance policies.

1 INTRODUCTION

The 2010-2011 Canterbury Earthquake Sequence caused unprecedented losses in Christchurch, New Zealand. The most damaging event occurred on 22 February 2011 resulting in 185 fatalities. The direct impacts on the community include $NZ 40 billion in financial loss (or 20% of New Zealand's GDP), demolition of approximately 60% of RC buildings in the Central Business District (CBD) of Christchurch, loss of land due to liquefaction, closure of parts of the CBD for over 2 years, and hundreds of thousands of insurance claims (Parker & Steenkamp, 2012). From 22 February to 30 April 2011, a National State of Emergency was declared under the Civil Defence Emergency Management Act (2002) to identify dangerous buildings and take required actions (demolition or make-safe work) for public safety. The Canterbury Earthquake Recovery Authority (CERA) was established in April 2011 to lead and facilitate the recovery of the community (CERA, 2012). One of CERA’s roles was to oversee building damage assessments and manage building demolition works in agreement with the building owners. The Christchurch Central Development Unit (CCDU) was formed to aid the recovery and renewal of the city by planning and executing anchor projects (CCDU, 2012). Five years since the earthquakes, the community recovery and reconstruction efforts are still ongoing.

Damage to concrete buildings ranged from collapse, to significant damage compromising structural integrity, to development of a capacity-designed mechanism and associated cracking in plastic hinges or limited evidence of plastic deformations. The former two cases have attracted significant attention, including the focus of the Canterbury Earthquakes Royal Commission (CERC 2013), and continue to influence changes in building codes and standards, both in New Zealand and internationally. While the predominance of the latter case in modern buildings indicated good compliance with life safety performance objectives, engineers, owners, and insurers were faced with challenges when conducting detailed post-earthquake assessments in the absence of reparability guidelines. This paper summarises two studies (Kim, 2015; Marquis, 2015) on post-earthquake repair/demolish decisions on concrete buildings in Christchurch, identifies factors influencing such decisions, and offers insights on emerging challenges for other earthquake-prone regions based on the Christchurch experience.

2 BUILDING DEMOLITION/REPAIR DECISIONS IN CHRISTCHURCH CBD

Figure 2 summarises the demolition/repair decisions on 223 concrete buildings, representing 88% of concrete buildings over two storeys in the Christchurch CBD. A total of 138 such buildings, equivalent to approximately 750,000 m^2 of floor space, have been demolished. Figure 2 compares the Decision Outcome with the placard and the damage ratio (a visual estimate of building damage as a ratio of repair cost to replacement cost from Level 2 assessments (NZSEE 2009)). Other more detailed forms of damage assessment (e.g. Detailed Engineering Evaluations (DEE)) are not used here since such data was available for less than half of the database buildings (Kim 2015). As expected, Figure 2 indicates demolitions are more prevalent for buildings with higher levels of damage; however, a significant number of buildings with low damage ratios were demolished. Notably, over 50% of buildings with damage ratio between 2-10% have been demolished, suggesting that other factors are likely at play in arriving at the demolition decision. Figure 2 also indicates that older buildings, frequently those considered "earthquake-prone" by NZ legislation, were more likely to be demolished. Buildings in the cordon for over a year also tended to be more likely to be demolished according to Figure 2e. A further logistic regression study (Kim 2015) indicated that older, taller, non-heritage, commercial buildings have a higher probability of demolition for a given Damage Ratio. Such effects of the independent variables, however, diminish with increase in assessed damage; that is, when a building experiences severe damage, other variables become less important in the likelihood of building demolition.

