A Snapshot of Societal Expectations for the Seismic Performance of Buildings in New Zealand – What This Reveals about Future Design Considerations for Non-Structural Elements

H. Ferner[1], C. Brown [2], S. Horsfall[2], S. Abeling[3], and H. Cowan[4]

[1] New Zealand Society for Earthquake Engineering
helenmferner@gmail.com
[2] Resilient Organizations
{charlotte.brown, sophie.horsfall}@resorgs.org.nz
[3] University of Auckland
shannonabeling@gmail.com>
[4] Hugh Cowan Consulting
hugh@hughcowan.com

Abstract.

New Zealand has just experienced its most sustained period of disruption caused by earthquakes since the mid-20th century. The impact of the recent earthquakes has been widely observed and commented upon by stakeholders, policy makers and the general public. The recent events caused extensive structural and non-structural damage with wide ranging social, economic and environmental impacts.

Structural engineers in New Zealand (NZ) historically have designed buildings to meet life safety objectives during and following earthquakes but there has been limited regard to usability following such events. This approach has been effective in reducing loss of life – fulfilling a core objective of the current NZ building code, but questions have arisen whether the observed levels of damage and disruption warrant a rethink of seismic performance objectives. Research to explore societal expectations and tolerance toward seismic risk has been completed as part of a programme of work to inform future performance objectives for the design of new buildings. The findings reveal the importance to NZ communities of restoring building functions following an earthquake, and therefore highlight the performance of non-structural elements as a key determinant of outcomes.

Keywords: seismic risk objectives, non-structural, seismic design, impact on seismic performance of buildings

1. INTRODUCTION

How do New Zealanders in the 2020s want buildings to perform during and after an earthquake? Do New Zealand's current systems and approaches provide buildings that meet these expectations? If not, what changes may be appropriate?

The impacts of the recent NZ earthquakes have been observed and commented upon by stakeholders, policymakers and the public, including both the direct and wider social impacts [CERC, 2012]. Design standards and the subsequent performance of our buildings have consequences for all.

Minimizing the likelihood of death and injury in earthquake and fire has been a fundamental imperative for building design standards for over 50 years. However, other performance outcomes have risen to prominence during recent years in New Zealand and abroad, including, for example, the ability to shelter in place in multi-storey residential buildings after a significant event and to reduce waste and carbon emissions by constructing repairable buildings.

The Resilient Buildings Project (RBP), a New Zealand Society for Earthquake Engineering (NZSEE) initiated project, was conceived to lay the groundwork for resilient building design, informed by the perspectives and expectations of building users. It complements the work currently underway updating New Zealand's National Seismic Hazard Model (NSHM) Both inputs will inform a planned series of updates to the seismic loadings standard NZS1170.5.

NZSEE undertook research to explore societal expectations and tolerance toward seismic risk [Brown et al., 2022] as part of the Resilient Buildings Project. Through a series of interviews and focus groups with diverse stakeholders across New Zealand, the research sought to understand perspectives on the seismic performance of buildings. The participants did not differentiate between different building components but considered the overall performance of a building hightlighting the importance of non-structural elements for stakeholders in addition to the structural elements when considering the performance expectations for seismic designs.

2. SOCIETAL EXPECTATIONS RESEARCH

This work is the first time in New Zealand that researchers have sought to document from a community perspective nationwide societal expectations for the seismic performance of buildings. The approach entailed a series of interviews and focus groups with diverse stakeholders across New Zealand to sample perspectives on the future seismic performance of buildings. The team interviewed 32 individuals who represented a range of experiences and interests across different seismic hazard zones, geographies, socioeconomic groups, and cultural contexts. The interviews focussed on understanding each participant's current role, background, and earthquake experience and their expectations of new building performance during a significant earthquake and during minor to moderate earthquakes.

A series of six geographically based focus groups were then convened, covering three urban centers and three smaller towns with differing levels of seismic hazard. The focus groups each comprised three to seven individuals representing different community perspectives (local civil defence, business community, health sector, welfare sector, environmental interests, and indigenous Māori). The research findings are summarised in a research report [Brown et al., 2022a], a detailed report on interviews [Abeling et al., 2022a] and a detailed report on focus groups [Horsfall et al., 2022].

3. WHAT DO NEW ZEALANDERS WANT FROM THEIR BUILDINGS?

The research findings show that life safety remains of primary importance when considering building performance in earthquakes. It is an expected outcome, indeed was assumed by the research participants. This focus on life safety aligns with New Zealand's current code settings for the building structure.

