Expectations of Seismic Performance for the Lightweight Timber Residential Building Stock of Aotearoa New Zealand

Prepared by: Catalina Miranda*, Kieran Haymes, Charlotte Toma, Lauren Vinnell, Julia Becker

Joint Centre for Disaster Research, Canterbury University and the University of Auckland

*C.Miranda1@massey.ac.nz

December 2025

With funding support from

Acknowledgements

This research was supported by funding from the Natural Hazards Commission Toka Tū Ake and the QuakeCoRE Centre for Earthquake Resilience. We also acknowledge the contributions of the Joint Centre for Disaster Research at Massey University and our collaborating institutions, the University of Canterbury and the University of Auckland.

We extend our deepest gratitude to our late Distinguished Professor David Johnston, whose guidance and encouragement were instrumental in shaping the research approach. His support as this work evolved from a PhD project to postdoctoral research continues to inspire our efforts.

Executive Summary

Timber-framed houses typically meet life-safety philosophy behind building codes during earthquakes; however, recent events have highlighted significant non-structural and structural damage houses have suffered. This damage often leads to costly repairs, long disruptions, and stress for homeowners. Our research aimed to understand what people expect from their homes during earthquakes and whether these expectations align with what current building standards provide.

We surveyed 830 homeowners in Auckland, Christchurch, and Wellington and carried out structural assessments of typical houses. The results were clear: most homeowners expect their houses to perform better than the minimum life-safety standard. While many homeowners believe strengthening their house will help, few have taken action—often because of cost concerns, lack of clear guidance, or uncertainty about what to do.

The physical surveys revealed common vulnerabilities, such as unconnected foundations and heavy masonry chimneys, alongside examples of effective retrofits like chimney removal and reroofing. These findings highlight a gap between public expectations and current building codes. To close this gap, we recommend clearer communication about what building standards entail, along with practical guidance for voluntary strengthening, not just for homeowners, but also for builders and engineers. Moving beyond life safety toward resilience and functional recovery will help communities recover more quickly after earthquakes.

Abstract

This study investigates societal expectations of seismic performance for lightweight timber-framed residential buildings in Aotearoa New Zealand and examines how these expectations align with current engineering design objectives. While timber-framed houses typically meet life-safety standards during earthquakes, recent events have highlighted significant non-structural and structural damage, raising questions about whether life safety alone is an adequate performance goal. Using mixed-methods research, including surveys of 830 homeowners across Auckland, Christchurch, and Wellington, and structural assessments of typical housing stock, this work explores perceptions of damage, outcome expectancy, and barriers to implementation. Results show that homeowners consistently expect better performance than current code objectives, with strong preferences for reduced disruption and faster functional recovery. Outcome expectancy was positive across all cities, though influenced by prior earthquake experience and local hazard context. Physical surveys revealed common vulnerabilities such as unconnected foundations and heavy masonry chimneys, alongside retrofit practices like chimney removal and reroofing. Findings underscore a gap between public expectations and regulatory frameworks, suggesting the need for integrated strategies that combine engineering and social science perspectives. Recommendations include clearer communication of performance objectives, targeted risk reduction education, and policy mechanisms to incentivise voluntary strengthening, supporting a transition from life safety toward resilience and functional recovery.

Keywords

Resilient buildings, earthquakes, timber-framed houses, expectations, and homeowners.

Introduction

It has been observed in recent earthquakes in Organisation for Economic Cooperation and Development countries, including in the United States of America, Japan, and Aotearoa New Zealand, that timber-framed houses generally perform well during earthquakes to preserve life safety. This building type has been shown to sustain extensive damage in significant shaking, however, which has had wide-ranging consequences for community resilience and recovery (Blackbourn & Davey, 2017; Lew, 1989; Porter, 2002; Porter et al., 2002; Todd et al., 1994). Accordingly, questions around the use of life safety as the primary design limit state basis of timber houses have subsequently arisen, particularly following the social impact and growing public recognition of these considerations.

It is apparent that societal expectations of damage to the building stock of Aotearoa New Zealand should be considered when decisions are made about seismic design processes for buildings, including the likelihood and extent of damage (Jennings et al., 2015; Tanner et al., 2020; The Resilient Buildings Project, 2022).

The perceptions held by the people of Aotearoa New Zealand about the seismic performance of housing have not been systematically examined. Of particular interest is whether the current settings for different levels of seismic performance would meet the expectations of the public (e.g., at what frequency should we accept the onset of damage, loss of continued functionality and occupancy, and life safety hazards). Although there is significant research studying the seismic performance of timber-framed houses (Beattie, 2012; Cooney, 1979; Ventura et al., 2005), existing work could be supported by efforts to characterise societal expectations of damage to timber-framed houses and factors influencing such expectations. Considerations made for experience of seismic events and perceptions of risk may inform future performance objectives to frame the engineering analysis and design.

Wellington faces a high seismic risk compared to other areas of Aotearoa New Zealand, deriving from a combination of the potential for strong earthquakes (high seismic hazard) and vulnerability of housing to poor seismic performance (slope effects, aging housing stock, housing availability crisis, and more). This risk has made the region a critical case study for evaluating earthquake resilient communities, leading to some recent studies (Miranda et al., 2022; Miranda et al., 2021; Miranda, Toma, & Stephens, 2023; Miranda, Toma, Stephens, et al., 2023) which examined the perceptions of homeowners about damage in the Wellington Region. The applicability of the conclusions from that work to other areas in New Zealand acts as an important consideration for setting nationwide design approaches; however, acknowledging that other regions have different earthquake experiences, hazard exposure, vulnerability and risk perception.

The present study seeks to combine social and engineering sciences into multidisciplinary and innovative research that contributes to the growing body of knowledge about societal expectations of damage, feeding into the ongoing work on building resilient communities. This research looks to inform government authorities and nongovernmental organisations when decisions are made about the required performance objectives so they can accurately reflect community expectations of the housing.

Literature Review

Expectation of damage and experienced damage

Observations of damage after major earthquakes generally align with the design philosophy of international standards, which aims to avoid building collapse and protect the life of building users – *life safety*. From an engineering perspective, building strengthening should also align with current seismic standards (FEMA P50-1, 2012; FEMA P50, 2012; King, 1999; NZSEE, 2017). That is, buildings are designed to reduce the likelihood of fatalities. Structural safety can be achieved through building legislation, standards and codes that can apply to both new buildings, and the retrofit of earthquake-prone existing buildings by controlling damage and preventing collapse (Ghobarah, 2001; Tanner et al., 2020).

However, economic losses after major earthquake events have been significant. For instance, repairing and replacing damaged residential houses exceeded NZ$10 billion after the 22 February 2011 Christchurch, New Zealand earthquake (Thomas & Shelton, 2012). It is suggested then, that housing should not only be engineered for *life safety* but should also be of a standard where it is unlikely to require significant repairs, thus limiting losses and ensuring housing remains liveable and functional (Kirkham et al., 2014; Todd et al., 1994).

In New Zealand, the government enacted legislation in the Building Act (2004b) to reduce seismic damage from Earthquake Prone Buildings (EPBs). The legislation seeks to strengthen EPBs up to current seismic standards (New Building Standard – NBS). However, after the Mw7.8 2016 Kaikōura earthquake, judgements of the efficacy of strengthening EPBs and support for the legislation decreased, likely because several high-profile new buildings (which were out of the EPB policy scope as they were considered already up to standard) were damaged to the extent of being unusable while older buildings overall fared well (Vinnell et al., 2019). However, the newer buildings that failed did not lead to fatalities and therefore satisfied life safety as intended. This event may have altered public perceptions, suggesting that Wellington homeowners may not widely understand the focus on life safety of current standards.

People's beliefs about building performance were affected by the damage they saw. People who attribute earthquake damage to poor seismic design have been shown to believe that damage, while unavoidable, could be reduced substantially (Egbelakin et al., 2011; McClure et al., 2007). If they thought building damage was due to structural defects (that could be fixed) rather than the earthquake itself, it increased their outcome expectancy for strengthening. These findings support the suggestions above that if people see a new building damaged, it can negatively influence their belief that strengthening will lead to a positive outcome. It is also critical to have a consensus on the appropriate strengthening solutions. Egbelakin and Wilkinson (2010) observed that disparities among consultant engineers when proposing strengthening solutions aggravated the mistrust in proposed strengthening and professionals.

As highlighted in the examples above, having prior earthquake experience can motivate preparation for future events by seeing the benefit of strengthening, but it also can act as an inhibitor. By disclosing the causes of observed damage, current seismic vulnerability of existing buildings, and clear objectives of building strengthening, seismic hazard education can be enabled (McClure et al., 2007) resulting in positive perceptions towards building strengthening. Providing information on potential outcomes of building performance during earthquakes can play a crucial role, especially when there is a lack of earthquake experience (Becker et al., 2017). Understanding what to expect in major earthquake events and what can be done to strengthen properties can motivate preparedness. In other words, a positive outcome expectancy about strengthening buildings can promote adopting strengthening mitigations (Egbelakin et al., 2011).

Research has highlighted that homeowners' expectations of the performance of their house in earthquakes, often differ from the actual damage experienced in real earthquakes, affecting people's motivation to retrofit or employ resilient designs. Miranda et al. (2022) found a lack of relationship between prior experience and expectation of damage, where participants expected more damage to their houses in a future major earthquake than they had experienced. The last earthquake experienced by most participants was the Kaikōura Earthquake (2016), which resulted in no to minimal damage to residential houses in Wellington (Kaiser et al., 2017) and could have increased optimism bias, where participants thought a future event might produce similar benign effects and did not see a benefit from strengthening their houses (i.e., a lack of positive outcome expectancy), or normalisation bias, where participants felt that the last earthquake was not too damaging resulting in beliefs of not needing to strengthen their house (Celsi et al., 2005; Spittal et al., 2005).

Becker et al. (2018) analysed surveys intended to understand people's experiences of the earthquake, including the immediate impacts, the need for evacuation, alternative accommodation arrangements, service disruption, and preparedness behaviour. Although most participants evacuated their buildings after the 2016 Kaikōura earthquake because of experiencing a 'long or strong' earthquake which implied the possibility of a tsunami, some participants evacuated after observing structural and non-structural damage to apartment buildings and were concerned about their safety during aftershocks.

Decisions about performance goals

In general, levels of seismic performance have been developed and widely accepted based on engineering terms such as the maximum displacement between stories of the building (i.e., drift), where immediate occupancy would consider a maximum drift of 1%, major damage or life safety 3%, and severe damage or collapse higher than 7% – for timber-framed buildings. Historically, engineering studies have defined the limits of seismic performance and building codes have been developed using those limits and with a baseline of *life-safety* as the performance objective. However, an adequate implementation and compliance with the building code requirements help to address most societal, development sustainability and resilience issues within the built environment (May, 2001). A building can meet life-safety standards yet still suffer substantial damage, from almost none to moderate or even extensive. Meanwhile, the step from life-safety damage to collapse can be surprisingly small (Priestly, 2000).

Questions about whether the life safety objectives used in codes worldwide are adequate or appropriate have arisen (Porter, 2021; Tanner et al., 2020); and some other studies have also mentioned the need to include societal demands in building codes as a factor that might contribute to the design of stronger buildings. While some studies have agreed that a resilient building might be one meeting immediate occupancy level, which would also satisfy societal expectations of damage (Filiatrault et al., 2006; Filiatrault & Folz, 2002; Ghobarah, 2001; Loss et al., 2018), those societal expectations of damage have not been systematically measured showing a clear disconnection between the social and engineering aspects of earthquake preparedness.

In an effort to provide solutions to the unintended consequences surrounding the use of performance-based building code, the MBIE started making changes to the building code on a bi-annual basis in 2018 to keep the building code up to the societal expectations and latest developments with clarity and consistency (MBIE, 2018b). Building code amendment helps the regulators proactively respond to the needs of the building sectors, society, and manufacturers while creating an enabling environment for the building professionals to deliver better buildings. Accordingly, recent changes in the building code make compliance much easier with better building code compliance pathways (MBIE, 2019i). However, improving the building code requires identifying the areas of deficiencies within the building code, standards and compliance documents. During the consultation, contributions from building code users should be backed with substantial evidence to prove noticeable deficiencies in the existing building code. The evidence-based approach helps the building code regulators assess the identified area of deficiencies and ascertain how to improve the building code that is practicable for better building performance and quality.