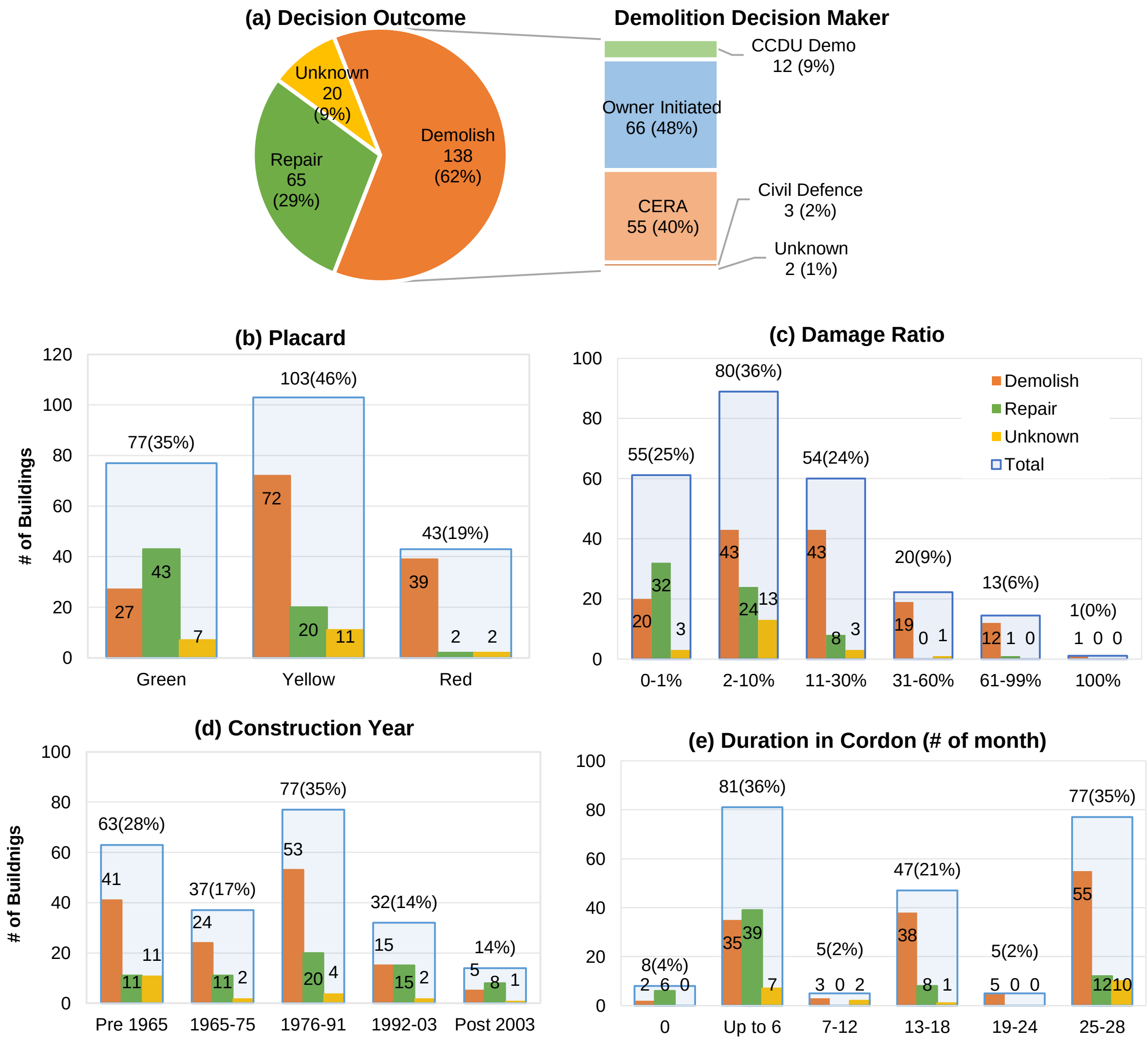

Figure 2: Demolition/repair decision statistics for 223 concrete buildings over 2 stories (Kim 2015)