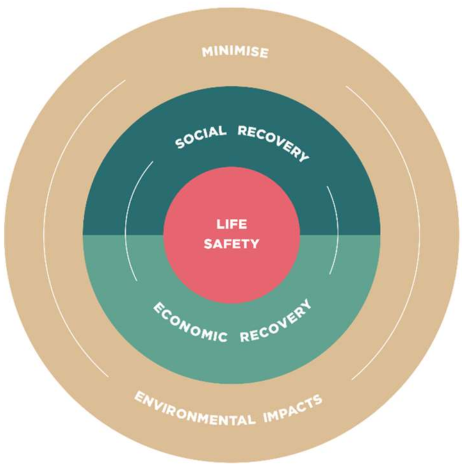
Participants in the research framed their responses in terms of expectations of overall building performance, but the expectations expressed bear directly on the performance of non-structural elements which has been attributed to 61% of all earthquake-related injuries in New Zealand between 2010 and 2014 [Yeow et al., 2020].

The research found the priorities for life safety are not simply about the number of people occupying a building but include consideration of the types of individuals likely to be in the building. Participants identified vulnerable people and those with essential skills for response and recovery (including economic recovery) as requiring protection. Another consideration the research participants identified was avoiding the potential for mass casualty events or areas with the potential for panic or chaos.

Participants agreed that prioritizing buildings with post-disaster functions, such as hospitals, was important but considered priority should be extended to more buildings, including supermarkets and food production facilities as well as multi-purpose spaces that can be used to support disaster recovery. Locations likely to experience or attract large numbers of people immediately after an earthquake, such as schools and community centers, were also identified as locations where higher building performance is expected due to the danger of aftershocks.

The findings indicate that New Zealanders want more than life safety, with social and economic recovery identified as important objectives following an earthquake.

Equitable access to essential goods and services, sustaining social connection and restoring normalcy that supports cultural identity and economic wellbeing were all noted as important for social and economic recovery. Different types of buildings were identified as high-priority gathering locations depending on the community. These ranged from community centres and places of worship to retail shops and restaurants in cities, and pubs, sports grounds and clubrooms in smaller towns.



1: LIFE SAFETY

Avoid mass casualty events
Protect vulnerable persons
Ensure safety at mass gathering points
Preserve high value skills and resources
Support immediate response activities
Maintain a perception of safety

2: SOCIAL RECOVERY

Ensure equitable access to essential goods and services
Enable effective governance
Have places to connect
Return sense of normalcy
Retain sense of place and cultural identity

3: ECONOMIC RECOVERY

Restore enabling services and industries
Enable people to work
Build business confidence

4: MINIMISE ENVIRONMENTAL IMPACT

Minimise waste generation
Avoid hazardous waste or potential public health risks
Reduce embodied carbon

Figure 1. Seismic Resilience Performance Objectives

3.1 Expectations of Earthquake Recovery

The research identified safe housing and confidence and certainty in the recovery process as core expectations of the period immediately following a major earthquake. This framing of expectations included prioritizing mental wellbeing and enabling conditions for individuals to contribute to the social and economic recovery of their community.

Participants considered the ability to shelter in place in their homes important and desired an early return of electricity, internet, and telecommunications even if water and sanitary systems were not functional. This expectation is based on the recent Christchurch experience, where many people continued to live in their damaged single-family homes, despite not having access to indoor plumbing, throughout the 14-month-long earthquake sequence.

Participants emphasized the importance of being able to retrieve essential belongings from damaged buildings. This could include allowing people to return to their apartments to collect important documents or their workplaces to collect essential business supplies, all of which depend on the post-earthquake integrity of non-structural elements.

The research highlighted the very strong synergies between economic and social recovery and that many buildings support both. The need for households to generate income soon after an earthquake was identified as important, along with schools reopening quickly, both to enable parents to return to work and to reduce stress on families. Schools also provide a vital function in assisting students in regaining a sense of normality by attending class and seeing their peers thus contributing to mental wellbeing.

Many participants identified the importance of electricity, internet, and telecommunications systems to support businesses to function after an earthquake but noted flexibility about requirements for a physical building for many businesses. Clearly, the recent experience of Covid-19 pandemic has shaped people's expectations of what is needed to support business functionality.