On the other hand, Sharpe (1992) identified that acceptable earthquake damage depends on the different seismic zones and that the location would define different performance criteria. May (2001) and in a context of risk perception, argues that risk perceptions might vary if it is analysed, for example, considering an individual and a collective group or private and public groups. At issue from a societal perspective is whether there is a collective desire to impose minimum standards beyond those of life safety. Similarly, Becker et al. (2018) found that expectations of damage during aftershocks or after the 2016 Kaikōura earthquake varied depending on the ownership, where renters felt less safe and evacuated apartment buildings than owners who claimed to know their apartment buildings. Consequently, expectations of damage must be carefully analysed to come up with measures that can improve the building code while balancing the diversity in the stakeholders' interests.

Using the performance-based earthquake engineering designs, owners might be able to make their own decisions about the performance goals (May, 2001). However, they might not understand the design and performance implications behind the philosophy of the building codes or might not understand what is available to build resilient houses (Porter, 2021).

Functional recovery, loss reduction and life safety

Given the wide-reaching impacts from past earthquakes, there appears to be an appetite for higher performance objectives in building codes, with researchers (Horspool et al., 2021; Porter, 2021; Tanner et al., 2020) trying to answer whether future updates of codes should include functional recovery in addition to life safety. The term ‘functional recovery’ means that buildings are designed and constructed not only for life safety but also to support the basic intended functions of the building’s pre-earthquake use and occupancy within a maximum acceptable time period (NEHRP, 2020; P-2090). The terms ‘acceptable level’ of damage and time, however, have not been systematically examined in a New Zealand context. Although the NZS 1170.5:2004 does specify that structures with a critical post-earthquake designation (i.e., Importance Level 4) are to be maintained operational or returned to a fully operational state within an acceptable short timeframe (usually minutes to hours rather than days).

Homeowners of dwellings in Wellington, Aotearoa New Zealand (a high-risk earthquake area with experience of previous earthquakes) expect better seismic performance of their house after voluntarily undertaking structural strengthening. Also, regardless of the use of strengthening, homeowners expect better seismic performance of their house than what is targeted by current seismic codes (Miranda et al., 2022). Wellington homeowners' expectations may differ from those living in lower risk areas with less earthquake experience.

After conducting a survey, Abeling et al. (2023b) found that participants' expectations of damage to buildings and building performance are more demanding than what the current seismic standards ensure – life safety. Although participants expect to see damage to non-structural elements in a weak to moderate earthquake and damage to structural elements in a moderate to severe earthquake, they expect to be back to full functionality within weeks and months which, for example, won't be possible if the building must be demolished and re-built – which would align with the life safety philosophy. Participants, however, seem to understand that different levels of shaking would cause different damage. On average, participants expect a building to be fully functional after a weak earthquake immediately or within days, after a moderate earthquake within days or weeks, and after a severe earthquake within weeks and months. Almost no participants expected aspects of the built environment or other buildings to be fully recovered after years, indicating that they expect many people's recovery times to be short, in opposition to what we have seen in past earthquakes, where decades of recovery have ensued.

The Legislative and Industrial Context of Engineering Practice for Residential Buildings in Aotearoa New Zealand

In New Zealand, the government enacted legislation in the Building Act (2004b) to reduce seismic damage from earthquake-prone buildings (EPBs). The legislation uses %NBS (New Building Standard) to characterise the expected seismic response of a building. The %NBS intends to identify buildings with a higher seismic risk compared to a similar new building, which is designed using Building Code standards. The %NBS is obtained through structural assessment and since many variables are considered, there can be some level of uncertainty in predicting the relative risk for a building. The uncertainty does not solely comes from the structure itself but also arises from the almost unpredictable nature of earthquakes, the complex response of buildings, and the construction quality (MBIE, 2022). Although this legislation seeks to reduce seismic damage to building by bringing them up to code (i.e., retrofitting), MBIE (2022) acknowledges that the risk to life – even for those buildings identified as vulnerable – is relatively low for most buildings because the chances of a significant earthquake happening in a specific area in the near future are minimal.

In 2020, the Seismic Risk Working Group (SRWG) identified gaps and inconsistencies in the building seismic performance regime and raised important questions on how objectives and priorities are set. The SRWG recommended reviewing current Building Code clauses (including consideration of seismic risk settings) to ensure they articulate societal expectations and are reflected in the Building Act (MBIE, 2022). At that point, there was no research in New Zealand on how to include societal expectations of damage in future Building Code updates nor what they are. Hence, questions have been raised with regards to: (1) whether the Building Code should be extended to consider recovery of functions in buildings after an earthquake; (2) whether key terms like low probability, amenity values, etc. should be clearly defined and clarified in guidance; (3) how gaps in the current regime should be addressed, including whether the design of future buildings should consider the impacts relating to adjacent buildings, and how to mitigate legacy issues for existing buildings such as precast concrete flooring systems and their supports; and (4) who decides what is prioritised and how these priorities should be expressed in a design sense. Currently, technical standards committees make critical value judgements about the importance levels of different types of buildings – by privileging schools but not marae (tribal community centre) or aged care homes, for example (The Resilient Buildings Project, 2022).

Considerations for Decision Making in Building Codes and Regulations when Including Public Expectations

The main challenge of including public expectations in Building Codes or regulations is the integration of engineering and social science disciplines (Tanner et al., 2020). Historically, Building Codes have been developed by technical experts and people's opinions might be included through public comments processes which have not considered the code objectives themselves. However, if including societal expectations of damage to buildings in future updates of Building Codes, we are attempting to address a social need in an engineering context. Making changes to well-established regulatory processes is difficult and the right parties must be involved.

To add complexity to the issue – understanding societal perspectives of seismic risk and people's desires is complex since (1) society is formed by groups of people with different interests, risk interpretation, experience, locations, and ownership, and (2) what an individual thinks doesn't necessarily directly translate into a collective perception. Earthquake damage to individual facilities can also have consequences that accrue beyond the individual, for instance, damage coming from surrounding buildings or damage to infrastructure (May, 2001). Similar, Buildings Codes are developed to govern the performance of individual buildings without consideration of the aggregated damage coming from the broader community (Tanner et al., 2020). May (2001) also indicates that perceptions of seismic risk might vary from a public or a private perspective. More recently, Payne et al. (2021) found that expectations of building performance vary for buildings located in large cities versus rural towns, which was attributed to less risk in rural areas in terms of population and cost.

Studies in New Zealand and overseas have shown that people generally do not understand the philosophy behind the Building Codes – life safety (Blake et al., 2021; Payne et al., 2021; Porter, 2021). The complexity of understanding engineering procedures has led to false expectations of damage to buildings (Blake et al., 2021). For example, even though the government has tried to emphasise that %NBS should be viewed as indicative of the engineer's confidence in the expected seismic performance of the building rather than an exact prediction (MBIE, 2022), users of buildings usually make decisions about building safety (e.g. stay, go, retrofit, etc) based primarily on the %NBS (Blake et al., 2021), rather than taking into consideration the wider context of seismic performance.

Understanding building safety or current minimum standards might also be a privilege and not understood by everyone. Blake et al. (2021) found that although people living in Wellington, New Zealand, might be informed about building risk, decisions of where to live depend on the connection between knowledge and financial capital. There is also a question of how government should be in safeguarding citizens who do not seem to be concerned about the risks. The low probably of occurrence of those events, along with the influences of technical experts in shaping how we response to risk, raises questions about the influence of experts on policy decisions. This, in turn, prompts questions on how different strategies aim to achieve risk mitigation in various sectors of our society (May, 2001).

Generally, people often likely undertake seismic strengthening with the expectation that the strengthening will meet a certain level of performance, which might not be achieved because current strengthening solutions might just aim to meet life safety standards — confirming once again that the public does not understand the philosophy behind the design of our buildings (Miranda et al., 2022; Porter, 2021). Going through the process of building strengthening helps to enhance seismic risk awareness (Miranda et al., 2021). However, when building owners are asked to strengthen buildings to comply with the EPB policy, building owners are put under financial and psychological hardship (Blake et al., 2021).

The conversation on building performance is also not just about life safety or the structural integrity of an individual building, but about serviceability or functionality of the broader community. Tanner et al. (2020) suggests that people not only might expect their building to performance beyond life-safety, but they also expect seismic safety terms of community functionality. Thus, complexity to understand and unpack expectations of damage must include serviceability or functionality as new and different variables in individual and community contexts. Similarly, research has shown that although life-safety is the base line for seismic design, functional recovery and recovery time contribute to public demands, which will vary depending on earthquake intensity, the type of building, and type of service (Abeling et al., 2023a; Payne et al., 2021).

Engineering Considerations and Public Perceptions for Lightweight Timber Residential Buildings

The most used design criteria internationally is the LRFD (Load Resistance Factor Design) which compares the design loads with a computed capacity to check individual members, components, and connections. Limiting this approach to the preservation of life (i.e., life safety) may not be sufficient for building systems to perform in accordance with the expectations of users (Rosowsky & Ellingwood, 2002). Indeed, observations from recent earthquakes have shown life safety is consistently met by the lightweight timber frame buildings that comprise most of the New Zealand's housing stock (Buchanan et al., 2011), but the limited interstorey drift capacity of gypsum walls often results in extensive damage to both structural and non-structural elements that span between levels including cladding, partition walls and glazing. Shake table testing conducted at the University of Canterbury by Francis et al. (2023) confirmed other findings that low intensity motions induced damage. Beyond life safety considerations, the seismic performance of housing desired by the owners and occupiers can exceed the checks that can be done using design standards often used in practice, such as the bracing unit system based on life safety checks in NZS3604 (Standards New Zealand, 2011).

Performance-Based Earthquake Engineering (PBEE) may offer an alternative approach (Krawinkler, 2000; Rosowsky & Ellingwood, 2002). The PBEE seeks to achieve reasonable agreement within the inherent limitations imposed by statistical sampling used by the LRFD between calculated and observed structural failure rates, so as to be able to use such estimates as a basis for building regulation. Properly validated system reliability analysis models are essential (Rosowsky & Ellingwood, 2002). The PBEE methodology proposes performance goals such as serviceability, immediate occupancy, life safety and collapse prevention, which are expressed in terms of structural responses such as interstorey drift, which have been correlated with damage. In engineering parlance, those goals can be translated to limit states which can vary depending on the structural system (i.e., concrete framed structures, light timber framed houses, hybrid buildings, etc.). Another variable that has been included in performance-based engineering is building occupancy, where performance requirements vary depending on the building use. These considerations may go towards achieving the shelter-in-place objectives often held by Civil Defence run by territorial authorities.

Similar to the PBEE, the Consequence-based engineering (CBE) was developed to integrate a sociotechnical systems perspective rather than an individual structure perspective used by the PBEE (Abrams, 2002). However, the CBE relies on the assumption that acceptable consequences are well-defined prior to the design. Using the CBE methodology, Bostrom et al. (2006) proposed that it might be better to show decision-makers the benefits of innovative earthquake mitigation measures and allow them to examine the effects of uncertainties, trade-offs and different decision structures. Although both PBEE and CBE intend to extend performance objectives of building structures from life-safety to other attributes such as serviceability and durability, expectations are influenced by the level of shaking and those attributes have not been considered in both philosophies and expectations of damage have not been systematically measured.

Another term that has been used in recent years by engineers and policymakers is functional recovery, which aims to achieve a seismic performance beyond life-safety. Functional recovery is the performance state of a building, in which it sustains and recovers its capacity to perform as intended (FEMA, 2021). Hence, procedures to design new buildings have been developed considering post-earthquake recovery times depending on the building’s risk category. In general, the methodologies use fragility functions to predict damage states based on story drift ratio or floor acceleration, translate these damage states into various performance metrics, such as casualties, repair costs, repair times, delays between the occurrence of an earthquake and the start of repairs; and define post-earthquake functionality levels (i.e., desired recovery states) such as stability (i.e., building’s structure and façade are stable enough and there is no need for a safety cordon), shelter-in-place (i.e., allow people to stay at home, even if damaged, as long there is no life-safety risk), reoccupancy (i.e., safe enough to occupy), functional recovery (i.e., building functionality is restored), and full recovery (i.e., restored to pre-earthquake condition) (Almufti & Willford, 2013; Costa et al., 2021; FEMA P-58-1, 2018; Mieler & Mitrani-Reiser, 2017; Molina Hutt et al., 2022). To account for the various uncertainties within the downtime estimation procedure, methodologies have used Monte Carlo simulations, which is a model used to predict the probability of a variety of downtimes (i.e., outcomes) when the potential for random variables is present (i.e., performance metrics).