Table 1: Case-study building profiles

		ID	Year of Design	Number of Storeys	Lateral System	Design Ductility	Overall NBS Pre-EQ	Site Sum Insured[2]	Building Value[3]	Replace-ment Value[4]	Placard[5]	Overall Damage Ratio[4]
DEMOLISHED	CERA	D1-O	1987	17	MRF	3.00	34-66	80	31.6	99.2	R1	11-30
DEMOLISHED	CERA	D2-H	1986	13	Shear Wall	n/a[1]	34-66	170	47.6	142.6	Y2	2-10
DEMOLISHED	CERA	D3-O	1986	8	Shear Wall	n/a[1]	34-66	14	6.3	23.0	R1	11-30
DEMOLISHED	OWNER INITIATED	D4-O	1987	22	MRF	3.00	34-66	95	43.8	139.4	Y1	11-30
DEMOLISHED	OWNER INITIATED	D5-O	1986	10	MRF/ SW	n/a[1]	20-33	28	10.7	31.1	R1	11-30
DEMOLISHED	OWNER INITIATED	D6-H	1971	12	MRF	1.25	20-33	37	18.1	51.9	Y2	2-10
DEMOLISHED	OWNER INITIATED	D7-O	1968	13	MRF	2.00	34-66	33	12.8	-	G2	2-10
DEMOLISHED	OWNER INITIATED	D8-X	1968	7	MRF/ SW	1.25	34-66	District Health Board Insurance		-	G2	2-10
REPAIRED		R1-H	1910 (Retrofit.)	3	Shear Wall	1.00	67-80	62.5	10.4	-	Y2	2-10
REPAIRED		R2-H	1988	6	Shear Wall	2.00	80-100	11.5	7.6	23.0	G1	0-1
REPAIRED		R3-O	1988	19	MRF	4.00	67-80	72	20	71.0	Y2	2-10
REPAIRED		R4-R	2002	8	MRF/ SW	1.25	34-66	40	30	-	Y1	2-10
REPAIRED		R5-O	1972	6	MRF	3.00	80-100	170	61.7	-	G2	0-1
REPAIRED		R6-U	1972	6	MRF	2.00	67-80	NZ University Collective		-	G2	-
REPAIRED		R7-P	2000	3	MRF/ SW	1.25	67-80	NZ Council Insurance		-	G2	0-1

Notes: Buildings are identified by outcome - demolished (D) or repaired (R) and occupancy type – office (O), hotel (H), hospital (X), multi-unit residential (R), university (U), and public assembly (P)

1) Data not available (Detailed Engineering Evaluation not on file)
2) Earthquake Cover - Sum insured for material damage (in $NZD million)
3) Pre-earthquake property's rating valuation, excluding land value (Christchurch City Council) (in $NZD million)
4) Estimated replacement costs for 1970s-90s case-study buildings (office and hotel), based on observations from the interviews, experience of local engineers, and actual construction cost for new buildings in Christchurch (in $NZD million)
5) From the latest Level 2 rapid assessment forms (NZSEE 2009)

From an engineering perspective, the level of damage and cost to repair typically dictate a recommendation for the course of action (demolish or repair) on earthquake-damaged buildings. As indicated in Figure 2, however, the Christchurch experience has demonstrated that the level of damage is not the only factor that contributes to post-earthquake decision making. Economic considerations, business strategies and government regulations can significantly influence the decision to demolish or repair. Data on such factors could not be collected across the full database described above, necessitating a detailed qualitative study of 15 case-study buildings in Christchurch including interviews with building owners and other stakeholders (Marquis et al. 2015). The following discussion of observations from these case studies highlights distinct local contextual factors that affected building demolition decisions; careful consideration of these factors will assist in framing future research directions, accounting for the true complexities of post-earthquake decisions.

As shown in Table 1, approximately half of the case-study buildings have been repaired (7), while the balance have been demolished (8), including a mix of owner-initiated and demolitions mandated by CERA. Further details of the case study buildings can be found in Marquis (2015). One important observation from this study is that there is no evident correlation between the type (and design ductility) of the lateral system and the level of damage (and subsequent demolish/repair decision). Second, the pre-earthquake %NBS (% New Building Standard) appears to be a strong indicator of the decision. Buildings achieving a capacity less than 67% NBS have been demolished, while buildings above 67% NBS have been repaired (with one exception). Two earthquake-prone buildings (less than 33% NBS pre-earthquake) were included in the study and both have been demolished. Third, similar to the observations in Figure 2, building damage assessments do not appear to be a good measure of the likelihood of demolition. It is important to mention that the estimated repair costs were typically much higher than the Damage Ratio provided from the Level 2 rapid assessment forms, in part because of the approximate nature of such assessments and uncertainties in the repair costs. Finally, the level of insurance coverage varies greatly between both repaired and demolished buildings and the site sum insured typically did not adequately represent the replacement costs. Based on estimates of replacement value by the authors for case-study buildings with sufficient information available (Table 1), only two buildings (D2-H and R3-O) had a sufficient sum insured to ensure full reinstatement.

