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

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ABSTRACT

The seismic performance of both structural and non-structural building components has the potential to affect the lives of building occupants, with poor performance likely to cause undue disruption and potential harm. In recent years, a growing effort has been made to understand whether the public's expectations of future damage and disruption to the built environment in earthquakes, align with what might happen in an actual earthquake. In 2021, a survey was undertaken in which members of the New Zealand public were asked about their expectations for the seismic performance of an existing multi-storey building they were most familiar with. The survey aimed to understand how participants expected their building would perform in weak, moderate, or severe earthquakes. A summary of the findings related to expected damage, functionality, and timeframes for repair are presented herein. Additionally, a brief discussion is provided about how respondents' expectations for damage align or diverge from current seismic performance objectives in the New Zealand building code.

1 INTRODUCTION

Following the 2010-2011 Canterbury earthquakes sequence, many buildings suffered significant damage or collapse, causing a 10% capital cost of rebuild in Aotearoa New Zealand (Parker and Steenkamp, 2012, Kam and Pampanin, 2011). Many people either temporarily or permanently lost their homes, while others lost their workplace and their livelihoods. The impacts on Canterbury communities are still being shaped not just by the nature and scale of the physical impacts, but also by the social environment that supports the complex and protracted processes of recovery. Both physical and social impacts also occurred following the 2016 Kaikōura earthquake in provincial towns such as Kaikōura, as well as the wider Wellington Region (Stevenson et al., 2017). Although observation of damage to buildings after earthquakes such as these has proved that, in general, engineering design codes do a good job of protecting building occupants' lives, studies have questioned whether the 'life safety' objectives used in codes worldwide are adequate with regard to the devastating social and economic consequences (Tanner et al., 2020, Koliou et al., 2018). In disaster resilience evaluations, these types of consequences, which include losses from the disaster and costs incurred during recovery, have been measured in relation to the variation of building and infrastructure functionality during a time period of interest (Kwok et al., 2016, Becker et al., 2011).

Given the wide-reaching impacts from past earthquakes, there appears to be an appetite for higher performance objectives in building codes, with researchers (Porter, 2021, Tanner et al., 2020, Horspool et al., 2021) 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, 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).

Other studies propose that the inclusion of societal demands of building performance and functionality could help to decrease damage to buildings (Tanner et al., 2020, Pampanin, 2012). For example, performance objectives in building codes could be set at a higher level to meet demands, ultimately reducing higher levels of damage; however, such demands might vary depending on the type of building or level of shaking. The complex analysis of understanding and including societal demands in future updates of building codes can also be aggravated by the fact that the public may not clearly understand the minimum standards of building codes (Porter, 2021).

Several appraisal factors can influence people's perceptions of earthquake damage, such as risk perception, fatalistic views, prior experience, optimism or normalisation biases, trust, etc (Miranda et al., 2021, Becker et al., 2017, Paton, 2019, McClure et al., 2001). For instance, 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.

Although in the interaction of those appraisal factors is important to understand perceptions of earthquake damage (some will be analysed in future papers), this paper seeks to give insight into understanding peoples' expectations for existing buildings' performance and acceptable recovery timeframes. Comparisons are made between different types of damage, levels of functionality, and expected recovery times in different levels of earthquake shaking. The results presented herein will help to inform and shape future conversations about potential updates to building codes.

2 PROCEDURES

An online quantitative survey was used to collect data from users of existing multi-storey buildings in Aotearoa New Zealand. The survey ran online via Qualtrics from 9 August 2021 to 26 September 2021, and it was voluntary and available to anyone over the age of 18 who resides in New Zealand. Survey participation was promoted through social media posts (e.g., Facebook), email, and the Wellington Region Emergency Management newsletter. The potential risks of conducting the survey were carefully considered, and a low-risk notification was submitted to the Massey University Human Ethics Committee before the collection of data (Massey University Ethics Notification Number: 4000023412).

A total of 116 responses were collected. The age and gender demographics of survey participants are shown in Figure 1. There is a slight under-representation of females (40%) when compared to the gender profile of

New Zealand, which estimates the population to be approximately 50% female (Stats NZ, 2022). The survey participants represented a wide range of occupations, including public servants, IT professionals, business analysts, medical professionals, and stay at home parents, among many others.