"Returning to normal" is considered a critical factor for recovery. While "normalcy" may look different for different communities, reopening schools, retail and arts and recreation facilities and access to buildings that support cultural wellbeing and identity are noted as key parts of the return to normalcy.

The research identified a significant intolerance to a long-drawn-out recovery, noting the adverse impacts on people's wellbeing and mental health when recovery is slow or uncertain. Many of the functions identified by participants as important for rapid recovery involve the non-structural components of buildings, suggesting that extensive damage to elements that preclude rapid recovery does not meet societal expectations.

This intolerance to disruption following an earthquake points to an expectation of no damage or minimal damage in all but the largest earthquakes, an expectation at variance with the current code settings in New Zealand.

3.2 How Quickly Do Communities Want Different Types of Buildings to be Available After an Earthquake?

Continued building functionality is expected for critical infrastructure and for buildings such as hospitals and emergency service facilities with critical post-disaster functions. This expectation matches the current New Zealand building code settings.

Expectations of time for other buildings to function again after an earthquake vary by building type but show that the expectation is days and weeks rather than months or years. Speed of return to function was identified as a particular priority for some building types that are not currently a priority, including supermarkets, aged care facilities, community centres and homes, refer Figure 2 below.

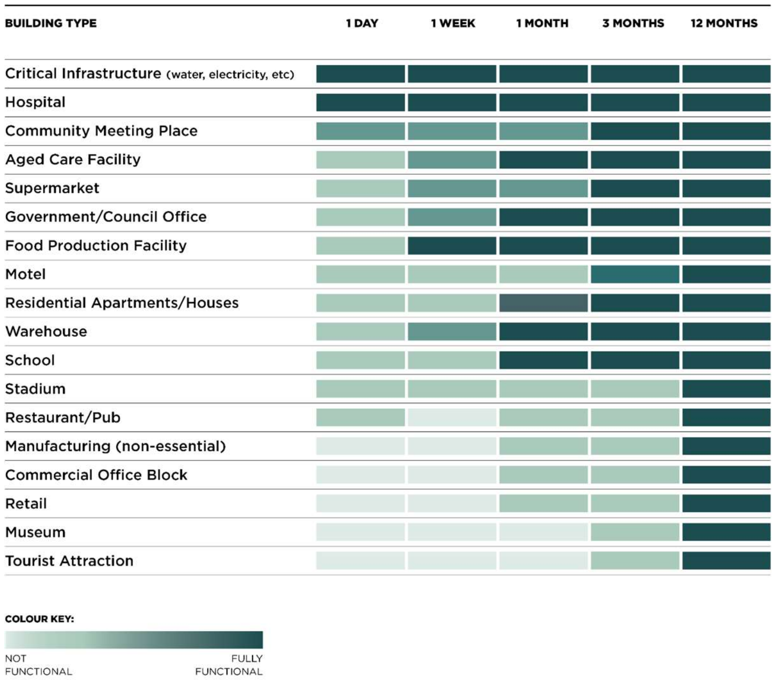


Figure 2. Time to Restore Building Function

In a review of the findings held in March 2022 [Abeling, 2022b], a group of New Zealand's earthquake standards and design experts expressed surprise about people's perceptions of acceptable recovery times for different building types. It was noted that the focus groups' expectations for timelines to return to function were significantly shorter than those anticipated by the 'experts' and were, perhaps, unattainable. The group also noted the need to avoid or limit damage to non structural elements if these expectations for return to function are to be in any way realised. The engineering community has acknowledged that the schema for prioritizing buildings for rapid return to function needs review, particularly with regard to vulnerable groups (e.g., aged care residents).

3.3 WHAT LEVELS OF DAMAGE ARE ACCEPTABLE?

The research sought to explore the extent to which people are willing to accept different levels of disruption due to earthquake damage. While tolerance for disruption due to earthquake damage can be subjective and influenced by factors such as previous earthquake experience, the vulnerability of the building occupants, and the primary use of the building, general trends for people's willingness to accept damage emerged.

The findings indicate that people are generally accepting of minor earthquake damage (defined in the research as repairs needed but minimal disruption to services).

Moderate damage (defined in the research as repairs needed with minor disruption to services – in the order of weeks) was also considered to be generally acceptable, but the descriptions of moderate damage provided by participants were similar to those provided for types of minor damage (e.g., cosmetic damage to paint, plaster and plasterboard and other superficial cracks) suggesting a lower level of acceptability to moderate damage than the initial responses indicated. This finding aligns with the research participants' expectations for a rapid return to function.