Although these methodologies have become more common in some regions in the last two decades, it must be emphasised that most of them consider physical science parameters to define desired functionality levels, and they do not consider people perceptions about whether building is ready to be reoccupied, whether the building is restored to its pre-earthquake condition, and whether people want to re-occupy that damaged building.

Relevant Studies Conducted in Aotearoa New Zealand

This section summarises key findings from three studies carried out in Aotearoa New Zealand. The first two studies employed qualitative social science research, while the third study combined social–quantitative questionnaire analysis with engineering predictions of damage.

Societal Expectations for Seismic Performance of Buildings

To answer the questions of the SRWG, the New Zealand Society in Earthquake Engineering (NZSEE) started the Resilient Buildings Project (New Zealand Society for Earthquake Engineering and Natural Hazard Commission Toka Tū Ake, 2022; Payne et al., 2021). They conducted 32 interviews and six geographically based focus groups and participants were identified as leaders in resilience issues associated with New Zealand's recent seismic events. Results from this indicate the following:

- Life safety: Participants consider life-safety as a minimum requirement and that new buildings should perform beyond life-safety.
- Different event scenarios: Participants indicated that different outcomes are expected, but all participants agreed that buildings should be operable following small frequent earthquakes, and life-safety remains a minimum requirement during stronger earthquakes.
- Different buildings: As per the current Building Code, participants agreed that buildings that have a post-earthquake function are important and this should be extended to buildings not already covered in the Code such as supermarkets and food production facilities, as well as buildings that can support recovery (e.g., schools, community centres, housing for vulnerable people, etc.).
- Acceptable risks: Considering an event that could occur several times during the life of a building, participants expect to continue as usual and accept minor and cosmetic damage.
- Recovery time: Although going back to 'normal' was different for participants, they had a most common desire of going back to normal in 3-6 months. Also, having confidence in recovery times frames was important particularly for those who experienced the 2010-11 Canterbury earthquakes.
- Ownership: Participants showed more interest and gave more importance to buildings they used or owned.
- Individual versus collective: Responses of expectations varied depending on the data collected, where one-to-one interviews responses differed from focus groups.

- Location: This study concluded that communities with lower tolerance for risk are in low-hazard zones and that communities with higher tolerance for risk are in high-hazard zones.

Public expectations of damage and disruption to existing multi-storey buildings in earthquakes

To better understand public expectations of damage and performance, an online quantitative survey collected data from users of existing multi-story buildings in Aotearoa New Zealand (Abeling et al., 2023a). Participants were asked to indicate what level of shaking they would expect could cause damage to a building they were familiar with. Three levels of shaking were described using the New Zealand Modified Mercalli Intensity (MMI) Scale, with a weak earthquake defined as MMI 3-4, a moderate earthquake defined as MMI 5-7, and severe earthquake defined as MMI 7+. Levels of shaking were considered as (1) weak, (2) moderate and (3) severe earthquake. Table 1 summaries the findings and shows that participants who expected to observe damage due to liquefaction and structural damage thought it could first occur between a moderate and severe earthquake. Participants expected to see damage to non-structural elements in a moderate earthquake and no damage in a weak earthquake.

Table 1 Summary of expected damage by (Abeling et al., 2023b)

Type of damage	N	Mean	SD
Liquefaction	63	2.76	0.49
Structural damage to 'Building A'	108	2.74	0.48
Damage to plumbing and electrical facilities	111	2.54	0.59
Non-structural damage (e.g., cracked GIB board, ceiling tiles falling, etc.)	114	1.97	0.55
No Damage	89	1.05	0.27

Participants were asked what level of functionality they would expect from different aspects of the built environment following a weak, moderate, and severe earthquake. The levels of functionally were defined as (1) remain fully functional, (2) remain partially functional, and (3) not expect any functionality. Table 2 summaries the findings and shows that following a weak earthquake, most participants expected the described aspects of the built environment to remain fully functional. Following a moderate earthquake, participants expected the same level of functionality of internal services and essential infrastructure. Following a severe earthquake, responses indicated that all aspects of the built environment are expected to have similar levels of functionality, between partially functional and non-functional.

Participants were asked what time period they believed was acceptable for the repair of internal services, external utilities, essential infrastructure, and other buildings to their original functional condition following a weak, moderate, and severe earthquake. The recovery times were assessed considering a scale from one to five: immediately (1), days (2), weeks (3), months (4) and years (5). Table 3 summarises the findings and shows that after a weak earthquake all aspects of the built environment were expected to be back to what they were before the shaking from immediately through to days. Following a moderate earthquake, expectations of recovery were more closely aligned with weeks, and following a severe earthquake, recovery expectations were more closely aligned with months (rather than years).

Table 2 Summary of functionality expectations by (Abeling et al., 2023b)

Aspects of the built environment	MMI 3-4		MMI 5-7		MMI 7+	
	Mean	SD	Mean	SD	Mean	SD
Internal services	1.28	.67	1.71	.54	2.44	.54
External utilities	1.10	.38	1.57	.56	2.39	.57
Essential infrastructure	1.13	.44	1.65	.53	2.33	.54
Other buildings	1.13	.40	1.86	.41	2.37	.52

Table 3 Summary of recovery time expectations considering the three scenarios by (Abeling et al., 2023b)

Aspects of the built environment	MMI 3-4		MMI 5-7		MMI 7+	
	Mean	SD	Mean	SD	Mean	SD
Internal services	1.58	.77	2.32	.84	3.52	.90
External utilities	1.44	.60	2.12	.75	3.27	.79
Essential infrastructure	1.40	.57	2.26	.87	3.46	.95
Other buildings	1.68	.85	2.74	.92	3.92	.81

Homeowners' Perceptions of Seismic Building Performance and Implications for Preparedness in Wellington, New Zealand

A questionnaire answered by owner-occupiers of wooden-framed houses was undertaken and analysed by Miranda et al. (2021, 2022), and some of results are presented herein. In the questionnaire, owner-occupiers were asked about expectations of damage to their house during a future hypothetical MM8 earthquake (described as involving difficulty standing, general alarm causing panic, and the whole city feeling the shaking). Owner-occupiers were given six levels of damage, which were described as shown in Table 4. The sample was grouped and analysed considering whether owner-occupiers stated that they have used – or not – retrofitting techniques to prepare their house for a future earthquake.

Consequently, owner-occupiers who had used retrofitting techniques were asked to pick a level of damage they thought would have happened to their house before using retrofitting techniques and a damage level that they would expect after using retrofitting techniques. Similarly, owner-occupiers that stated they had not used retrofitting techniques were asked to imagine that that they had retrofitted their house, and then were asked the same questions (i.e., with and without retrofitting techniques). On average, (Miranda et al., 2022) found that both groups expected the damage to be between moderate and minor before/without retrofitting solutions and to be between minor and minimal damage after/with retrofitting solutions. However, a statistical t-test showed that owner-occupiers who had used retrofitting solutions were more positive about the benefits of retrofitting than those who had not used them.

Miranda, Toma, Stephens, et al. (2023) equated and aligned expected levels of damage to owner-occupiers' house and response measures from numerical simulation of wooden-framed houses located on slopes. Where 1% drift was considered as minor damage and 3% drift as moderate and above damage. Miranda, Toma and Stephens (2023) identified and defined a typology of wooden-framed houses located on slopes and based on dominant characteristics a case study was selected, modelled and analysed. The case study was analysed considering different dimensions of the house and subjected multiple ground motion suites that were selected to represent a range of hazards in Wellington using OpenSeesPy. A summary of the results is presented in Figure 1.

Numerical models provided data to estimate the probability of exceedance for 1% and 3% drift for earthquakes at 500 years return period intensity, which aligns with the earthquake descriptions given to owner-occupiers. Table 4 shows a summary of the fragility functions developed by Miranda, Toma, Stephens, et al. (2023), where the probability of exceeding minor and moderate damage was calculated as the average drift considering all three locations where drift was measured – see Miranda, Toma, Stephens, et al. (2023)'s work for further details. Considering a 500-year return period earthquake, Miranda, Toma, Stephens, et al. (2023) found that the probability of exceeding minor damage is 94% for retrofitted houses and 86% for retrofitted houses, while the probability of exceeding moderate damage is 38% for retrofitted houses and 26% for retrofitted houses.

Figure 2 summaries the findings of Miranda et al. (2023b) where 86 out of 100 retrofitted houses might exceed minor damage and 89 out of 100 owner-occupiers who had used retrofitting techniques expected minor or less damage. Figure 2(a) shows 100 houses, where the red houses are going to exceed minor damage and the green houses won't, while Figure 2(b) shows 100 homeowners, where the red homeowners expect to exceed minor damage and the green homeowners expect not to exceed minor damage. When both Figures overlapped in Figure 2(c), the common area represent the intersection of houses' (i.e., numerical simulations) and homeowners' expectations of damage, where the intersection area matches expectation of damage by homeowners and numerical simulations regardless of whether it exceeds or not minor damage. In this case, the common area includes 11 houses and homeowners which expectations match with exceeding minor damage, and 14 homeowners and houses which expectations match on not exceeding minor damage. Outside the common area, 86 homeowners and houses won't meet their expectations.

Gaps in research

Past work has shown that retrofitting current housing and incorporating earthquake-resilient design into new housing remains patchy and depends on aspects such as previous experience, perceived benefits, and sources of information. Although several factors can influence the decision-making process of building strengthening, two have been identified as critical factors influencing the final implementation of building strengthening: expectations of damage following an event (i.e., outcome expectancy).

Research has highlighted that homeowners' expectations of the performance of their house in earthquakes often differ from the actual damage that is experienced in real earthquakes, affecting people's motivation to retrofit or employ resilient designs. A better understanding of expectations, perceptions of voluntary earthquake strengthening, and mechanisms that might support this (e.g., sources of information, public education, codes, standards, and policies) is required to reduce damage when earthquakes occur. While some work has been done to understand building performance expectations from an agency or stakeholder context, there is still a gap in understanding broader homeowner expectations and what this means for retrofitting.

Procedure

Ten thousand flyers were distributed in Auckland and Christchurch during January and February 2025. The flyers included a QR code linked to the online questionnaire. Flyers were delivered exclusively to low-rise wooden-framed houses because these houses are generally out of the scope of the Building Act (2004a) provisions related to building strengthening; voluntary structural strengthening is needed; and the type of voluntary strengthening techniques that homeowners might be able to use can be found in local and international guidance (EQC, 2020; FEMA P50, 2012).

By April 2025, 159 successfully completed questionnaires were received back in Auckland and 179 in Christchurch. By June 2025, data collection on the structural features of houses was concluded. The information was entered into the Statistical Package for the Social Sciences (SPSS) software for analyses such as *t*-tests and chi-square tests. To analyse differences in the data, paired-sample t-tests were used to compare homeowners' expectations of damage before and after strengthening (or with and without strengthening) within the same group, while independent-sample t-tests assessed differences between separate groups, such as participants from different cities. These tests determine whether observed differences in mean scores are statistically significant. In addition, chi-square tests were applied to examine relationships between categorical variables, such as location and awareness or use of seismic strengthening. This test assesses whether the distribution of responses deviates from what would be expected by chance, suggesting an association between variables.

The sample was analysed separately, considering the two cities, and compared against prior data collected in Wellington. This project was evaluated by peer review and was considered low-risk. Consequently, it was not reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are thus responsible for the ethical conduct of this research (Low Risk Ethics Notification Number: 4000029915).