Insurance has played a particularly key role in the post-earthquake environment in Christchurch. New Zealand has one of the highest insurance penetration rates in the world; in fact, approximately 80% of the economic losses in Christchurch was borne by the insurance industry, considerably higher than other major disasters worldwide (Bevere and Grollimund, 2012). This statistic is clearly influenced by widely available residential insurance offered by the Earthquake Commission (King et al, 2014), however, this study will focus on commercial insurance policies given the prevalence of concrete construction in this sector. The traditional approach for New Zealand policies for commercial buildings is to provide full value earthquake cover on a reinstatement basis. As shown in Table 2, the definition of reinstatement is based on the amount of damage and repairability of the structure. A "destroyed" building implies that the structure is so damaged that demolition is the only course of action available, both from a technical and economical perspective. However, where the property is damaged but not destroyed, the definition of reinstatement is more vague and includes a reference to "restoration … to a condition … when new". Following the earthquakes, the standard interpretation of "when new" conditions typically consisted of a repaired property which is compliant with current building regulations and equivalent in appearance, quality, working order, and structural capacity as it was before the earthquake, without deduction for depreciation. Most commercial policies also specified a sum insured which is the maximum insurer's liability for each earthquake occurrence during the policy period. A sufficient sum insured is critical to receive full reinstatement if the structure was deemed non-repairable and subsequently replaced with a new building, equivalent to the previous building.

It is worth noting that following the Canterbury earthquakes, most insurers modified their policy wordings and introduced new coverage restrictions and exclusions (Vero 2013). For comparison purposes, Table 2 provides a summary of the key modifications in the definition of reinstatement cover. Importantly, the "condition when new" phrase still remains, however any additional cost necessary only to comply with regulations in connection with the seismic capacity of the building is now typically excluded from standard policies. Nevertheless, owners of earthquake-damaged buildings are still required to comply with all regulations, regardless of their insurance coverage.

Table 2: Earthquake reinstatement cover – policy wording (Axco 2014, Vero 2007, Vero 2013)

	Previous Policies (pre-2011)	**Current Policies**
The property is lost or destroyed	Replacement by an equivalent building that is as nearly as practicable the same as the building lost or destroyed, using currently equivalent materials and techniques and incorporating such alterations as are necessary to comply with any regulations.	Replacement by an equivalent building that is nearly as practicable the same as the building lost or destroyed, using modern equivalent materials, skills and techniques <u>that are readily available in the country that the lost or destroyed building is located in</u>, and incorporating such alterations that are necessary to comply with any regulations that are <u>in force on the date that the damage occurs</u> (subject to any limitations or exclusions specified in the policy).
The property is damaged but not destroyed	Restoration of the damaged portion of the property to a condition substantially the same as, but not better or more extensive than, its condition when new.	Restoration of the damaged portion of the property to a condition substantially the same as, but not better or more extensive than, its condition when new, <u>using modern equivalent materials, skills and techniques that are readily available in the country that the damaged building is located in</u>. <u>Exclusion: the extra costs to comply with current earthquake standards (e.g. earthquake-prone building regulations as described in the Building Act 2004) are excluded. Only the costs to reinstate up to the level of seismic capacity prior to the damage are covered.</u>