The participants were asked to identify a multi-storey building that they use regularly and provide details about that building (i.e., location, number of storeys, approximate year of construction, primary structural material, and primary use). The identified building was referred to as ‘Building A’ throughout the survey. Most participants identified buildings located in Wellington and surrounding suburbs (88%). Nine percent of identified buildings were in Christchurch, and 3% were in Auckland. Seventeen percent of buildings were low-rise (1-3 storeys), 43% of buildings were mid-rise (4-8 storeys), and 40% of buildings were high rise (9 or more storeys).

Most of the buildings were residential apartments (49%) or office buildings (33%). The year of construction of the buildings ranges from before 1940 to after 2010, with the a majority of buildings constructed between 1960 and 1980 (30%) or between 1990 and 2010 (23%). A range of materials were identified as the primary construction materials for the buildings, though most were either concrete (18%) or concrete and steel (57%). A complete list of building uses, years of construction, and primary construction materials are shown in Figure 2.

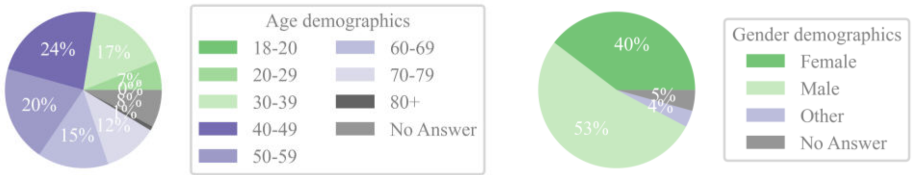

Figure 1 Age and gender demographics of survey participants

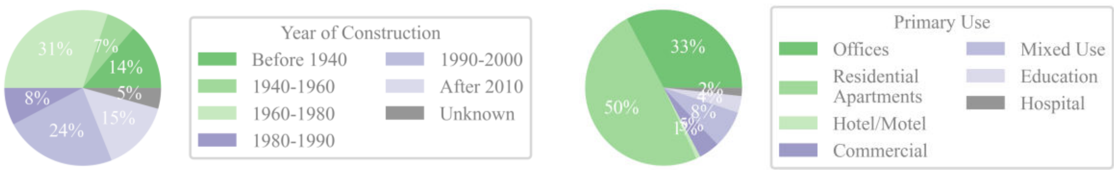

Figure 2 Year of construction and primary use of identified buildings

2.1 Instruments

The survey began with a cover page that outlined the purpose of the survey, which was to investigate (1) how participants expected their building would perform in weak, moderate, or severe earthquakes and (2) whether the building’s actual performance in previous New Zealand earthquakes had met expectations. The descriptions of earthquake severity were related to the New Zealand Modified Mercalli Intensity (MMI) Scale (Dowrick et al., 2008), with a weak earthquake defined as MMI 3-4, a moderate earthquake defined as MMI 5-7, and severe earthquake defined as MMI >7.

The survey consisted of four blocks of questions. Block one consisted of questions to understand the participant’s previous earthquake experience. Block two included questions about how the participant expected ‘Building A’ and other aspects of the built environment to perform in weak, moderate, or severe earthquakes. Block three included specific questions that were aimed at capturing expectations for post-earthquake functionality and repair time. The fourth block of the survey included questions that were designed to understand whether the building’s actual performance had met expectations. While blocks two and three will be analysed herein, blocks one and four will be analysed in future publications.

3 RESULTS

3.1 Expected damage

Participants were asked to indicate what level of shaking – weak, moderate, and severe – they would expect to cause damage to 'Building A.' The types of damage participants were asked to consider were damage from liquefaction, structural damage, damage to plumbing and electrical facilities, and non-structural damage. If a participant did not check any boxes, it was assumed they did not expect 'Building A' to experience that type of damage.

Figure 3 shows the proportion of participants that expect to see the different types of damage in 'Building A' and the different levels of shaking. Most participants expect to see structural damage, damage to plumbing and electrical facilities, and non-structural damage in severe earthquakes (N=108, 111, & 114 respectively). Fewer participants expect to see damage from liquefaction in severe earthquakes (N=64), likely because they were aware that 'Building A' was constructed on soil that is not liquefiable, as was indicated by some participants in a provided comment box. An interesting finding is that nearly a quarter (23%) of survey participants expect some type of damage (typically non-structural damage) even in a weak earthquake.

To determine the average minimum shaking intensity that the survey participants would expect to cause damage to 'Building A,' the discrete shaking levels were numbered one to three – weak (1), moderate (2), and severe (3) – and the mean (M) and standard deviation (SD) were calculated. For example, participants who expected to observe damaging liquefaction thought it could first occur in a weak (n=2), moderate (n=11) or severe (n=51) earthquake, resulting in a mean of 2.77 with a standard deviation of 0.49. Figure 5 shows the mean and standard deviations for all types of damage. Participants typically expect to see damage from liquefaction, structural damage, and damage to plumbing and electrical facilities at higher shaking intensities (near MM7+), while damage to non-structural elements is expected at more moderate intensities of shaking (around MM5-7).