One participant reflected on moderate damage at a community level and noted. "*It shouldn't be more than 10% of buildings that would require a week-long remediation.*"

Significant damage (defined in the research repairs needed with significant disruption to services – in the order of months) was identified as less acceptable, with people noting that significant damage would likely require a building to be closed while repairs are planned and undertaken, significantly disrupting occupants and normal building function.

Major damage (defined in the research unoccupiable, possibly requiring replacement) within a nominal 50-year lifecycle was generally considered to be unacceptable..

3.4 WHAT ABOUT MODERATE EARTHQUAKES?

The research shows that in addition to an expectation of safety in smaller earthquakes people expect minimal or no impact on building functionality and limited damage to the non structural elements that support building functionality. In homes, the expectation is that kitchens and bathrooms should remain usable. In offices, building systems (e.g., HVAC systems, telecommunications, and emergency systems such as fire protection systems) should continue to work uninterrupted. Buildings are expected to remain watertight. It is typically expected that the building contents will have moved around and there may be some cosmetic cracking (e.g., cracks in plasterboard). However, any damage should be both minor in nature and limited in extent such that it will be easily repairable and not include any structural damage.

The psychological impacts of ground shaking and earthquake induced building damage is a particular concern. Participants often noted they wanted to "feel safe" within their buildings following an earthquake. Even small earthquakes can cause anxiety, triggering recollection of past events or concern that another larger earthquake is going to follow. Visual reminders of past earthquakes through damage (e.g., cracked plasterboard) can cause anxiety to building occupants. Prevention or remediation of minor damage can reduce unease about building safety.

Participants noted that damage to non-structural elements can be both costly and time-consuming to repair. Buildings may be demolished in the worst-case scenario if they become economically infeasible to repair despite being structurally sound. Maintaining building weathertightness, a key expectation in a moderate earthquake, relies to a great extent on the cladding system in many buildings. Damage to infrastructure service connections or the services themselves can also cause disruptions, such as power outages and damage to pipes that affect water supply will affect a building's ability to function.

3.5 ARE SEISMIC RISK PRIORITIES UNIFORM ACROSS NEW ZEALAND COMMUNITIES?

Mass casualties and impacts that cause intergenerational effects are perceived to be intolerable for communities throughout New Zealand. The community context though was found to deeply influence risk tolerance, with restoration priorities and timeframes for the return to function of various assets and industries dependent on community-specific priorities. This variance in building risk prioritization demonstrates that buildings are part of broader social and economic systems that support community resilience.

The seismic hazard, level of geographic isolation, density of the built environment, and the capacity for a community to recover from disruption all influence the risk tolerance of communities. In addition, the social and economic context of a community directly influence their risk mitigation priorities.

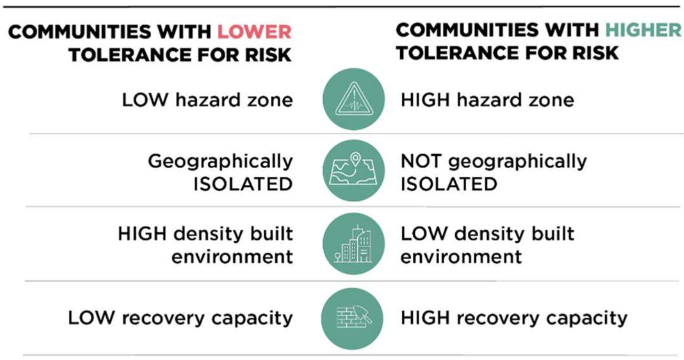


Figure 3. Factors affecting risk tolerance of communities

Communities with dominantly agricultural economies prioritize buildings related to agricultural employment and production. (e.g., food production facilities and transport/logistics hubs) while such facilities are perceived to be less important in urban centres.

While not assessed directly, overall tolerance for seismic risk appears to have declined as a consequence of recent earthquake impacts on NZ urban centers. This is reflected in the recommendations of an official inquiry into the Canterbury Earthquakes to "both explore the performance of buildings in Christchurch in the earthquakes and the adequacy of the current legal and best practice requirements for the design, construction and maintenance of buildings in central business districts in New Zealand to address the known risk of earthquakes" [CERC, 2012].