The aftermath of the Canterbury earthquake sequence revealed important lessons around the extent and limitations of insurance policies. First, the sum insured was less than the actual rebuild cost for most commercial properties considered in this study, in part due to inadequate valuations. An adequate sum insured was essential in order to achieve appropriate remediation works for repairable buildings, including strengthening to at least 34% NBS for earthquake-prone buildings (i.e. compliant with current building regulations, as detailed below). Although a repair scenario would have made sense from an engineering perspective, buildings were often considered uneconomical to repair because of underinsurance and the difficulty for engineers to actually reinstate "when new" conditions (Brown et al. 2013). Underinsurance and the lack of clarity in policy wordings resulted in building owners pursuing aggressive policy coverage arguments in order to maximize their insurance payout. Moreover, most insurers agreed to cash settle insurance claims without much resistance when the estimated repair costs were beyond a certain percentage of the sum insured, although this outcome was not an entitlement under standard policies if the building was actually not reinstated (repaired or replaced). Insurers favoured cash settlements because of challenges of providing and managing full reinstatement on hundreds of claims. Similarly, property investors generally considered it a favourable outcome if their building was declared a total loss by their insurer and subsequently demolished, because of the availability of cash settlement, providing maximum flexibility and rapidity. Cash settlements enabled building owners to recover more quickly from the earthquakes and walk away from the uncertainties in the recovery of Christchurch, sometimes with more equity then prior to the earthquakes (Marquis et al. 2015). For building owners and insurers, this outcome was also less financially risky than going through complex repairs or rebuilds. All demolished case-study buildings in Table 1 have cash-settled.

The changes in the local legislation following the earthquakes also contributed to the predominance of building demolitions in Christchurch. After the September 2010 earthquake, the Christchurch City Council recommended that building strengthening work aim to meet 67% NBS, raising the target from a prior required minimum of 34% NBS (CCC 2010). However, a High Court decision in 2013, and a Supreme Court decision in December 2014, ruled that property owners and insurers are only obliged to strengthen the buildings to 34% NBS, causing confusion as to whether or not insurers were required to pay for the additional remediation (NZSC 2014). Building owners were also confused if they were required or not to upgrade to at least 67% in order to receive a building consent (permit) for earthquake repairs. Furthermore, the building code was amended in May 2011 to include a 36% increase in the basic seismic design load (Z factor increased from 0.22 to 0.3), accounting for the heightened level of seismicity in Canterbury region. Therefore, the changes in the Christchurch's earthquake-prone building policy, in addition to the increased seismic design requirements for Canterbury, have impacted post-earthquake decisions and the cost of the repair by increasing the level of strengthening potentially required for a repaired building. The changes around building regulations created uncertainties around the repair scope and methodology, and the additional costs resulting from these changes made a repair scenario sometimes less financially attractive for the owner. All these factors may have led to more building demolitions than would have occurred without the legislation changes. Additionally, some buildings were located in areas designated for Crown purchase or compulsory acquisition for CCDU projects (denoted as "CCDU Demo" in Figure 2), which affected the course of action for a small number of repairable buildings (Kim 2015).

3 POST-EARTHQUAKE ASSESSMENT AND REPAIR GUIDELINES

3.1 *Challenges faced in Christchurch*

For engineers, the Christchurch experience has highlighted several challenges related to the detailed post-earthquake assessment of buildings, particularly in the context of the insurance policies described in the previous section. The focus here is on modern ductile buildings since there was generally consensus among engineers for the assessments of buildings exhibiting brittle modes of failure.

First, the assessment of earthquake-damaged buildings and the repairs necessary to comply with the "condition when new" clause of insurance policies was an entirely new environment for most engineers. Assessing a building under such conditions was a change from the traditional assessment for a life safety or collapse prevention performance level. No guidance was available for interpretation of the "condition when new" clause from an engineering perspective based on the observed damage. This lack of guidance and experience led to significant variability in the structural assessments and repair costs, particularly when comparing assessments by engineers hired by building owners and (re)insurance companies.