The mean values were compared using paired sample t-test, with each type of damage compared to all other types. The results are summarised in Table 1. The difference between the means of damage from liquefaction (M=2.77) and structural damage (M=2.74) was not statistically significant, which means that participants would expect roughly the same level of earthquake shaking to cause 'Building A' damage from liquefaction as they would for structural damage. On the other hand, participants typically expect damage to plumbing and electrical facilities and damage to non-structural elements at lower and different levels of earthquake shaking (M=2.54 and M=1.97, respectively).

Table 1 Paired sample t-test results of comparing each type of damage to all others

Damage	Vs. Damage	t	df	*p* value	Damage	Vs. Damage	t	df	*p* value
Liquefaction (L)	SD	0.69	62	> 0.05	non-structural damage (NSD)	L	-10.79	61	< 0.05
	DPE	3.4	60	< 0.05		SD	-17.39	105	< 0.05
	NSD	10.79	61	< 0.05		DPE	-11.7	109	< 0.05
Structural Damage (SD)	L	-0.69	62	> 0.05	Damage to plumbing and electrical facilities (DPE)	L	-3.4	60	< 0.05
	DPE	4.19	102	< 0.05		SD	-4.19	102	< 0.05
	NSD	17.39	105	< 0.05		NSD	11.7	109	< 0.05

3.2 Functionality

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 aspects of the built environment considered included the internal services of 'Building A' (e.g., fire sprinkler lines, elevator, etc.), external utilities (power, water, sewerage, etc.), essential infrastructure (e.g., roads, bridges, pipelines, water treatment plants, etc.), and other buildings (e.g., offices, shops, service stations, etc.) The expected levels of functionality were measured from one to three, with the discrete options being to remain fully functional (1), remain partially functional (2), or not expect any functionality (3). Figure 5 shows a summary of the mean expected level of functionality for each aspect of the built environment and earthquake shaking intensity.

To understand the expected relative levels of functionality of each aspect of the built environment at different levels of shaking, mean values were compared using paired sample t-test. Two analyses were carried out: (1) a comparison of different aspects of the built environment at same level of shaking considering the three levels of shaking, and (2) an analysis of a singular aspect of the built environment at the three levels of shaking.

(1) Comparing different aspects of the built environment at same level of shaking

Following a weak earthquake, most participants expect the described aspects of the built environment to remain fully functional. The mean expected level of functionality for other buildings, essential infrastructure, and external utilities are similar, being 1.13, 1.11, and 1.11, respectively. Participants generally expected the internal services of their 'Building A' to perform slightly worse, though still typically fully functional, with a mean of 1.29.

Following a moderate earthquake, participants expect the same level of functionality - between fully functional and partially functional - of internal services and essential infrastructure since their respective means, 1.66 and 1.65, are not statistically significantly different ($t(113) = 1.12$, $p = .26 > .05$). Functionality levels between full and partial are also expected for external utilities and other buildings. However, participants expect external utilities to perform slightly better than internal services ($t(112) = 2.62$, $p = .01 < .05$), and other buildings to perform slightly worse than internal services ($t(113) = -3.06$, $p = 0.003 < .05$).

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. This was proved by conducting a paired t-test considering the mean of internal services compared to the means of external utilities ($t(113) = .86$, $p = .38 > .05$), essential infrastructure ($t(114) = 1.76$, $p = .08 > .05$) and other buildings ($t(114) = 1.22$, $p = .23 > .05$).

(2) Analysis of a singular aspect of the built environment at the three levels of shaking

Figure 5 shows that the expected level of functionality of all four aspects of the built environment differ depending on the level of shaking, with the expected level of functionality decreasing as shaking intensity increases. This observation was confirmed through several paired *t*-test. Results are summarised in Table 2. For example, the expected level of functionality of internal service for weak ($M = 1.17$) and moderate ($M = 1.66$) earthquakes are statistically significantly different ($t(113) = -7.06$, $p = 0.0 < .05$). The recovery time of internal service between a moderate ($M = 1.66$) and severe ($M = 2.44$) earthquakes are also statistically significantly different ($t(113) = -12.8$, $p = 0.0 < .05$).