Table 4 Levels of damage and percentage of owner-occupiers selecting them

		Percentage of owner-occupiers' who have used retrofitting techniques		Percentage of owner-occupiers' who have not used retrofitting techniques	
Damage	**Description**	**Before**	**After**	**With**	**Without**
Undamaged (1)	No damage at all	5	16	2	12
Minimal (2)	Internal hair-line cracks in wall, which can be solved by painting over	19	43	16	42
Minor (3)	Cladding or stucco fell, or some windows broken	18	30	35	35
Moderate (4)	Some walls replaced or fixed up. The chimney fell. Cracks in floor or damage to foundations.	49	11	42	10
Major (5)	The houses would not collapse but it would be inhabitable.	9	0	5	1
Extreme (6)	Total Collapse	0	0	0	0

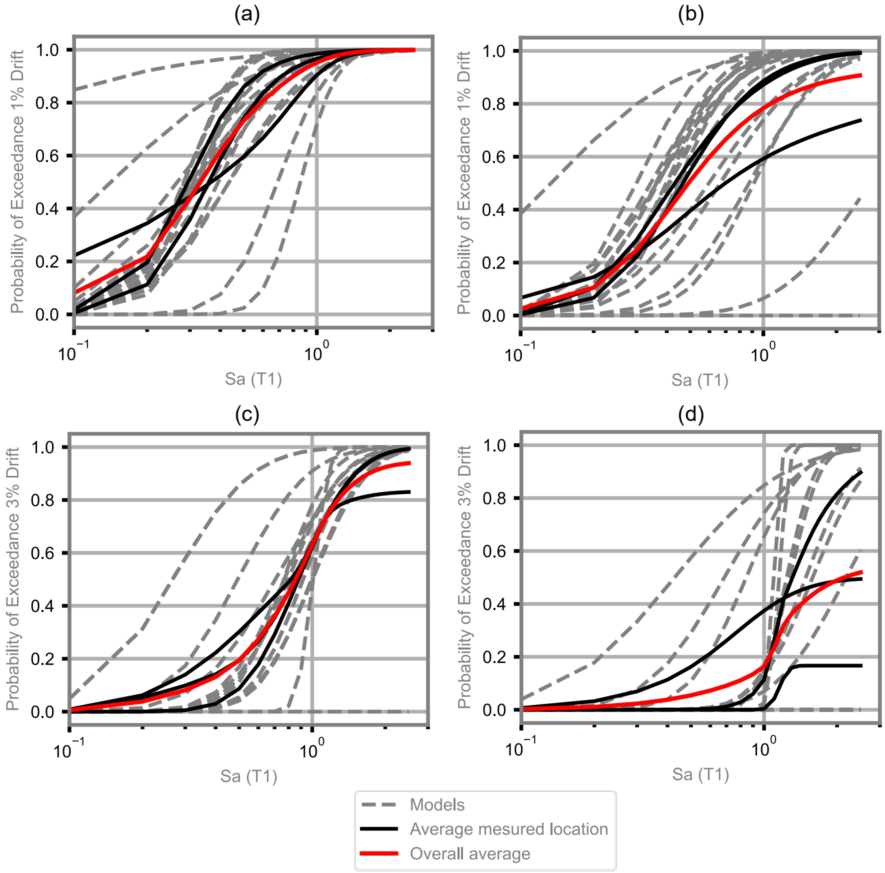

Figure 1 Summary of the fragility functions developed by Miranda et al. (2023b) where (a) probability of exceeding 1% drift of non-retrofitted models, (b) probability of exceeding 1% drift of retrofitted models, (c) probability of exceeding 3% drift of non-retrofitted models, and (d) probability of exceeding 3% drift of retrofitted models.

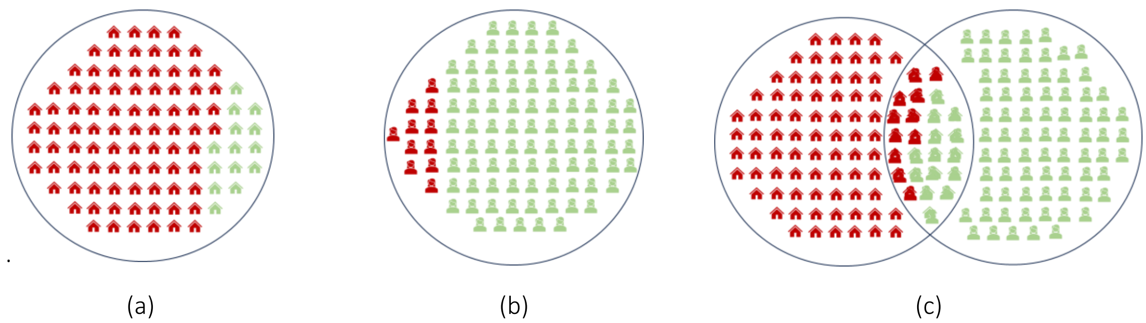

Figure 2 Summary the findings of Miranda et al. (2023b). (a) 100 retrofitted houses, where red exceed minor damage and greens do not, (b) 100 homeowners, where red expect more than minor damage and greens do not, and (c) intersection of expectations of minor damage

Figure 3 Summary the findings of Miranda et al. (2023b). (a) 100 retrofitted houses, where red exceed major damage and greens do not, (b) 100 homeowners (green) that do not expect to exceed major damage, (c) intersection of expectations of major damage.

Instruments

The questionnaire was divided into four main sections. In the first section, participants provided information about ownership (e.g., owner-occupier or renter), year of construction, materiality, etc. In section two, participants reported their personal experience of earthquakes and earthquake damage. In the four sections, participants reported whether and which strengthening techniques they had implemented, expectations of future damage, perceptions of safety, and trust in information sources. Final questions of the questionnaire asked participants to participate in a follow-up structural survey.

This structural survey aimed to collect data on the typical features of houses in Auckland and Christchurch. For example, plan shapes, type of foundations, typically used strengthening, if any, and roof, walls, and foundation materials.

In order to capture perceptions of damage to houses during earthquakes, and compare results with existing Wellington data, the questionnaire used response items for questions about observation of damage used in the Wellington 2020 study. Levels of damage were defined based on the intensity levels of the New Zealand Modified Mercalli Intensity scale (MMI). MMI is well-known as one of the most suitable approaches for measuring the intensity of earthquakes, as it considers people's perceptions of shaking and visual damage (Dowrick et al., 2008). For this questionnaire, the 11 intensity levels given by the MMI were grouped into six levels of damage (see Table 5).

The Wellington study considered a strong earthquake as a scenario, while the questionnaire conducted in Auckland and Christchurch used two scenarios, strong and medium. This will allow further analysis on perceptions of the level of shaking and damage. The strong earthquake was defined as: intensity shaking where alarm may approach panic. You will have difficulty standing, and the whole town will be able to feel the shaking. The medium earthquake was defined as: intensity shaking. Felt by all. People and animals are alarmed, and many run outside. Walking steadily is difficult. Furniture and appliances may move on smooth surfaces, and objects fall from walls and shelves.

Table 5 Questionnaire levels of damage

Undamaged	Minimal	Minor	Moderate	Major	Extreme
	Internal air-line cracks in walls, which would have been solved by painting over	Cladding or stucco fell, or some windows were broken	Some walls were replaced or fixed up. The chimney fell. Cracks in floors or damage to foundations	The house didn't collapse, but it was uninhabitable afterwards	Total collapse

Results

Results across the three cities will be presented by groups based on their use and awareness of seismic strengthening, as indicated in Figure 4. Homeowners who reported being aware of strengthening techniques were identified as AP, while those who were not aware of strengthening possibilities were identified as UUP. Among AP, those who had applied some to their house as PP, while those who have not implemented any strengthening as AUP. Hence, AUP and UUP will make a bigger group of unprepared participants (UP). Additionally, 'before' and 'after' refer to expectations of damage from homeowners who have implemented strengthening (Prepared Participants). 'With' and 'without' refer to imagined expectations from homeowners who have not implemented strengthening (Aware Unprepared and Unaware Unprepared Participants).

Auckland Sample

159 participants completed the questionnaire, of whom 113 indicated their gender. Out of the ones answering the gender question, 44% (N=50) identified as female or women, and 56% (N=63) as male.

Four were under 30 years old, 14 aged 30–39 years, nine aged 40–49 years, 30 aged 50–59 years, 30 aged 60–69 years, 22 aged 70–79 years, three aged 80–89 years, and one over 90 years, (n = 113, SD = 14.82, min = 18, max = 90).

Participants were asked about the primary material their house was made of (not considering the foundations or subfloors, such as timber or concrete piles). Six options were given: (1) timber-framed, (2) concrete, (3) mixed timber and concrete (4) Mixed timber and concrete (e.g., ground floor concrete and first floor timber), (5) Mixed timber and masonry (e.g., ground floor masonry and first floor timber), and (6) Steel (e.g., cold-formed steel). Most of the participants indicated timber-framed, N=105 (66%), followed by mixed timber and masonry, mixed timber and concrete, and concrete and masonry, with percentages of 5.7% (N=9), 5.0% (N=8), 1.9% (N=3), and 1.3% (N=2), respectively.

Participants indicated the number of storeys (it was mentioned not to include the subfloor/foundation/basement). 46.5% (N=74) indicated that their house has one story, 30.8% (N=49) two storeys, and 2.5%(N=4) three storeys.

One hundred and twenty-two participants indicated the year of construction of their houses. On average, houses were built in 1938 (SD = 33.56), the oldest in 1900 and the newest in 2020. The number of houses per year is shown in Figure 5.

Participants were asked whether they were homeowners or tenants. 71.7% (N=114) indicated they were homeowners, while 5.7% (N=9) indicated they were tenants. From now on, the results will include just homeowners as the Wellington data only considered homeowners.

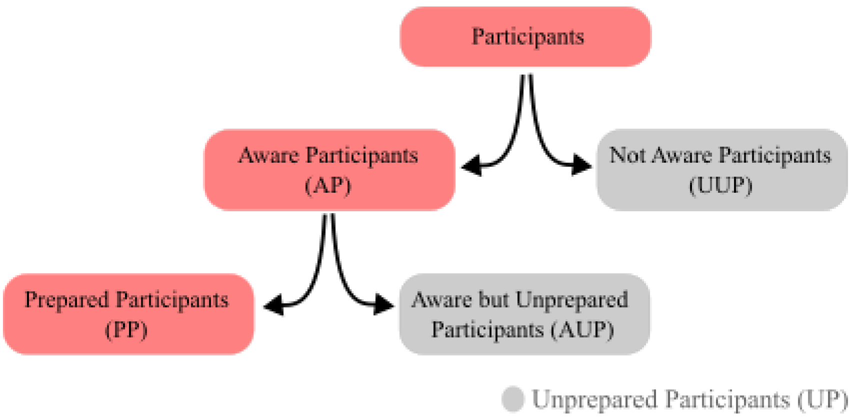

Figure 4 Participants' groups

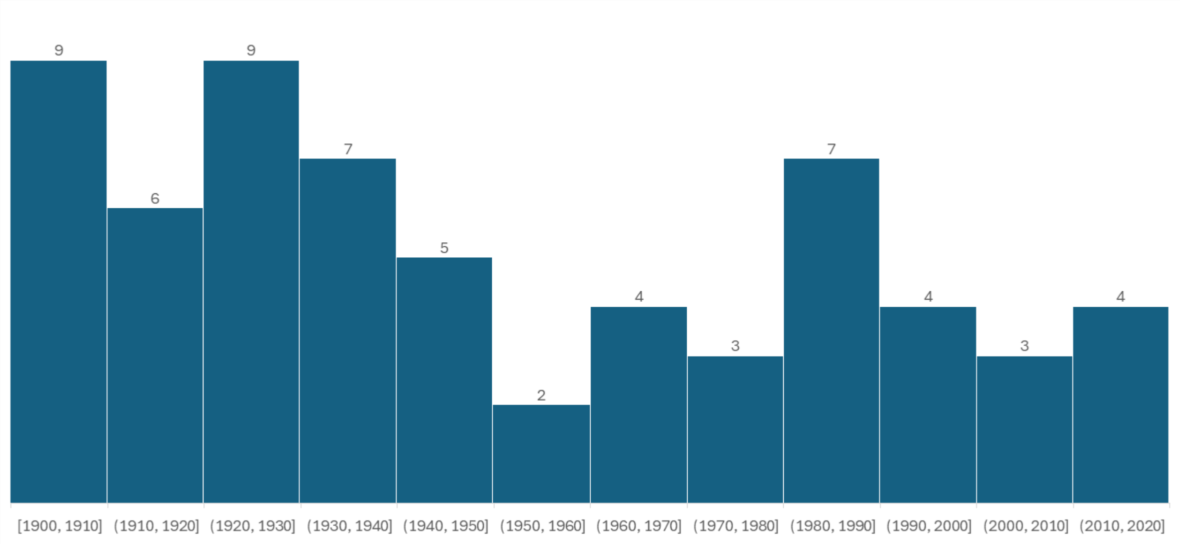

Figure 5 Number of houses per year, Auckland Survey

Prior experience

When homeowners were asked if they had ever lived in a house that had been damaged in an earthquake, 91.2% (N=104) indicated they hadn't, and 8.8% (N=10) indicated they had. Considering that a low number of homeowners have experienced damage to their house, prior experience questions won't be analysed for the Auckland case.