Secondly, in the absence of clear guidelines for assessment of residual capacity, new methods of measuring the extent of damage were introduced with limited opportunity for validation. In particular, hardness tests on reinforcement were extensively used to estimate the plastic strain experienced by reinforcement in plastic hinges. Such measurements were used to identify where prior strain demands may limit the strain capacity of the reinforcement, and hence rotation capacity of the plastic hinge, in future earthquakes.

Finally, there was limited knowledge on the impact of various factors on residual capacity of concrete elements and structural systems, generally leading to conservative assessments of residual capacity. For example, the repeated aftershocks raised concern that plastic hinges may experience low-cycle fatigue failures. Limited numbers of cracks observed in plastic hinges also raised concerns regarding high strain demands at these cracks and the ability of epoxy repair to ensure redistribution of cracks and avoid strain localisation in reinforcement. There was further concern that strain aging of reinforcement may lead to embrittlement, further reducing the strain capacity in future events (Erasmus and Pussegoda, 1977). Existing guidance documents for assessment of earthquake-damaged concrete wall buildings developed after the Northridge Earthquake in US (FEMA 1998) did not address the concerns above and are not easily modified for the New Zealand regulatory context, and hence, was not felt appropriate for application in Christchurch.

3.2 *Residual Capacity*

The uncertainty and lack of knowledge and guidance on assessment of residual capacity of earthquake-damaged buildings has generally led to conservative assessments in Christchurch. This, combined with the factors highlighted in Section 2, has resulted in demolition of potentially salvageable buildings and substantial loss of the built environment. This experience points to the need for further research and guidelines to assess residual capacity and reparability of earthquake-damaged concrete buildings. The Building Performance Branch of the Ministry for Business Innovation and Employment in NZ has recognized the need to develop such guidance and has formed a Working Group to recommend a practical means of assessing the residual capacity of reinforced concrete buildings subjected to inelastic seismic demand given the current state of knowledge regarding: reinforcing steel strain capacity, plastic hinge crack distributions, and impacts of plastic hinging on system capacity. This Working Group is building on ongoing studies at the University of Canterbury and Auckland (e.g. Cuevas Ramirez and Pampanin, 2015; Huffadine et al, 2015)

A fundamental challenge in developing such guidance documents lies in establishing appropriate metrics for assessing performance of the damaged structure. One approach is to measure the performance relative to the performance of the undamaged building. Simplistically, this may be illustrated using the pushover response of a component (or structure) before and after it is subjected to a damaging earthquake as shown in Figure 3. Two metrics are suggested: reduction in strength (ΔV) or reduction in deformation capacity (ΔD). For a ductile component (or system) which has experienced yielding and where significant degradation of flexural strength is not anticipated, ΔV will likely be minimal and not provide a suitable metric. Earthquake damage may result in ΔD, *i.e.* a change in the deformation capacity (defined here based on the deformation at a 20% drop in lateral load capacity) from a monotonic push of the component or system. It must be recognised, however, that deformation capacities are typically calculated using models calibrated to reversed-cyclic tests (e.g. ASCE 41 (2006)). Such tests, typically with two or three cycles per drift level, include many more cycles at large drifts than would be expected to be imposed on a component during most earthquakes. This leads to the conclusion that deformation capacities used in performance assessment already have implicitly included the impact of prior cycles and thus provide an estimate of the deformation capacity *after* earthquake damage, rather than *before*. It is clear, however, that prior earthquake damage will result in a reduction in stiffness (ΔK) and associated increase in deformation demands in future events. Hence the critical metric for assessing an earthquake damaged building may be the increase in deformation demands due to the reduced stiffness, relative to the deformation capacity assessed from models calibrated to reverse cyclic tests.

An alternative metric is to define the residual capacity in terms of the number of cycles to failure. Several models exist to estimate the low cycle fatigue capacity for concrete components (e.g. Dutta and Mander 2001); however to implement such a measure one would require seismic hazard models to provide estimates of number of cycles for different locations. Such information is not typically available.