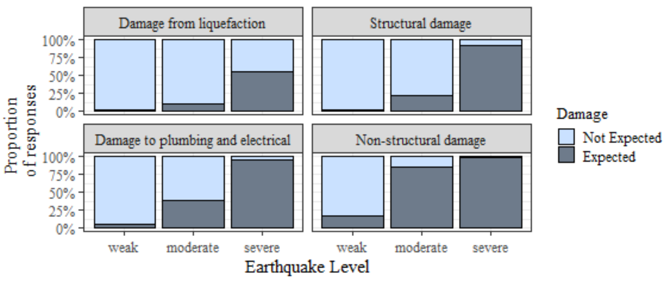

Figure 3 Participants' expectations of damage from liquefaction, structural damage, damage to plumbing and electrical facilities, and non-structural damage based on earthquake level.

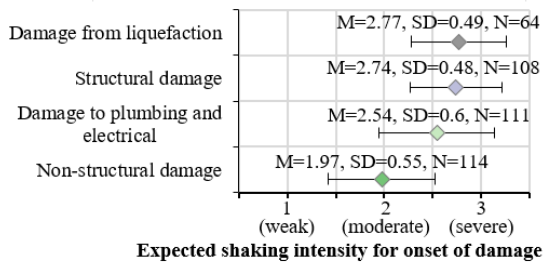

Figure 4 The mean and standard deviation for participant's expected level of shaking that would cause damage

Table 2 Paired sample t-test results of comparing expected level of functionality of aspects of the built environment

Shaking scenario	Aspects of the built environment	t	df	*p* value	Aspects of the built environment	t	df	*p* value
Weak-moderate	Internal services	-7.06	113	< .05	essential infrastructure	-10.1	114	< .05
Moderate-severe		-12.8	113	< .05		-11.5	114	< .05
Weak-moderate	External utilities	-8.9	113	< .05	other buildings	-15.6	114	< .05
Moderate-severe		-14.1	113	< .05		-9.36	114	< .05

3.3 Recovery Time

Participants were asked what period they believe is 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 discrete options for recovery times were assessed considering a scale from one to five: immediately (1), days (2), weeks (3), months (4) and years (5). Figure 6 shows a summary of the means for acceptable recovery time for each aspect of the built environment and shaking intensity.

Similar to the analysis described in Section 3.2 Functionality, two types of comparisons for recovery time were undertaken using paired sample t-tests to compare means for (1) different aspects of the built environment at the same level of shaking and (2) a singular aspect of the built environment at the three levels of shaking.

(1) Comparing different aspects of the built environment in the same level of shaking

A paired t-test was used to compare the mean recovery time considered acceptable by participants for the internal services of 'Building A' after a weak earthquake to the mean acceptable recovery time for external utilities, essential infrastructure, and other buildings. Results indicate that the recovery time of internal services and other buildings were not statistically significantly different ($t(113) = -1.29$, $p = 0.19 > .05$), while the recovery time between internal services and both external utilities and essential infrastructure was statistically significantly different ($t(113) = 2.2$, $p = 0.02 < .05$ – and $t(113) = 2.7$, $p = 0.0 < .05$ respectively). This means that, in general, participants thought that following a weak earthquake, the internal utilities of 'Building A' should be repaired and operational within a similar timeframe to the recovery period for other buildings, with the period being a timeframe between immediately and days ($M = 1.59$ and $M=1.69$ respectively). External utilities and essential infrastructure were also typically accepted to be repaired and operational within the period between immediately and days, though the timeframe is slightly shorter ($M = 1.44$ and $M=1.40$ respectively).

Following a moderate earthquake, on average, Figure 6 shows that particpants accept all aspects of the built environment should recover in the days to weeks. Results indicate that the recovery time of internal services and essential infrastructure were not statistically significantly different ($t(114) = 0.64$, $p = 0.52 > .05$), while the recovery time between internal services and both external utilities and other buildings was statistically significantly different ($t(1134) = 2.9$, $p = 0.0 < .05$ – and $t(114) = -4.87$, $p = 0.0 < .05$ respectively).

Similarly, following a severe earthquake, particpants accept all aspects of the built environment should recover in the weeks to months. Results indicate that the recovery time of internal services and essential infrastructure were not statistically significantly different ($t(115) = 0.7$, $p = 0.48 > .05$), while the recovery time between internal services and both external utilities and other buildings was statistically significantly different ($t(115) = 3.8$, $p = 0.00 < .05$ and $t(115) = -4.8$, $p = 0.0 < .05$ respectively).