Awareness and use of strengthening techniques

Sixty-six percent (N=77) of homeowners reported they were aware of strengthening techniques capable of improving the structural performance of their house during an earthquake (i.e. aware participants – AP) while 30.7% (N=35) stated they were not aware of strengthening possibilities (i.e., unaware and hence unprepared participants – UUP).

Among AP, 16.9% (N=13) affirmed that they had applied some to their house (i.e. prepared participants – PP) while 83.1% (N=64) affirmed that they had not implemented any strengthening (i.e., aware unprepared participants – AUP).

Expectations of damage

Participants were asked about perceptions of damage to houses during earthquakes, before and after having used seismic strengthening, and the situation that applies to PP. Also, imagining they have used seismic strengthening (i.e., with seismic strengthening) and without seismic strengthening, the current situation for AUP and UUP.

Considering the strong earthquake scenario, and as indicated in Table 6, PP were asked to indicate the expected level of damage before strengthening the house, where one indicated minor, five indicated moderate and four major (N=10, M=4.3, SD=0.675). Then they indicated the expected level of damage after strengthening the house, one indicated minimal, five indicated minor, three indicated moderate, and one indicated major (N=10, M=3.4, SD=0.843).

Considering the medium earthquake scenario, and as indicated in Table 6, PP were asked to indicate the expected level of damage before strengthening the house, one indicated minimal, four indicated minor, four indicated moderate, and one indicated major (N=10, M=3.5, SD=0.85). Then they indicated the expected level of damage after strengthening the house, one indicated undamaged, three indicated minimal, five indicated minor, and one indicated major (N=10, M=2.7, SD=1.06).

To examine whether strengthening actions influenced expectations of seismic performance, paired-sample t-tests were conducted comparing perceived house performance with and without strengthening.

For strong earthquake scenarios in Auckland, UUP (N=32) would expect a significantly better performance when they imagined they had undertaken seismic strengthening, $t(32) = 0.66$, $p < .05$. Similarly, when considering a medium earthquake scenario, $t(32) = 0.672$, $p < .05$. As

Similarly, AUP would expect a significantly better performance when they imagined they had undertaken seismic strengthening in both strong and medium earthquake scenarios, $t(59) = 0.627$, $p < .05$ and $t(60) = 0.675$, $p < .05$, respectively.

Outcome Expectancy

Outcome expectancy was calculated as the difference between expected performance before and after, or with and without. This variable represents the extent to which participants think that strengthening would reduce damage to their house in the event of an earthquake. A higher score represents a stronger perception of outcome expectancy. Results are summarised in Table 7.

An independent sample t-test to compare the outcome expectancy between UUP and AUP revealed that the mean score of outcome expectancy among UPP does not significantly differ from the mean score for AUP, including strong and medium earthquake scenarios, $t(91) = 0.538$, $p>0.05$ and $t(89) = 1.345$, $p>0.05$, respectively. Both groups demonstrated a positive outcome expectancy; findings suggest that unprepared participants (including UUP and AUP) have similar perceptions of efficacy of seismic strengthening.

Why did participants use or not use seismic strengthening?

PP were asked to indicate what they had done as seismic strengthening. Through a multi-choice question, out of the 10 PP, six have done work on the sub-floor area and replied foundations, five have done work on the sub-floor area and strengthened the connections, five have renovated all walls (plasterboards), three have done partial renovation of the wall (plasterboards), two have re-roofed the house, three have strengthened the connection in the floor area, and four have done some work in the chimney, such as removing it.

Table 6 Frequencies of expected level of damage for Prepared Participants (PP), Aware Unprepared Participants (AUP) and Unaware and hence Unprepared Participants (UPP) (Auckland)

	PP				UUP				AUP			
Scenario	**Strong**		**Medium**		**Strong**		**Medium**		**Strong**		**Medium**	
Use	**Before**	**After**	**Before**	**After**	**Without**	**With**	**Without**	**With**	**Without**	**With**	**Without**	**With**
Undamaged	0	0	0	1	1	2	2	10	0	0	3	7
Minimal	0	1	1	3	1	8	10	11	6	13	18	27
Minor	1	5	4	5	7	12	10	8	11	28	25	17
Moderate	5	3	4	0	14	8	8	3	35	17	12	9
Major	4	1	1	1	9	2	2	0	9	1	3	0
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
N	10	10	10	10	32	32	32	32	61	59	61	60
Mean	4.3	3.4	3.5	2.7	3.91	3.00	2.94	2.13	3.77	3.10	2.90	2.47
SD	0.68	0.84	0.85	1.1	0.963	1.02	1.05	0.98	0.82	0.76	0.94	0.89

Table 7 Outcome expectancy results (N= number of participants, SD = Standard Deviation) – Auckland scenario

Scenario	Participants	N	Mean	SD
Strong	PP	10	.80	.79
	UUP	32	.97	.74
	AUP	61	0.87	.90
Medium	PP	10	.70	.82
	UUP	32	.88	.71
	AUP	59	.66	.73

Three of the PP indicated they have done the work to be better prepared for earthquakes, while seven indicated they did the work as a major renovation.

When undertaking the work, participants indicated that three of them worked with a project manager, seven with a builder, four with an engineer and two indicated they did the work themselves. Four of them indicated they applied for building consent through the council, while six of them indicated they did not apply for building consent as the work fell under Schedule 1 of the Building Act (i.e., like-for-like).

When PP were asked through a multi-choice question where they originally got the information about seismic strengthening, two indicated they got the information from friends, three from Council guidelines, one from the news, one from social media, two from an engineer, six from builders, and none from the Natural Hazard Commission Toka Tū Ake (as indicated in Table 9)

UUP were asked why they had not undertaken any seismic strengthening actions, despite being aware of the possibility. They were asked to rank 10 reasons, where 1 is the most important reason and 10 the least important. The most important reason was 'I am unsure about the cost benefit' (M=2.94), followed by 'I did not know it was possible to improve the structural performance of my house' (M=3.25), 'I think structural strengthening is too expensive' (M=3.53), 'I don't have a clear idea of what to do' (M=4.28), 'I have private insurance which will cover any structural damage to my house' (M=4.91), 'I don't want to apply for consent (council process)' (M=5.94), 'The Natural Hazards Commission Toka Tū Ake will cover any structural damage to my house' (M=6.31), 'I don't trust the proposed methods' (M=7.25), 'I don't spend much time in my house' (M=7.47), and others (i.e., "Auckland seems fairly low risk for big earthquakes", and "This type of house withstood the recent ChCh earthquake" (M=9.13), (as shown in Table 8)

When UUP were asked through a multiple-choice question where they would look for further information about seismic strengthening, most of them indicated they would reach out to the Natural Hazards Commission Toka Tū Ake or an Expert Engineering consultant, as shown in Table 9.

Table 8 Reason for not undertaking seismic strengthening Prepared Participants (PP), and Aware Unprepared Participants (AUP)

Reasons	UUP (ranking 1-10)	AUP (ranking (1-10)
I am unsure about the cost/benefit	2.94 (1)	2.55 (1)
I did not know it was possible to improve the structural performance of my house	3.25 (2)	6.98 (8)
I think structural strengthening is too expensive	3.53 (3)	2.90 (2)

Reasons	UUP (ranking 1-10)	AUP (ranking (1-10)
I don't have a clear idea of what to do	4.28 (4)	4.68 (4)
I have private insurance which will cover any structural damage to my house	4.91 (5)	4.6 (3)
I don't want to apply for consent (council process)	5.94 (6)	5.85 (5)
The Natural Hazards Commission Toka Tū Ake will cover any structural damage to my house	6.31 (7)	5.93 (6)
I don't trust the proposed methods	7.25 (8)	6.43 (7)
I don't spend much time in my house	7.47 (9)	7.00 (9)
Other	9.13 (10)	8.07 (10)

AUP were asked why they had undertaken any seismic strengthening event. They were asked to rank 10 reasons, where 1 is the most important reason and 10 the least important. As UUP, the most important reason was 'I am unsure about the cost benefit' (M=2.55). Then the ranking was slightly different from UUP, the second reason was 'I think structural strengthening is too expensive (as shown in Table 8).

When AUP were asked through a multiple-choice question where they would look for further information about seismic strengthening, most of them indicated they would reach out to an Expert Engineering consultant, the Natural Hazards Commission Toka Tū Ake, and Council guidelines, as shown in Table 9, which is slightly different from UUP.

Table 9 Sources of information Prepared Participants (PP), Aware Unprepared Participants (AUP) and Unaware and hence Unprepared Participants (UPP)

Sources of information	PP (N)	UUP (N)	AUP (N)
Friends	2	6	6
Council guidelines	3	14	32
Natural Hazards Commission Toka Tū Ake	0	20	30
News	1	4	1
Social media	1	5	0
Expert Engineering consultant	2	19	41
Builders	6	21	24

Christchurch Sample

In Christchurch, 171 participants completed the questionnaire, of whom 147 indicated their gender. Out of the ones answering the gender question, 33.3% (N=58) identified as female or women, and 51.1% (N=89) as male.

Two were under 30 years old, 13 aged 30–39 years, 20 aged 40–49 years, 37 aged 50–59 years, 36 aged 60–69 years, 32 aged 70–79 years, and eight aged 80–89 years, (n = 148, M= 59, min = 28, max = 84).

Participants were asked about the primary material their house was made of (not considering the foundations or subfloors, such as timber or concrete piles). Six options were given: (1) timber-framed, (2) concrete, (3) mixed timber and concrete (4) Mixed timber and concrete (e.g., ground floor concrete and first floor timber), (5) Mixed timber and masonry (e.g., ground floor masonry and first floor timber), and (6) Steel (e.g., cold-formed steel). Most of the participants indicated timber-framed, N=101 (58%), followed by masonry (while in Auckland was mixed timber and masonry), mixed timber and concrete, Mixed timber and masonry, with percentages of 11.5% (N=20), 7.5% (N=13), and 5.7% (N=10), respectively.

Participants indicated the number of storeys (it was mentioned not to include the subfloor/foundation/basement). 57.5% (N=100) indicated that their house has one story, 25.9% (N=45) two storeys, and 6.3%(N=11) three storeys.

One hundred and fifty-two participants indicated the year of construction of their houses. On average, houses were built in 1974 (SD = 31.17), the oldest in 1900 and the newest in 2020.

Participants were asked whether they were homeowners or tenants. 91.4% (N=159) indicated they were homeowners, while 0.6% (N=1) indicated they were tenants. From now on, the results will include just homeowners.

Prior experience

When homeowners were asked if they had ever lived in a house that had been damaged in an earthquake, 91.2% (N=145) indicated they had, and 8.8% (N=14) indicated they had not.

Participants were asked about the greatest level of damage their house suffered. The same scale from undamaged to extreme was used (1-6). As shown in Table 10, 145 homeowners answered the question, where the damage was between minor and moderate (M=3.35, SD=1.05).

Most of the participants indicated that the damage was mainly caused by the 22 February 2011 Christchurch (N=134), followed by the 6 September 2010 Darfield (N=69), the 14 November 2016 Kaikōura (N=7), and the 16 August 2013 Lake Grassmere (N=1).