3.6 WHAT INFLUENCES WILLINGNESS TO REDUCE SEISMIC RISK IN BUILDINGS?

The research on societal expectations explored qualitative trade-offs between the benefits and costs of reducing seismic risk. This revealed that building owners with a long-term perspective of their buildings are more likely to invest in reducing seismic risk to reduce whole-of-life costs and enhance return on investment over the longer term. Other benefits identified are to protect reputation, attract tenants, obtain and maintain insurability, reduce downtime and rebuild costs in the event of an earthquake, and support the local community.

Many factors were also identified as a deterrent or hindrance to the construction of buildings with enhanced seismic resilience. Some participants expressed concern that higher building standards for enhanced seismic risk mitigation are likely to be prohibitively expensive, and the benefits may not exceed the costs, especially over a typical debt repayment period of about 20 years. There was also concern that the market may not understand or be able to adequately value the benefits of seismic resilience, with building owners and tenants unwilling to pay for enhanced levels of building performance. Additionally, the expected performance of neighbouring buildings was identified as a significant inhibitor. Building owners were concerned they may not be able to realize the benefits of a seismically enhanced building due to damage to surrounding infrastructure or damage to neighbouring buildings resulting in mandatory exclusion and perceptions of lack of safety in the area.

The availability and affordability of earthquake insurance also influence building owners' willingness to build more seismically resilient buildings. Some participants described how, instead of building to higher standards, risk could be mitigated given the current (high) availability of earthquake insurance in New Zealand and assumed government support for post-event recovery. Similarly, some larger businesses selfinsure and/or rely on their geographic spread to manage risk. These businesses have calculated that a disruption in one region or the loss of one site can be compensated by other parts of their operations.

The study also identified a lack of trust in engineering and the construction sector to design a building to a given performance outcome, manage building sites to ensure that what is designed is built and for contractors to build quality products. These perceptions may be influenced by damage to relatively modern buildings following the 2016 Kaikōura earthquake.

3.7 How Important is Seismic Risk Relative to Other Aspects of the Built Environment?

Seismic resilience is one among many competing demands on the built environment. The research sought to contextualize seismic risk relative to other key performance objectives and found that safety is considered the most important performance objective. Safety includes the safety of building users' day-to-day, fire safety, as well as life safety during an earthquake. User health and wellbeing and building functionality are considered important and are supported by factors such as acoustics, lighting temperature, air quality, accessibility, usability, and access to amenities.

Longevity and sustainability of buildings are also seen as important design objectives. There was considerable surprise that earthquake design considerations are expressed in relation to a nominal 50-year building design life. Many thought buildings should (and already do) last much longer than 50 years and that earthquake-related design should contemplate longer timeframes, given that reducing building damage will support economic recovery by reducing recovery costs and business disruption. Improving the longevity of buildings would also improve building sustainability and reduce the carbon footprint of the built environment by minimizing the demolition of damaged buildings following an earthquake.

Architectural values and heritage both scored significantly lower in terms of importance. It was noted though that effective architectural design is a key component of building performance if it provides a functional and aesthetically pleasing space and supports the wellbeing of users, and if material choices and design detailing support building durability, sustainability, and longevity.

The research highlighted the highly interconnected nature of the drivers and the strong links between seismic resilience and wellbeing of users, longevity, and environmental sustainability.

4. WHAT'S NEXT FOR SEISMIC DESIGN AND ESPECIALLY FOR NON-STRUCTURAL ELEMENTS?

These social science findings indicate that engineers have been relatively successful designing for earthquakes in New Zealand thereby reducing life safety risk. This represents a significant advance from 50 years ago when the concepts of ductile design and a hierarchy of failure intended to protect life were first introduced into the building codes. Like the impact of vaccines, which have largely eliminated the horrors of once-common diseases, the codified requirements for earthquake-resistant design now underpin expectations of safety for buildings. The societal focus for building seismic performance now extends to reducing social and economic impacts.

The findings also identified that members of the public may sometimes conflate life safety with lack of damage and functionality. While engineers have a clear understanding that life safety means to escape from a building without loss of life or injury in an earthquake, even though the building may be significantly damaged and no longer functional, this may not be sufficient for some. Societal expectations as expressed by the research participants are for very limited damage and a swift return to reoccupancy and full functionality.

The expectation of a rapid return to function for most buildings (days and weeks) is causing surprise amongst the engineering community in New Zealand. Engineers have noted these expectations for return to function are significantly shorter than anticipated and are questioning if they are obtainable. This view is, of course, informed by current design and construction approaches and practices in New Zealand and the observations of building performance in the recent earthquakes. It presents a challenge to structural engineers that New Zealand's current building codes are not well aligned with societal expectations for the onset of damage and implications for building performance.