While not practical for immediate implementation, ideally the performance of the damaged structure should be assessed based on change in risk, or probability of failure (different failure states may be considered including structural collapse). Given analytical models capable of capturing the change in component behaviour after damage, a building fragility curve as illustrated in Figure 4 can be developed and compared to the fragility prior to damage. If the probability of collapse remains below an "acceptable level" then the building may be considered to still satisfy the intent of the code. ASCE 7 (2010) targets a probability of collapse of 1% in 50 yrs or 10% given the occurrence of Maximum Considered Earthquake (MCE) as an acceptable level of risk. No such targets exist for NZ Building Code. A risk assessment would also enable a more holistic approach to assessing costs of reinstatement satisfying the "condition when new" clause in insurance policies. A repair strategy could be selected such that the probability of collapse of the repaired building fell below that for the original "new" building.

To realise the holistic risk assessment described above requires further research, namely:

- Development of nonlinear structural models capturing the impact of strain hardening (and ageing), strain rates, and low cycle fatigue on the response of damaged components; including the calibration of such models with experimental data.
- Development of nonlinear structural models capturing the performance of epoxy repaired components.
- Benchmarking of current NZ code design buildings to assess the risk expected from modern buildings.

Research is underway at the Universities of Auckland and Canterbury to fill these knowledge gaps.

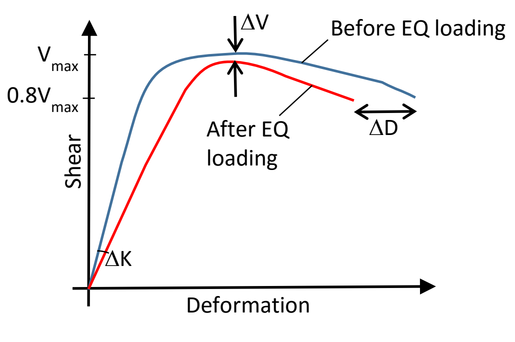

Figure 3: Illustrative pushover response before and after a damaging earthquake

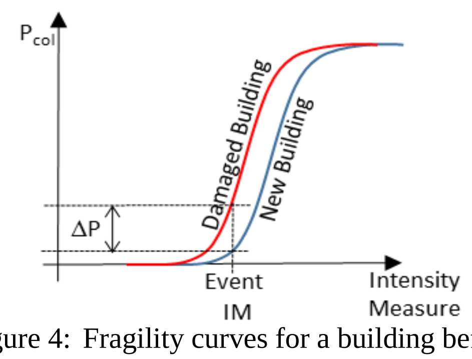

Figure 4: Fragility curves for a building before and after a damaging earthquake

4 FUTURE DIRECTIONS

The Christchurch experience suggests that building owners, engineers and insurers need to further investigate the implications of the terms and conditions of insurance policies. Insurance penetration rates are expected to remain high in New Zealand, primarily driven by the low cost of premiums currently available in the market. Therefore, we anticipate that the role of insurance for future events will remain critical when making decisions on damaged buildings. As detailed above, most insurers have amended their policy to reduce their risk exposure and liability for future events. However, the acceptable standard of repair (condition as *when new*) remains poorly defined and technically difficult to satisfy, given the uncertainties around assessing residual capacity for reinforced concrete structures and the current lack of post-earthquake legislation. Insurance companies need to clarify the scope of their reinstatement coverage. Ideally the definition of reinstatement should be based on risk instead of strength and capacity as suggested above.

Furthermore, the repair of earthquake damage needs to be explicitly considered by building codes and local government policies. The current approach aims at determining the capacity of the damaged building relative to current code requirements with an arbitrary cut-off (33% NBS) for seismic strengthening. This metric is typically used when making decisions to retrofit existing buildings, however this value is may not be appropriate when considering earthquake-damaged buildings, particularly considering the “condition when new” clause.

Reparability guidelines will provide a pragmatic basis for structural and geotechnical engineers to perform post-earthquake evaluations and assess potential repair strategy. This guidance needs to align with the terms and conditions of insurance policies in order to establish compatible and reasonable assessment criteria, balancing safety and financial considerations. Collaborative research work between engineers and insurance industry players would be beneficial in creating such guidelines.