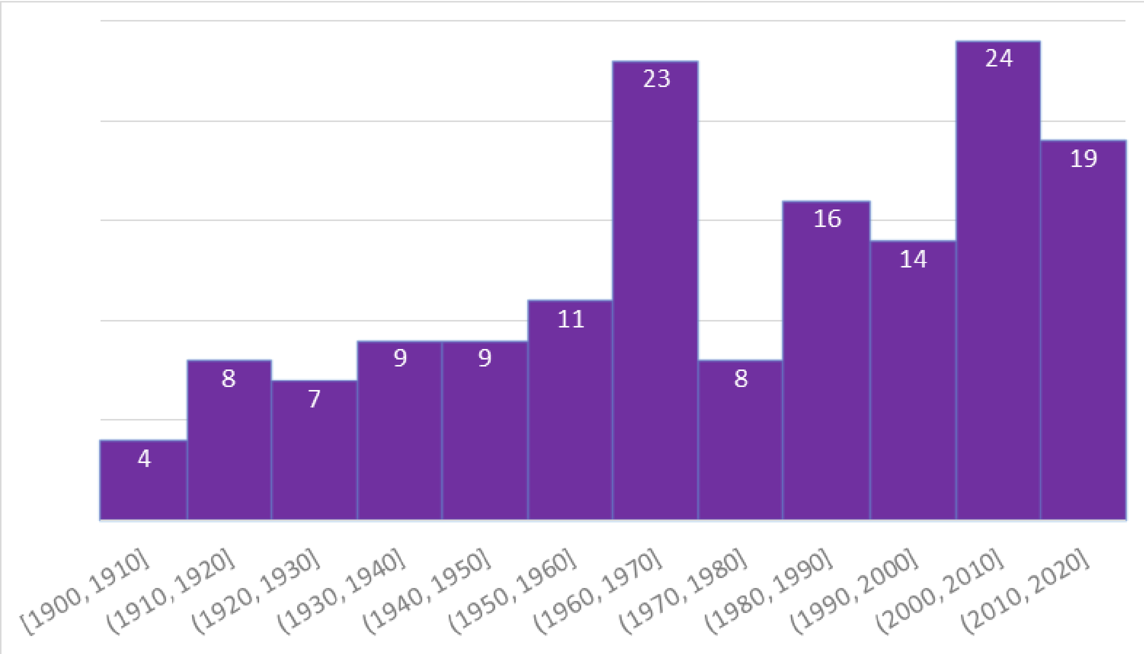

Figure 6 Year of construction – Christchurch sample

Table 10 Experienced damage to houses (N= number of participants)

Level of damage	% (N)
Undamaged (1)	0.6 (1)
Minimal (2)	27 (43)
Minor (3)	12.6 (20)
Moderate (4)	42.8 (68)
Major (5)	6.9 (11)
Extreme (6)	1.3 (2)

Awareness and use of strengthening techniques

Sixty-two percent (N=98) of homeowners reported they were aware of strengthening techniques capable of improving the structural performance of their house during an earthquake (i.e. aware participants – AP) while 37.7% (N=60) stated they were not aware of strengthening possibilities (i.e., unaware and hence unprepared participants – UUP).

Among AP, 31.6% (N=31) affirmed that they had applied some to their house (i.e. prepared participants – PP) while 68.4% (N=67) affirmed that they had not implemented any strengthening (i.e., aware unprepared participants – AUP).

Awareness, use and prior experience

To examine the relationship between prior earthquake experience and awareness of seismic strengthening, an independent samples t-test was carried out. The test compared the level of damage to houses (undamaged to extreme) for those who were aware of strengthening and those who were not. The test indicated that there was a significant association between the level of observed damage and awareness of seismic strengthening, $t(156)=0.63$, $p>.05$.

Expectations of damage

Prepared participants (PP) expected between moderate and minor damage before applying strengthening techniques, while after using strengthening techniques, they expect between minor and minimal damage, as shown in Table 11.

Again, paired-sample t-tests were conducted comparing perceived house performance with and without strengthening.

For strong earthquake scenarios in Christchurch, UUP would expect a significantly better performance when they imagined they had undertaken seismic strengthening, $t(55) = 0.57$, $p < .05$. Similarly, when considering a medium earthquake scenario, $t(56) = 0.62$, $p < .05$.

Similarly, AUP would expect a significantly better performance when they imagined they had undertaken seismic strengthening in both strong and medium earthquake scenarios, $t(57) = 0.723$, $p < .05$ and $t(58) = 0.568$, $p < .05$, respectively. While sample sizes limit statistical comparisons, these overall patterns appear similar to those found in Auckland, suggesting that regardless of location and earthquake experience, New Zealand homeowners generally view seismic strengthening as beneficial; however, this includes those homeowners who have not undertaken strengthening, suggesting that it is important to further explore whether this is an issue of magnitude (i.e., whether outcome expectancy does not merely have to be positive, but has to be strongly positive) or whether there are other influential factors which may differ between these two groups.

Outcome Expectancy

The outcome expectancy is presented in the Table 12, where it is possible to observe that all groups demonstrated a positive outcome expectancy.

An independent sample t-test to compare the outcome expectancy between UUP and AUP revealed that the mean score of outcome expectancy among UPP does not significantly differ from the mean score for AUP, including strong and medium earthquake scenarios, $t(98.7) = 0.761$, $p>0.05$ and $t(110) = 0.183$, $p>0.05$, respectively.

Table 11 Frequencies of expected level of damage for Prepared Participants (PP), and Aware Unprepared Participants (AUP) (Christchurch)

	PP				UUP				AUP			
Scenario	Strong		Medium		Strong		Medium		Strong		Medium	
Use	Before	after	Before	after	Without	With	without	With	Without	With	without	With
Undamaged		2	2	5		3	3	14	1	5	3	13
Minimal	3	8	9	14	10	25	22	24	16	26	25	29
Minor	6	10	10	7	19	15	20	13	19	21	24	13
Moderate	12	6	6		27	12	13	5	23	4	10	2
Major	4	2			3	1		1	2	2		
Extreme	3											
N	28	28	27	26	59	56	58	57	61	58	62	58
Mean	3.93	2.93	2.74	2.08	3.39	2.7	2.74	2.21	3.15	2.52	2.66	2.12
SD	1.1	1.05	0.9	0.69	0.83	0.93	0.87	0.98	0.91	0.88	0.81	0.86

Table 12 Outcome expectancy results – Auckland scenario

Scenario	Participants	N	Mean	SD
Strong	PP	27	1.07	0.68
	UUP	53	0.79	0.77
	AUP	55	0.69	0.6
Medium	PP	27	1.7	0.99
	UUP	55	1.96	1.12
	AUP	57	2	0.98

Why did participants use or not use seismic strengthening?

PP were asked to indicate what they had done as seismic strengthening. Through a multi-choice question, out of the 31 PP, 10 have done work on the sub-floor area and replied foundations, 15 have done work on the sub-floor area and strengthened the connections, nine have renovated all walls (plasterboards), 15 have done partial renovation of the wall (plasterboards), seven have re-roofed the house, 10 have strengthened the connection in the floor area, and six have done some work in the chimney, such as removing it.

When PP were asked why they had decided to undertake this work, 12 indicated they had done it to be better prepared for earthquakes, eight indicated they did it as part of a major renovation, and 16 indicated other reasons, with the most common reason being as part of earthquake repairs.

When undertaking the work, participants indicated that 12 of them worked with a project manager, 21 with a builder, 13 with an engineer and six indicated they did the work themselves. 17 of them indicated they applied for building consent through the council, while eight of them indicated they did not apply for building consent as the work fell under Schedule 1 of the Building Act (i.e., like-for-like).

When PP were asked through a multi-choice question where they originally got the information about seismic strengthening, two indicated they got the information from friends, three from Council guidelines, three from the Natural Hazard Commission Toka Tū Ake, 15 from an engineer and 13 from builders, and none (as indicated in Table 13)

UUP were asked why they had undertaken any seismic strengthening event, although they were aware of it. They were asked to rank 10 reasons, where 1 is the most important reason and 10 the least important. The most important reason was ‘I did not know it was possible to improve the structural performance of my house’ (M=2.72), followed by ‘I am unsure about the cost/benefit’, ‘I think structural strengthening is too expensive’, ‘I don’t have a clear idea of what to do’, ‘I have private insurance which will cover any structural damage to my house’, ‘I don’t want to apply for consent (council process)’, ‘The Natural Hazards Commission Toka Tū Ake will cover any structural damage to my house’, ‘I don’t trust the proposed methods’, ‘I don’t spend much time in my house’, and others (i.e., ‘we have survived major earthquakes’, or ‘I am not sure if there is a real or urgent need’), which means were 3.07, 3.56, 4.60, 4.72, 6.18, 6.81, 6.93, 7.16 and 9.19, respectively (as shown in

Table 14).

When UUP were asked through a multiple-choice question where they would look for further information about seismic strengthening, most of them indicated they would reach out to Council Guidelines, followed closely by Expert Engineering consultant, as shown in Table 13.

AUP were asked why they had undertaken any seismic strengthening event. They were asked to rank 10 reasons, where 1 is the most important reason and 10 the least important. As UUP, the most important reason was 'I think structural strengthening is too expensive' (M=2.84). Then the ranking was slightly different from UUP, the second and third reasons were I am unsure about the cost/benefit' and 'I have private insurance which will cover any structural damage to my house', respectively (as shown in

Table 14).

Table 13 Sources of information for Prepared Participants (PP), and Aware Unprepared Participants (AUP) – Christchurch

Sources of information	PP (N)	UUP (N)	AUP (N)
Friends	4	10	7
Council guidelines	3	27	29
Natural Hazards Commission Toka Tū Ake	3	21	27
News	0	5	4
Social media	0	1	1
Expert Engineering consultant	15	26	47
Builders	13	23	28

Table 14 Reason for not undertaking seismic strengthening for Prepared Participants (PP), and Aware Unprepared Participants (AUP) – Christchurch

Reasons	UUP (ranking 1-10)	AUP (ranking 1-10)
I did not know it was possible to improve the structural performance of my house	2.72 (1)	6.40 (7)
I am unsure about the cost/benefit	3.07 (2)	2.89 (2)
I think structural strengthening is too expensive	3.56 (3)	2.84 (1)
I don't have a clear idea of what to do	4.60 (4)	5.00 (4)
I have private insurance which will cover any structural damage to my house	4.72 (5)	4.15 (3)
The Natural Hazards Commission Toka Tū Ake will cover any structural damage to my house	6.18 (6)	5.81 (5)

Reasons	UUP (ranking 1-10)	AUP (ranking 1-10)
I don't trust the proposed methods	6.81 (7)	6.48 (8)
I don't want to apply for consent (council process)	6.93 (8)	6.35 (6)
I don't spend much time in my house	7.16 (9)	6.98 (9)
Other	9.19 (10)	8.10 (10)

When AUP were asked through a multiple-choice question where they would look for further information about seismic strengthening, most of them indicated they would reach out to an Expert Engineering consultant as shown in Table 13, which is slightly different from UUP.

Comparison of Auckland, Wellington and Christchurch

In total, 830 participants have answered the question about the expectation of damage to their house, where 119, 149 and 560 were from Auckland, Christchurch and Wellington, respectively. A chi-square test was performed to examine the relationship between location and awareness and use of seismic strengthening. The relation between these variables was significant, X^2 (4) = 26.27, $p < .001$, suggesting that the location of participants is related to awareness and use of seismic strengthening (see Table 15).

The expectations of damage to before (without) and after (without) undertaking seismic strengthening, and outcome expectancy are shown in Table 16. It is possible to observe that all participants in the three cities have a positive outcome expectancy.

Auckland participants tend to expect larger damage to their houses after a moderate earthquake before using any seismic strengthening, followed by Christchurch and then Wellington. This suggests that Aucklanders perceive their dwellings as more vulnerable prior to intervention, or that earthquakes might be more damaging in Auckland.

Wellington participants exhibited the largest outcome expectancy, indicating a stronger belief in the effectiveness of strengthening once it is applied. In contrast, Christchurch participants consistently reported the lowest outcome expectancy, which may be influenced by prior experiences of perceived building performance. However, prepared participants in Christchurch presented the largest outcome expectancy scores, reflecting again the positive influence of prior experiences.