(2) Comparing the same service in the three levels of shaking

Figure 6 shows that the acceptable recovery times of all four aspects of the built environment differ depending on the level of shaking, with expected recovery time increasing as shaking intensity increases. This observation was confirmed through several paired *t*-test. Results are summarised in Table 3. For example, the recovery time of internal service for weak ($M= 1.59$) and moderate ($M=2.32$) earthquakes are statistically significantly different (t(113) =-10.7, p = 0.0 < .05). The recovery time of internal service between a moderate (M= 2.32) and severe (M=3.53) earthquakes are also statistically significantly different (t(114) =-18.06, p = 0.0 < .05).

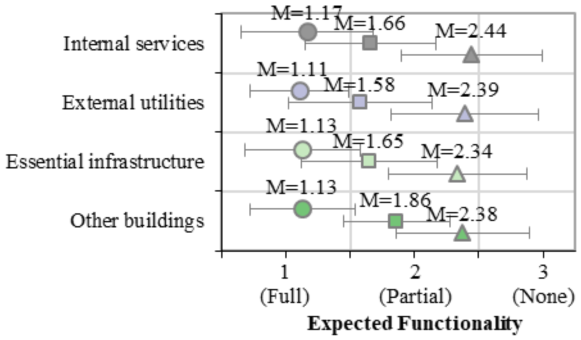

Figure 5 Expected level of functionality of internal services, external utilities, essential infrastructure, and other buildings in three levels of earthquake shaking

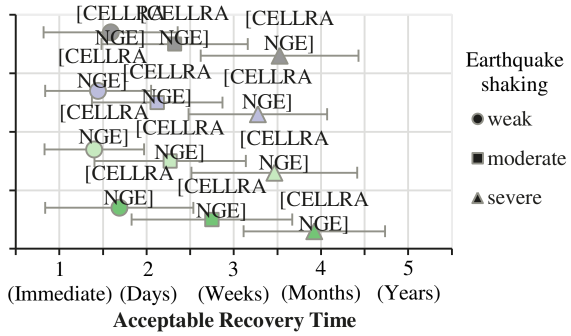

Figure 6 Acceptable recovery time of internal services, external utilities, essential infrastructure, and other buildings in three different earthquake scenarios.

Table 3 Paired sample t-test results of comparing recovery times of aspects of the built environment

Shaking scenario	Aspects of the built environment	t	df	*p* value
Weak-moderate	Internal services	-10.7	113	< .05
Moderate-severe		-18.06	114	< .05
Weak-moderate	External utilities	-13.4	114	< .05
Moderate-severe		-19.28	114	< .05

Aspects of the built environment	t	df	*p* value
essential infrastructure	-13.6	114	< .05
	-18.6	114	< .05
other buildings	-14.8	114	< .05
	-19.7	114	< .05

4 CONCLUSIONS

Results confirm that, on average, participants had high expectations for functional performance, which is similar to what has been found in previous studies (Miranda et al., 2022, Tanner et al., 2020). For example, 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. This timeframe for recovery won't be achievable if the building needs extensive invasive repairs or to be demolished and re-built, which is a concievable outcome for many existing buildings. Participants, however, seem to understand that different levels of shaking would cause different damage, since damage to plumbing and electrical facilities is expected to be observed at lower intensities. People also had higher performance expections of external services after an earthquake, compared with their own building and its internal services.

Depending on the level of shaking, participants expect similar or different levels of functionality of different aspects of the built environment after an earthquake. Participants also expect different lower functionality for stronger earthquakes. Considering the four aspects of the built environment, on average after a weak earthquake participants expect a building to be fully functional 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 expect that many people recovery times to be short, in opposition to what we have seen in past earthquakes where decades of recovery have ensued.

Findings presented herein can support future changes in New Zealand's Building Code. Expectations of damage to buildings, as well as expected functionally and recovery timeframes, could be realised in updated performance objectives within the New Zealand building code, that more accurately represent societal demands for performance in earthquakes.

4.1 Limitations

This study has some limitations. First, the demographic representation does not fully represent the New Zealand's context. Second, analysed questions asked about expectation of damage and functionality, however, it does not mean that those expectations are what people would like to happen to a building. Third, most buildings identified by participants are concrete or concrete and mixed materials, and are apartments or office blocks, which might have influenced responses since varied earthquake performance of different types of buildings has been observed in prior earthquakes. Fourth, participants were not asked if any seismic strengthening had been done and/or they knew of any measure / assessment of seismic performance. This could act as a causal factor for perceptions of damage and it would be worth analysis for future studies.

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