The relevance of these findings for the design of non-structural elements is clear – an expectation of a rapid return to function and full recovery with minimal disruption. This effectively means avoiding or limiting damage to minimal or minor effects in all but very large earthquakes, including and perhaps especially for all the non-structural elements.

These expectations align with observations of the economic impact of damage to non-structural elements in recent past earthquakes. Analyses of the losses due to the 1994 Northridge earthquake indicated that of the approximate US$6.3 billion of direct economic losses to non-residential buildings, only about US$1.1billion was due to structural damage [Kircher, 2003]. A similar study completed in 2004 suggested that losses associated with damage to non-structural elements and building contents represents 50% of the total costs of an earthquake in a developed country [Bachman, 2004].

The Canterbury Earthquakes Royal Commission [CERC, 2012] identified the need to improve the performance of non-structural elements in earthquakes (recommendation 70), and this research indicates a clear imperative to improve the seismic performance of non-structural elements. An associated challenge is determining how to meet these expectations for improved seismic performance while also meeting the expectation that building resilience can be improved without significantly increasing building costs.

5. LESSONS FOR NON-STRUCTURAL ELEMENTS IN THE DESIGN PROCESS

The performance of non-structural elements in earthquakes are dependent on a range of intersecting factors, from the location of the element within the building to the rigidity of the element itself and its response to shaking, allowances for its movement, and connection detailing.

Design considerations of the individual elements are not sufficient. The interconnectedness between non-structural elements and building functionality points to the need for building design to be a much more integrated process between different parts of the building and different design disciplines, including for example building services, fire, architecture, and structural design. The performance of suspended ceilings is influenced by in-ceiling services and above-ceiling services and vice versa as well as the structure itself [Chen et al, 2012]. Alarm systems are supported by the ceilings, egress route fire ratings are dependent on the integrity of the plasterboard walls lining the corridors and stairways [Ferner et al, 2016].

Work currently underway in New Zealand to codify the updated national seismic hazard model (NSHM) highlights the uncertainty of earthquake demands. Ground shaking at a site is unavoidably uncertain, so the consistent application of earthquake engineering design principles is essential. NZSEE has recently published guidance for structural engineers on earthquake design for uncertainty [NZSEE, 2022]. This advisory emphasizes that focusing on designing for specific code-defined specific hazard levels is not sufficient.

"Certainty of building performance is best achieved by scheming structures so that they behave in a controlled, predictable manner during earthquakes even when subjected to shaking that is more intense than anticipated. This means more reliable and less fragile buildings. This approach **manages the actual risk holistically**, *rather than just the hazard (loads) specifically."*

Designing non-structural elements to behave in a controlled and predictable manner during earthquakes, even when subjected to shaking that is more intense than anticipated, is important to meet societal expectations for buildings.

Reducing building drifts and avoiding torsional response through considered and careful design will reduce the likelihood of drift-induced damage to both the structure and non-structural elements. There is also a need for greater attention to the possible effects of accelerations in the design of non-structural elements and their fixings to limit possible impacts. Careful detailing that is demonstrably compatible with deformations such as drifts and second order effects such as geometric (or plastic) elongations is vital. Other options include designing out or relocating some non-structural elements to reduce the potential for damage. Questions designers should consider include: "Are the hung ceilings necessary, or is there another option?" and "Can the building services plant be located in a basement rather than on the roof while still managing other threats such as possible flooding?"

This interconnectedness of building elements for building seismic performance suggests a much more integrated design approach is required [Ferner and Baird, 2016]. Tradition dictates that non-structural elements and their bracing are designed after the building consent process for the main structure and by a designer employed by the subcontractor installing the element. Integrating consideration of the non-structural elements into the main design process for the building would focus all parties on achieving cost-effective performance outcomes that align with contemporary societal expectations of building performance in earthquakes.

6. CONCLUSIONS

The presented research on societal expectations of building performance in earthquakes reveals that New Zealand people want more resilient buildings and expect a rapid return to functionality in large earthquakes. They also expect no or minimal damage and no loss of functionality in moderate earthquakes. The performance of non-structural elements within a building is key to meeting these expectations.

Integrating the design of non-structural elements into the design process of the main structure would focus the design (and construction) team on the importance of the non-structural elements and would seem to point the way forward to better meet these societal expectations.

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