Table 15 Crosstab of participants and location for Prepared Participants (PP), and Aware Unprepared Participants (AUP)

		Participant			Total
		PP	UUP	AUP	
Auckland	Count	12	35	72	119
	% within Auckland	10%	29%	61%	100%
	% within Participant	6%	12%	20%	14%
	% of Total	1%	4%	9%	14%
Christchurch	Count	28	58	63	149
	% within Christchurch	19%	39%	42%	100%
	% within Participant	15%	21%	18%	18%
	% of Total	3%	7%	8%	18%
Wellington	Count	153	189	220	562
	% within Wellington	27%	34%	39%	100%
	% within Participant	79%	67%	62%	68%
	% of Total	18%	23%	27%	68%
Total	Count	193	282	355	830
	% within City	23%	34%	43%	100%
	% within Participant	100%	100%	100%	100%
	% of Total	23%	34%	43%	100%

Table 16 Summary of the expectation of damage and outcome expectancy for all participants from the three different cities for Prepared Participants (PP), and Aware Unprepared Participants (AUP). OE (outcome expectancy)

	PP			UUP			AUP			All Participants		
Use	Before	After	OE	Without	With	OE	Without	With	OE	B/W	After/WO	OE
Auckland	4.27 (0.64)	3.45 (0.82)	0.75 (0.75)	3.91 (0.96)	2.94 (1.04)	0.88 (0.75)	3.7 (0.87)	2.79 (0.96)	0.95 (0.8)	3.81 (0.75)	2.89 (0.98)	0.91 (0.77)
Christchurch	3.93 (1.1)	2.74 (0.9)	1.46 (1.18)	3.38 (0.82)	2.75 (0.87)	0.74 (0.64)	3.16 (0.91)	2.68 (0.82)	0.58 (0.56)	3.39 (0.95)	2.72 (0.85)	0.79 (0.79)
Wellington	3.41 (1.05)	2.37 (0.89)	1.07 (0.78)	3.41 (0.87)	2.42 (0.85)	1.03 (0.73)	3.26 (0.9)	2.49 (0.88)	0.81 (0.65)	3.35 (0.93)	2.43 (0.88)	0.96 (0.72)

In-Person Structural Survey

A structural survey identified common parameters of timber-framed houses in Auckland and Christchurch. In the last question of the social science questionnaire (presented in prior sections), participants were asked to participate in a structured survey designed to gather data on the geometric properties and structural form of houses. More than 70% of the questionnaire responders expressed interest in participating in the structural survey, from which 40 were randomly chosen in both cities and contacted to proceed with the data collection. Information collected in the structural survey included materiality of subfloor structure and shear walls, as well as horizontal and vertical wall distributions. The data collection was supported with photographs of internal and external views and structural drawings. Discussions with house owners about their experiences were also conducted, and key conclusions are summarised herein.

Physical survey of Housing

The physical survey of housing involved the collection of approximate plan layouts and materials to better inform the modelling of housing. The variety of the data collected acts as evidence of the diversity in the architectural and structural layout and materials of houses in New Zealand, particularly with age. The distribution of building elements in plan and elevation is commonly irregular, with different locations of openings, structural systems, roofing materials, and foundation types. This follows recent work by Wang et al. (2025) which found L-shaped houses designed with bracing arrangements that are within the irregularity limits of NZS3604 had much greater inter-storey drift ratios and significant torsion in earthquakes than the regularly braced house. It is apparent, then, that effective retrofit strategies must accommodate this diversity.

All houses surveyed in Christchurch have gone through the 2010-2011 Canterbury Earthquake Sequences. People have indicated that damage has been fixed. Common interventions that improved seismic performance included the bracing or removal of chimneys, replacement of heavy tile roofing with lightweight steel, repiling and/or the tying of foundations to the superstructure, and the seismic restraint of non-structural elements and contents.

Observations of Auckland houses and conversations with homeowners indicated that some of the existing structural features might or might not meet current seismic design standards – some can be questioned. For example, homeowners who have indicated going through major renovations indicated their house has been retrofitted for earthquakes as per the building code (see Figure 7a). Figure 7b also shows that although piles were relatively new, no connection was observed between bearers, footings and short timber piles. Most of the visited houses in Auckland had masonry chimneys (see

Figure 7c), which have been identified as a major hazard in prior earthquakes in New Zealand.

(a) (b) (c)

Figure 7 Example of house features in Auckland

Conversations with Property Owners

Awareness of Local Risk – Both Christchurch and Auckland homeowners seemed to have a good understanding of the local natural hazards that posed risk to their properties, with Aucklanders discussing flood risk and Christchurch residents discussing earthquake hazard. This appeared to be predominantly from recent lived experience. All participants had direct experience of events and often drew from anecdotes when discussing preparedness.

Construction without robust documentation – Some older buildings had construction work, during initial build or later alteration, that was not documented. This poses a challenge for identifying expected seismic performance.

Damage under lower strength / more frequent earthquakes – Many buildings experienced damage in earthquake-induced ground motions that were far below the levels typically considered in design, those associated with life safety in very strong motion. Observed damage included partition wall damage, damage to cladding, dislocation of roofing, chimney collapse, cracking in ring foundations and issues with untied foundation piles.

Uncertainty and disruption when damage required repair – Some of the Canterbury homeowners involved in this work told of difficulty in coordinating quality work following the earthquake sequence. Malpractice resulting in poor repair work, poor transparency in processes, conflicting engineering reports, and bureaucratic hurdles had resulted in re-work, extended delays, and significant interruptions in their lives. These challenges appear to act as social costs that may not be considered when insurance is relied upon instead of improving seismic performance.

Discussion

This study highlights important insights into homeowners' expectations of earthquake damage, their perceptions of seismic strengthening, and the current conditions of timber-framed houses in Aotearoa New Zealand. Table 17 summaries the collective building performance expectations from the surveys across Wellington, Christchurch, and Auckland, and underlines the reasons for these expectations and the barriers to achieving them.

Across Auckland, Christchurch, and Wellington, participants consistently demonstrated a positive outcome expectancy (OE), suggesting that homeowners generally believe that strengthening measures can reduce the extent of earthquake damage. This finding reinforces earlier research showing that outcome expectancy is a critical factor in motivating preparedness and retrofitting decisions (Huaa et al., 2020; Miranda et al., 2022; Scovell et al., 2020). There is the potential for risk communication and policy interventions to leverage existing public recognition of the value of seismic strengthening.

Differences between cities suggest that local experience and hazard context strongly influence expectations of damage, suggesting that risk communication and policy interventions can be targeted locally. This aligns with prior work suggesting that where earthquake experience is low, public perceptions of risk may be influenced more by other factors such as unrealistic optimism and fatalism (Becker et al., 2017; Burger & Palmer, 1992; McClure et al., 2001).

The physical surveys and homeowner interviews provide additional context. In Christchurch, common strengthening interventions—such as chimney removal, reroofing, and foundation tying—were widely observed, reflecting lessons learned from the Canterbury Earthquake Sequence. In Auckland, several houses showed features not fully aligned with seismic design standards or recommendations, including unconnected piles and heavy masonry chimneys. These observations echo engineering research showing that while timber-framed houses generally meet life-safety objectives (Buchanan et al., 2011), there are retrofits people can do to improve the overall seismic performance of houses beyond life-safety. The findings also resonate with debates in the engineering literature about whether life safety alone is an adequate design objective, given public demands for reduced disruption and functional recovery (Porter, 2021; Tanner et al., 2020). This includes clarifying how communities interpret different levels of performance in relation to engineering definitions. To date, there has been limited research on the interpretation of functional recovery terminology.

Participants also reported barriers to strengthening. Christchurch homeowners described challenges with post-earthquake repair processes, including poor-quality workmanship, inconsistent engineering advice, and bureaucratic obstacles. These findings highlight that beyond the technical aspects of retrofit, policy frameworks must also address the social costs and administrative burdens that undermine confidence in resilience-building measures.

Overall, the findings underscore that while life safety remains the primary design limit state for timber-framed housing, community expectations extend beyond life safety. Homeowners expect strengthening to reduce damage. This supports existing literature on incorporating functional recovery into seismic performance objectives (Abeling et al., 2023b; NEHRP, 2020). Bridging the gap between public expectations and current design or retrofit practices will require integrated strategies, including clear public education, accessible guidance on voluntary strengthening, and financial incentives that reduce barriers to action.

Table 17 Summary of results

Aspect	Summary insights
Overall expectations	Homeowners expect performance beyond life-safety.
Outcome expectancy (belief that strengthening works)	Auckland, Wellington and Christchurch show positive outcome expectancy (damage reduction with strengthening)
Wellington	Highest outcome expectancy overall—stronger belief that strengthening improves performance, consistent with local hazard context.
Christchurch	Lower outcome expectancy on average, likely shaped by lived earthquake experience.
Auckland	Participants expect larger damage before strengthening, suggesting perceived vulnerability to earthquakes as they are less frequent.
Drivers and barriers	Prior experience (especially in Christchurch) shapes expectations and preparedness Cost & cost-benefit uncertainty, lack of clear guidance, and reliance on insurance/EQC

Conclusions

This study examined homeowners' expectations of seismic damage to timber-framed houses in Auckland, Christchurch, and Wellington, and explored how perceptions of seismic strengthening shape preparedness. Although some differences were observed across the three cities, homeowners generally believe that strengthening reduces seismic damage. Patterns suggest that local hazard and past earthquake experience strongly influence perceptions of damage, awareness and use of seismic strengthening. Overall, the findings reinforce that while the Building Code's focus on life safety is effective in preventing collapse, it does not fully align with public expectations of reduced damage. Bridging this gap requires clearer communication of building performance objectives, and stronger integration of public expectations into policy. Addressing these issues will help ensure that the timber housing stock of Aotearoa New Zealand is not only safe, but also resilient in ways that reflect community needs.

Publications, communications and engagement

Building Strengthening. Public Talk, Te Papa Museum, Wellington, Aotearoa New Zealand.

Predictions and Societal Expectations of Damage to Existing Buildings in Earthquakes in Aotearoa New Zealand. Miranda C., Becker J., Toma C., & Stephens M. World Conference in Earthquake Engineering, Milan, Italy

Overlaying social and Engineering aspects of Earthquake Preparedness. Wellington, New Zealand. Wellington Earthquake Resilience Collaboratory.

References

Abeling, S., Miranda, C., & Becker, J. (2023a). Public expectations of damage and disruption to existing multi-storey buildings in earthquakes. *NZSEE 2023 Annual Conference*.

Abeling, S., Miranda, C., & Becker, J. S. (2023b). *Public expectations of damage and disruption to existing multi-storey buildings in earthquakes* New Zealand Society of Earthquake Engineering Technical Conference, Auckland, New Zealand.

Abrams, D. (2002). Consequence-based engineering approaches for reducing loss in mid-America.

Almufti, I., & Willford, M. (2013). *REDi™ Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings*. https://doi.org/DOI: 10.13140/RG.2.2.20267.75043

Beattie, G. (2012). *The Response of Houses to the Canterbury Earthquake Series 2010-2011* World Conference Earthquake Engineering, Lisboa.

Becker, J., Paton, D., Johnston, D., Ronan, K., & McClure, J. (2017). The role of prior experience in informing and motivating earthquake preparedness. *International Journal of Disaster Risk Reduction*, *Vol. 22a*. https://doi.org/http://dx.doi.org/10.1016/j.ijdrr.2017.03.006

Becker, J. S., Garden, E., Van der Velde, M., Coomer, M. A., Rampton, A., Johnston, D. M., Blake, D., & Newman-Hall, G. (2018). *Impact of the 2016 Kaikōura Earthquake on Wellington CBD Apartment Residents: Results of a Survey*.

Blackbourn, T., & Davey, R. (2017). *Seismic Fragility Assessment of Canterbury Buildings* New Zealand Society of Earthquake Engineering, Auckland.