REFERENCES:

ASCE (2010) Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10), American Society of Civil Engineers, Reston, Virginia.

ASCE (2013) Seismic Evaluation and Retrofit of Existing Buildings (ASCE/SEI 41-13), American Society of Civil Engineers, Reston, Virginia.

Axco. (2014) Insurance Market Report – Lines of Business: Non-Life (P&C). Canada and New Zealand.

Bevere, L., and Grollimund, B. (2012). Lessons from recent major earthquakes. Zurich, Switzerland: Swiss Reinsurance Company. Retrieved from: http://www.swissre.com/clients/Lessons_from_recent_major_earthquakes.html

Brown, C., Seville, E., & Vargo, J. (2013) The role of insurance in organizational recovery following the 2010 and 2011 Canterbury earthquakes. Resilient Organisations Research Report 2013/4.

CCDU (2012) Christchurch central recovery plan, Christchurch Central Development Unit.

CERA (2012) Canterbury earthquake recovery authority (CERA) annual report 2012. Christchurch: Canterbury Earthquake Recovery Authority. Retrieved from http://cera.govt.nz/annual-report

CERC (2012) Volume 2: The Performance of Christchurch CBD Buildings, Canterbury Earthquakes Royal Commission available at http://canterbury.royalcommission.govt.nz/Final-Report-Volume-Two-Contents (accessed February 2015).

Civil Defence Emergency Management Act (2002) Wellington, New Zealand: New Zealand Government.

Christchurch City Council (CCC) (2010) Christchurch City Council Earthquake-prone, dangerous and insanitary buildings policy, 2010. Christchurch City Council, 10 September 2010.

Cuevas Ramirez, A., and Pampanin, S., (2015) Effects of strain-rate and material characteristics on the seismic residual capacity of reinforced concrete plastic hinges: numerical investigation, NZSEE Conference, Rotorua, New Zealand.

Dutta, A. and Mander, J. B., (2001) Energy Based Methodology for Ductile Design of Concrete Columns, *Journal of Structural Engineering*, ASCE, 127(12).

Erasmus, L. and Pussegoda L. (1977) Strain age embrittlement of reinforcing steels. *New Zealand Engineering* 32(8).

FEMA (1998) FEMA 306: Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Federal Emergency Management Agency, Washington.

Huffadine, J. A., Van Bysterveldt, A. G., Clifton, G. C., & Ferguson, G. W. (2015). The Cracking Behaviour of Reinforced Concrete Beams Under Static and Dynamic Loading. NZSEE Conference, Rotorua, New Zealand.

Kim, J. H. (2015) Quantitative analysis of factors influencing post-earthquake decisions on concrete buildings in Christchurch, New Zealand. Master’s Thesis, University of British Columbia, Vancouver, Canada.

Marquis, F., Kim, J. H., Elwood, K. J., & Chang, S. E. (2015) Understanding post-earthquake decisions on multi-storey concrete buildings in Christchurch, New Zealand. *Bulletin of Earthquake Engineering*, DOI 10.1007/s10518-015-9772-8.

Marquis, F. (2015) A Framework for Understanding Post-Earthquake Decisions on Multi-Storey Concrete Buildings in Christchurch, New Zealand, Master's Thesis, University of British Columbia, Vancouver, Canada.

NZSEE (2009) Building safety evaluation during a state of emergency: Guidelines for Territorial Authorities. New Zealand Society for Earthquake Engineering.

New Zealand Supreme Court (NZSC) (2014) University of Canterbury v Insurance Council of New Zealand [22 December 2014] NZSC 193.

Parker, M., and Steenkamp, D. (2012) The economic impact of the Canterbury earthquakes major earthquakes. Reserve Bank of New Zealand: Bulletin, 75(3), 13–25.

Vero (2007) Business Plan Policy. Version 6. Policy Wording, available at: https://www.vero.co.nz/ business-insurance (accessed June 2015)

Vero (2013) Business Plan Policy Endorsement. July 2013, available at: https://www.vero.co.nz/ business-insurance (accessed January 2015).