Blake, D., Becker, J. S., Hodgetts, D., & Elwood, K. J. (2021). The Impact of Earthquakes on Apartment Owners and Renters in Te Whanganui-a-Tara (Wellington) Aotearoa New Zealand. *Applied Sciences*, *11*(15). https://doi.org/https://doi.org/10.3390/app11156818

Bostrom, A., Mohana, R., & Ponomariovc, B. (2006). Earthquake Mitigation Decisions and Consequences. *Earthquake Spectra*, *Vol 22*.

Buchanan, A., Carradine, D., Beattie, G., & Morris, H. (2011). *Performance of houses during the Christchurch Earthquake of 22 February 2011*.

[Record #332 is using a reference type undefined in this output style.]

[Record #323 is using a reference type undefined in this output style.]

Burger, J. M., & Palmer, M. I. (1992). Changes in and generalization of unrealistic optimism following experiences with stressful events: reactions to the 1989 California Earthquake. *Personality and Social Psychology Bulletin*, *Vol. 18*(1). https://doi.org/https://doi.org/10.1177/0146167292181006

Celsi, R., Wolfinbarger, M., & Wald, D. (2005). The Effects of Earthquake Measurement Concepts and Magnitude Anchoring on Individuals' Perceptions of Earthquake Risk. *Earthquake Spectra*, *Volume 21, No. 4, pages 987–1008*.

Cooney, R. (1979). The Structural Performance Of Houses In Earthquakes. *Bulletin Of The New Zealand National Society For Earthquake Engineering*, *Vol. 12*(No. 3).

Costa, R., Haukaas, T., & Chang, S. E., M. (2021). Agent-based model for post-earthquake housing recovery. *Earthquake Spectra*, *37*, 46–72. https://doi.org/DOI: 10.1177/8755293020944175
Dowrick, D., Hancox, G., Perrin, N., & Dellow, G. (2008). *The Modified Mercalli Intensity Scale – Revisions Arising From New Zealand Experience*.
Egbelakin, T., & Wilkinson, S. (2010). Sociological and behavioural impediments to earthquake hazard mitigation.
Egbelakin, T., Wilkinson, S., Potangaroa, R., & Ingham, J. (2011). Challenges to successful seismic retro¢t implementation: a socio-behavioural perspective. *Building Research & Information*.
EQC. (2020). *Fix. Fasten. Don't forget*.
FEMA. (2021). *FEMA P-2090/ NIST SP-1254. Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancyand Functional Recovery Time. Federal Emergency Management Agency (FEMA). NIST-FEMA Special Publication FEMA P-2090/NIST SP-1254.* https://doi.org/https://doi.org/10.6028/NIST.SP.1254
[Record #77 is using a reference type undefined in this output style.]
[Record #76 is using a reference type undefined in this output style.]
FEMA P-58-1. (2018). *Seismic Performance Assessment of Buildings. Federal Emergency Management Agency*. Applied Technology Council (ATC).
Filiatrault, A., Christovasilis, I., Wanitkorkul, A., & Folz, B. (2006). *Displacement-Based Seismic Design of Light-Frame Wood Buildings* 9th World Conference in Timber Engineering, Portland, OR.
Filiatrault, A., & Folz, B. (2002). Performance-based seismic design of wood framed buildings. *Journal of Structural Engineering*, *Vol. 128*(Issue 1), Pages 39-47. https://doi.org/©ASCE, ISSN 0733-9445/2002/1-39–47
Francis, T., Sullivan, T., & Filiatrault, A. (2023). Shake Table Testing and Modeling of New Zealand Light-Frame Wood Buildings. *Journal of Structural Engineering*, *149*(12). https://doi.org/10.1061/JSENDH.STENG-12413
Ghobarah, A. (2001). Performance-based design in earthquake engineering: state of development. *Engineering Structures*, *Vol. 23*, 878–884.
Horspool, N., Gerstenberger, M. C., & Elwood, K. J. (2021). *Risk Targeted Hazard Spectra for Seismic Design in New Zealand* NZSEE 2021 Annual Conference, New Zealand.
Huaa, C., Huangb, S., Lindellc, M., & Yu, C. (2020). Rural households' perceptions and behavior expectations in response to seismic hazard in Sichuan, China. *Safety science*. https://doi.org/https://doi.org/10.1016/j.ssci.2020.104622
Jennings, E., van de Lindt, J. W., & Peek, L. (2015). *Multi-objective community-level seismic retrofit optimization for resiliency using engineering and socioeconomic variables* Proceedings of the 12th International Conference on Applications of Statistics and Probability in Civil Engineering (ICASP12), Vancouver, Canada.
Kaiser, A., Balfour, B., Fry, C., Holden, N., Litchfield, M., Gerstenberger, M., D'Anastasio, E., Horspool, N., McVerry, G., Ristau, J., Bannister, S., Christophersen, A., Clark, K., Power, W., Rhoades, D., Massey, C., Hamling, I., Wallace, L., Mountjoy, J., Kaneko, Y., Benites, R., Van Houtte, C., Dellow, S., Wotherspoon, L., Elwood, K., & Gledhill, K. (2017). The 2016 Kaikōura, New Zealand, Earthquake: Preliminary Seismological

Report. *Seismological Research Letters*, *Vol. 88*. https://doi.org/doi: 10.1785/0220170018
King, A. (1999). *A Guide to the Performance Expectations of New Zealand Housing Systems*.
Kirkham, W., Gupta, R., & Miller, T. (2014). State of the Art: Seismic Behavior of Wood-Frame Residential Structures. *Journal of Structural Engineering*.
Krawinkler, H. (2000). Advancing Performance-Based Earthquake Engineering, Civil and Environmental Engineering.
Lew, S. (1989). *Performance of Structures During the Loma Prieta Earthquake of October 17, 1989* (Vol. Vol. 778.). United States Department of Commerce National Institute of Standards and Technology.
Loss, C., Tannert, T., & Tesfamariam, S. (2018). State of the art review of displacement-based seismic design of timber buildings. *Construction and Building Materials ELSEVIER*, *Vol. 191*, Pages. 481–497. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.09.205
May, P. (2001). Societal Perspectives about Earthquake Performance: The Fallacy of ''Acceptable Risk''. *Earthquake Spectra*, *17*(4). https://doi.org/https://doi.org/10.1193/1.1423904
Risk Guidance for Buildings, (2022).
McClure, J., Allen, M. W., & Walkey, F. (2001). Countering fatalism: Causal information in news reports affects judgments about earthquake damage. *Basic and Applied Social Psychology*, *Vol. 23*, 109-121. https://doi.org/doi: 10.1207/S15324834BASP2302_3
McClure, J., Sutton, R., & Wilson, M. (2007). How information about building design influences causal attributions for earthquake damage. *Asian Journal of Social Psychology*, *Vol. 10*, 233–242.
Mieler, M. W., & Mitrani-Reiser, J., . . (2017). Review of the State of the Art in Assessing Earthquake-Induced Loss of Functionality in Buildings. *Journal of Structural Engineering*, *144*(3). https://doi.org/https://doi.org/10.1061/(ASCE)ST.1943-541X.0001959
Miranda, C., Becker, J. S., Toma, C. L., & Vinnell, L. J. (2022). Homeowners' Perceptions of Seismic Building Performance and Implications for Preparedness in New Zealand. *Natural Hazards Review*, *24*(1). https://doi.org/https://doi.org/10.1061/(ASCE)NH.1527-6996.0000600
Miranda, C., Becker, J. S., Vinnell, L. J., Toma, C. L., & Johnston, D. M. (2021). Seismic experience and structural preparedness of residential houses in Aotearoa New Zealand. *International Journal of Disaster Risk Reduction*, *66*. https://doi.org/https://doi.org/10.1016/j.ijdrr.2021.102590
Miranda, C., Toma, C., & Stephens, M. T. (2023). Predictions of Damage to Timber-Framed Houses. I: Seismic Performance of Wood-Framed Houses Located on Slopes. *Natural Hazards Review*, *24*(4). https://doi.org/10.1061/NHREFO.NHENG-1811
Miranda, C., Toma, C., Stephens, M. T., & Becker, J. (2023). Predictions of Damage to Timber-Framed Houses. II: Aligning Social and Engineering Predictions of Earthquake Damage before and after Strengthening. *Natural Hazards Review*, *24*(4). https://doi.org/https://doi.org/10.1061/NHREFO.NHENG-1812

Molina Hutt, C., Vahanvaty, T., & Kourehpaz, P. (2022). An analytical framework to assess earthquake-induced downtime and model recovery of buildings. *Earthquake Spectra*, *38*(2), 1283-1320. https://doi.org/DOI: 10.1177/87552930211060856
[Record #510 is using a reference type undefined in this output style.]
New Zealand Society for Earthquake Engineering and Natural Hazard Commission Toka Tū Ake. (2022). *Societal Expectations for Seismic Performance of Buildings*.
[Record #59 is using a reference type undefined in this output style.]
P-2090, F. *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time*.
Payne, B. A., Abeling, S., Becker, J. S., Elwood, K. J., Ferner, H., Brunsdon, D., & Johnston, D. M. (2021). *Earthquake Stories: Experiences of Building Performance in Earthquakes to Inform Future Standards* New Zealand Society of Earthquake Engineering Technical Conference,
Porter, K. (2002). Learning from Earthquakes: a Survey of Surveys. *EERI Invitational Workshop: An Action Plan to Develop Earthquake Damage and Loss Data Protocols - Earthquake Engineering Research Institute, Oakland, CA.*
Porter, K. A. (2021). Should we build better? The case for resilient earthquake design in the United States. *Earthquake Spectra*, *37*(1), 523-544. https://doi.org/https://doi.org/10.1177/875529302094418
Porter, K. A., Beck, J. L., Seligson, H. A., Scawthorn, C. R., Tobin, L. T., & Boyd, T. (2002). *Improving Loss Estimation for Woodframe Buildings*.
Priestly, M. (2000). *PERFORMANCE BASED SEISMIC DESIGN* 12th World Conference in Earthquake Engineering,
Rosowsky, D., & Ellingwood, B. (2002). Performance-Based Engineering of Wood Frame Housing: Fragility Analysis Methodology. *Journal of Structural Engineering*, *Vol. 128*, 32-38. https://doi.org/10.1061/(ASCE)0733-9445(2002)128:1(32)
Scovell, M., McShane, C., Swinbourne, A., & Smith, D. (2020). Experience and the perceived efficacy of cyclone preparedness behaviour. *International Journal of Disaster Resilience in the Built Environment*.
Sharpe, R. L. (1992). Acceptable earthquake damage or desired performance.
Spittal, M., McClure, J., Siegert, R., & Walkey, F. (2005). Optimistic bias in relation to preparedness for earthquakes. *Australasian Journal of Disaster and Trauma Studies*.
SPSS. (2019). *IBM Corp. Released*. In
Tanner, A., Chang, S., & Elwood, K. J. (2020). Incorporating societal expectations into seismic performance objectives in building codes. *Earthquake Spectra*, *36*(4), 2165-2176. https://doi.org/https://doi.org/10.1177/8755293020919417
The Resilient Buildings Project. (2022). POLICY BRIEF FOR NZSEE PROJECT ON RESILIENT BUILDINGS. How do Kiwis want buildings to perform during and after an earthquake?
Thomas, G., & Shelton, R. (2012). *Performance of house lining and cladding systems in the 22 February Lyttleton earthquake* 2012 NZSEE Conference,
Todd, D., Carino, N., Chung, R., Lew, H., Taylor, A., Walton, W., Cooper, J., & R., N. (1994). *1994 Northridge Earthquake. Performance of Structures, Lifelines and Protection Systems*.

Ventura, C., Finn, L., Onur, T., Blanquera, A., & Rezai, M. (2005). Regional seismic risk in British Columbia — Classification of buildings and development of damage probability functions.

Vinnell, L. J., Milfont, T., & McClure, J. (2019). Do Social Norms Affect Support for Earthquake Strengthening Legislation? Comparing the Effects of Descriptive and Injunctive Norms. *Environment and Behavior*, *Vol. 51(4) 376–400*.

Wang, X., Li, M., Liu, A., & Dhakal, R. P. (2025). *Effect of bracing irregularity on seismic performance of l-shaped light timber-framed residential houses* World Conference in Timber Engineering Brisbane.